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Marginal costs of infrastructure use - towards a simplified approach

Final report

Report

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Executive summary

Increasing interest in marginal social cost charging
In subsequent Green and White Papers, the European Commission has expressed interest in the instrument of charging for infrastructure use as a means to increase efficiency and sustainability of the transport system. In parallel, several research projects carried out under the umbrella of the Fourth and Fifth Framework Programmes were carried out to deepen theoretical knowledge and to bridge the gap to implementation. Particularly the UNITE research project was an ambitious attempt to broaden the theoretical and practical basis for so-called marginal social cost charging.

Need for simplified approaches
At the moment, both theoretical and applied research into marginal social cost charging seem to have arrived at a level that ease of access to information and transparency of information have become bottlenecks in policy making. Therefore, this study aims at making the research results from UNITE and from comparable studies more accessible and transparent. Moreover, most recommended methods are too complicated, time-consuming and have too high data requirements to be applicable in practice. Therefore, the Commission feels the need for simplified approaches for getting estimations of marginal costs.

The main objective of this study is to make the methodology to calculate marginal social costs for different transport modes easier accessible and applicable and more transparent to a broader group of users than just the inner circle of economist and transport experts involved in the research so far. The report takes into account infrastructure costs, congestion and scarcity costs, accident costs, air pollution and noise for the modes road, rail and air transport.

Part 1 of this report: overview of scientific approaches
This report consists of two parts. The first part concentrates on a review of the different scientific approaches to determine marginal costs. As it mainly builds on the results of other studies people will find no major 'novelties' on marginal costs in the first part.

Approaches are described on a high level of abstraction. For each marginal costs category an overview is given of:
- The key cost drivers: the variables, which denote the key cause of various, transport costs.
- The main (recent) approaches to determine the marginal costs.
- Applications of different methods and its main outcomes.
- The main discussion points between the most common approaches.
- The recommended method in general.
- Data requirements.
- Relevant literature.

Part 2 of this report: simplified approaches
The results of part 1 are input to the second part of the report, which deals with simplified approaches. In principle, the more sophisticated approaches discussed in the first part of the report are to be preferred. However, we propose simplified methods for situations in which data availability or other resource strains preclude the use of these first best approaches.

The proposed simplified approaches may provide a lower degree of accuracy compared to the more sophisticated approaches discussed in the first part of the report, but have the advantage of being relatively easy to apply. In many cases they can serve to provide a quick indication of the marginal cost level. For each cost item we present one or more possible approaches. We discuss the pros and cons of the different approaches and pay attention to the important issue of data requirements. Each chapter also contains examples to illustrate the application of the simplified approaches.

Both the econometric and engineering approaches are in many cases too complicated to be suitable as a simplified approach. For most cost items the simplified approaches are based on cost allocation. However, these cost allocation approaches make use of generalisations of data that have been obtained by engineering and econometric studies.

Illustrations of the simplified approaches
Apart from the illustrations throughout the report, we present two fictitious case studies to indicate how to apply the proposed simplified approaches. These examples concern:
1. Road: a HGV travelling from Hamburg to Munich in Germany.
2. Rail: a freight train travelling from Rotterdam in the Netherlands to the border with Germany at Venlo.

For both cases all cost types that have been elaborated in this report are calculated using the proposed simplified approaches. The examples illustrate the relative ease with which the proposed approaches can be applied.

1 Introduction

1.1 Background and objective

In subsequent Green and White Papers, the European Commission has expressed interest in the instrument of charging for infrastructure use as a means to increase efficiency and sustainability of the transport system. In parallel, several research projects carried out under the umbrella of the Fourth and Fifth Framework Programmes were carried out to deepen theoretical knowledge and to bridge the gap to implementation.

Particularly the UNITE research project was an ambitious attempt to broaden the theoretical and practical basis for so-called *marginal social cost charging*. The project started off with a series of methodological and theoretical studies which have been applied in case studies during the second stage of UNITE. These case studies were summarised in a synthesis report.

At the moment, both theoretical and applied research into marginal social cost charging seem to have arrived at a level that ease of access to information and transparency of information have become bottlenecks in policy making. Therefore, this study aims at making the research results from UNITE and from comparable studies more accessible and transparent. Moreover, most recommended methods are too complicated, time-consuming and have too high data requirements to be applicable in practice. Therefore, the Commission feels the need for simplified approaches for getting estimations of marginal costs.

The main objective of this study is to make the methodology to calculate marginal social costs for different transport modes easier accessible and applicable and more transparent to a broader group of users than just the inner circle of economist and transport experts involved in the research so far. The report takes into account infrastructure costs, congestion and scarcity costs, accident costs, air pollution and noise for the modes road, rail and air transport.

Referring to the High level Group and UNITE guidance this report concentrates on short run marginal costs of transport. Short-run marginal costs are those variable costs that reflect the cost of an additional vehicle or transport unit using the infrastructure. In contrary to long run marginal costs it is assumed the infrastructure capacity is fixed, so development costs of additional infrastructure are not taken into account.

This report consists of two parts. The first part concentrates on a review of the different scientific approaches to determine marginal costs. The second part deals with simplified approaches that are easy to apply.

1.2 Part 1: Review of state-of-the-art approaches

The first part of the report gives per cost item and per mode a state-of-the art review of used methodologies. Approaches are described on a high level of abstraction and mainly based on desk-research of the following studies:

- ECMT European Conference of Ministers of Transport (2003), *Reforming Transport Taxes*, Paris.
- High Level Group on Infrastructure Charging (1999), *Calculating Transport Environmental Costs*.
- INFRAS-IWW (2000), *'External Costs of Transport'*, Zürich.
- Institute for Transport Studies et al, (2003), *UNITE UNIfication of accounts and marginal costs for Transport Efficiency, Deliverables 3, 15 and 16*, Leeds.
- RECORDIT (2001), *'Real Cost Reduction of Door-to-Door Intermodal Transport'*, Brussels.
- TRL, IWW, NEA, PTV AG and University of Antwerp (2001) '*A study on the cost of transport in the European Union in order to estimate and assess the marginal costs of the use of transport'.*

For each marginal costs category an overview is given of:

- The key cost drivers: the variables, which denote the key cause of various, transport costs.
- The main (recent) approaches to determine the marginal costs.
- Applications of different methods and its main outcomes.
- The main discussion points between the most common approaches.
- The recommended method in general.
- Data requirements.
- Relevant literature.

The results of part 1 are input to the second part of the report. As the first part mainly builds on the results of other studies people will find no major 'novelties' on marginal costs in the first part.

1.3 Part 2: Towards a practical approach

The practical application of most of the recommended[1] approaches is very time-consuming and has high data requirements. Therefore, it is not always feasible to build on general recommended approaches. In practice, simplified approaches for obtaining estimates of marginal costs, like cost allocation methods or average cost methods, will sometimes be indispensable.
The second part of this report deals with the simplified approaches for all cost items. Simplified approaches may be less recommendable but serve to get a quick indication of marginal costs with relative ease. Referring to the main question of this study to derive easier accessible and more transparent cost functions, we present different ways for a more 'practical' approach. For each cost item we provide an overview of possible simplified approaches and for the recommended approach we give an overview of data requirements and, if

1 For clarity, *recommended* approaches refer to the theoretically best approaches. In the second part of the report we discuss *simplified* approaches.

possible, the consequences for the accuracy with which the marginal costs can be estimated.

1.4 Introduction on marginal cost theory

Although we have attempted to write this report in a comprehensive way making it instructive for both economists and people with a less economical background we could not avoid that the report has a very theoretical economic character at some places. We therefore start the report with a short introductory chapter on marginal cost theory dealing with frequently used concepts. We have also added a comprehensive glossary at the end of part 2.

2 Introduction on marginal cost theory

Towards an efficient allocation of resources
It is very often stated that in transport the available resources are not efficiently allocated. Some examples. Air transport is regarded to be an important source of air pollution, but passengers by aircraft hardly pay for this. With regard to the maintenance costs of infrastructure, road users pay to a large extent the maintenance costs, whereas railway infrastructure managers in some countries only partly recover these costs, resulting in unfair competition between road and rail transport. Congestion occurs a lot but road users are not 'punished' for their contribution.

As a consequence the transport system is regarded to be not very efficient and sustainable. Moreover competition between transport modes does not take place on a level-playing field.

Pricing in conformance with 'the-polluter-pays principle' is regarded to offer a solution for a more efficient use of infrastructure. Both the European White Paper *Fair payment for infrastructure use* and its predecessor the Green Paper *Towards fair and efficient pricing in transport* highlight an efficient allocation of resources in a way that prices charged reflect the costs produced by of an additional vehicle, referred to as *marginal costs.*

More in particular the White Paper focuses on the need to relate charges more closely to the underlying costs associated with infrastructure use (for example maintenance and congestion costs) extending these costs to include social or external costs (for example the costs of noise and emissions). The consequences of this efficient allocation of resources are:
- Direct costs of infrastructure are covered per transport mode.
- Transparency between transport modes is ensured.
- Fair competition between transport modes is facilitated.

As stated before, the application of marginal cost pricing is the best way to come to an efficient allocation of resources. In this chapter we pay more attention to this pricing principle, the differences with other 'cost pricing methodologies' such as average cost pricing and to the valuation and transferability of marginal cost figures.

Not all economic terms used in this report are explained in this chapter. At the end of part 2, a comprehensive glossary is included containing all relevant terms.

Marginal versus average costs
An efficient allocation of resources assumes 'the-polluter-pays'-principle; i.e. charges are dependent on the amount of kilometres travelled with a vehicle, its noise and emission production, the time-of-day etc. So in the ideal situation costs should be attributed to the 'polluting' source as much as possible.

In general the costs of extra vehicles can be determined by two different methodologies:

- The marginal cost methodology aims to determine the extra costs of specific one extra vehicle unit by determining the impact of that vehicle. In UNITE marginal social cost is defined as the costs of an additional transport unit – vehicle kilometre for road, train km for rail, aircraft km for air, ship km for waterborne modes. Infrastructure capacity is assumed to be fixed, while the rolling stock may vary.

  In this view marginal costs are very site-specific. An example. For people living in a house nearby a busy road the noise nuisance of an extra vehicle is very low as already many cars pass the house daily. This is different for people living in a quiet street where an additional vehicle indeed can have a significant impact. In the first case marginal costs are therefore lower than in the second case.
- The average cost methodology simply 'divides the total costs (for example the total noise or maintenance costs) of a transport mode in a specific area by the total mileage.' In this way outcomes are much less site–specific. In its simplest form only one figure results. Referring to the example above costs do not differ between busy and calm roads.

Scientifically, application of the marginal cost methodology is recommended as it takes into account site-specific differences. However in practice, certainly when one is looking for simplified and quick approaches (as in this study) average cost methodologies are often used as a proxy for marginal costs.

Valuation of marginal costs

Generally spoken the determination of marginal costs is part of a long calculation process. First of all impacts have to be determined and calculated, and finally these impacts must be monetarised. For the monetarisation of impacts frequent use is made of so-called economic valuation methods. In this subsection we pay attention to some key valuation methods. These methods are as much as possible distinguished to different cost items.

Willingness-to-pay / Willingness-to-accept

Especially with regard to the valuation of external costs the willingness-to-pay (WTP) methodology is often used. In general, market prices do not exist for externalities, or are not suitable for the different impacts. The valuation will then be based on the concepts of compensating and equivalent variation.

The compensating variation (CV) measures changes in welfare starting from the welfare level before implementation of the measure concerned (i.e. what is the willingness to pay for a future improvement, or what is the willingness to accept compensation for a future deterioration), while the equivalent variation (EV) measures changes in welfare starting from the welfare level after implementation of a measure (i.e. what is the willingness to pay for the removal of an existing impairment, or what is the willingness to accept compensation for renouncing to an existing benefit).

Depending on whether the measure induces an increase or decrease in welfare, the question arises to willingness to pay (WTP) or willingness to accept compensation (WTA). The CV asks for the WTP - starting from the status quo - in the case of an improvement and for the WTA in the case of deterioration in environmental quality. Since cost-benefit analyses normally start from the status quo, the CV-concept is generally used. The benefits of an environmental improvement, for example, are thus normally measured against the WTP of the population for this measure, the benefit losses in the case of an environmental deterioration correspondingly measured against the WTA.

WTP and WTA can be measured directly or indirectly. Direct methods measure the willingness to pay for environmental goods by surveys, while indirect methods derive the willingness to pay from observed market data. Direct methods measure stated preferences (hypothetical markets) while indirect methods measure revealed preferences (surrogate markets). In recent years both methods have been discussed and applied exhaustively. Methods have converged and agreement has been reached on the use of specific methods and on corresponding estimations within the scientific community for most marginal cost categories. In this report especially with regard to methodologies for noise and air pollution we will handle this subject in more detail.

Value-of-time
With regard to the monetarisation of travel time gains (or losses), for example in a situation with congestion, value-of-time-figures are commonly used. The value-of-time expresses the amount of money some-one wants to pay for a trip time decrease (or increase) of one hour. Different values are given for different wage rates, the values of time for journeys in the course of work is for example derived from wage rates, while non-work journey time values are derived from studies showing the people's willingness to trade time for money.

Table 1 and Table 2 [EU15 average, Values 1998] show some value-of-time figures for passenger and freight transport used in the UNITE-project. So a business traveler would pay € 21 for getting one hour quicker at his place of destination.

Table 1 Illustration of values of time for passenger transport

Passenger transport	Values-of-time (per person hour)
Interurban rail	Business: € 21.00 per person hour Commuting / Private: € 6.40 per person hour Leisure / Holiday: € 3.20 per person hour
Car	Business: € 21.00 per person hour Commuting / Private: € 6.00 per person hour Leisure / Holiday: € 4.00 per person hour

Table 2 Illustration of values of time for freight transport

Freight transport	Values-of-time
Rail transport (values per ton hour)	Full trainload (950 tonnes): € 725.00 Wagon load (40 tonnes): € 30.00 Average per tonne: € 0.76
Road transport (values per vehicle hour)	LGV: € 40.00 HGV: € 43.00

Value-of-statistical life
With regard to the valuation of accidents often use is made of the so-called value of statistical life (VOSL). It indicates individuals' willingness-to-pay for safety. In this methodology an individual states (or reveals) a willingness-to-pay for a small reduction in risk for a fatal accident. Note that individuals are not asked for the value they attach to life itself, but to value changes in risk for a fatal accident. If this risk change is summed over all individuals, so that statistically the risk reduction will save one life we can also sum their WTP; this sum of the WTPs then become the Value of Statistical Life.

The value of statistical life differs between studies. An average of € 1.5 million was used in the UNITE-project and is common used in other studies.

Transferability of results
When using marginal cost figures it is important that figures from one country can not directly be used in another country. A Purchasing Power Parity to reflect differences in purchasing power between the countries involved, is often used to determine the differences between the involved countries by multiplication of the value by the ratio of Real GDP per capita (at PPP) in the second country to Real GDP per capita (at PPP) in the first country. Table 3 gives an overview of these figures[2] for the EU15-countries.

2 Source: UNITE D5-Annex. The basis of the UNITE-values is a Netherlands/Sweden/UK average, not an EU-15 average.

Table 3 Value transfers for EU-15 countries

Country	GDP/Capita at 1998 PPP	Value transfer
Austria	23,900	1,079
Belgium	23,677	1,069
Denmark	25,459	1,149
Finland	21,833	0,986
France	21,132	0,954
Germany	23,010	1,039
Greece	14,171	0,640
Ireland	23,194	1,047
Italy	21,531	0,972
Luxembourg	37,491	1,693
Netherlands	24,141	1,090
Norway	27,391	1,237
Portugal	15,891	0,717
Spain	17,223	0,778
Sweden	21,799	0,984
United Kingdom	21,673	0,979
Average Netherlands + Sweden + UK	22,149	1,000
EU-15[3]	22,591	1,020

Furthermore it is important to use the same base-year when figures for different countries are used. If necessary, figures should be corrected country-specific for inflation.

Finally one should make use of factor costs and not of ‘market prices’. The difference in definition is a common source of confusion. Essentially:
- Consumption and production are subject to a range of indirect taxes, including VAT, fuel duty, vehicle ownership taxes, property taxes, etc.
- Consumption and production may also be subsidized.
- In the *factor cost* unit of account, items are valued as if no indirect taxation or subsidy were applied; whereas.
- In the *market price* unit of account, items are valued as if they were being traded in consumer markets with all indirect taxes and subsidies in place.

With regard to the first point, Table 4 gives the average rate of indirect taxation on consumer expenditure in some European countries.

3 Approximately, estimation based on OECD-figures.

Table 4 Average rates of indirect taxation

Country	% Average Rate of Indirect Taxation
Austria	23.0%
Belgium	18.9%
Denmark	28.4%
Finland	23.9%
France	26.8%
Germany	17.3%
Greece	19.1%
Italy	32.0%
Luxembourg	29.2%
Netherlands	21.3%
Portugal	23.1%
Spain	14.2%
Sweden	24.2%
United Kingdom	21.9%

For more information on the transferability of results, we would like to refer to Deliverable 5 Annex 3 *Valuation Conventions for UNITE* of the UNITE-project.

Part 1

Review of state of the art approaches

3 Marginal infrastructure costs

3.1 Introduction

By making use of infrastructure, each vehicle has in general a negative impact on the quality of infrastructure. Marginal infrastructure costs can be understood as the increased costs of operating, maintaining and repairing infrastructure, noise walls and technical facilities as a result of an additional transport unit entering the flow [UNITE, 2002].

Marginal costs include the damage to infrastructure (such as maintenance of road surfaces and tracks and some repairs to bridges, noise walls and technical facilities) and the cost of services or other infrastructure operations (such as the cost of supplying power to electric trains) [TRL, 2001].

3.2 Key cost drivers

Marginal infrastructure costs can vary in different circumstances. In this section we pay attention to the main cost drivers, i.e. the variables that denote the key cause of infrastructure costs. The axle weight is for example an important cost driver. In practice especially heavy goods vehicles damage road infrastructure. Below attention is paid to the key cost drivers for marginal infrastructure costs. The cost drivers[4] are distinguished by mode: road, rail and air.

Road transport
The main cost drivers per vehicle kilometre for road transport are *axle weight* (the heavier a vehicle the more damage of infrastructure) and *vehicle speed* (road damage increases with higher speeds). Closely related to axle weight is the vehicle type (heavy goods vehicle versus a passenger car).

Other cost drivers are specific infrastructure characteristics like type of road, number of lanes, number and type of bridges, construction and maintenance standards and the number of road crossings (accelerating and decelerating damages road surface). Finally, geographical aspects such as weather conditions (extreme weather damages road surface) and the wage level are important cost drivers.

Rail transport
The main cost drivers per vehicle kilometre for rail transport are *axle weight* (the higher the axle weight the more damage is caused to the infrastructure) and *vehicle speed* (both design speed and actual speed positively influence damage cost). Closely related to the axle weight are the vehicle type, the number and type of wagons and the maintenance level of wagons.

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4 This discussion is based on Deliverables 3 (The marginal cost methodology) and 15 (Guidance on adapting marginal cost estimates) of UNITE.

In addition infrastructural aspects as the track geometry, operating requirements (the number of stops for example influences rail track damage) and construction and maintenance standards and practice are important cost drivers. Climate and wage levels also influence marginal maintenance cost.

Aviation
The main cost driver per vehicle kilometre for airports is the *maximum take-off weight* (the weight of an aircraft determines to a large extent the damage to infrastructure). Closely related to the maximum take-of weight are aspects such as the passengers/freight mix (determines the weight of the aircraft) and the type of aircraft.

Other cost drivers are the share of domestic and international flights (cost variability for certain terminal services such as safety control, police etc. depends on the share of international flights, which may during peak-periods require additional costs in contrast to domestic flights), the type of infrastructure (some types of infrastructure are more sensible to damage), personnel and operating costs and climate conditions (extreme climate conditions can damage airport infrastructure).

3.3 Current methodologies

For, infrastructure costs, two main approaches exist:

- The **econometric approach** - where the total cost is considered to be the dependent variable (which is to be 'explained') and transport outputs (e.g. trainkms) are among the independent[5] variables. With cross sectional and / or time series data an econometric analysis can be used to determine and estimate a total cost function from which marginal costs may be derived.
- The **engineering approach** - where total costs are disaggregated into sub-categories, and for each of these categories, separate analysis provides the technical relationship between input and output measures.

Characteristic for the econometric approach is that the starting point is total costs for maintenance and subsequently determines variables that can 'explain' the variation in these costs for different line segments or time periods. The analysis results in parameter values indication the way in which the chosen variables influence total costs. On the other hand, the engineering approach starts from a theoretical model with different hypotheses/assumptions and then tries to estimate the parameters accompanying the hypotheses.

[5] In the econometric model, variations in the dependent variable are explained by variations in independent variables. 'Independent' refers to the fact that these variables are not influenced by the so-called dependent variable.

Example of an econometric approach for rail infrastructure costs

A typical example of the econometric approach has been the study by Johansson and Nilsson in the UNITE framework on track maintenance costs in Sweden and Finland. For Sweden, data for 1995 to 1997 on maintenance costs, track length, the number of switches, bridges and tunnels, a track quality index and the gross tonnes per track section were collected. Furthermore a dummy indicating whether the track section concerned was a primary or secondary line was included.

Maintenance costs for track unit *i* in district *j* at time *t* C_{ijt} are related to the explaining variables (including factor prices) by a translog specification. After estimating this function, marginal prices can be derived. The signs of the parameters of interest were as expected and the main parameters of interest (with respect to track length and utilization) were significant, except the second-order term for track length.

Mean elasticities of track length and utilisation for Sweden, subdivided into main and secondary lines as reported in Johansson and Nilson.

	All	Main	Secondary
Mean elasticity w.r.t track length	0.796	0.713	0.972
Standard deviation	0.235	0.231	0.244
Mean elasticity with respect to utilization	0.169	0.139	0.233
Standard deviation	0.035	0.037	0.034

Source: Johansson and Nilsson [2002].

The estimated elasticities can be used to derive estimates of marginal costs for each single track unit.

	1995	2000
All	0.117	0.120
Main	0.082	0.084
Secondary	0.909	0.930

Source: Johansson and Nilsson [2002].

For a full understanding of the work carried out under this study and the conversion from estimates of elasticities to estimates of marginal cost, we refer to the original document.

The engineering approach typically analyses single infrastructure sections or lines and generalises the results afterwards. On contrast, the econometric approach starts from the total costs, or total cost components, and seeks for a functional form explaining the variation in total costs for different line segments of time periods. From the parameters in this cost function, approximations of marginal costs can be derived.
Within both approaches cost functions can be derived by using, either cross-section analysis or regression analysis based on time series. The example described above for Sweden typically uses a combination of cross-section and time series data, as information on 260 line segments for three years is used.

For infrastructure costs, both the econometric and the engineering approach are valid, but the econometric approach has rarely been applied other than for rail – where interest has generally focused on combined infrastructure and operating costs, rather than purely infrastructure costs. However, from a theoretical perspective the econometric approach is generally preferred since it provides objective evidence of cost causation as one looks for real figures on specific cost drivers. For the engineering approach ‘subjective’ assumptions on causal relationships are an inevitable input.

Moreover, the econometric approach is best for obtaining general information about cost elasticity’s; however to identify the impact of different types of vehicles in great detail data requirements are extremely high. The engineering approach has slightly lower but still substantial data requirements. An alternative, more practical approach due to lower data requirements is the cost allocation method.

Cost allocation approach
An other often more practical approach used but theoretically less appreciated is the cost allocation method (or cost accounting approach), a traditional method in which variable infrastructure costs are allocated to different cost drivers (axle load, vehicle kilometres, etc), according to engineering, empirical and expert evaluation. One ‘simply divides all costs into fixed and variable’ and tries to allocate as much as possible variable infrastructure costs to specific different cost drivers. Often the outcomes are average costs instead of marginal costs. Comparing recent studies on marginal infrastructure costs in road, rail and aviation, this method is especially used at airport infrastructure as detailed information is missing. An example is the Trackshare model applied by ZETA-TECH for rail in the US. This approach can be regarded as a simplified approach and therefore is further discussed in the second part of this report.

Example of a cost allocation approach for rail infrastructure costs

TrackShare is a model employed by ZETA-TECH Associates, Inc. and provides us with an example of the cost allocation approach. It calculates the 'relative' damage to the track structure for each traffic/track segment combination and uses this relative damage to adjust against either system average maintenance expenditures of precise segment expenditures, which are used as input to the model.

The first step of the methodology is to develop appropriate local condition 'engineering adjustment factors' (EAF's) for track segments. An EAF below 1 indicates that traffic on that segment causes less damage than the average. Local track data (including grade, curvature and type of rail) and train/vehicle category data (including axle load, wheel diameter and profile) are collected for the specific geographical segments.

In ZETA-TECH [2000] an exemplenary output of the model is given. Total (variable) costs sum to $2,5 million. For three different line segments and four train types damage factors are calculated.

Damage factors by traffic type

Business user	MGT/year	Segment 1	Segment 2	Segment 3
Loaded Unit Trains	18	1.77	1.31	1.53
Empty Unit Trains	6	0.80	0.69	0.75
Passenger Trains	1	1.32	1.03	1.17
Mixed Freight	10	1.52	1.16	1.33

Source: ZETA-TECH (2000)

Damage factors are next transformed into EAF's, a process that ensures that the total of adjusted costs is equal to the actual costs. This leads to the cost allocation as shown in the next table.

Engineering adjustment factors and estimated cost

Traffic Type	EAF	Maintenance of Way (MOW) unit cost (per Gross Tonne Mile)	Total MOW cost
Loaded Unit Train	1,150	$ 0.0014	$ 1,489,800
Empty Unit Train	0,567	$ 0.0007	$ 245,000
Passenger Train	0,882	$ 0.0011	$ 63,500
Mixed Freight	1,002	$ 0.0012	$ 721,700

Source: ZETA-TECH (2000)

For a full understanding of this method and the example, we refer to the original document.

3.4 Applications

For road and rail, previous studies tended to use a cost allocation approach, based on a simple division into fixed and variable costs. For an example of this approach see [Sansom et al., 2001]. In this case, road marginal cost is estimated as around 50% of average cost, with marginal cost varying between vehicle types mainly on the basis of standard axle kilometres. In contrast to the widely used cost allocation methods, UNITE does provide insight by applying state-of-the-art econometric and engineering methods for rail and road transport. An exception was made for aviation (Helsinki Airport) due to missing data.

Rail

The most successful application of the econometric approach in UNITE was the case study on railway infrastructure cost in Sweden and Finland, where detailed data on costs for a large number of individual track segments and several years was obtained. Alternatively, an engineering model was used by Railtrack for heavily used railways in Great Britain.

With reference to rail, UNITE focuses on short-run marginal costs corresponding to the damage to rail infrastructure - essentially wear and tear of tracks - due to an additional train. Other studies, such as [INFRAS-IWW, 2000] focus either on long-term marginal costs, including operational costs (e.g. signalling), or on average costs, as in EUNET [EUNET D12, 1998].

When a comparison is made between the pure short-run track maintenance marginal costs estimated in UNITE case studies and other estimates based on a similar marginal costs definition, such as [PETS, 2000] and [CERNA, 2000] variations are very limited when the same methodological approach is being used, i.e. for the econometric approach where values range from 5.2 to 6.8 €ct/train km for the total network. For average infrastructure costs (including administration, operational services and railway-police services) substantially higher estimates have been made: 1.8 €/ train km in Sweden and 1.1 €/ train km in Finland [see TRL et. al, 2001].

Road

For roads the econometric approach has also been attempted in UNITE but data difficulties were more acute. As described before studies on infrastructure costs mainly rely on cost allocation methods [Sansom et al, 2001], [DIW, 1998] and [RECORDIT, 2001]. In practice these allocation methods lead to *a high degree of variation* across European countries owing to differences in accounting rules adopted for the fixed and variable part of infrastructure expenditures, and in the allocation by cost drivers. For instance with regard to the cost allocation method with reference to the total road network, the range of marginal costs varies between 0.02 and 0.14 €ct/vkm for passenger cars, between 0.02 and 0.17 €ct/vkm for LGV, while the range of values for HGV is even broader, extending from 1.73 to 14.4 €ct/vkm.

The econometric and engineering approaches show smaller variations; from 3.6 to 5.1 €ct/vkm for marginal costs of maintenance and upgrades in Switzerland (econometric approaches) and from 0.8 to 1.9 €ct/vkm for marginal renewal costs in Sweden (engineering approach), both estimates being related to truck damage. On the other hand, it should be stressed that a direct comparison of results between the econometric and engineering approaches is hazardous, owing to differences in quality and availability of data.

Aviation
The UNITE airport case study was different from the others as it addressed the issue of marginal operating costs in terms of staff. It examined this by relating staff numbers to number of flights by time of day and season, and in this way obtained a marginal cost for an aircraft movement of € 38.00, which is clearly very low compared with the total cost of maintaining and operating an airport. The estimation of infrastructure costs is based on linear regression analysis. A study on marginal short-run airside cost based on a regression model in USA (the California Corridor) yields values of € 84.00 per scheduled air carrier movement, € 18.40 per commuter carrier movement and € 13.00 per general aviation movement [see Gillen, A. and D. Levinson, 1999].

3.5 Analysis of discussion points

In literature both the engineering and econometric approach are regarded to be theoretically correct. Discussion (in for example UNITE) is mainly on the application of the econometric and engineering approach on one hand and the application of cost allocation approaches on the other hand. Cost allocation approaches are often used as these are relatively simple to apply.

However, there is no agreement on which costs are fixed and which are variable, or with which output measure they vary[6]. So, generally the method leads to estimations of average costs instead of approximations of the truly marginal costs. However, given sufficient data on more detailed cost categories, in combination with the application of harmonised definitions over the various EU-countries the cost allocation method should provide useful insights.

3.6 Recommended method

The engineering and econometric approaches are both accepted. The econometric approach is generally preferred since it provides objective evidence of cost causation. In the engineering approach one makes its ‘own’ assumptions on causal relationships, making it less objective. If sufficient data is available the econometric approach is to be preferred.

However, this last requirement may in practice be hard to fulfil. To get an adequate sample size generally requires disaggregated data for individual stretches of infrastructure, rather than data for an organisation or a country as a whole. Expenditure on maintenance and renewals may be lagged many years behind the traffic that caused it, so that misleading results may be obtained if an organisation is not pursuing a ‘steady state’ maintenance policy. Despite the econometric method being the preferred approach, data availability sometimes forces the use of the engineering method, especially to obtain precise information on the influence of different vehicle types.

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[6] To some extent this is also a ‘difficulty’ in the engineering approach.

3.7 Data requirements

Both approaches require the following data for road and rail transport:

- Infrastructure data:
  - Divided into types of investment, maintenance and operation, administration, including the identification of fixed and variable costs.
  - Data on network categories.
  - Data split up in specific segments and over several years,
- Infrastructure usage data:
  - Mileage broken-down to vehicle categories, in particular to weight classes and with a separate treatment of buses.
  - Train-kilometres and truck axle-weight kilometres, broken-down to traffic types.
  - Data over several years.

For aviation (and water transport) similar data requirements apply. Actual data availability is however limited, because infrastructure managers tend to regard this information as confidential.

The type of data requirements between the econometric and the engineering does actually not differ a lot. However for the econometric approach one wants very detailed and more data as one seeks for a functional form explaining the variation in total costs for different line segments of time periods. In addition one wants data for the whole network as for the engineering approach 'only' data for specific line segments is required.

In the end the engineering method requires less data and is as a consequence easier to carry out.

Availability of data
As described before data availability can sometimes be a problem, necessarily leading to use of simpler methods, such as cost allocation methods.

3.8 Literature overview

Besides the six studies mentioned in section 1.2 the following studies have been used to compile this review:

- CERNA (2000) *Les péages d'infrastructures ferroviaires en Europe II*, Manuel Baritaud et Francois Lévêque, Ecole des Mines de Paris
- DIW, INFRAS, Consultancy Dr. Herry, NERA (1998), *Infrastructure Capital, Maintenance and Road Damage Costs for Different Heavy Goods Vehicles in the EU*. Final Report, Berlin March 1998
- EU Task Force on Rail Infrastructure charging in the framework of Developing European Railways Committee - Final Report (2002)
- EUNET (1998) *Socio-Economic and Spatial Impacts of Transport, Deliverable D 12. The Transport Cost Database Report and Software Prototype*. Authors: Dr. G.-D. Jansen
- (PC); O. Hamann (PC); S. Kotzagiorgis (PC), EC RTD 4th Framework Project

- Gillen, A. and D. Levinson (1999), *The full cost of air travel in the California Corridor*, Transportation Research Board, Paper No. 990305, 78th Annual Meeting 1999
- Johansson, P. and Nilsson, J.E. Deliverable 10: Infrastructure Cost Case Studies, Annex A3: An economic Analysis of Track Maintenance Costs (UNIfication of accounts and marginal costs for Transport Efficiency) Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds. June 2002, version 0.3
- PETS (2000) *Pricing European Transport Systems, Final Report*, Project Coordinator: Professor Chris Nash. Institute for Transport Studies, University of Leeds, UK, December 2000. EC RTD 4th Framework Project
- Sansom et al. (2001). Sansom T, Nash CA, Mackie PJ, Shires J, Watkiss P (2001) *Surface Transport Costs and Charges: Final Report*. For the Department of the Environment, Transport and the Regions. Institute for Transport Studies, University of Leeds, Leeds, July 2001
- ZETA-TECH (2000): TrackShare, ZETA-TECH's Model for Determining and Negotiating Shared Costs of Open Access Charges on Railway Lines, http://www.zetatech.com/CORPQIII44.htm, February 2000

4 Congestion and scarcity costs

4.1 Introduction

The marginal external transport user costs relate to the increased operating costs and the changes in journey time caused by an additional user to all the users already present on the infrastructure.

In practice four kinds of marginal costs transport user categories are distinguished[7]:

- Congestion arises when one vehicle delays another. Marginal congestion costs can be defined as the additional social costs of an extra traffic unit. For the transport user this will result in additional user time costs, fuel costs, environmental costs and accident costs. This is the 'negative' case of marginal external transport user costs as the activity of one user causes extra costs for others.
- In the positive case, when users' activities improve the welfare situation of other users we talk about the 'Mohring effect'. This effect is a form of user economies of scale in public transport services. As demand on particular routes increases, public transport operators tend to improve the frequency of service, and to provide other benefits to passengers like a wider range of places and a mix of express and stopping services etc.
- Scarcity costs arise when one vehicle prevents another from gaining access to the network and can be defined as the valuation of the opportunity costs associated with service provision limits for collective transport. Scarcity costs express the disutility for the end users which either would not actually travel, or would have to reschedule their journey and/or change their mode of transport because of infrastructure capacity shortage at the right time. Scarcity is thus a concept that applies to scheduled public transports (essentially rail and air transport) using an infrastructure with strictly limited access.
- In-vehicle congestion or crowding effects in public transport as the amount of passengers in a vehicle exceeds the capacity of a vehicle.

In this study we focus on congestion and scarcity costs; Mohring benefits and crowding effects are not taken into account.

Individual and scheduled transport

With regard to congestion and scarcity costs (and for research methodology subsequently also) we distinguish:

- Congestion costs in individual transport.
- Congestion costs in scheduled / public transport systems which share the road infrastructure with the 'general' road traffic, such as bus and tramway services in urban areas for example.
- Congestion and scarcity costs in scheduled / public transport systems operated on their own infrastructure, i.e. rail transport and aviation.

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7 UNITE, Deliverables D3 & D15; High Level Group on Infrastructure Charging, 1999.

In the case of road public transport such as urban bus services for example, passengers (end users) suffer from congestion within the general road traffic, as users of private car do, but also the operator has to put more busses on the road during peak hours[8] not necessarily to accommodate an increasing demand but to keep service' headways at an acceptable level (if not a mandatory level to comply with its public service obligations), not to mention additional fuel costs as travelling at low speeds is more fuel consuming than travelling at 'reasonable' speed.

The definition of user costs in scheduled transport operated on their own infrastructure is different from the definition of congestion in road traffic. In public transport the number of users (or the traffic demand) is not directly related with the occupancy of transport infrastructure, e.g. the relationship between demand and average user costs is less obvious in public transport than it is in individual transport. Congestion costs in public transport are arising indirectly as the operator adapts the level of service to the demand of his customers. In contrast to road traffic, where individual users demand for a particular infrastructure capacity without taking into consideration the effects they impose on others, the effect of extended traffic in rail and air transport is known (and anticipated) by the operator. Therefore, there are arguments to say that in scheduled transport there are no external congestion costs existing. However, in practice it is obvious that also in public transport high levels of demand are leading to capacity problems and delays, which are not anticipated in the timetables defined by the operator and/or the infrastructure manager.

4.2 Key cost drivers

Marginal congestion and scarcity costs are not everywhere and always the same. In this section we pay attention to the main cost drivers, i.e. the variables that denote the key cause of various transport costs. The infrastructure capacity is for example an important cost driver. The higher the capacity of road the lower congestion will exist. Below attention is paid to the key cost drivers for congestion and scarcity costs.

Cost drivers in individual and commercial road transport
The main cost drivers of individual and commercial transport for congestion costs are the overall road infrastructure capacity, the traffic control efficiency and the development of traffic conditions when capacity limits are approached. The *demand elasticity* is also a main cost driver concerning the reaction of traffic demand to changing traffic conditions, transport alternatives, user charges[9] as a determiner of the choices regarding route, travel time and mode of transport (for example public transport).
Determining the relative importance of cost drivers mentioned above are aspects like the location (inner city, outer city, interurban, rural etc.), travel purpose

[8] Which raises the problem of a component of the marginal congestion cost that is linked to a discrete process.
[9] Not forgetting that outside of the City of London, road user congestion charging is not yet current practice in the EU.

(private, commuting, business), use of vehicles capacity, time-of-day and fuel consumption functions[10] and other vehicle-related costs.

In practice scarcity costs only occur related to a form of public transport and are therefore not considered here.

Cost drivers in scheduled transport
For **scheduled road public transport**, cost drivers for congestion are the same as for individual and commercial road transport: *road infrastructure capacity*, *traffic control efficiency*, *general road traffic conditions* and possibly *alighting and boarding times at major stops / stations*[11]. *Demand elasticity* to quality of service as a result of changing traffic conditions can also indirectly exert influence on related congestion costs, but to a lesser extent than for individual road transport.

For **scheduled transport operated on their own infrastructure (rail and air transport)**, congestion develops under the form of delays generated in a cascade-type effect due to various initial causes: technical breakdown of the vehicles or of fixed equipments, long boarding / alighting times, passengers uneasiness, etc, are among the most common ones. Key cost drivers are for congestion and scarcity, as well as for 'traditional' congestion of the individual transport, the *infrastructure capacity and configuration*, the *infrastructure use*, the *current level of traffic*, in terms of temporal density and geographical pattern of scheduled services on given infrastructures, the *operation efficiency*, notably in terms of traffic control, and *demand elasticity*.

4.3 Current methodologies

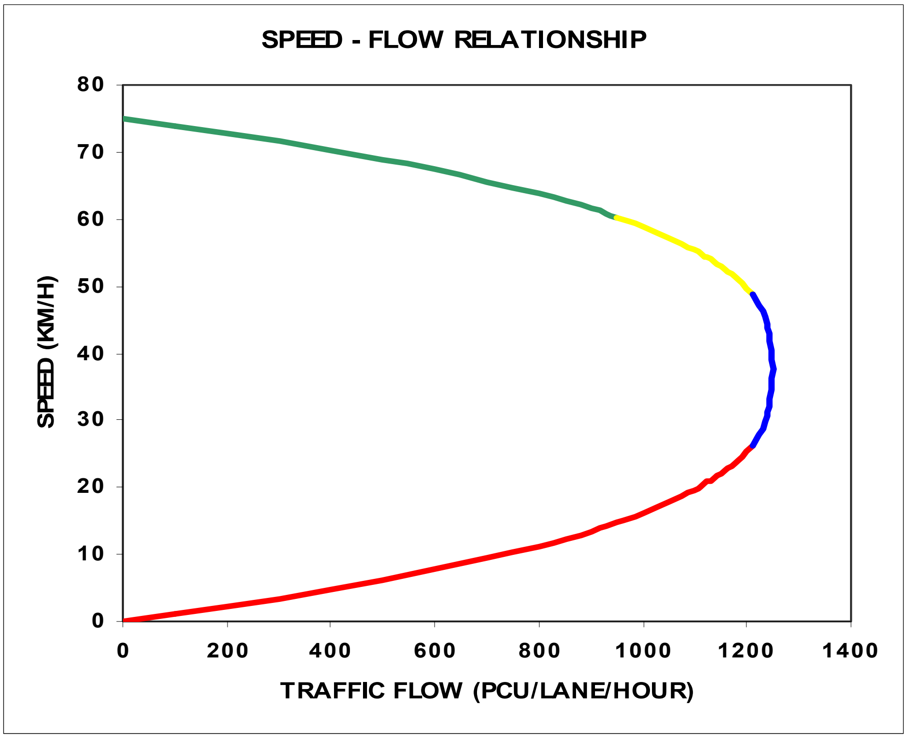
4.3.1 Congestion

For **congestion,** different approaches apply as a consequence of the central allocation of a fixed capacity to a limited number of known operators in rail transport and aviation. However many methods have been based on speed-flow functions (road transport) or delay-demand functions (rail and air transport).

[10] Not to mention additional emissions of pollutants and carbon dioxide resulting from additional fuel consumption at low speed: this is addressed in section 6 dedicated to external environmental costs.

[11] A phenomenon which currently happens in urban congested areas is by a bus being delayed because of traffic conditions and meanwhile waiting passengers abnormally accumulating at subsequent stops, with a result that not only the delay of this bus progressively increases at each stop but also this bus is finally caught up by the next bus of the same service: the service is disturbed altogether in terms of delay and irregularity.

Figure 1 Example of speed flow curve



An example of a speed-flow curve is shown in Figure 1 a single stretch of road: the capacity of the road is the value of the flow for the extreme right part of the curve; it is generally expressed in passenger car units (PCU) per lane per hour. The curve express the facts that:

- From free flow condition (i.e. when the demand-flow is very small) the speed slowly decreases with increasing flow along the upper part of the curve (green stretch of the curve).
- When the flow exceeds 75 to 80% of the capacity (yellow stretch of the curve), the progression of the vehicles is then under the form of continuous lines on each lane and taking over becomes difficult.
- At the approach of saturation (blue stretch of the curve), i.e. when the flow reaches the capacity level, the flow becomes unstable and speed varies erratically as flow progress under the form of a succession of accelerations and slowing down.
- If the traffic flow which tries to enter on the stretch of road being considered increases beyond the road capacity, the speed evolves as shown by the lower part of the curve (red stretch): density of vehicles along the stretch increases and vehicles are progressing 'bumper *against* bumper' at very low speeds, but the related flow is no more the demand at the entrance of the road stretch, but only the flow which is actually passing on the stretch, and the remaining part is queuing at the entrance of the stretch, but the curve cannot indicate how long it will be (red stretch of the curve).

In other words, as long as the demand does not exceed 80% of the capacity, the curve describes well the progressive effects of vehicles hampering each other progression. When demand approaches capacity, the curve becomes ambiguous because the relation between speed and flow is no more univocal, and if the demand increases beyond the capacity, the curve provides only with partial information about the traffic situation.

It should also be pointed out that in **urban areas** there are additional complexities resulting from the demand spatial structure, the intricacy of the network, the conflicts between flows at junctions and the related tailbacks when entering traffics exceed related capacities, to an extent that journey times often depend more on junction capacities and efficiency of the traffic control system than on the way traffic flows along street sections, which is something traditional speed-flow curves do not describe properly.

Main conclusion of this short review of advantages and demerits of methods solely based on speed-flow curves is that for the calculation of marginal external costs on the road network, when traffic demand on individual roads exceeds 80% of the related capacity, more sophisticated methods must be referred to in the view of estimating appropriate time-flow functions whose derivative will produce estimates of the marginal congestion cost. Instead of using 'static' methods based on speed-flow curves, such methods would have a 'dynamic' character, i.e. they should enable to simulate the progression of individual vehicles or platoons of vehicles considering:

- On the one hand the origin-destination and temporal patterns of the demand, the mix of trip purposes and the mix of classes of travelling vehicles.
- On the other hand the functional network description: links (road stretches), nodes (junctions) and their respective characteristics which significantly influence capacity, speeds and journey times.

Several traffic simulation software[12] enable to perform such tasks.

Congestion costs in individual transport

In general the preferred methodology starts from the assumption that the capacity of the commonly used infrastructure (road, rail and airports) is limited and that operating costs increase when these limits are approached. External congestion costs are furthermore extremely sensitive to small changes in traffic demand ad thus their internalisation by means of pricing will influence their level strongly. Most generally speaking, i.e. for a set of motorways and trunk roads in an interurban corridor or of the expressways, trunk roads and principal roads of an urban or metropolitan network, including interchanges and junctions, the methodology for individual transport comprises four major working steps.

Step 1: Classification and valuation:

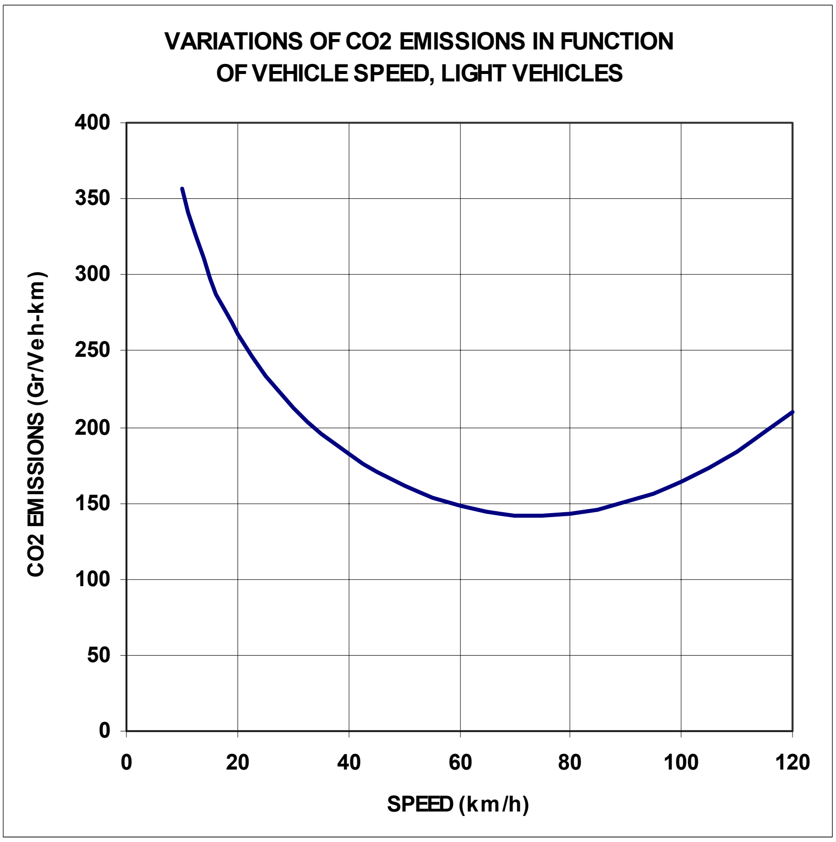
- Classification of road types on the basis of their carrying capacity measured in passenger car unit (PCU) per hour. Commonly it is distinguished between type or road (motorways, trunk roads, local roads etc) and the number of lanes.
- Selection of speed-flow curves: for each class of road specified above speed-flow functions for the selected types of vehicles are to be determined, or

[12] Such as SATURN, CONTRAM, VISSIM, etc.

selected from existing specialized works[13], so as to be able to take account of the capacity of the various links of the network.

- Identification and characterisation of junctions/interchanges on the basis of their number of entrances and exits, number of lanes per entrance / access, of which separate lanes for turning movements, traffic light cycles, etc, so as to be able to take account of the junctions/interchanges capacity.
- Classification of vehicles according to travel purpose, capacity use (equivalent PCU) and occupancy rate.
- Determination of cost functions based on journey time and value of time (VOT) per travel purpose, fuel cost and emissions functions per vehicle type and traffic condition (curves drawn from such functions are shown hereunder) and operating cots for freight vehicles if not contained in the related VOT.

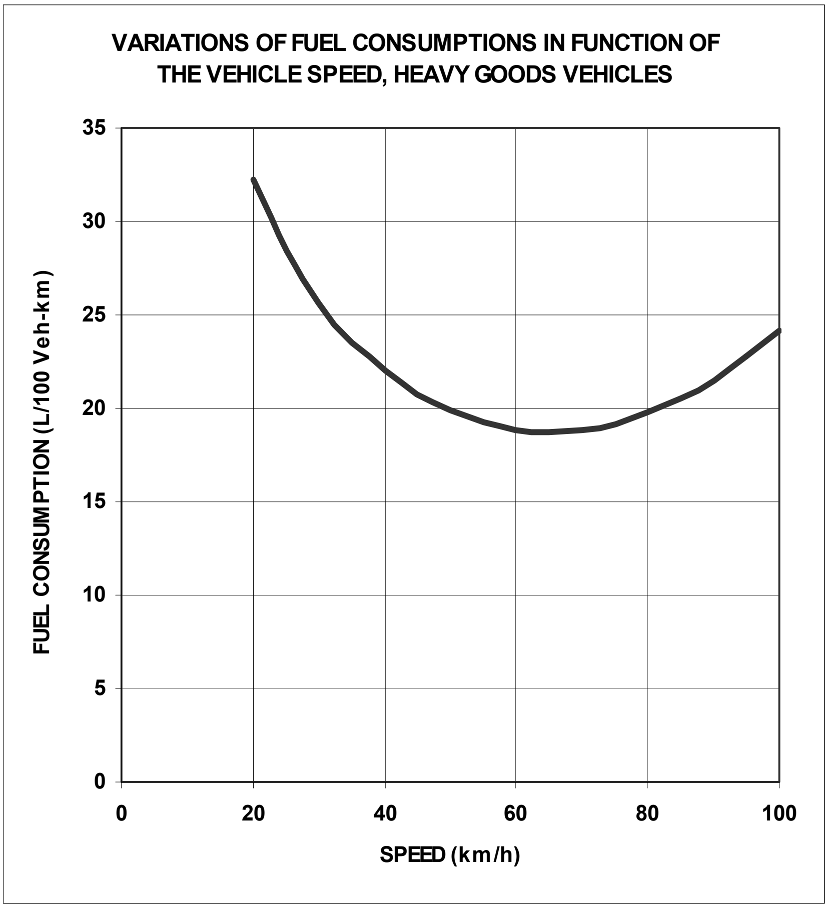
Figure 2 Variations of CO_2-emissions in function of vehicle speed, light vehicles



Source: MEET project

[13] It should be kept in mind that such curves have not always remained stable over a long period, and that they can also differ from country to country for the same class of road.

Figure 3 Variations of fuel consumption in function of vehicle speed, heavy goods vehicles



Source: MEET project

Step 2: Data collection:

- Travel demand data should be available under the form of an origin-destination matrix for the period of time being concerned, so as to enable simulation (see first bullet of step 3) of the demand supply equilibrium; an alternative solution consists of carrying out traffic counts on a certain number of sections of the road network being concerned and use a *matrix estimation* software to produce an origin-destination matrix on the base of:
  - these traffic counts.
  - an older origin-destination matrix which could thereby be updated.
- Distribution of traffic between vehicle classes and purpose of travellers: this data can be estimated through limited demand surveys.

- Determination of end users utility functions[14] based on attributes such as price, journey time and comfort so as to assess the demand reaction to variations of journey time, comfort and user costs. The reaction of traffic demand on raising user costs and reduction of journey times is a function of alternatives concerning the choice of mode, route and departure time or to give up travelling. This implies that alternative modes of transport should also be known at least in terms of cost and journey times and that the methodology would also enable to simulate the choices of users regarding choice of route and travel time.

Step 3: Costs computing:

- Identification of traffic conditions: for each road classified above: traffic conditions should be estimated in terms of PCU-km, speed and journey time per link (road stretch) and node (junction, interchange) on the base of travel demand and traffic composition (share of freight traffic, road public transport, commuters to/from work, commuters to/from school, professional or private purpose, etc). This task is currently carried out with the help of traffic assignment software, which simulates the route choice by the users, assigns traffic flows to the various elements of the network being concerned and thereafter computes related traffic conditions. Iterations are generally needed until equilibrium is achieved between traffic flows and capacities[15] of the network elements.
- Time values: determination of the time value per vehicle-km by demand pattern (mix of travel purposes), traffic condition and road type.
- User costs: by class of road, considering traffic pattern (vehicle classes and travellers purposes) compute costs functions including fuel and operating costs per PCU-km.

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[14] The micro-economic consumer theory is based on the concept of *utility*. Assuming that consumer n has to make a choice regarding several alternatives, utility of alternative i for consumer n is defined as:
$U_i^n = V_i^n + E_i^n$

Wherein V_i^n is a deterministic term and E_i^n is a random variable, and
$V_i^n = a_{i0} + a_{i1}x_{i1}^n + a_{i2}x_{i2}^n + \ldots + a_{im}x_{im}^n$

Wherein:
- x_{ik}^n are the relevant characteristics of consumer n and alternative i.
- a_{i0} is the basic bias, in favour or against alternative I.
- a_{im} are the respective weights of the various characteristics x_{im}^n.

The probability that consumer n will chose alternative i against any other alternative j is.
$P_n(i) = P_n(U_i^n \geq U_j^n)$.

Pn(i) can be estimated using logit models, such as:

$$P(i) = \frac{e^{Vi}}{\sum_j e^{Vj}}$$

Logit models are currently used to simulate traveller choices regarding mode of transport, route, departure time, i.e. to estimate the probability that the various possible alternative will be chosen. Logit models are to be calibrated on the base of revealed preference data or stated preference data.

[15] As the choice of route is based on journey time but in turn journey time depends on the number of vehicles. travelling along the various possible routes on the network.

Step 4: Computation of marginal external costs:

- Aggregation of PCU-km and user costs for the roads or the area being concerned.
- Step 3 and first stage of step4 are to be re-run for two or three travel demands of slightly higher levels than the existing one and for two or three travel demands with slightly lower levels than the existing one, in order to enable drawing a curve showing the variations of the user costs in function of the traffic expressed in vkm.
- The marginal external cost can then be estimated through subtracting the average user cost (i.e. the ratio of the total cost for all users to the total mileage travelled during the period investigated) from the derivative of the total user cost function (which can be approximated through the ratio of the increase of total user cost related to a small traffic increment[16]).

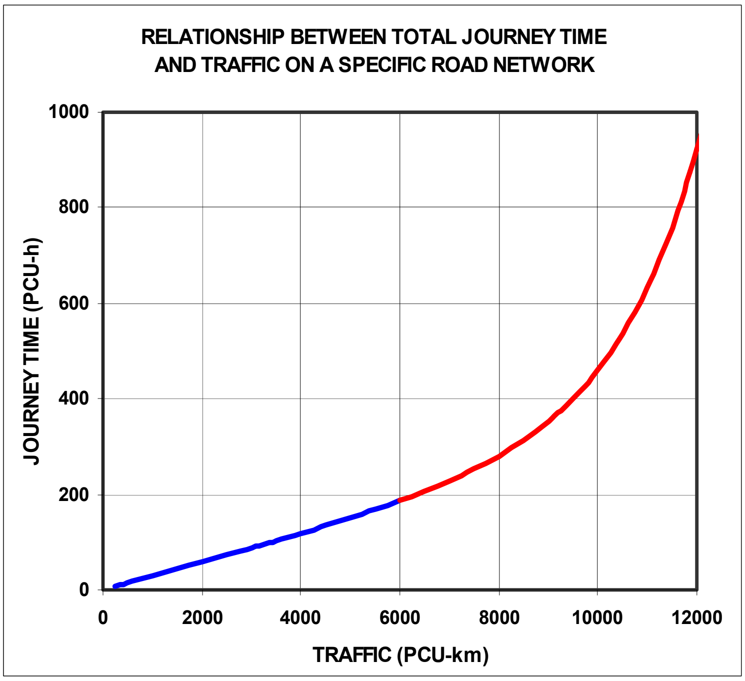
It must be pointed out that of all the user costs that are to be considered, the value of time currently represents 90% of the marginal external cost. A good approximation can thus be obtained through only taking the value of time into account.

It must be pointed out that of all the user costs that are to be considered, the value of time currently represents 90% of the marginal external cost. A good approximation can thus be obtained through only taking the value of time into account.

Hereafter graphs show the type of curves that can be obtained with the methodology.
The first graph shows the variation of the total travel time as a function of the total mileage travelled by the vehicles; It consists of two parts: the first one which is practically linear refers to the levels of traffic which do not bring about congestion; the second parts refers to traffic levels which provoke congestion.

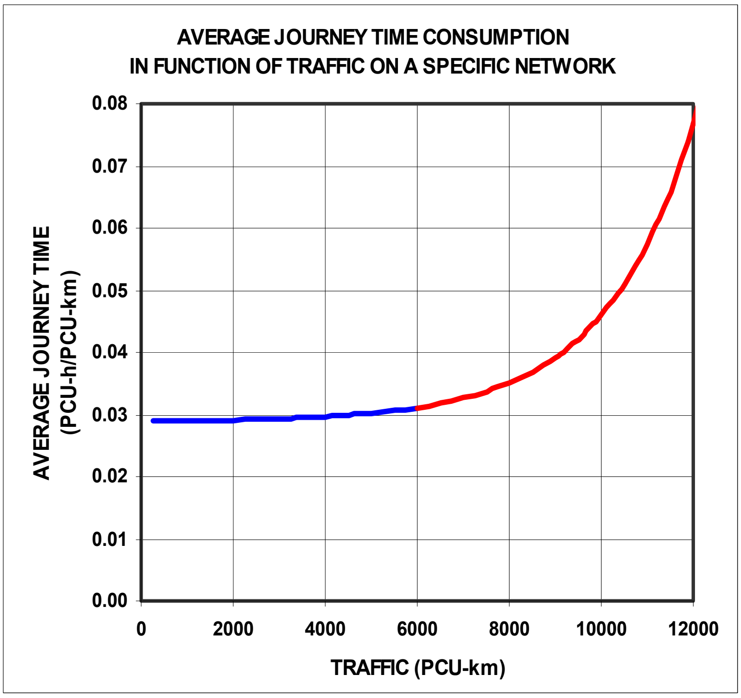
[16] A more sophisticated solution consists of calibrating a function on the base of the different levels of travel demand envisaged in the procedure and the related total user cost and to calculate the mathematical derivative of that function.

Figure 4 Variation of the total travel time in function of the total vehicle mileage



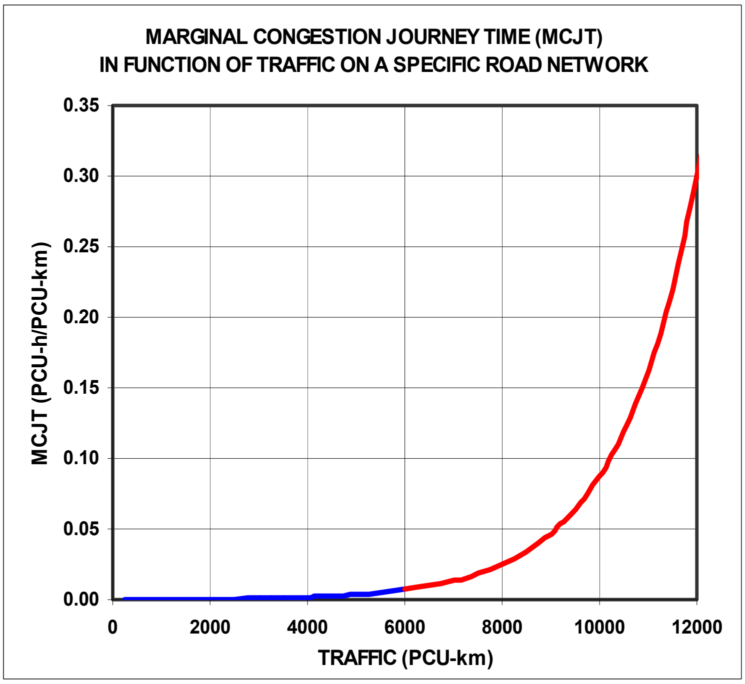
The second graph shows related variations of the average vehicle time travelled in function of the total travelled mileage, and the increase of the average travel time due to congestion.

Figure 5 Variations of the average travel time in function of the total travelled mileage



The third graph shows the variations of the marginal consumption of vehicle time in function of the total mileage travelled and its rapid growth due to congestion development.

Figure 6 Variations of the marginal congestion vehicle time in function of the traffic



Other simplification could of course result from a simple configuration of the infrastructure, for example a motorway comprising two or three stretches, for which computation of traffic conditions would likely be much easier, except if travel demand exceeds the infrastructure capacity and induce queuing.

Congestion costs in public transport

For **road public transport services** which share the road capacity with individual users the approach should of course be linked to the approach recommended for the congestion costs to individual transports. Some traffic simulation software[17] enables to take account separately of individual transports and public road transport services. The related methodology includes practically the same major steps as for individual transport.

The approach towards congestion costs in scheduled public transport operated on their own infrastructure is consistent with the methodology for individual transport. The extension to address the two-level problem of public transport is the determinant of the user costs, which is not only the number of users in the system, but also the number of carrying units (trains, planes, vessels etc), which of course is in turn depending on the number of users and the capacity of the carrying units.

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17 SATURN for example.

For **railway services** the delay of a single train can impact the progression of a more or less important number of trains during the highly trafficked periods, depending on the network configuration and the geographical and temporal patterns of the train services. A typical example for this is the case of the Belgian rail network wherein a high proportion (at least 75%) of the trains services are radial services across the whole Belgium, through the so called North-South Link (*Jonction Nord - Midi*) in Brussels. This link actually consists of a set of 6 tracks and is partly underground. During the daily morning and evening peak periods, trains are following each other on this link in a sort of continuous flow, and any single irregularity, resulting in loss of compliance vis-à-vis a service time schedule, can trigger disturbances to the progression of many other trains of several of the services being concerned. As far as these services are operated under the form of shuttles, these disturbances can be brought around in the country for long periods.

In this respect, it is interesting to note that a study is actually performed[18] for the *Syndicat des Transports d'Île-de-France* (as organizing authority for public transport), the *Société Nationale des Chemins de fer Français (SNCF)* and the *Régie Autonome des Transports Parisiens (RATP)* concerning irregularities on the express railway transport system in the *Île-de-France* Region. This study is aimed at addressing the irregularities topic for both the operator and end user point of view. It will comprise an extensive quantitative approach, under the form of a stated preference survey, with a view to calibrate utility functions - likely for the main travel purposes - and logit models to be used in assessing sets of measures aimed at improving the quality of regional railway services.

Findings of the analysis of the rail operation aspects were as follows:

- The proportion of trains being either delayed or discontinued amounts to 4 to 18% of the total number of trains according to the service.
- The process of trains being delayed currently starts early in the morning peak and develops during that period; recovery during off peak period is usually limited as disturbances subsist at beginning of the evening peak period and develops again until end of that period; disturbances can develop on lines with high frequency services as well as on lines which are less densely trafficked!
- Statistically speaking, main causes of disturbances observed for 2 services (Cergy le Haut - Paris Saint Lazare, a rather good one in this respect, and the RER C service Versailles Rive Gauche - Juvisy, a rather 'bad' one) and related frequency as compared to the total number of trains which were either delayed or discontinued:
  - External events (passenger uneasiness, suicide, people or animals on the tracks, etc: respectively 41 and 39%.
  - Rolling stock problems: 16 and 33%.
  - Track: 9 and 21%.
  - Energy supply: 8 and15%.

[18] By Rand Europe and STRATEC.

- More generally speaking, the operator insisted on:
  - The locomotives being 40 years old in the average and becoming less reliable as time goes by.
  - Part of the infrastructure having initially been designed for freight traffic and thereafter converted to passenger traffic without having been adapted to the related needs.

In other words, the major part of the disturbance causes of disturbances are is either external or peculiar to the Paris case.
Situation can differ significantly in case of long distance services with few connections with other parts of the network, or with specific infrastructure such as for HST services. In such case, densely trafficked stretches and periods can more easily be identified and the traffic which can be at the origin of delays can possibly be estimated in a less ambiguous way.

Generally speaking, it must also be pointed out that while congestion in individual transport has a rather deterministic and recurrent character (congestion always develops on a motorway whose traffic exceeds 80% of its capacity, which is currently during daily or seasonal peak periods) while 'congestion' in railway system typically has a random character: if services have been properly time scheduled with regard to capacities, and there is neither any loss of compliance vis-à-vis the service time schedules nor any technical problem nor any unexpected large number of alighting and/or boarding passengers, there would be no 'congestion', but if an event of that type occurs 'congestion' will develop although temporal traffic density remains unchanged. This has as a result that **we must speak here about 'congestion' probability**.

For **air transport services**, 'congestion' arises when a plane is delayed and it must be moved out of its original arrival/departure time schedule, whereby it imposes changes in departure or arrival times for other flights, which subsequently generates additional delays in a cascade type of effects[19]. If the airline operators cannot make up the initial delay through recovering time during the flight[20], delays are brought around to the various destination airports being concerned, and finally more or less amplified and brought back to the departure airport.

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19 This can also be amplified in case of airports with hub activities.

20 Because the distance is not long enough to enable time recovering, notably in case of domestic flights.

Consequently it is very difficult to link delays at a given airport to the airport were it was initially caused and to link them to the related level of traffic, unless data enabling to reconstruct the sequence of events being concerned (identification of successive delays for a sample of planes and flights and of their causes[21]) are actually available.

For air transport as well as for rail transport, it must be pointed out that the development of 'congestion' situations shows a random character as the occurrence of such situations is triggered by random events which do not result of variations of the temporal density of traffic.

Two conclusions can be derived from this discussion:

- For transport systems operated on their own infrastructure, the traffic which may altogether cause and/or suffer congestion must be very carefully identified, on the base of a case by case approach.
- For rail transport as well as for air transport, the occurrence of situations of the type which is evoked here above is usually triggered by random incidents[22] which are not caused by high levels of traffic, but whose impacts on progression of more or less important parts of the traffic are amplified and difficultly recovered due to high traffic levels or densities.

As far as methodology is concerned, few attempts have been made to date to produce estimates of marginal congestion costs for transport systems operated on own infrastructure with strictly limited access. The general idea is to estimate possible relationships between on the one hand indicators of the 'congestion' of transport services and on the other hand capacity use indicators or traffic level or density indicators, but in this latter case the type of infrastructure must be specified. Should also be considered as an explanatory variable the disturbances of external origin such as delayed arrivals of carrying units and possibly the importance of such delays.

Indicators of 'congestion' can be as follows:

- Number of carrying units[23] being delayed.
- Sum of delays of carrying units.
- Frequency of carrying units being delayed by more than x minutes and not more than y minutes, by more than y minutes and not more than z minutes, etc.
- Indicators of the same type as here-above but addressing related impacts for passengers, as measured.

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21 And if the initial cause of a flight being delayed is a technical default of the plane, which part of the delay is the airline responsibility and which part can be considered as due to too high a level of traffic at the airport where the technical problem has occurred, not to mention the fact that a flight delayed for such technical reason might itself become a cause of congestion if it is finally ready to take off at a time the airport is already highly trafficked. Similarly if a plane' arrival is delayed at a given airport and its departure from the same airport is also delayed, whose airport traffic can be considered as the cause of the second delay of the plane, notably in case the time elapsed between arrival and departure does not exceed the scheduled 'waiting' time.

22 Generally being referred to as 'traffic irregularities'.

23 Trains or planes.

- Either at the departure facilities (e.g. railway stations or airports) or along lines.
- During one year or parts of the year, for specific periods of the day (e.g. morning peak, off peak, evening peak).

Considering the random character of the causes of transport services irregularities and related ‘congestion’ impacts, the indicator(s) based on frequency of delays will be most promising for the analysis.

It must also be noted that data concerning compliance of rail or air transport services vis-à-vis the theoretical services timetables are generally available with more or less precision and detail, as is also the case for the number of passengers per plane while number of passengers per train is usually the matter of rather crude estimates.

Indicators of capacity use could be expressed as a percentage of the capacity which is actually strictly needed for the existing traffic in accordance with the theoretical timetable of the transport services.

In this respects, it must be noted that capacity of railway lines is not an univocal concept: if traffic is homogenous, in terms of train speed, stops, braking and acceleration features, security signalling systems, etc, capacity may be estimated in an univocal way, else it depends of the mix of type of trains, of possible clusters of trains of the same type. Generally speaking the higher the difference between the characteristics of the various types of train on the line, the lower the effective capacity of the line (or of the station/terminal). Estimating the capacity of a single line would therefore not always be an easy task, and carrying that exercise for a network or part of a network requires the use of sophisticated traffic simulation modelling tools.

Similar comments must be expressed for airports as capacity depends then on the one hand on infrastructures and facilities for planes (taking off/landing strips, runways, parking spaces, refuelling stations, catering, etc), for the passengers (land access, check-in and luggage handling facilities, security control equipments, etc) and of the characteristics of the planes (size, number of carried passengers, etc). Again, airport capacity is a complex concept.

Consequently, if the idea of referring to a capacity use indicator as an explanatory variable is attractive, it can in fact difficultly be put into practice, except for very simple cases. Independent variable to be referred to should be expressed in terms of carrying unit movements and exogenous disturbances, i.e. delayed arrival of carrying units.

The steps for a methodology based on the development of delay – demand functions could then be as follows for rail transport.

Step 1: Classification and valuation:

- Identification of traffics being concerned, i.e. traffics which can be involved in one way or another in the congestion development to be analysed.
- Identification of infrastructure being actually concerned (lies, terminals, junctions, etc) and of their relevant characteristics such as length, number of tracks per section and per direction, maximum allowed speed, signalling system (block lengths, etc.), conditions of station servicing (number of platforms, etc).
- Identification of the capacity of the various types of carrying units.
- Classification of passengers according to travel purpose, determination of value of time (VOT) per travel purpose.
- Determination of the transport service costs according to mileage and journey times, per type of transport service and carrying unit.

Step 2: Data collection:

- Traffic data: theoretical and actual timetables of transport services (including arrival time at destination(s), discontinued services, estimations of average patronage per train, number of passengers per leaving flight.
- Determination of end users utility functions based on attributes such as price, journey time and comfort so as to assess the demand reaction to variations of journey time, comfort and user costs. The reaction of traffic demand on raising user costs and reduction of journey times is also a function of alternatives concerning the choice of mode. This implies that alternative modes of transport should also be known at least in terms of cost and journey times.
- Distribution of end user traffic between type of services, type of carrying unit and travel purpose: this data can be estimated through limited demand surveys.

Step 3: Cost computing:

- Structuration of traffic data per time period, for example considering successive time periods of 1 or 2 hours during the day.
- Analysis of traffic conditions and estimation of relationships between 'congestion' indicators on the one end, traffic density and exogenous disturbances indicators on the other hand, i.e. derivation of regression functions linking the frequency of carrying units being either delayed by a certain amount of time, or discontinued[24], to the traffic density indicator and exogenous disturbances frequency; regression functions could possibly be differentiated according to relevant segments of traffic – characterised by type of carrying unit, transport service, category of destination or day of the week for example). Such functions could be expressed as follows:

$$FREQ_i\,(X < DELAY \leq Y) = f\,(AC_i,\ AC_{i-1},\ Ac_{i-2}\ \ldots,\ DAC_i,\ DAC_{i-1},\ DAC_{i-2},\ \ldots,\ LC_i)$$

[24] In such case it is assumed that passengers being concerned will have left with the next carrying unit of the same mode of transport that enables them to reach their final destination.

Wherein:

- $FREQ_i$ (X min < DELAY ≤ Y min) is the number of carrying units leaving with a delay of more than x min and not greater than y min during time period i.
- AC_i, AC_{i-1}, AC_{i-2} … are the number of carrying units which arrived respectively during time periods i, i-1, i-2, … with a delay of less than 5 minutes.
- DAC_i, DAC_{i-1}, DAC_{i-2} , … are the number of carrying units which arrived respectively during time periods i, i-1, i-2, … with a delay equal to or greater than 5 minutes.
- LC_i the number of carrying units due to leave during time period i.
- Time values: determine the value of the delay expectation[25] to passengers of the leaving carrying units, considering the related end user demand (mix of travel purposes) per time period and relevant traffic segment.
- User cost functions: compute cost functions including crew time, fuel or electrical energy, rolling stock maintenance and depreciation cost per train-km, per relevant traffic segment.

Step 4: Computation of marginal external costs:

- Aggregation of passenger time value and user cost functions per time period and relevant traffic segments.
- Per time period and relevant traffic segment, the marginal external cost can then be estimated through subtracting the average time value for passengers and operator costs from the derivative of the aggregated passenger time value and operator costs functions.
- Based on estimates of number of passenger per train; congestion costs per train.

Uncertainty

For the **individual road transport**, a major source of uncertainty in the proposed methodologies might appear to be the form of the speed-flow relationship and the influence of factors such as size and performance characteristics of the vehicle (e.g. a truck implies higher marginal costs due to its size, speed and other characteristics). The influence of the shape of the speed-flow functions on the level of external costs prior to capacity saturation is significant[26]. Even if the free-flow speed and the capacity of two road segments are identical, the marginal costs are much lower with a flat curve than with a curve which is exponentially declining.

For **public transport operated on own infrastructure** (rail and air transport), uncertainty would actually be linked to the more or less high level of significance of regression functions linking the frequency of carrying units being delayed to indicators of traffic density and exogenous disturbances.

[25] Based on observed frequencies.

[26] Even if the free-flow speed and the capacity of two road segments are identical, the marginal costs are much lower with a flat curve than with a curve which is exponentially declining.

4.3.2 Scarcity costs

Scarcity is the situation wherein transport services cannot be produced due to lack of infrastructure capacity. As far as individual transport is concerned, the scarcity concept doe not apply as long as there isn't any limitation to access to infrastructure and consequence of possible unsatisfactory capacity is through increased journey times, notably under the form of queuing. In case of infrastructures with strictly limited access such as airports and railway infrastructure the concept actually materializes through the process of slot allocation either between competing services in case of a single operator or between operators when several ones are potential users of the same infrastructure slots.

A major difficulty in assessing scarcity costs is the fact that 'victims' of scarcities cannot be easily identified in terms of number of passengers and demand structure, because they have either given up travelling or rescheduled their travel (change of travel time, route, or even mode of transport). Same consideration applies for freight traffic.

Also there are questions on how and when do end users perceive the absence[27] of a service as a consequence of scarcity. When is scarcity actually perceived as such? For example one can think that scarcity does not exist when frequency of a service is high as compared to the travel time. The problem is thus twofold:

- Which is the perception of scarcity by end users, how do they react in case of scarcity (rescheduling of the trip to be travelled, change of route, change of mode of transport), what is the consequence in terms of delay vis-à-vis the preferred departure and arrival times, comfort of the travel, and how do they value these dissatisfactions?
- What is the importance of scarcity, in terms of number of flights / train services not operated because of the lack of infrastructure capacity?

To date very little has actually been made in that direction. On can envisage three possible ways to obtain information on these matters:

- To survey a sample of end users using both the techniques of stated preference and revealed preference surveys; one can expect that interviewing frequent travellers will be more productive than interviewing casual ones, preferably at airports and railway stations where or wherefrom saturation of capacities is presently observed.
- To interview rail infrastructure managers and airport managers so as to identify possible scarce situations.
- To interview transport service operators whose marketing departments are expected to have some knowledge about the potential demand which cannot be accommodated as necessary slots are not available for trains or flights, and about the related turnover; This approach might enable to quantitatively estimate the relative importance of scarcity cases, in terms of services being

[27] And not forgetting that the absence of a service might also result from end user demand being low to an extent that no profitable service can actually be supplied.

not operated and number of disappointed passengers, to identify scarcity thresholds if any.

Two approaches can be envisaged to estimate scarcity costs: a market based approach and a cost-benefit one.

Market based approach

In a free market, the infrastructure manager would seek to charge operators according to what they are willing to pay and design transport service timetable that maximises its revenue. In theory, the most attractive way to simultaneously estimate scarcity costs and allocate capacity is through auctioning scarce slots. These would then go to the highest bidder and economic welfare would be maximised if the bids reflects the social value of the related transport service.

This does not allow however to acquire a convenient set of slots to provide an attractive timetable allowing good resources utilisation. To overcome this difficulty, allocation of rail slots is the subject of a negotiations procedure whereby, in reply to operator requests, the infrastructure manager designs sets of slots that could be operationally attractive. Operators in turn possibly adapt their requests until an agreement is completed. This procedure is performed once or twice a year on the base of a predetermined fixed calendar.

In air transport where there is little political involvement on how air services are provided and private initiative is more and more predominant, there is almost no use of auctioning and in EU airports scarcity is not taken into account in designing landing charges which are essentially aimed at recovering airport costs. This is however a matter of concern of the Commission and the problem has recently been reviewed[28] with an aim to design solutions to remedy the present inefficiencies.

Regarding the inefficiencies, the situation is as follows as a consequence of using an administrative procedure and charging airport costs[29] instead of relying on market mechanisms and airlines' willingness to pay for slot allocation.

- The most important factor is the inertia of the existing system: at congested airports, airlines will wish to continue to use slots which they have historic rights provided that they can make a marginal profit on the service; there is limited scope that slots could be sold within the existing framework, even if other airlines are disposed to value them more highly. The resulting lack of slot mobility makes it very difficult to obtain a series of slots to launch or develop a service: at congested airports slots tend to be available at unattractive times or are not available for a series. This is a barrier to competition as new services may not be launched and attractive services cannot be expanded[30]. The barrier affects new entrants and competitors to incumbent airlines in particular, but may also prevent incumbents from improving their network of services.

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28 NERA, 2004, *Study to Assess the Effects of Different Slot Allocation Procedures*.

29 Not forgetting that allocated slots are not charged when they are not used.

30 Except if slots have been obtain through secondary training or leasing agreements between airlines.

- The lack of entry opportunities reduces the competitive threats faced by incumbent airlines and weakens the incentives to reduce costs, and cost minimisation is unlikely to be achieved.
- Another form of inefficiency is slots that have been allocated to airlines are not returned to the pool in good time to participate to the bi-annual allocation sessions as there is neither incentives nor administrative constraints to do so, and it will not be possible to reallocate the slots which are returned late.
- Even at airports where airlines demand exceeds available capacity, slots are not used efficiently as it is airlines' interest to request more slots than they really need to benefit greater flexibility in finalising their schedule when they do not bear the real slot opportunity cost. Statistics of actual slot use show that in airports where demand exceeds capacity, actual use is significantly lower than the allocated movements, and slots may be kept by airlines under condition it is used at least 80% of the times.
- The existing system is an incentive to operate services at high frequency with small aircrafts, while it would be more cost efficient for the airline as well as for the airport to reduce frequency and use larger aircrafts.

Market mechanisms are expected to have the potential to improve efficiency as it can be ensured that slots are allocated to those airlines that value them most, in contrast with the present administrative procedure under which slot allocation is based on criteria such as historical precedence which have nothing to do with the airlines' willingness to pay.

The market mechanisms being envisaged are as follows:
1 **A secondary trading mechanism** whereby desired adjustments would take place under the form of bilateral agreements between airlines: it is easy to implement, but potential compatible sellers and buyers might not be able to identify each other, and airlines might ignore the potential proceeds from selling their slots and continue to run services that fail to make efficient use of scarce capacity.
2 **A primary trading procedure whereby airports would sell available slots to airlines at higher posted prices** with a view to clear the market level of prices, but administrative primary allocation procedure and criteria will still be needed, and residual inefficiencies are therefore likely to remain.
3 **A combination of a primary trading procedure based on higher posted prices and of secondary trading mechanism**: it might have the greatest potential to achieve the allocation of slots under the ideal market mechanism as engaging in secondary trading may help to address residual inefficiencies that would not have been cleared by the higher posted price; however secondary trading might not be effective enough in fine tuning the allocation of slots among those airlines willing to pay the higher posted prices.
4 **A combination of a primary trading procedure implying auctions of the pool of available slots and of secondary trading mechanism**: it also has a potential to achieve substantial improvements in the slot allocation. For existing slots it allows secondary trading, and for newly created slots it enables achieving a more efficient initial allocation.

5 **A combination of a primary trading procedure implying auctions of 10% of the slots and of secondary trading mechanism**: theoretically it should produce the most efficient allocation of slots possible, but in practice the auctions are going to be very complex for the auctions organisers as well as for the airlines bidding for slots and it is probably unlikely that an efficient allocation of slots will result from its implementation.

At congested airports, passenger numbers are likely to increase for the following reasons:

a A shift in the mix of services using congested airports, notably an increase of the proportion of long haul services.

b A general shift to services with higher load factors within each category of services; within short haul services, some regional services and services operated by full service carriers other than the hub carrier will be withdrawn and more services will be operated by low cost carriers; some of the least profitable long haul services will also be withdrawn.

c Airlines will shift services to off-peak times or to uncongested airports when possible; this will most likely affect charter services and perhaps some long haul services and will free capacity for other services. For many services however shifting to off-peak times or uncongested airports will not be a realistic option.

d Slot utilisation will improve as the fact that airlines pay higher prices for slots will be an incentive to reduce the number of slots that remained unused during congested periods or to sell to other airlines the slots which they don't actually.

At present, slot trading has only taken place in four major US airports[31], for domestic services only, and in London airports:

- In US airports, trading was on the base of bilateral negotiations between airlines and facilitated by regular meetings organised by the Air Transport Association. Slot brooking activities also developed in these airports. When this was made possible, substantial numbers of slots were initially traded and since the trading activity has decreased and became rather uniform. A result has notably been the increase of the slot share by major airlines, but it is not obvious whether this reflects efficiency improvement or anti-competitive behaviour.
- In London trading was mainly by British Airways notably to consolidate its long haul operation at Heathrow.

Available literature doesn't bring any information regarding the financial aspect of existing trading activities.

To go back to the railway side, Directive 2001/14 seeks to circumvent the problem of incentives to the appropriate use of scarce resources by requiring rail infrastructure manager to undertake studies in the view of determining the cost of expanding capacity and testing through cost-benefit analysis whether it is justified.

31 JF Kennedy and La Guardia in New York, O'Hare in Chicago and R Reagan National in Washington.

Cost-benefit approach
In great Britain, the Strategic Rail Authority has decided in favour of a planned approach based on cost-benefit analysis. This could enable to determine the opportunity cost of any particular allocation of a slot, but information requirements are considerable: it is necessary to know what type of train would be displaced and what would its passengers do: take another train at another departure time, route or speed, chose another mode of transport or not travel at all. Results of methodological research undertaken in this view have been gathered in the Passenger Demand Forecasting Handbook which provides guidelines to study the value people place on departure time shifts to estimate the value to its customers of the cost of travelling earlier or later than they wished, or to travel at lower speed based on passenger value of time. If passengers would use another mode, it is also necessary to know the costs involved. In case of roads this means the type of road and time of day since the marginal social cost of road use vary greatly with place and time.

4.4 Applications

In recent years in different studies congestion costs have been estimated. In Table 5 is given an overview of the results from the most important studies. Congestion costs have especially been calculated for road transport. For rail and air transport, methods for estimating congestion have rarely been implemented. Arguments are that congestion for non-road modes is internal (particularly if only one service operator exists) or is overcome through realistic timetabling, have often dominated. For rail and air regression analysis to relate delays to capacity utilization has been undertaken.

Road
The marginal road congestion costs have been addressed in UNITE both at urban and inter-urban level: corridors for passenger and freight transport at inter-urban level, and four urban cases. The methodological approach adopted varies from the application of speed-flow relationships defined at inter-urban level to traffic models with the definition of speed-flow curves per link at urban level.

Marginal congestion costs have also been estimated by the [INFRAS/IWW, 2000] study for the European main road network through the use of continuous speed-flow relationships for different classes of roads and vehicle types, where the basic input is provided by the European Road Traffic database. The use of speed-flow relationships, which provide empirical relationships between traffic, capacity and speed of a given road, have also been taken into account for the estimations carried out in RECORDIT (freight traffic) on specific corridors.

Other approaches are based on exponential congestion functions like in [TRENEN, 1999] relying on extensive tests with detailed urban network models in cities with different structures and on speed flow relationships calculated[32] from the UK National Road Traffic Forecast database. This study calculates speed-flow curves by area types (London and conurbations) and road types

[32] By Sansom et al. (2001).

(motorways, trunk and principal and other); however it calculates marginal cost for existing rather than optimal traffic volumes and is therefore naturally much higher than estimates at the optimum.

Discrepancies, particularly at the urban level between for example UNITE and TRENEN, can be explained by the adoption of different time values, as well as by specific methodological aspects that can hamper comparisons (the UNITE urban marginal congestion costs for instance are expressed in €/pcu-km, the other studies in €/vkm). In fact, the UNITE urban case studies include smaller cities such as Edinburgh and Salzburg while estimates from other studies relate to large conurbations such as London, with presumably higher congestion costs. Furthermore, congestion costs are strictly related to the specific characteristics of the routes, i.e. traffic volume, infrastructure bottlenecks, etc.

Data from Table 5 and Table 6 gives an overview of the variation of marginal road congestion costs, as estimated through using modelling tools. What must be noted on this table is the rather wide range of variation of the marginal congestion costs, whatever be the source, which means that there exists a wide range of possible situations for urban traffic as well as for interurban traffic. For urban situations for example, the size of the urban areas and the land use density would likely explain differences between marginal congestion costs estimates. In a study[33] performed by CE Delft, 4cast and the *Vrije Universiteit Amsterdam*, estimated optimum congestion charges on the interurban Dutch primary road network varied from 1 to more than 50 €cts.

[33] Returns on Roads, Optimising road investments and use with the 'user pays principles', 2002.

Table 5 Comparison of marginal road congestion costs

Type of network	Period of day	Class of vehicles	Costs (€ ct/vkm)	Study
Urban	Peak and off peak	All	2 - 40 (1)	UNITE
Major urban	Peak	All	34.3 - 128.6	DETR, Surface Transport Costs and Charges (1998)
	Off peak	All	16.6 - 70.7	
Interurban	Peak and off peak	All	2.8 - 329.2	IWW – [INFRAS, 2000], average data from European countries
Brussels	Peak and off peak	All	0.4 - 131.5	[Mayeres et al,. 1996]
Urban trunk and principal		All	104.5	Central London
Interurban	Peak and off peak	Passenger car	0 - 15	UNITE, Paris - Brussels and Paris - München
		All	1.2 - 216.1	[IWW - INFRAS, 2000], average data from European countries
		Freight vehicles	0 - 0.7	UNITE, Köln - Milan and Duisburg - Mannheim
Motorway		All	19.19	DETR, Surface Transport Costs and [Charges, 1998]
Rural trunk principal			13.66 - 13.81	
Motorway	High congestion	HGV	28.1	ARUP, SRA, data par HGV-km
	Medium congestion		13.7	
	Low congestion		2.3	
London and conurbation, trunk and principal		HGV	71.2	ARUP, SRA, data per HGV-km, London and Conurbations
London and conurbation, other roads			78.7	
Rural and urban, trunk and principal		HGV	27.0	ARUP, SRA, data per HGV-km
Rural and urban, other roads			2.4	

(1) In € ct/PCU-km instead of € ct/veh-km

Table 6 Congestion costs of heave goods vehicles, per type of area

Area type	Area size (km^2)	Congestion cost (1) (€ ct/HGV-km)
Central London		311.8
Inner London		182.8
Outer London		95.6
Central Conurbation		151.0
Outer Conurbation		81.6
Urban	Greater than 25	18.7
	15 to 25	10.6
	5 to 15	2.4
	Less than 5	2.3
Rural		20.3
All types of area		20.4

(1) In 1998 prices
Source: ARUP, SRA, Revaluation of the marginal costs and revenue impacts of transferring freight from road to rail (2002)

Congestion costs for scheduled services (Rail and Air)

In general it is regarded to be debatable to what extent congestion costs (external user costs generated by marginal users' decisions) arising from delays in scheduled transport can be properly defined as 'external', since the impact of an additional unit of traffic demand can be anticipated by the planner (rail operator). Only those costs imposed by one operator on another are truly external.

Within UNITE the overall methodology used was regression analysis relating delays to volume of traffic. In the case-studies of UNITE different approaches are used that differ considerably and no single one dominates. The approaches differ at the use of regression analysis to assess (linear) delay-demand functions, the different cost drivers taken into account and the relationship with capacity utilization. UNITE concludes that the precise methodology depends strongly on the specific situation and is still of an experimental nature.

An alternative approach towards the quantification of marginal external user costs in public transport for urban areas is developed by TRENEN II STRAN project[34]. Here, link-related speed-flow relationships have been replaced by area-related functions, which have been estimated using a set of relationships between total mileage performed in the network and the related average travel speed in the area considered. In general in the UNITE approach it is recommended to compute marginal costs on a link/node-cluster basis. However, in a pragmatic way also TRENEN-approach might be applied here.

In the UK, rail congestion costs arising from an additional train and the corresponding delays have been estimated[35] through running a simulation model provided by Railtrack. Concerning freight services, due to the higher degree of flexibility in scheduling, and the preferred use of off peak slots, congestion costs imposed to others are assumed to be low and are consequently excluded from the analysis.

Approximately for passenger rail transport congestion costs amount to € 0.298-0.719 per train-km during peak and € 0.077 -0.191 per train-km off-peak.

No estimation is provided for marginal congestion/delay costs in aviation. A case study[36] exists for a flight from UK to Palma de Mallorca. However, this study does not relate delays to capacity utilisation. A case study has been performed for the situation of Madrid airport[37] during the months of July 1997 to 2000, but the estimated marginal congestion costs were in terms of cost per flight delayed by more than 15 min at arrival (€ 7,100.00 in July 2000) and at departure (€ 6,700.00 in July 2000) and not in function of the airport capacity.

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34 Proost et al., 1999.

35 Sansom et al (2001).

36 By TRL, et al. (2001).

37 UNITE, Case Study 7i.

Scarcity costs
In general the assessment of opportunity costs of scarce railway and airport capacities remains a difficult and under researched area. The analysis of slot trading mechanisms and marginal willingness to pay for additional slots (for air and rail transport) should provide opportunities to improve the situation.

4.5 Analysis of discussion points

Congestion costs
Methods for the calculation of congestion costs do differ between the different modes, or do differ between individual and public transport on the other hand. With regard to individual and commercial transport like road transport the use of speed - flow function has been accepted and applied.

However, as has been underlined above, using the speed - flow function does not produce reliable values for urban networks and at the approach of saturation and specialized traffic simulation modelling techniques should then preferably be used.

With regard to public transport like rail transport and aviation discussion is much going about the question whether there is congestion. Arguments are that congestion for non-road modes is internal or is overcome through realistic timetabling, have often dominated. What actually happens is that single irregularities due to random causes can generate significant disruptions vis-à-vis the transport service time schedules because of high level of end user demand and related traffic density. If congestion costs are calculated unanimously the use of delay - demand functions or delay - capacity utilization functions is generally accepted, under condition that they have been inferred from a careful analysis of the congestion phenomenon whereby links between delays and the traffic being actually involved have been clearly identified.

Scarcity costs
Conclusion from reviewing previous works shows that dealing with scarcity is actually at an experimental stage.

4.6 Recommended methods

Congestion
For the calculation of marginal congestion costs in road transport, considering the imperfections of methods based solely on speed - flow functions, alternative methods should be envisaged that enable to be altogether more rigorous and more transparent regarding the effects of congestion, in particular tailback process. This implies off course that the traffic conditions should be estimated at an area level so that interactions between links could be properly be accounted for. Speed - flow functions could however be used on single interurban links were traffic flow does not exceed 80% of the capacity, under condition that there is no tailback from the next link(s) or at the next junction / interchange.

As at the level of the link-node pairs the variability of congestion costs can be confusing[38], in particular in urban regions, it is also recommended - in particular in the view of installing a congestion pricing scheme - to envisage methods whereby links and nodes can be aggregated through production of travel time - traffic functions at an area' network level[39]:

- In urban areas - where links and nodes are by nature interacting very tightly with each other as regards traffic conditions and congestion - considered as a whole for small entities or as a set of two or three areas of a more or less homogenous type (in terms of land use density, type of land use, road network structure and density, level of service of public transport, etc) for medium and large urban areas and metropolitan areas.
- Under the form of corridors or parts of corridors for interurban relations.

Models simulating dynamic traffic conditions in urban areas or corridors should be used to produce estimates of the total vehicle-km travelled and total vehicle-hours spent in the areas being considered for several levels of road traffic and to infer appropriate travel time - traffic functions; such functions can even be differentiated according to classes of vehicles (private cars , freight vehicles, public transport vehicles)as available software's enable to take account of several vehicle classes.

Performing typical case studies (in terms of area types and levels of traffic) should enable to derive typical travel time - traffic functions that should be transferable to areas with similar characteristics (in terms of size, network structure and density, traffic patterns).

In case of charging significant costs on users, it must be expected that users change their behaviour, in terms of change of departure time or of (combination of) transport mode. Calibrated utility functions and logit models would therefore be needed to assess such changes and estimate the new equilibrium and related congestion costs.

For congestion of rail and air infrastructure the recommended approach is to regress delays on measures of capacity utilization (delay - demand function), including where possible variables that are likely to affect the relationship, such as the nature of the infrastructure and the type of traffic.

Scarcity
Recommended approach would be, after identification of sites where scarcity actually happens, to estimate, on the base of data collected from transport operators being concerned, the type of scarcity (lack of capacity on a railway line, a railway station, a departure airport, an arrival airport, etc) the number of impacted potential passengers and importance of delay suffered vis-à-vis the preferred time schedule. As far as capacity is saturated at least at one of the steps of the trip, it is of little interest to try to infer delay - capacity utilization functions. It should likely be more productive to infer distributions of delays in function of the characteristics of the demand: purpose, departure site, destination

[38] It can even become infinite on links where traffic is completely blocked.
[39] Which is similar to the concept used by TRENEN.

or line being concerned, preferred route and/or departure time, etc and value these delays on the base of known values of time.

A more sophisticated approach would be to value the delays on the base of end users utility functions, but this implies more work in passenger surveys and utility functions calibration.

4.7 Data requirements

4.7.1 Individual and commercial transport, public road transport

For Individual and commercial transport (congestion); the problem is two fold:

- The data that are needed to derive a comprehensive set of travel time - traffic functions.
- The data that are needed to use these functions for congestion costs estimations.

To derive travel time (in vhours) - traffic functions (in vkm), the following data is required:

- Value of time by travel purpose.
- Operating cost functions.
- Spatial structure of the demand, i.e. number of vehicles of each class being considered by origin - destination pair during the studied period in the existing situation.
- Vehicle occupancy rates.
- Area' network description: travel time on links (speed-flow curves by type of infrastructure in case of long interurban stretches), capacity layouts and traffic light cycles, etc.

To use these travel time - traffic functions, following data are needed:

- Value of time by travel purpose.
- Operating cost functions.
- Total traffic in the area or on the link/stretch being considered (in vkm).
- Vehicle occupancy rates.

In addition, if time or modal shifts must be estimated, appropriate utility functions and logit models would be available.

Availability of data
In practice data availability is often a problem for road transport as currently the available one lacks the required comprehensiveness, notably regarding demand features.

4.7.2 Public transport operated on own infrastructure

For Public transport (congestion and scarcity) the problem is twofold as well as it is for road transport:

- The data that are needed to derive a comprehensive set of delay - traffic (or delay - capacity utilization) functions or distribution of delays due to scarcity.

- The data that are needed to use these functions for congestion costs estimations.

To derive delay - traffic (or delay - capacity utilization) functions or delay distributions, the following data are needed regarding the site being concerned for the period being considered:
- Carrying units scheduled traffic.
- Recordings of delays and delay causes.
- Passenger traffic.

To use the delay -traffic (or delay - capacity utilization) functions, the following data is needed:
- Value of time by travel purpose.
- Price-elasticity of demand by travel purpose.
- Delay - traffic (or delay - capacity) functions.
- Vehicle occupancy rates.

Availability of data
For rail and air transport data availability concerning delays and traffic would likely be often available, as well; as unit value of time. Data concerning demand might likely be scarce.

4.8 Literature overview

Besides the six studies mentioned in section 1.2 the following studies have been used to compose this overview:
- FISCUS, (1998a), Cost Evaluation and Financing Schemes for Urban Transport Systems, Deliverable 3, Real Cost Scheme, Karlsruhe / Lissabon
- FISCUS, (1998b), Cost Evaluation and Financing Schemes for Urban Transport Systems, Deliverable 2, External Costs, State of the Art, Karlsruhe / Lissabon
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- TRENEN II STRAN, (1999), Policy Analysis for Externalities in Road Transport: Models and Results, Brussels
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- Link H, 2003, *Rail Infrastructure Charging and on-Track Competition in Germany – Nine Years after*, Proceedings of the European Transport Conference

- Nash CA, Matthews B, 2003, *Rail Infrastructure Charges – The Issue of Scarcity*, Proceedings of the European Transport Conference
- Wardman M, Shires J, Lythgoe W, Tyler J, 2003, *The Benefits and Demand Impacts of Regular Train Timetables*, Proceedings of the European Transport Conference
- NERA, 2004, *Study to Assess the Effects of Different Slot Allocation Schemes*, Final Report for the European Commission
- Reforming Transport Pricing in the European Union, edited by De Borger B and Proost S, 2001, Edward Elgar Publishing Limited

5 Marginal external accident costs

5.1 Introduction

By entering the traffic flow, the user exposes himself to the average accident risk in that specific transport mode. In his decision he internalises the risk he exposes himself to. At the same time, however, he can affect the accident risk for all users of the same mode. Finally, his entrance exposes users of other transport modes (for example walkers and cyclists) with an accident risk; this risk may also increase, decrease or stay constant. The economic values assigned to the consequences of the entrance of an additional user express the marginal accident costs [High Level Group, 1999].

The total marginal accident cost is the extra cost imposed by a user on all other users (including himself) ad the general public to his travel decision. The user internalises in his decision the risk he exposes himself to, valued as his willingness-to-pay for safety. The marginal external accident costs refer to the change in accident costs of other users due to the entrance of the additional user; the external marginal accident costs also represent the remaining costs after internalisations. These costs include repair costs, medical costs, suffering and delays imposed on others as a result of an accident.

An additional infrastructure user influences the risk rate. If the risk rate is increased, clearly the marginal external accident costs are positive. It has been argued that in certain cases the risk rate may decrease with the entrance of additional users. An example might be the introduction of relatively slow traffic, which leads other infrastructure users to be more cautious. This effect can, al least in theory, be so large that the marginal external accidents costs might actually be negative.

Risk elasticity
The relation between imposed cost and travel decision is determined by the relationship between traffic volume and risk, i.e. the risk elasticity. The risk elasticity expresses the percentage change in the accident risk in response to a one percent increase or decrease in traffic volume. When an additional user is victim of an accident, the only externality is the cost imposed on the general public due to his travel decision, the costs are internal (not external). However, in case when he is an injurer (the additional user is the cause of costs for other users) all costs are external except for paid compensation and fines. External costs depend on (risk) elasticity.

5.2 Key cost drivers

With respect to marginal external accident costs, the weather conditions are an important cost driver. In rainy weather marginal accident costs are higher than at a sunny afternoon. Below attention is paid to the key cost drivers for marginal external accident costs. The cost drivers[40] are distinguished by mode: road, rail and air.

Cost drivers in road transport
For road transport the most important cost drivers are the *vehicle speed* (in general the higher the speed compared to the speed limit the higher the risk[41]), the *traffic volume* (more traffic in general increases the accident risk, although also the opposite can occur in already busy road conditions)*,* the *infrastructure type* (generally highways are safer than rural roads) and *driver characteristics*.

Closely related to the above mentioned cost drivers are cost drivers like vehicle type (generally a passenger car has lower accident costs than a heavy goods vehicle), location of road, weather and climate conditions, composition of traffic, time-of-day and consumption of alcohol and drugs: Consumption obviously increases the accident risk. In addition is the proportion of costs already born by the user is an important cost driver; in many countries road users are insured against road accident, in this way road users don’t have to pay the full costs when being involved in an accident.

Cost drivers in rail transport
In rail transport the *type of level crossing* with road infrastructure is one of the most important cost drivers. Roughly three types of level do exist: barrier, open cross, unprotected. In practice the less protected a level crossing is, the higher the risk of accidents. Directly related to the type of level crossing is the location of the level crossing (inside or outside a city), the time-of-day (at night road users passing an unprotected level crossing are less cautious than during the day).

Information on cost drivers of train-train collisions is scarce. Rail transport is a kind of regulated transport. One cannot enter the rail track any time one wants in contrast to road, not withstanding trains can collide with each other when access to rail track is given by mistake.

Cost drivers in aviation
For aviation not much research has been carried out into the cost drivers of accident costs. One could assume the *traffic density, the maintenance level of aircrafts and guidance systems (at sight or by computer), the education level of the pilot and the weather* to be key cost drivers.

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[40] The discussion on cost drivers is based on UNITE deliverables 3 (The marginal cost methodology) and 15 (Guidance on adapting marginal cost estimates).

[41] Obviously risks also occur when driving below the speed limit.

5.3 Current methodologies

The risk elasticity approach
The issue of valuation of marginal accident costs is complicated. Different approaches do exist. The so-called risk elasticity approach is applicable to all modes of transport and is recommended. This approach considers the risks that a user imposes on himself, on others using the same mode, and on users of other modes (including pedestrians). In addition, the way in which such risks vary with an additional unit of traffic, i.e. the risk elasticity, is also incorporated.

The methodology of the risk elasticity approach consists out of four steps:

- The first step is to estimate the risk for injurers (user that causes the accident) and victims (user that suffers from accidents).
- The second is to apply risk elasticity. For this one estimates the relationship between traffic volume and accident frequency; and calculate the marginal increase of the expected number of accidents. For example if traffic volumes increase with 5%, accident levels will increase with 2%. Information on risk elasticity will be taken from case-studies, literature review or planning models. The risk elasticity only focuses on the relationship between traffic volume and accident frequency. Other ‘risk drivers’ like time-of-day, speed, gender etc are taken into account in the determination of the risk for injurers and victims in the first step of the methodology.
- The third step is to evaluate the monetary value of these changes by the means of willingness-to-pay/avoid method. The so-called value of statistical life (VOSL) is a term often used to express the individual’s willingness-to-pay for safety. The marginal cost is the change in the frequency of accidents multiplied by the costs per occurrence.
- The fourth and last step is to estimate the parts of this added cost that are internal and external by correcting these costs for paid compensation and fines that are internal costs. The difference between the marginal accident cost and the internal/private cost gives the external marginal accident cost.

Other approaches
Besides the risk-elasticity approach there are several other approaches. Many studies on marginal accident costs in the past have failed correctly to distinguish between internal and external accident costs or used simple average figures. As a consequence average costs were calculated and not marginal costs.

Frequently approaches based on cost allocation are used. The external accident is often seen as an average cost with some assumptions on internal and external components and an allocation of the cost between categories and modes. Although theoretically less satisfactory, does the cost allocation approach have its merits. It is application is much easier and data availability is better.

With regard to the risk-elasticity approach the actual estimation of the risk-elasticity is often the largest problem. An alternative approach is to use planning models. For example the manuals for the Swedish Road Administration propose a model to estimate the number of accidents in level road crossings. From this model the relevant elasticity can be derived. This method was used in the PETS-project where elasticity's were taken from road planning models in Sweden and the United Kingdom.

So far research has focused on marginal accident costs for road and rail transport. Aviation has hardly received any attention.

5.4 Applications

In recent years in different studies marginal accident costs have been estimated. Below an overview is given of the most important studies. Marginal accident costs have especially been calculated for road and rail transport. The general pattern arising from these case-studies is that external accident costs are found to be quite low for all modes. An explanation is that typically increasing traffic results with a less than proportionate increase in accidents.

Road
Marginal road external accident costs have been estimated in two UNITE case studies. The methodology is based on the calculation of risk values combined with values of statistical life (VOSL). A crucial issue is whether to assume that the mean accident risk has been internalised. If not, the results are in the same order of magnitude as those from other studies that follow a similar approach, [i.e. PETS, 2000], the [SIKA (the Swedish Road Administration) study, 2000] and the UK study [Sansom et. al., 2001]. Approximately marginal accident costs for urban roads are between 1.76 and 4.31 €ct(1998)/vkm. At interurban roads for passenger cars estimates of marginal accident costs vary between 0.87 and 2.77 €ct/vkm, for freight traffic between 1.14 and 2.46 €ct/vkm.

Rail
In general, there is only little information available concerning the relationship between train frequency and accident risk. The available estimates of marginal accident costs for rail can be classified in two categories, depending on the scale of analysis:
1 Studies carried out at wide area level, i.e. a country or the whole of Europe.
2 Studies referring to narrow areas, i.e. a corridor or a city.

In the former category the marginal cost estimations range from 0.150 to 0.300 €/vkm for freight transport, depending on whether the 'damage to relatives' component is included or not as in the PETS case study on Transalpine freight transport[42].

At corridor level, as for road accident costs, marginal accident costs for rail have been estimated in different studies, taking into account average costs as a proxy variable [INFRAS/IWW 2000] or calculating marginal external costs through specific risk elasticities (as in PETS case studies). Nevertheless, in PETS case studies, (Deliverable D10), the estimates of marginal accident costs in the freight

[42] PETS D10 The Transalpine freight case study, June 1999.

sector are identical to the average costs. The estimates from RECORDIT also take into account the risk elasticity from PETS. The outcomes vary widely.

Aviation
There are no extensive estimations of the marginal accident costs for air transport. Those available are hardly comparable, as they range from the estimation of average external costs based on average fatality risk [INFRAS/IWW 2000] to the utilisation of willingness-to-pay for other people, safety and material costs (PETS case studies).

Cost estimates vary from € 0.135 per vkm[43] to € 0.00064 per pkm in 1998[44]. One should mention that these results are only partly consistent with the UNITE guidance. In fact, although both studies include the same cost components, i.e. immaterial (intangible) costs based on willingness-to-pay techniques and material costs (e.g. net lost production, medical care, administrative cost), no deduction of internal/private costs - in order to derive external marginal accident costs - has been applied.

5.5 Analysis of discussion points

The risk-elasticity approach is generally accepted in recent years and besides this approach not many other approaches do exist. Less recent studies were more often based on cost allocation, providing average costs instead of marginal cost. Just like with environmental and infrastructure user costs more and more is accepted that marginal accident should follow an engineering bottom-up approach instead of a top-down approach. Only in this way it becomes possible to derive specific cost drivers of marginal costs.

Another issue is whether it is possible to transfer risk elasticity's between the countries. This would assume that the driver's reaction to transport volume changes is the same all over Europe. If this should not be the case, risk elasticity's have to be assessed in each country, which requires a considerable effort in data collection and research analysis. For this reason a more pragmatic approach was followed by [FISCUS, 1999] and [INFRAS/IWW, 2000]. Average costs per mode and road type were calculated instead of marginal costs. These studies show that, provided that adequate national accident statistics exist, a reasonably reliable estimation of external costs on motorways, country roads and urban roads is possible. However, this approach is criticised by [Lindberg, 2000] who argues that setting average costs equal to marginal costs implies a risk elasticity of zero, i.e. the risk is constant with traffic volume. Concluding, the literature survey shows that no agreement has yet been reached on the influence of the volume of traffic flows on accident rates. In this particular case this implies that no state-of-the-art methodology has yet been identified.

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43 PETS case studies.
44 INFRAS/IWW 2000.

The attribution of costs to different the modes of transport are also subject of discussion. FISCUS proposes the kinetic energy approach, which is based on the idea that fast and heavy vehicles usually cause much more severe accidents. PETS allocates the costs of intermodal accidents for 95% to the heaviest vehicle involved. [INFRAS/IWW, 2000] distributes the costs according to the causer of the accident, derived from accident statistics based on police reports [TRL et al, 2001].

The *cost allocation approach*, although theoretically less satisfactory, does have its merits. It is application is much easier, data availability is better, and it is up to now not certain that the results of average cost approaches are substantially different from results from a perfectly done marginal case study - i.e. one that *includes* risk avoidance costs. The reason for this is that low risk elasticity will generally go hand in hand with high risk avoidance costs vice versa.

5.6 Recommended method

UNITE concludes that the risk elasticity is the overall recommended method that can be applied for all modes, but as stated before the cost allocation approach, although theoretically less satisfactory, does have its merits.

5.7 Date requirements

The risk elasticity approach has the following data requirements:

- Traffic volume and composition data.
- Risk elasticity: The relationship between traffic volume and accident frequency.
- Level crossing data (for rail).
- Liability system per country.

Availability of data
Despite being the crucial element of this approach, information on the risk elasticity is scarce, especially for rail transport and aviation.

5.8 Literature overview

- Besides the six studies mentioned in section 1.2 the following studies have been used to compile this overview
- FISCUS, (1998a), Cost Evaluation and Financing Schemes for Urban Transport Systems, Deliverable 3, Real Cost Scheme, Karlsruhe/Lissabon
- FISCUS, (1998b), Cost Evaluation and Financing Schemes for Urban Transport Systems, Deliverable 2, External Costs, State of the Art, Karlsruhe/Lissabon
- Janson, J.O., Lindberg G. (1997), *PETS – Pricing European Transport Systems – Pricing Principles*, European Commission
- Lindberg, G. (2000), Marginal Cost Methodology for Accidents, UNITE Interim report 8.3, Funded by 5th Framework RTD Programme, VTI, Börlange, October 2000

- PETS (2000) *Pricing European Transport Systems, Final Report*, Project Coordinator: Professor Chris Nash. Institute for Transport Studies, University of Leeds, UK, December 2000. EC RTD 4th Framework Project
- Sansom et al. (2001). Sansom T, Nash CA, Mackie PJ, Shires J, Watkiss P (2001) *Surface Transport Costs and Charges: Final Report*. For the Department of the Environment, Transport and the Regions. Institute for Transport Studies, University of Leeds, Leeds, July 2001
- SIKA (2000): Översyn av Förutsättningarna för Marginalkostnadsbaserade Avgifter I Transportsystemet, Slutredovisning

6 Marginal air pollution costs

6.1 Introduction

Transport has a considerable impact on the environment, mostly representing externalities. For example the emission of CO_2 of traffic contributes to global warming. In the medium and long term this can result in negative health impacts and in external environmental costs.

Environmental external effects of transport also cover a wide range of different impacts, like the various impacts of emissions of noise and a large number of pollutants on human health, materials, ecosystems flora and fauna [UNITE, 2002]. In this study we focus on the marginal costs of noise and air pollution. Other external environmental costs like global warming, nuclear risks and soil and water pollution are not taken into account.

Marginal air pollution costs can be defined as the impact of air pollution of one additional unit on human health, the natural environment and on building materials.

6.2 Key cost drivers

Emission standards and emission factors are important cost drivers for air pollution costs. Below attention is paid to the key cost drivers for marginal air pollution costs. The cost drivers[45] are distinguished by mode: road, rail and air.

For all three modes the so-called *receptor density close to the emission source* is a key cost driver. This gives an indication of the population exposed to pollutants. Generally spoken, the closer to an emission source, the more air pollution will exist, and the higher marginal costs will be. The departure of a aircraft from an airport in a densely populated area will for example cause higher marginal pollution costs compared to the departure of the same aircraft from an airport in a more rural area. Closely related to the receptor density is the distribution and distance of the exposed persons from the source. Below more specific attention is paid to cost drivers for each mode.

Road
Apart from the receptor density, the *emission standard / emission factor* is a key cost driver for road traffic as mentioned above. Determining the emission factors are cost drivers such as the vehicle speed, the fuel type, the load factor, the vehicle type, size and age of the vehicle, the driving pattern and the geographical location of the road.

[45] This discussion is based on Deliverables 3 (The marginal cost methodology) and 15 (Guidance on adapting marginal cost estimates) of UNITE.

In addition are *the environmental conditions next to the road,* the ‘present’ conditions determine to a large extent the perception of an extra road vehicle for some-one living nearby the road, a key cost driver.

Rail
In rail transport in general two types of traction are used: an internal combustion engine or electric traction. Vehicles with internal combustion engine represent line emission sources, emitting continuously along a route. For vehicles with electric traction the emissions occur at the stage of ‘fuel’ - i.e. electricity production, there are no direct emissions during the operation of the vehicle. So the way electricity is produced (by natural resources like water or wind energy or by coals) determines to a large extent the cleanliness of trains with electric traction. For rail traffic the *geographical location of power plants and the power plant mix* are key cost drivers in addition to key cost drivers mentioned above. The train speed, the train type and the load factor determine to a large extent the amount of electricity needed and thus indirectly the amount of air pollution of the power plants.

Air
In addition to the key cost drivers mentioned above the e*ngine type and engine mode* determine the amount of emissions.

6.3 Current methodologies

Two general approaches for the calculation of marginal air pollution costs two approaches exist:
- A top-down approach: The starting point in this approach forms the macro-level, most times a whole geographical unit, a country for example. For such a unit the total cost due to an externality (for example an estimation of health costs, building damages and crop losses) is determined. This amount is then divided by the total amount of activity leading to the externality. In practice allocation is based on the shares of total pollutant emissions, vehicle mileage etc. In the end average costs result (not marginal costs) and the average costs thus obtained do in general not account for the differences in locations and conditions.
- A bottom-up approach: The starting point of this approach is the micro level, i.e. the traffic flow on a particular route segment. The marginal external costs of one additional vehicle are then calculated for a single trip on this route segment. This is done by modelling the path from emission to impact and costs. This involves modelling emissions, dispersion of emissions, estimation of impacts (e.g. on health), and finally applying monetary values to these impacts. In practice this method is called ‘the impact pathway approach’ and was developed in the ExternE-project.

One could say that most early studies, like [WHO, 1999] on health costs, [INFRAS, 1992] and [INFRAS/Econcept/Prognos, 1996] on building damages and INFRAS/Econcept/Prognos (1996) on crop losses, followed the former (top-down) approach, leading to average costs rather than marginal costs. The bottom-up approach, i.e. the Impact Pathway Approach (IPA) was developed in the ExternE project (funded by the European Commission from 1996 to 2001 and is often applied in more recent studies on marginal costs like [UNITE, 2003], [INFRAS/IWW, 2000], [TRL et al, 2001]. At this moment the Impact Pathway Approach can be considered as the state of the art for air pollution and noise valuation methods. Below we will describe the Impact Pathway Approach in more detail.

The impact pathway approach
The impact pathway, developed in the ExternE-project, consists of five steps:

Step 1: Estimate the emission from the source of airborne pollutants
In the first step the emission per vehicle should be estimated and modelled. So with regard to air pollution it concerns the emissions per vehicle km of SO_2, NO_x, particles and hydrocarbons. For all of the categories of transport activity the output of emissions must be determined along with the concentration of these emissions in the different transport environments. The degree of concentration and exposure to emissions then determines the 'dose' of pollution received.

Step 2: Determine the type of impact to human health, agriculture, natural environment etc)
In the second step one determines the impact of additional emission on its receptors. One determines for example the relation of additional emission with human health or whether there is an impact of more vehicle movements (more vibrations) on building damage. With 'dose-response' relationships the impact of different pollutants can be measured.

A dose-response relationship for example describes the impact of an emission (for example) SO_2 on human health (reduction in life expectancy). Table 7 gives an overview of health and environmental effects included in the analysis of air pollution costs in UNITE. Figure 7 gives examples of dose-response functions.

Figure 7 lists the exposure response functions used for the assessment of health effects. The exposure response functions are taken from the 2nd edition of the ExternE Methodology report (European Commission 1999a), with some modifications resulting from recent recommendations of the health experts in the final phase of the ExternE Core / Transport project (Friedrich and Bickel 2001).

Table 7 Illustration of health and environment effects

Impact category	Pollutant	Effects included
Public health – mortality	$PM_{2.5}$, PM_{10} [1)] SO_2, O_3	Reduction in life expectancy due to acute and chronic mortality Reduction in life expectancy due to acute mortality
Public health – morbidity	$PM_{2.5}$, PM_{10}, O_3	respiratory hospital admissions
		restricted activity days
	$PM_{2.5}$, PM_{10} only	cerebrovascular hospital admissions
		congestive heart failure
		cases of bronchodilator usage
		cases of chronic bronchitis
		cases of chronic cough in children
		cough in asthmatics
		lower respiratory symptoms
	O_3 only	asthma attacks
		symptom days
Material damage	SO_2, acid deposition	Ageing of galvanised steel, limestone, natural stone, mortar, sandstone, paint, rendering, zinc
Crops	SO_2	Yield change for wheat, barley, rye, oats, potato, sugar beet
	O_3	Yield loss for wheat, potato, rice, rye, oats, tobacco, barley, wheat
	Acid deposition	increased need for liming
	N, S	fertiliser effects

1) including secondary particles (sulphate and nitrate aerosols).

Source: IER

Figure 7 Examples of dose-response functions

Table A-2
Quantification of human health impacts due to air pollution [1)]

Receptor	Impact Category	Reference	Pollutant	f_{er}
ASTHMATICS (3.5% of population)				
Adults	Bronchodilator usage	Dusseldorp et al., 1995	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.163 0.163 0.272 0.272
	Cough	Dusseldorp et al., 1995	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.168 0.168 0.280 0.280
	Lower respiratory symptoms (wheeze)	Dusseldorp et al., 1995	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.061 0.061 0.101 0.101
Children	Bronchodilator usage	Roemer et al., 1993	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.078 0.078 0.129 0.129
	Cough	Pope and Dockery, 1992	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.133 0.133 0.223 0.223
	Lower respiratory symptoms (wheeze)	Roemer et al., 1993	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.103 0.103 0.172 0.172
All	Asthma attacks (AA)	Whittemore and Korn, 1980	O_3	4.29E-3
ELDERLY 65+ (14% of population)				
	Congestive heart failure	Schwartz and Morris, 1995	PM_{10} Nitrates $PM_{2.5}$ Sulphates CO	1.85E-5 1.85E-5 3.09E-5 3.09E-5 5.55E-7
CHILDREN (20% of population)				
	Chronic cough	Dockery et al., 1989	PM_{10} Nitrates $PM_{2.5}$ Sulphates	2.07E-3 2.07E-3 3.46E-3 3.46E-3
ADULTS (80% of population)				
	Restricted activity days (RAD)	Ostro, 1987	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.025 0.025 0.042 0.042
	Minor restricted activity days (MRAD)	Ostro and Rothschild, 1989	O_3	9.76E-3
	Chronic bronchitis	Abbey et al., 1995	PM_{10} Nitrates $PM_{2.5}$ Sulphates	2.45E-5 2.45E-5 3.9E-5 3.9E-5
ENTIRE POPULATION				
	Chronic Mortality (CM)	Pope et al., 1995	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.129% 0.129% 0.214% 0.214%
	Respiratory hospital admissions (RHA)	Dab et al., 1996	PM_{10} Nitrates $PM_{2.5}$ Sulphates	2.07E-6 2.07E-6 3.46E-6 3.46E-6
		Ponce de Leon, 1996	SO_2 O_3	2.04E-6 3.54E-6
	Cerebrovascular hospital admissions	Wordley et al., 1997	PM_{10} Nitrates $PM_{2.5}$ Sulphates	5.04E-6 5.04E-6 8.42E-6 8.42E-6
	Symptom days	Krupnick et al., 1990	O_3	0.033
	Cancer risk estimates	Pilkington et al., 1997; based on US EPA evaluations	Benzene Benzo-[a]-Pyrene 1,3-buta-diene Diesel particles	1.14E-7 1.43E-3 4.29E-6 4.86E-7
	Acute Mortality (AM)	Spix et al. / Verhoeff et al.,1996	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.040% 0.040% 0.068% 0.068%
		Anderson et al. / Touloumi et al., 1996	SO_2	0.072%
		Sunyer et al., 1996	O_3	0.059%

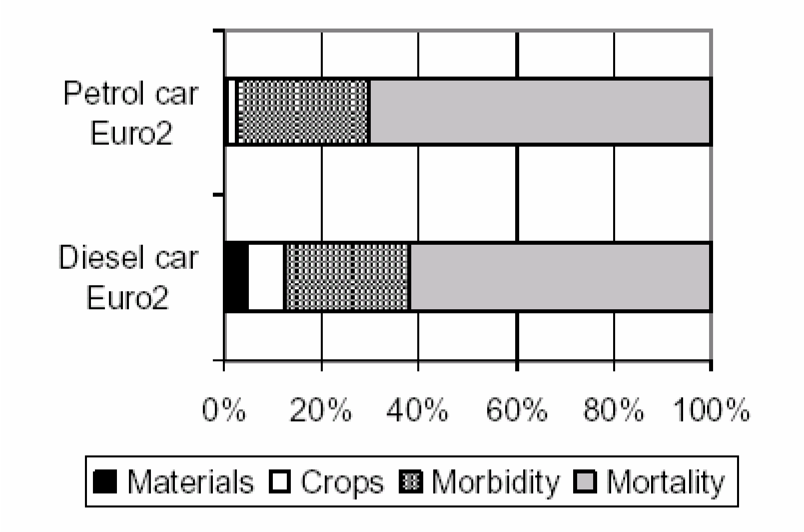
1) The exposure response slope, f_{er}, has units of [cases/(yr-person-µg/m^3)] for morbidity, and [%change in annual mortality rate/(µg/m^3)] for mortality. Concentrations of SO_2, PM_{10}, PM_{10}, sulphates and nitrates as annual mean concentration, concentration of ozone as seasonal 6-h average concentration.

Source: Friedrich and Bickel 2001.

Step 3: Estimate the number of persons, animals, plants exposed to various ambient concentrations over time
Step 1 and 2 are very theoretical, in step 3 and 4 the results of the first steps are to be applied to a practical, existing situation. In step 3 the emission factors are related to a specific situation.

Step 4: Establish the relationship between exposure to each pollutant and the various health and welfare effects; and predict the physical effects of the emissions on the basis of these relationships
Having calculated the total amount of concentrations one can predict the physical impact on human health, crops, buildings etc. Figure 8 gives an example of the split of air pollution costs (excluding greenhouse gases) in Stuttgart[46].

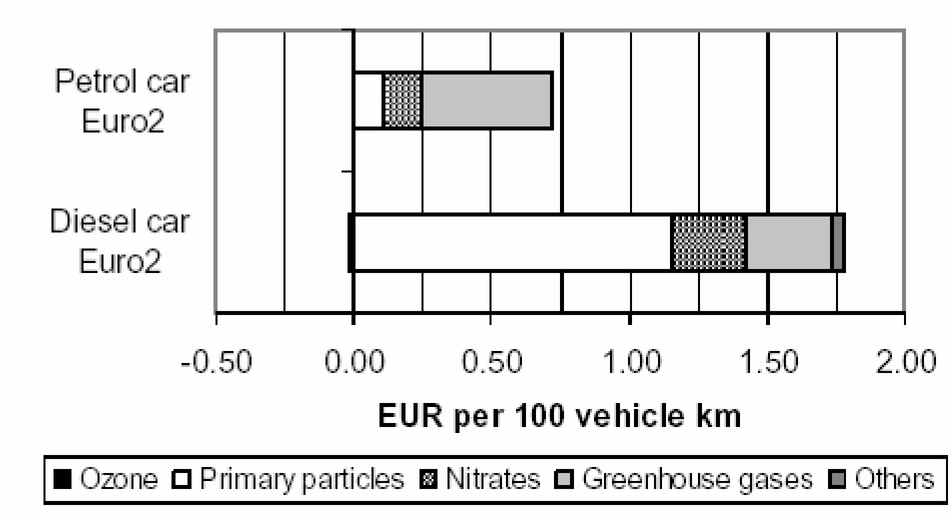
Figure 8 Illustration of distribution of pollution costs



Step 5: Calculate the monetary value of effect on health and other. An appropriate method would be market prices if market exists, and otherwise the willingness to pay to avoid or to accept small changes in risks if no market price is available
Assuming that the appropriate impact is identified, its monetary value should than be appraised. In Figure 9 for example the costs due to airborne emissions from vehicle use in Stuttgart are shown[47].

46 Source: UNITE, Deliverable 9D: Urban Road and Rail Case Studies Germany.
47 Source: UNITE, Deliverable 9D: Urban Road and Rail Case Studies Germany.

Figure 9	Illustration of level of pollution costs



In general market prices do not exist for externalities. The valuation will then be based on the concepts of compensating and equivalent variation (see e.g. chapter 2).

Both direct (for example contingent valuation method) and indirect methods (for example hedonic pricing) are often used in monetary valuation of air pollution impacts. UNITE recommends direct methods to monetarise air pollution. Although indirect methods are based on real market behaviour, the disadvantage is that they may not cover all aspects, which are relevant for the WTP of people (for more information on these monetary valuation methods see chapter 2 and the glossary).

The principle of this approach can be applied to all modes. However, there exist mode specific differences that have to be taken into account. Below we pay attention to some specific items of the impact pathway approach for air pollution:

- Specific for rail in comparison to road and air transport are that two kinds of emission sources have to be distinguished: internal combustion and electric traction.
- Contrary to noise emissions air pollutants are often transported over hundreds or even thousands of kilometres, as a consequence the analysis of air pollution must not be made on the local level, but (at least) for some categories of pollutants up to a nationwide or European scale.

6.4 Applications

In this section we look at the applications of the bottom-up and top-down approach in Europe for the three distinguished modes.

In the literature (see below) studied for this report hardly any attention is paid to top-down approaches. Due to general view that marginal external costs should be calculated using a bottom-up approach (Impact Pathway Approach) in recent years the top-down approach has not been applied. As a consequence this subsection only deals with bottom-up approaches.

Use of Impact pathway approach

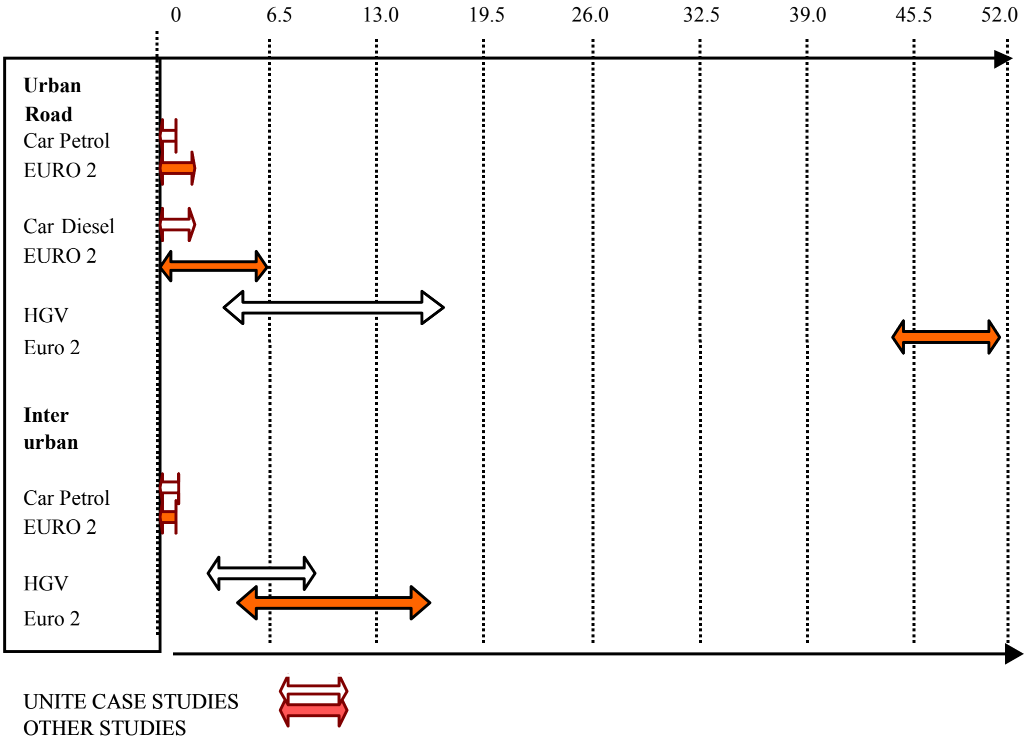
The Impact Pathway Approach is a detailed work out of the bottom-up approach for calculating marginal external costs. The Integrated Pathway was developed within the Extern E project between 1996 and 2001 and represents the state of the art. The project has involved over 30 multidisciplinary teams from research institutes and consultants from Member States and interested teams from other European countries. In this framework project the approach has been undertaken for local and regional airborne emissions. Within the UNITE-study this approach has been extended to quantification of noise impacts and emissions. Later on the Integrated Pathway Approach was also applied in the INFRAS/IWW-study.

The procedure of calculating marginal externalities requires a considerable input of data and time. In practice it is impossible to carry out a detailed assessment for all route segments through Europe. Instead, results of selected cases can be generalised. Based on a sample covering all relevant road types, vehicle types and locations in Europe, it is possible to derive equations for quantifying externalities. These equations express the relation between parameters like population density close to a route, vehicle emissions etc. and the resulting external costs.

Road air pollution costs

Besides six UNITE case studies marginal road air pollution costs have been estimated in numerous European projects, e.g. [RECORDIT, 2001], [INFRAS/IWW, 2000], [SIKA, 2000], [ExternE, 2001] and [Sansom et al., 2001] all applying the Impact Pathway Approach. The studies confirm that heavy goods vehicles and diesel vehicles generate higher impacts than passenger cars on petrol, particularly in the urban context. Where identical methodological approaches have been used (IPA), in general an only small degree of variation results. An exception is the marginal cost of Heavy Goods Vehicles in urban areas, where the INFRAS/IWW study produced substantially higher values than UNITE. This can be observed in Figure 10 (with figures *only* for Euro 2 vehicles).

Figure 10 Variations in marginal air pollution costs for Euro 2 vehicles in the road sector in €ct(1998)/vkm



Source: UNITE, D15

Rail air pollution costs

For the air pollution by rail, results between different studies are comparable. Besides UNITE air pollution was for example calculated in [INFRAS/IWW, 2000], [RECORDIT, 2001] and [PETS, 2000]. With regard to air pollution all studies have used the Impact Pathway Approach.

Marginal external costs of air pollution (and global warming) for the rail sector largely depends on the share of fossil fuel used for producing electricity. The results from UNITE case studies, i.e. the inter-urban case studies for Germany and Italy, are consistent with the average of other studies, i.e. between 0.07 and 2.2 € / train km (passenger and freight) for air pollution.

Aviation air pollution costs

Marginal air pollution costs for air pollution in the aviation sector, based on a bottom-up approach for different air traffic situations have been calculated by [INFRAS/IWW, 2000]. In addition estimates of marginal costs of air pollution per type of aircraft have also been provided by [CSERGE, 2000], using shadow prices for the economic value of air pollution damage. In contrast to road and rail air pollution costs outcomes between studies do differ a lot.

6.5 Analysis of discussion points

As described above for marginal external costs two main approaches do exist:

- The top-down approach starting from a whole geographical unit.
- The bottom-up approach starting from the micro level. In recent years this approach is in detail worked out in the Impact Pathway Approach.

Two important issues closely related to each other are subject to discussion:

1 A top-down approach leads to average costs and not in marginal costs by calculating the total costs for a whole geographical unit and subsequently dividing these costs by the total amount of activity leading to the externality.
2 Due to its technique the average external costs thus obtained will (in most cases) not differ from one transport route to another. In other words the importance of different cost drivers does these methods not sufficiently take into account.

Although the bottom-approach is regarded to be a better approach than the top-down approach, the approach requires a detailed analysis of all (European) transport routes. By this the bottom-approach is for more ambitious approach.

6.6 Recommended method

Due to average costs figures that result from top-down approaches in general the bottom up impact pathway approaches are regarded to be the best way of calculating environmental costs. Top-down approaches are not capable of adequately measuring the impacts of an additional vehicle, in particular when it comes to site-specificity. The advantage of the bottom-up approach is that emission data are generated and the impacts can be attributed to specific polluters. So for each polluter or polluting items the pollution it causes can be determined. For both air pollution and noise the Integrated Pathway Approach is suitably generic that it may be applied to all modes of transport. Although substantial uncertainties remain at each stage of simulation, no robust alternative approach exists.

For air pollution the preferred approach is the IPA, which first forecasts the emissions of each pollutant, then their dispersion and finally looks at all the various impacts these have and costs them. The overall IPA is generally transferable for all categories of pollutant. However, one should hold in mind that in spite of considerable progress made in recent years, the quantification and valuation of environmental damage still suffers from significant uncertainties. Effect of particles on human health, effect of nitrate aerosols on health, valuation of mortality (ExternE for example recommends the use of Value of a Life Year Lost rather than the Value of Statistical Life.), impacts from ozone, omission of effects.

6.7 Data requirements

The Impact Pathway Approach is the recommended method for the calculation of air pollution costs but suffers from heavy data requirements. Another problem is that to be correct each transport routes should be separately reviewed.

Basis for the Impact Pathway Model is a transport model used to assess transport on different infrastructure segments. So data is required on transport flows like origin-destination data (for example the amount of road traffic between Paris and Lille). In addition disaggregated data at the level of by vehicle technology and occupancy rates / load factors are needed. Emission functions are needed to estimate local transport emissions and a distribution model should be used to calculate emissions. This concerns data on emission factors by type of vehicle for all modes involved. For modelling the chemical transformation of the pollutants in the atmosphere, emission databases covering all emission sources are needed for the different spatial scales. A geographical information system subsequently allows estimating the area affected, including ecosystems, number of persons and buildings. This requires receptor data (geographical co-ordinates, population density and other geo-morphical information) and meteorological data (mainly wind speed and direction). Dose response functions are needed to estimate the impacts on health, buildings and ecosystems. Finally the costs per unit damaged or affected are needed to determine the marginal costs. This requires the availability of willingness-to-pay/willingness-to-accept data etc.

Availability of data
Despite the fact that many models exist, many uncertainties remain. Crucial areas of uncertainties[48] concern the effects of particles and nitrate aerosols on human health, the valuation of mortality, the impacts from ozone and not taking into account all effects on human health.

6.8 Literature overview

Besides the six studies mentioned in section 1.2 the following studies have been used for this chapter:

- CSERGE (2000) Pearce, Brian; Pearce David. *Setting Environmental taxes for aircraft: A case study of the UK*. CSERGE Working Paper GEC 2000-26. Centre for social and Economic Research on the Global Environment, University College London and University of East Anglia
- DETR (2000) *Valuing the External Costs of Aviation*. Department of the Environment, Transport and the Regions. London December 2000
- EXTERNE (2001), *The externalities of transport*
- INFRAS (1992), *Gebäudeschäden durch verkehrsbedingte Luftverschmutzung, im Auftrag des Dienstes GVF*, Zürich
- INFRAS/Econcept/Prognos (1996), *Die vergessenen Milliarden, Externe Kosten im Energie- und Verkehrsbereich*, Zürich

[48] As identified in UNITE D15.

- PETS (2000) *Pricing European Transport Systems, Final Report*, Project Coordinator: Professor Chris Nash. Institute for Transport Studies, University of Leeds, UK, December 2000. EC RTD 4th Framework Project
- QUITS (1998), *Quality Indicators for Transport Systems*. Final Report for Publication, Project Coordinator: ISIS. EC RTD 4th Framework Project, Rome April 1998
- Sansom et al. (2001). Sansom T, Nash CA, Mackie PJ, Shires J, Watkiss P (2001) *Surface Transport Costs and Charges: Final Report*. For the Department of the Environment, Transport and the Regions. Institute for Transport Studies, University of Leeds, Leeds, July 2001
- SIKA (2000): Översyn av Förutsättningarna för Marginalkostnadsbaserade Avgifter I Transportsystemet, Slutredovisning
- WHO (1999), *Health Costs Due to Road Traffic-Related Air Pollution, an impact assessment project of Austria, France and Switzerland, economic evaluation, technical report*, London

7 Marginal noise costs

7.1 Introduction

Transport is a source of considerable environmental impacts, mostly representing externalities. For example aircrafts lead to noise disturbance for local residents and freight trains can wake people up at night. In the medium and long term this can result in substantial negative health impacts.

Noise can be defined as the unwanted sound or sounds of duration, intensity, or other quality that causes physiological or psychological harm to humans. Transport noise in particular not only imposes undesired social disturbances, but also influences the individual well being which can entail health damages. Marginal noise costs can then be defined as the impact of noise of one additional vehicle or movement on amenity and human health. Vibrations lead to amenity losses and damages of buildings.

7.2 Key cost drivers

The time of day is an important cost driver for marginal noise cost. Noise disturbance at night will lead to higher marginal costs than at other times of the day. Below attention is paid to the key cost drivers for marginal noise costs. The cost drivers[49] are distinguished by mode: road, rail and air.

For all three modes the three the so-called *receptor density close to the emission source* is a key cost driver. This gives an indication of the population exposed to noise. Generally spoken, the closer to an emission source, the more nuisances will appear, and the higher marginal costs will be. For example the departure of an aircraft from an airport in a densely populated area will cause higher marginal noise costs compared to the departure of the same aircraft from an airport in a more rural area. Closely related to the receptor density is the location and distance of the exposed persons in relation to the source.

Besides the aforementioned cost drivers, for all modes the *existing noise levels* (depending on traffic volume, traffic mix and speed) and the *time of the day* (day, evening or night) are key cost drivers. The impact of time of day was already announced before. With regard to existing noise levels it may be clear that along an already busy road the marginal noise costs of additional vehicle are small in comparison with a rural road. The higher the existing background noise level is, the lower the marginal costs of additional vehicles. An additional cost driver is the maintenance level. Although the maintenance policy is considered to be a 'given', maintenance levels do influence the amount of noise.

On top of these cost drivers, there are several mode-specific cost drivers.

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[49] This discussion is based on Deliverables 3 (The marginal cost methodology) and 15 (Guidance on adapting marginal cost estimates) of UNITE.

Road

In road transport the sound emitted is mainly made up by the sound of the propulsion system and the sound of rolling. The ratio of both sources depends on the speed. As a consequence in addition to the cost drivers mentioned above other key cost drivers are the *vehicle speed, the vehicle type and the kind of surface (including the level of maintenance).* Closely related to these are cost drivers like the vehicle age, the slope of road and the kind of surface (including the presence of noise walls).

Rail

The dominant component in the noise emissions of trains is the rolling surface of the steel wheel on the steel track. As a consequence in addition to the cost drivers mentioned above other key cost drivers are *train speed, the coach/wagon type and type of track (including the level of maintenance)*[50]. Closely related to these are cost drivers like the type of brakes, the length of the train and the presence of noise walls.

Aviation

For aviation there is one specific cost drivers: *the engine type.*

7.3 Current methodologies

For marginal external costs in general and for the calculation of marginal noise costs in particular two approaches do exist:

- A top-down approach: The starting point in this approach forms the macro-level, most times a whole geographical unit and a country for example. For such a unit the total noise costs (for example an estimation of health costs, and building damages) is determined. This cost is then divided by the total amount of activity leading to this externality. In practice allocation is based on the shares of total noise emissions, in the vehicle mileage etc. In the end average costs result (no marginal costs) and the average costs thus obtained do in general not account for the differences in locations and conditions.
- A bottom-up approach: The starting point of this approach is the micro level, i.e. the traffic flow on a particular route segment. The marginal external costs of one additional vehicle then are calculated for a single trip on this route segment. This is done by modelling the path from noise emission to impact and costs. This involves modelling noise emissions, dispersion of emissions, estimation of impacts (e.g. on health), and finally applying monetary values to these impacts. In practice this method is called 'the impact pathway approach' and was developed in the ExternE-project.

One could say that most early studies, like [WHO, 1999] on health costs, [INFRAS, 1992] and [INFRAS/Econcept/Prognos, 1996] on building damages and [INFRAS/Econcept/Prognos, 1996] on crop losses, followed a top-down approach, giving average costs rather than marginal costs. The bottom-up

[50] It may be clear that not only the level of maintenance but for example also the determined safety requirements for infrastructure 'cause' noise levels and noise costs. Please note that in general the required level for a marginal cost item (for example also safety and maintenance) can determine to a large extent the size of other marginal costs.

approach, i.e. the Impact Pathway Approach (IPA) was developed in the ExternE project (funded by the European Commission from 1996 to 2001 and is often applied in more recent studies on marginal costs like [UNITE, 2003], [INFRAS/IWW, 2000], [TRL et al, 2001]. At this moment the Impact Pathway Approach can be considered as the state of the art for air pollution and noise valuation methods. Below we will describe the Impact Pathway Approach in more detail.

The impact pathway approach

The impact pathway, developed in the ExternE-project, consists of five steps:

Step 1: Estimate the emission from the source of noise

In the first step the noise emission per vehicle should be estimated and modelled. So with regard to air pollution it concerns the emission of sound, measured in dBA. For all of the categories of transport activity the output of emissions must be determined along with the concentration of these emissions in the different transport environments. The degree of concentration and exposure to emissions then determines the 'dose' of pollution, received.

Step 2: Determine the type of impact to human health, agriculture, natural environment, material damage etc)

In the second step one determines the impact of more noise on its receptors. One determines for example the relation of more noise with human health or whether there is an impact of more vehicle movements (more vibrations) on building damage. With 'dose-response' relationships the impact of different pollutants can be measured.

Step 3: Estimate the number of persons, animals, plants exposed to various ambient noise levels over time

Step 1 and 2 are very theoretical, in step 3 and 4 one applies the result of the first steps to a practical, existing situation. In step 3 the emission factors are related to a specific situation. Table 8 gives an example of Contour areas and population affected by noise exposure from Heathrow Airport 1998[51].

Table 8 Contour areas and population affected at Heathrow in 1998

Leq Level dB(A)	Area affected (km^2)	Population affected (1,000 persons)
>57	163.7	311.5
>60	94.6	160.9
>63	55.4	79.9
>66	35.2	39.6
>69	22.8	15.2
>72	13.1	5.2

[51] Source: Department for Transport (2000) Noise Exposure Contours for Heathrow Airport 1998, published 29 February 2000, http://www.aviation.dft.gov.uk/nec98/heathrow/index.htm.

Step 4: Establish the relationship between exposure to noise and the various health and welfare effects; and predict the physical effects of the emissions on the basis of these relationships
Having calculated the total noise levels one can predict the physical impact on human health, crops, buildings etc.

Step 5: Calculate the monetary value of effect on health and other. An appropriate method would be market prices if market exists, and otherwise the willingness to pay to avoid or to accept small changes in risks if no market price is available
Assuming that the appropriate impact is identified, its monetary value (for example impact on property values) should than be appraised. In general market prices do not exist for externalities. The valuation will then be based on the so-called concepts of compensating and equivalent variation (see also chapter 2).

With regard to the valuation of noise the most popular method is hedonic pricing, but studies have also used contingent valuation, abatement costs, avoidance costs and productivity loss to estimate the external costs of noise. As discussed before indirect methods are recommended to valuate noise costs.

The principle of this approach can be applied to all modes. However, there are several mode specific differences that have to be taken into account. Below we pay attention to specific items of the impact pathway approach for noise and for the three distinguished modes.

Specific items for noise pollution in the integrated pathway approach:
- Sound sources differ between road, rail and aviation. The sound emitted by road vehicles is mainly made up by the sound of the propulsion system and the sound of rolling. In rail the rolling of the steel wheel on the steel track, which increases with speed, produces the dominant component of wayside noise from a running train. For aircrafts the jet exhaust, mixing with the surrounding air is a major noise source.
- For air transport, in general only the noise emitted in the airport surroundings during take-off and landing of civil airlines is considered.

7.4 Applications

In this section we look at the applications of the bottom-up and top-down approach in Europe for the three distinguished modes.

In the literature (see below) studied for this report hardly any attention is paid to top-down approaches. Due to general view that marginal external costs should be calculated using a bottom-up approach (read Impact Pathway Approach) in recent years the top-down has not been used. As a consequence this subsection only deals with bottom-up approaches.

Use of Impact pathway approach
The Impact Pathway Approach is a detailed work out of the bottom-up approach for calculating marginal external costs. The Integrated Pathway was developed within the ExternE project between 1996 and 2001 and represents the state of the art. The project has involved over 30 multidisciplinary teams from research institutes and consultants from Member States and interested teams from other European countries. In this framework project the approach has been undertaken for local and regional airborne emissions. Within the UNITE-study this approach has been extended to quantification of noise impacts and emissions. Later on the Integrated Pathway Approach was also applied in the INFRAS/IWW-study.

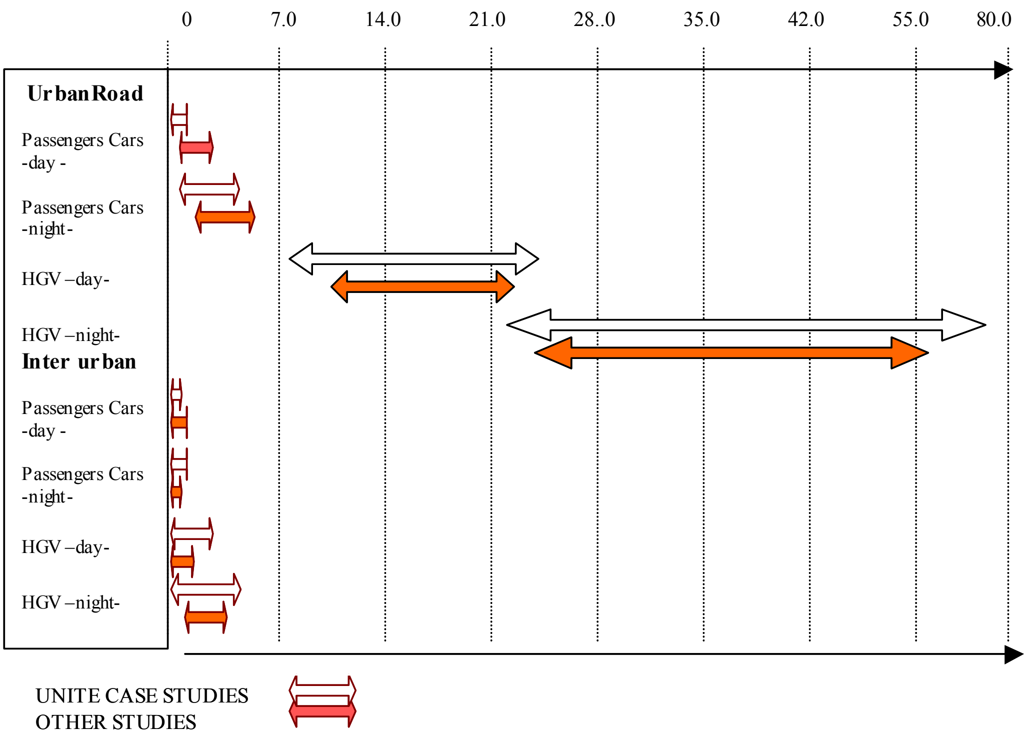
The procedure of calculating marginal externalities requires a considerable input of data and time. In practice it is impossible to carry out a detailed assessment for all route segments through Europe. Instead, results of selected case can be generalised. Based on a sample covering all relevant road types, vehicle types and locations in Europe, it is possible to derive equations for quantifying externalities. These equations express the relation between parameters like population density close to a route, vehicle noise emissions etc. and the resulting external costs. The method of using case studies and generalising afterwards was for example applied in the UNITE-study.

When looking at costs due to noise nuisance in particular, road transport and aviation have been studied in most detail. Many estimates are based on revealed preference studies, measuring the reduction in market value of housing due to noise. Compared to these, studies quantifying prevention costs usually come to lower costs. Studies using stated preference methods yield the highest results. Furthermore, also the costs due to noise related health effects have been used to estimate noise costs.

Below we pay attention to different methods and outcomes for noise pollution for road, rail and aviation.

Road noise costs
Besides UNITE marginal cost estimations can be found in several European projects, e.g. [INFRAS/IWW, 2000], [RECORDIT, 2001], [PETS, [2000]. The integrated pathway approach was used in the UNITE case studies, as well as in the RECORDIT estimations and in the PETS case studies, while INFRAS/IWW relied on a top-down approach based on inventories of households and persons affected by road noise. A significant cost driver is the time-of-day the noise is emitted combined with the type of vehicle (with HGV having higher road noise costs than passenger cars). Despite some different approaches and the high dependency of noise costs from site-specific characteristics, i.e. location of noise receptors, distance from the source, the variation in results from different case studies is limited, as can be observed in Figure 11.

Figure 11 Variation in marginal noise costs in the road sector €ct(1998)/vkm



Sourse: UNITE, D15

Rail noise costs
For rail noise costs too results between different studies are comparable. Besides in UNITE noise costs have been calculated in [INFRAS/IWW, 2000], [RECORDIT ,2001] and [PETS, 2000]. For noise INFRAS/IWW made use of a top-down approach, analogues to the methodology for road noise costs. The results for noise show different values according to the site–specific characteristics, such as the receptor density. The results show a wide variability, particularly in the freight sector, for which marginal external costs range from € 0.070 to € 0.828 per train-km. However, no systematic bias in the results can be attributed to the choice of one or the other of the two approaches. For passenger rail traffic marginal external costs range from approximately € 0.100 to € 0.600 per train-km.

Aviation noise costs
Existing estimates of marginal noise costs for aviation are scarce and ranging from average values for short and long distance at the European level [INFRAS/IWW, 2000] to estimates based on hedonic house pricing at Heathrow airport [DETR, 2000 and CSERGE, 2000]. The outcomes vary widely. The cost estimates based on the Heathrow airport case study for example vary between € 17.15 and € 322.99 per LTO (landing and take off event), depending on the type of aircraft.

The INFRAS/IWW approach is not completely consistent with the UNITE or High Level Group guidance. Due to the current lack of information on emission-dispersion models for airport noise emissions the study team decided to derive values for marginal costs based on a ratio between marginal and average costs for road and rail. So the relation between marginal and average costs for road and rail was used to derive the marginal costs of airport noise.

7.5 Analysis of discussion points

As described before for marginal external costs two main approaches do exist:
- The top-down approach starting from a whole geographical unit.
- The bottom-up approach starting from the micro level. The Impact Pathway Approach follows this line.

Two important issues closely related to each other are subject to discussion:
1. A top-down approach leads to average costs and not in marginal costs by calculating the total costs for a whole geographical unit and subsequently dividing these costs by the total amount of activity leading to the externality.
2. Due to its technique the average noise costs thus obtained will (in most cases) not differ from one transport route to another. In other words the importance of different cost drivers does these methods not sufficiently take into account.

Although the bottom-approach is regarded to be a better approach than the top-down approach, the approach requires a detailed analysis of all (European) transport routes. The bottom-approach is a far more ambitious approach.

7.6 Recommended method

Due to average costs figures that result from top-down approaches in general the bottom up impact pathway approaches are regarded to be the best way of calculating environmental costs. Top-down approaches are not capable of adequately measuring the impacts of an additional vehicle, in particular when it comes to site-specificity. The advantage of the bottom-up approach is that noise emission data are generated and the impacts can be attributed to specific noise emitters. So for each noise producer the noise it causes can be determined. For both air pollution and noise the Integrated Pathway Approach is suitably generic that it may be applied to all modes of transport. Although substantial uncertainties remain at each stage of simulation, no robust alternative approach exists.
For noise, a particular challenge lies in modelling noise emissions from vehicle flows and noise dispersion to take account of factors such as topography and noise barriers, to a degree of accuracy that yields plausible results. The IPA approach for noise has been successfully applied to a number of road and rail case studies.

7.7 Data requirements

The Impact Pathway Approach is the recommended method for the calculation of noise costs but requires a lot of data, which is only one of the many difficulties to overcome. Especially when taking into account the site-specific characteristics of each situation, theoretically requiring all transport routes to be reviewed, this will lead to heavy data requirements.

Basis for the Impact Pathway Model is a transport model used to assess transport on different infrastructure segments. So data is required on transport flows like Origin-Destination data relevant to specific routes. In addition disaggregation of data by vehicle technology and occupancy rates / load factors are needed. Noise emission functions are needed to estimate local transport noise emissions and a distribution model should be used to calculate noise emissions. This concerns data on noise emission factors by technology for all modes involved. A geographical information system subsequently allows estimating the area affected, including ecosystems, number of persons and buildings. This requires receptor data (geographical co-ordinates, population density and other geo-morphical information) and meteorological data (mainly wind speed and direction). Dose response functions are needed to estimate the impacts on health, buildings and ecosystems. Finally the costs per unit damaged or affected are needed to determine the marginal costs. This requires the availability of willingness-to-pay/willingness-to-accept data etc.

Availability of data
Despite the fact that many models exist, many uncertainties remain. Crucial areas of uncertainties[52] concern the fact that not all impacts on human health can be taken into account.

7.8 Literature overview

Besides the six studies mentioned in section 1.2 the following studies have been used for this chapter:

- CSERGE (2000) Pearce, Brian; Pearce David. *Setting Environmental taxes for aircraft: A case study of the UK*. CSERGE Working Paper GEC 2000-26. Centre for social and Economic Research on the Global Environment, University College London and University of East Anglia
- DETR (2000) *Valuing the External Costs of Aviation*. Department of the Environment, Transport and the Regions. London December 2000
- EXTERNE (2001), *The externalities of transport*
- INFRAS/Econcept/Prognos (1996), *Die vergessenen Milliarden, Externe Kosten im Energie- und Verkehrsbereich*, Zürich
- PETS (2000) *Pricing European Transport Systems, Final Report*, Project Coordinator: Professor Chris Nash. Institute for Transport Studies, University of Leeds, UK, December 2000. EC RTD 4th Framework Project
- QUITS (1998), *Quality Indicators for Transport Systems*. Final Report for Publication, Project Coordinator: ISIS. EC RTD 4th Framework Project, Rome April 1998
- Sansom et al. (2001). Sansom T, Nash CA, Mackie PJ, Shires J, Watkiss P (2001) *Surface Transport Costs and Charges: Final Report*. For the Department of the Environment, Transport and the Regions. Institute for Transport Studies, University of Leeds, Leeds, July 2001

[52] As identified in UNITE D15.

Part 2

Towards a practical approach

8 Introduction

The first part of the report of this report presented per cost item and per mode a state-of-the art review of used methods. These methods are in many cases not easy to apply. To be able to calculate the marginal costs, many parameters are needed that reflect the characteristics of a specific transport.

This second part of the report deals with the simplified approaches for all cost items. Simplified approaches are maybe less accurate but are easier to carry out and can in many cases give a quick indication of marginal costs. For each cost item we present several approaches. We discuss the pros and cons of the different approaches and also pay attention to the important issue of data requirements. In each chapter we give examples of application of the approaches.

Both econometric and engineering approaches are in many cases too complicated to be suitable as a simplified approach. For all cost items we propose a cost allocation based approach. However, these cost allocation approaches will make use of generalisations of data that have been obtained by engineering and econometric studies.

9 Marginal infrastructure costs

As we have seen earlier in this report, there are two original research methods to assess marginal infrastructure costs: the engineering and the econometric approach.

Where the heavy data requirements that underlie both these methods can be met, they are certainly preferred to simplified methods.

Apart from heavy data requirements, both these methods can be very time and resource consuming. For these reasons we also propose alternative and simplified approaches to estimate marginal costs of infrastructure use. The main aim is to set basic calculation rules that can be applied with a limited set of data on infrastructure use.

The method proposed consists of a step-by-step top-down cost allocation approach that is based on insights gained from econometric and engineering cost calculations. We distinguish basically the following steps:

1 Determine the total cost of infrastructure maintenance.
2 Determine the share of variable and fixed infrastructure costs. The share of variable cost clearly depends on usage. However, also the marginal cost may depend on usage and may even increase for higher usage levels[53].
3 Approximate marginal infrastructure cost by allocating the variable infrastructure cost to different vehicle types such as passenger and freight vehicles and different vehicle sizes.

We will briefly go into steps 1 and 2, and describe possible options in case these data are not readily available. Our focus, however, lies on step 3.

The costs allocations methods presented in this chapter produce average variable costs. Though these differ from marginal cost, they generally provide good estimates of the long term marginal infrastructure costs.

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53 As an example consider renewal cost. If infrastructure usage is low, the main cause of deterioration will be the weather. This will determine when to renew the infrastructure. At higher usage levels, the wear due to traffic determines when to replace infrastructure. This implies that at marginal renewal costs are zero for low traffic levels, and positive at higher usage levels.

9.1 Road transport

9.1.1 Total cost of infrastructure maintenance

The total cost of infrastructure maintenance for each Member State can be derived from the national accounts or of those of the infrastructure manager. To ensure consistency across Member States, care should be taken that identical definitions are used. For example, overhead costs are partly associated with infrastructure maintenance and should therefore (at least partly) be included. The same holds for renewal costs.

9.1.2 Determination the share of variable and fixed infrastructure costs

The *first best approach* is when the infrastructure manager derives the share of variable infrastructure costs from his accounts. This will only be possible for Member States where the infrastructure manager can meet these data requirements. If data availability prohibits this approach, an alternative approach should be followed.

A *second best solution* would be to estimate the share of variable cost by adopting the share of variable cost from other Member States. To answer the question which Member States are comparable, one can allow for the 'freight intensity' of the network. Clearly, the share of variable costs quite heavily depends on the intensity of road usage. As the damage incurred by heavy lorries is incomparably much higher than that of all other vehicles, the freight intensity of the network is crucial for the share of variable costs.

This raises the question how the 'freight intensity' can be expressed. Ideally one would like to base the 'freight intensity' on damage class weighted lorry kilometres divided by the road infrastructure capacity. As this could lead to data availability problems, a reasonably accurate and feasible metric could be: the total annual transport volume (tonne-kilometres) divided by the capacity or the length of the road network.

The aforementioned approach, using a 'freight intensity', is similar to the approach proposed in this study for rail transport (section 9.2.3). For rail, however, an appropriate relation between the 'freight intensity' metric and the share of variable costs has already been found.

Once the share of variable costs is known, the total expenditure on variable road maintenance can be readily calculated by multiplying the total maintenance costs by the share of variable costs.

9.1.3 Cost allocation to different vehicle types

The next step is to approximate marginal maintenance costs by allocating total variable road maintenance expenditure to individual vehicle types. This cost allocation should be based on the main cost drivers, which in turn depend on the type of cost (High level group on infrastructure charging, 1999). Costs for police, operation servicing and ongoing maintenance should be allocated on the basis of road usage. Vehicle kilometres are the best indicator of road usage. All other costs can be allocated on the basis of road damage that vehicles inflict, which depend mainly on the axle weight and road use.

Cost allocation on the basis of vehicle kilometres is unproblematic and can be readily implemented in a simplified approach. Allocation on the basis of road damage is more complicated.

The 4th power rule and AASHO factors
Many estimations of road damage are based directly or indirectly on a series of tests conducted by the American Association of State Highway Officials (AASHO) in the 1950s. Vehicles of different weight and composition were driven on a test track to establish the damage they inflicted on the surface. From these tests, two approaches for calculating road damage emerged.

The first was the so-called fourth power rule, which stated that road damage is proportional to the fourth power of the axle weight. The second, more sophisticated approach is the calculation of the equivalent single axle load (ESAL). ESAL tables convert actual axle configurations and weights into a standard axle load. The fourth power of the ESAL is proportional to the damage. Often the damage factor is referred to as AASHO-factor. In Germany, AASHO-factors are the basis for the allocation of marginal costs [DIW et al. 1998]. ESAL tables have been frequently updated since the 1950s.

Discussion on the 4th power rule
The fourth power rule is a very common relation between axle weight and road damage. However, it has often been criticised, having its basis in research at one test site many years ago. Furthermore, some authors have criticised the data analysis. They argue that the data do not show a fourth power rule, but rather a third power rule or even a quadratic relation between axle weight and road damage (Batelle Team, 1995: *Comprehensive truck size and weight study. Phase 1: synthesis. Pavement and truck size weight regulation. Working paper 3*, Columbus, Ohio). This means that by using the fourth power rule to allocate costs, approximations are made.

More sophisticated approach[54]
Recent research uses the following formula to assess road damage (COST 334, 2000, Effects of Wide Single Tyres and Dual Tyres: Final Report of the Action, European Commission, Directorate General Transport and Brussels):

VWF (Vehicle Wear Factor) = ∑ AWF (AxleWearFactor)

And,

AWF = TCF (Tyre Configuration Factor) * ACF (Axle Configuration Factor) * SCF (Suspension Configuration Factor) * LEF (Load Equivalency Factor)

It should be noted that this formula is an engineering formula that expresses empirical relations, not necessarily causal relations, and not necessarily all causal factors. However, it seems to be the best formula available and is widely used in Europe.

The *Tyre Configuration Factor (TCF)* is a correction factor for tyres that cause relatively high wear. COST 334 has found that wear of wide tyres can be 17% to 97% higher than of dual narrow tyres, which they often replace. We recommend to take a penalty of 50% into account for lorries with wide tyres, corresponding with a value of 1.50 for the TCF. For narrow tyres a value of 1 can be used.

The Axle Configuration Factor (ACF) is a correction factor for tandem and tridem axles. The EU project COST 334 concluded that on some surface types tandem or tridem axles cause higher wear than two or three single axles, while on other surface types the wear of tandem or tridem turns out to be lower. The impact of axle configuration is generally low and therefore was not investigated in COST 334. In a simplified approach, a value of 1 for the ACF can be assumed.

The *Suspension Configuration Factor (SCF)* is a penalty for damaging suspensions (in line with OECD, 1998: Dynamic interaction between vehicles and infrastructure experiment (DIVINE) technical report, Paris). Most new lorries and trucks do have road friendly suspension. DIVINE estimates that the wear of lorries with no road-friendly suspension is 15% to 36% higher than road-friendly types like air-suspension (depending on the type of wear). We recommend to take a penalty of 25% into account for lorries with no road-friendly suspension, corresponding with a value of 1.25 for the SCF. For road-friendly types suspension a value of 1 can be used.

The *Load Equivalency Factor (LEF)* is a factor that relates the damage done by the actual axis load to the damage done by a standard axle. The general formula for the LEF is:

LEF= $(P_{actual}/P_{nominal})^n$

[54] This approach is conceptually identical to ESAL.

P_{actual}, the actual axle load, equals the maximum gross weight of the vehicle divided by the number of axles. $P_{nominal}$, the load of the standard axle, is a constant. The value of n is harder to determine. This factor varies with the surface, and the type of damage done. It is very hard to determine from experimental data (COST 334, 2000). The COST 334 (2000) study used the following values of n: 1 to 2 for primary rutting, 4 for secondary rutting and 4 to 5 for fatigue cracking. Some road surfaces suffer mainly from one specific type of damage, other suffer from all types. If the distribution ratio of road surfaces is known, an average n can in principle be calculated. If this is too much work, one could fall back on the fourth power rule and use n=4, although this is a simplification.

Altogether this yields the following simplified formula:

$$AWF = TCF * SCF * (P_{actual}/P_{nominal})^n$$

(TCF = 1 or 1.5 ; SCF = 1 or 1.25)

If there are no appropriate data available about the types of tyres and suspension used, both TCF and SCF can be set to 1.
This formula is applied below to calculate equivalence factors for damage classes.

Definition of damage classes
The approach described above is still rather sophisticated and will be in many cases being too complex to apply. Therefore, we also propose an approach that is easier to apply, that makes use of predefined damage classes. The definition of these damage classes is important as it heavily influences the distribution of costs among users.

There is general agreement that the damage classes should be defined on the basis of maximum GVW and number of axles.

We calculated equivalency factors based on the formula for the vehicle wear factor (using TCF=1; SCF= 1; n=4), shown in Table 9.

Table 9 Proposed equivalency factors for road damage[55]

Number of axles	2	3	4	5	6+
Maximum vehicle weight (tonnes)					
0-3.5	0.0001				
3.5-7.5	0.09	0.03			
7.5-12	0.9	0.3	0.1	0.04	0.02
12-20	6.6	1.9	0.8	0.3	0.1
20-28	33.2	9.8	4.1	1.4	0.6
28-36		31.1	13.1	4.4	2.0
36-44			32.0	10.7	4.9
>44				22.2	10.2

The equivalency factors from Table 9 should be multiplied by the number of vehicle kilometres to obtain the cost allocation factor for road damage. The equivalence factors for trucks with wide tyres or road-unfriendly suspension can be obtained by multiplying these equivalence factors by respectively the correction factors TCF or SCF.

The number of damage classes in Table 9 is still rather high. Table 10 gives a further simplification by grouping damage classes resulting a reduction of the total number of classes.

Table 10 Grouping to reduce the number of damage classes for road damage[56]

Number of axles	2	3	4	5	6+
Maximum vehicle weight (tonnes)					
0-3.5	A				
3.5-7.5	C	B			
7.5-12	E	D	C	B	B
12-20	F	E	D	D	C
20-28	H	G	F	E	D
28-36		H	G	F	E
36-44			H	G	F
>44				H	G

The equivalence factors for each of the classes A - H are obtained by averaging the equivalence factors of Table 9 and presented in Table 11.

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55 The table assumes one tandem axles for 5-axle combinations, and one tridem axe for 6-axle combinations. If these multiple axles are not present, the equivalency factors should be multiplied with 1,5 in the case of 5-axle combinations, and with 1,9 in the case of 6-axle combinations.

56 The table assumes one tandem axles for 5-axle combinations, and one tridem axe for 6-axle combinations. If these multiple axles are not present, the equivalency factors should be multiplied with 1,5 in the case of 5-axle combinations, and with 1,9 in the case of 6-axle combinations.

Table 11 Equivalence factors per damage class

Class	Bandwidth equivalence factors	Equivalence factor per class
A	<0.01	0.0001
B	0.01-0.05	0.03
C	0.05-0.2	0.1
D	0.2-0.8	0.5
E	0.8-2	1.5
F	2-8	5
G	8-15	11
H	>15	30

Once the total variable costs vehicle for road damage are known, the cost allocation to each class can be calculated by the following formula:

Costs for road damage = Total variable costs road damage * Equivalence factor * Vehicle-km / Σ (Equivalence factor * Vehicle-km)

Once more, this formula only covers damage costs which depend mainly on the axle weight and road use (like maintenance of road surface). Other variable costs like costs for police, operation servicing and ongoing maintenance should be allocated on the basis of vehicle kilometres:

Other variable costs = Total other variable costs * Vehicle-km / Σ(Vehicle-km)

The total variable costs for a class are the sum of the cost for road damage of that class and the other variable costs of that class. The costs per vehicle-kilometre can be calculated by dividing the total variable costs in a class by the total number of vehicle kilometres in that class. This cost allocation approach is illustrated below.

Illustration (with fictive annual figures for a motorway network)[57]:

Total variable infrastructure costs: 13 million €
Total variable infrastructure costs for road surface: 10 million €
Other variable infrastructure costs: 3 million €
Total vehicle kilometres: 2 billion

Basis for cost allocation:

Class	Share in Vehicle-km	Share in road surface costs
A	90%	0.01%
B	1%	0.03%
C	1%	0,11%
D	1%	0.53%
E	1%	1.59%
F	2%	10.62%
G	2%	23.37%
H	2%	63.74%

57 This is an illustrative example with fictive figures but with normal magnitudes

In this example, the variable infrastructure costs for a lorry with a GVW of 40 tonnes can be calculated as follows:

Total costs for damage class G: 23.37%*10 + 2%*3 = 2.4 million
Number of vehicle-kilometres per year for damage class G: 2%*2 billion = 40 million €.
Costs per vehicle-km for damage class G: 6 €ct.

So, if this lorry of 40 tonnes drives over a distance of 100 km, the total variable infrastructure costs are € 6.00.

9.2 Rail

The simplified approach we will discuss below is top-down cost allocation approach. Several cost categories are distinguished, each to be attributed in a different manner to railway users. The main bottleneck of this approach is the determination of the variable infrastructure cost. Although this is not the main focus of this study, we do realize this is a very tricky step. We do describe how this might be done, but the shares we propose to use are based on one particular study in one particular country. The empirical basis is for the use of these shares in other countries with different conditions is not very strong.

Therefore we want to stress that if data availability and resources allow, to use first best techniques for the determination of variable cost, such as the econometric studies for Sweden, Finland and Austria, or the cost allocation method derived from the British study, as described in part one.

Having said that, we will next describe the simplified approach, which is in fact based on the shares suggested in the British study. The simplified approach we suggest for infrastructure maintenance for rail is a top-down cost allocation approach. In contrast to the approach for road, we distinguish five steps:
- Step 1: Determination of scope, i.e. determine which networks are to be considered separately.
- Step 2: Collection of data on maintenance costs for five cost categories.
- Step 3: Determination of variable costs by one of the following approaches:
  - if distinguished in data source, use it.
  - if not readily available, use percentages mentioned in this report.
- Step 4: Collection of data on cost drivers, i.e. traffic volumes (gross tonnes and train kilometres) and where appropriate use of stations and electricity consumption.
- Step 5: Allocation of cost to user.

These steps are explained in the following paragraphs.

9.2.1 Step 1: Determination of scope

Data on the costs of infrastructure maintenance can be collected at line level, regional network level or country level, dependent on the availability of data and the Member States wishes[58]. A more regional approach will increase the accuracy with which cost are allocated to the users of the network.

We propose to distinguish at least the costs of dedicated lines. These include for example High Speed Lines and dedicated freight lines. Separate cost accounts for dedicated lines can be expected to be available. In general, the total cost of infrastructure maintenance for each Member State can be derived from the national accounts or of those of the infrastructure manager.

High Speed Lines are characterised by highly homogenous users. Speed and axle-load (the main cost drivers) differ hardly among users of these lines. For this reason it is, certainly in a simplified approach, not advisable to differentiate the cost allocation with respect to these characteristics. We therefore propose to allocate the variable costs (as a proxy for marginal costs) of these lines to the users on the following basis:

- Determine the total number of wagon-kilometres.
- Allocate costs on the basis of wagon-kilometres.

Second examples of dedicated lines are dedicated freight lines. Axle load can differ substantially for freight trains on these lines. We propose to separate the maintenance costs of these lines from the costs of railroad lines of which both freight and passenger trains make use. For either category we propose to use the simplified cost allocation scheme, described in the next sections. However, the parameters that should be used in this scheme when applied to for dedicated lines can differ substantially from the values mentioned in the next sections. Therefore, the values of the parameters should preferably be determined for the lines concerned.

9.2.2 Step 2: Collection of data on maintenance cost

For the network to be considered, data on the cost of infrastructure maintenance has to be collected. Care should be taken that Member States use identical definitions of maintenance. We propose to include overhead costs associated with maintenance, as well as renewal costs[59]. The costs of building new infrastructure are not to be included (nor are depreciations).

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58 For some countries, costs may be expected to differ widely over regions, due to geographical circumstances. In these cases it is advisable to calculate costs at the scope of lines or regions and not at country level.

59 This is consistent with the Final Report of the EU Task Force on 'Rail infrastructure charging', 2002.

For each of the lines / network to be distinguished, information is needed on several cost categories[60]:

- Costs related to track maintenance and track renewals.
- Costs related to structures.
- Costs related to signals.
- Costs related to electrification[61].
- Costs related to stations.

For each of these costs, the share of variable / marginal cost needs to be determined. In the next section we discuss how this can be estimated for situations where the infrastructure manager is not able to provide this information.

9.2.3 Step 3: Determination of variable cost

The *marginal* costs of infrastructure use are generally very hard to determine when making use of simplified approaches. We therefore propose to use *average variable* costs as a proxy for marginal costs. It is unclear whether this results in a higher or a lower estimate of marginal cost.

Ideally, the infrastructure manager can provide information with respect to the share of variable cost. This would be the first best approach.

If data availability prohibits this approach, a second best solution could be to estimate the share of variable costs.

A very straightforward approach is to adopt a default share of marginal cost for all Member States. An overview of the studies on this topic is presented in Table 12. Please note that these studies apply to *track* maintenance costs only.

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[60] A further refinement of this simplified approach is possible by distinguishing several subcategories, see table 13.

[61] We refer to costs related to the maintenance and renewal of the catenary system, we expect electricity to be charged separately.

Table 12 Overview of the share of variable[62] track maintenance costs according to different studies

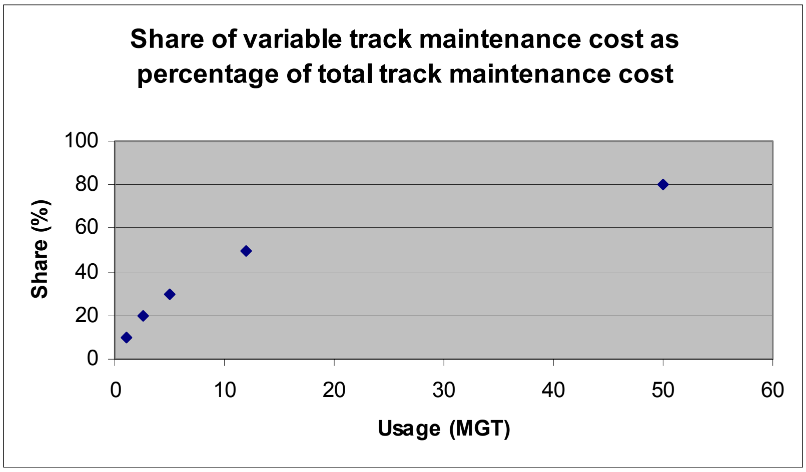
Study	Country	Share variable track maintenance costs of total track maintenance costs	Approach	Comment
Unite D10, Johansson and Nilsson (2002)	Sweden	13% to 28%	Econometric	main lines only
	Finland	17%	Econometric	main lines only
Idström (2000)	Finland	27% to 32%	Econometric	all lines
Munduch et al. (2002)	Austria	27%	Econometric	all lines
Booz Allen Hamilton (2000)	UK	33%	Engineering	all lines

See also: Final Report of the EU Task Force on 'Rail infrastructure charging', 2002.

However, as stated before, the share of variable costs quite heavily depends on the intensity of rail usage[63]. A good proxy for rail usage would be: the total transport volume (gross tonne-kilometres) divided by the length of the rail network.

The bottleneck of this approach is how the rail usage relates to the share of variable costs. In the UK a study has been done on this topic by comparing the results of a number of international studies, yielding a relation between usage and the share of variable costs. Figure 12 shows this relation, where maintenance cost include variable and fixed renewal costs. Knowing the usage of a stretch (expressed in Million Gross Tonnes per year, MGT) an indication of the share of variable costs can be read from the vertical axis.

Figure 12 Relation between share of variable cost and rail usage



Source: (BAH, 2000)

62 Throughout the different studies the notion of marginal cost is not used consistently, in most cases something as average variable costs are estimated.

63 Another important determinant for the share of variable track maintenance cost is track quality / track standard. We do not see any possibilities to account for this in a simplified approach.

This relation could be a suitable basis to establish the share of variable *track* costs. Note that average usage for the UK was estimated to lie around 5 MGT per year[64], corresponding to a share of about 33% of variable track maintenance cost.

For the other cost categories distinguished in section 9.2.2 there is less research available for the share of marginal cost for *non-track* cost items. The only study found is a UK source of which the results are presented in Table 13[65]. This study does not provide estimation for the share of variable costs related to stations. For this, one will have to rely on the expert judgement of the infrastructure manager.

Table 13 Variability per asset type

Cost item	% variable
Track	**33**
Maintenance	30
Renewals	
Rail	95
Sleepers	25
Ballast	30
Switches & Crossings	25
Structures	**10**
Signals	**1**
Maintenance	5
Renewals	0
Electrification	**24**
Maintenance	
Alternating Current	10
Direct Current	10
Renewals	
Alternating Current	35
Direct Current	41

Source: (BAH, 2000)

The percentages in Table 13 relate to the British network, with a MGT of around 5 per year. Except for track related cost, see Figure 12, we do not know how these percentages vary with use.

However, for non-track costs the above data are the only available data in the literature known to us. Therefore, we propose these (static) figures above as a basis for these costs. For track related cost, the best option is to base the estimate of the share of variable cost on Figure 12.

Once the shares of variable cost are known for each cost category, the total expenditure on variable rail maintenance can be readily calculated by multiplying the total maintenance costs by the share of variable costs.

64 Although usage on one third of the network is expected to lie below 2 MGT per year.

65 Note that on the basis of the numbers in this table, the variable share of track related cost can also be determined in greater detail. This gives the opportunity of a refinement of the proposed simplified approach.

9.2.4 Step 4: Collection of data on cost drivers and Step 5: Allocation to user

The next step comprises the collection of data on cost drivers. Before we come to this, we will first describe which cost drivers are to be used for the allocation of variable rail maintenance cost to individual users for each of the five cost categories distinguished.

As we have seen in part 1 of this report, marginal / variable rail infrastructure costs are influenced by quite a variety of cost drivers. For wear and tear costs (track and structures) axle load, speed and distance travelled are the most important cost drivers and allocation of costs should therefore be based on some combination of these cost drivers. For overhead and other costs (signals) an allocation based on train kilometres seems more appropriate.
Furthermore, it seems fair that costs that are made for specific users, such as the (variable) cost of the catenary system (electrification), are exclusively allocated to these specific users. A second cost category for which this holds are the variable costs associated with railroad stations (stations). We propose to allocate the former on the basis of electricity used and the latter on the number of stops at stations. The variable costs with respect to signals are best allocated on the basis of train kilometres. How to allocate the variable cost related to wear and tear is discussed separately, since the relation between cost and cost drivers is less straightforward and these costs constitute a substantial part of total variable maintenance cost.

Cost allocation of wear and tear costs (track and structures)
The main cost drivers for wear and tear cost are train weight and speed.

Ideally the *train weight* would comprise a measure of axle load and number of axles (per wagon and in total).

Speed can be measured in various ways, average speed, top speed, technical operating speed, speed allowed on the track. Average speed[66] will be low for trains that make many stops, while accelerating and braking result in relatively more damage. Realised top speed may therefore be a theoretically better indicator. The technical operating speed, a distance-based average speed based on time tables, was used in the study for the UK. A very practical measure would be the speed allowed on the track, but it is unclear how this relates to marginal cost. Furthermore, for freight trains the operating speed may be 50% below the line speed. Again clearly, a trade off between practicability and theoretical best indicator needs to be made.

The study for the UK approximates relative damage of trains by calculating damage-equivalence factors per wagon / vehicle. These factors take, inter alia, speed and axle load into account. Separate damage-equivalence factors have been calculated with respect to the variable track cost and the variable costs of structures.

[66] A complicating factor when using average speed is that the operator is not always responsible for non-commercial stops.

For track-related costs, the variable costs per wagon are related to (an estimate of actual and **not** maximum) axle load to the power 1.49[67] and speed to the power 0.64[68]:

Costs ~ axle load$^{1.49}$ x speed$^{0.64}$

For structures (such as bridges and tunnels), the following formula was estimated:

Costs ~ axle load$^{4.83}$ x speed$^{1.52}$

The formulas were derived by a so-called track usage model. BAH (1999) makes the following reservation:

'The validity of the track usage model is therefore the critical component of the usage cost determination. However, whilst the track usage model contains state-of-the-art engineering models of cost causation, we do not consider that the approach is conducive for pricing purposes:

- The track models are cost models, attempting to explain the causality of cost incidence.
- Although representing current knowledge, the models are not comprehensive in their determination of usage-related costs; furthermore, the coefficients within the model are determined from experimental and field date but the statistical significance of some of the estimates appears weak.
- Some of the identified shortcomings of the current version of the model can be overcome with alternative assumptions and this may significantly alter the attribution of costs between passenger and freight users; but more generally it is a considerable further step to use that cost modelling for pricing purposes.
- Track condition should be at the centre of a cost model: maintenance costs will be a function of condition and current condition is an important issue in calibration of the model, yet the general assumptions on condition are made within the models.
- Although regression analysis demonstrates that the relativities between costs per vehicle type are consistent with experience elsewhere, the absolute level of activity and costs against which the models are calibrated cannot be independently verified.'

The formula for track related cost suggests that costs are over-proportionally related to axle load, and under-proportionally to speed. Studies for Austria,

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67 Note that the formula in the original document, BAH (1999), links the **cost per GTM** with axle load and speed (and some additional factors, with respect to locomotives and loaded hoppers). Axle load has a power factor 0.442 (in a later document, BAH (2000) further refined to 0.49) in this formula. This implies **total variable cost** and axle load are linked with a power factor of 1.442 (or 1.49 due to the further refinement). The power factor with respect to speed was estimated to be 0.65 in BAH (2000), instead of 0.365 in BAH (1999), partly due to the use of a different definition for speed.

68 The power factor with respect to speed was estimated to be 0.65 in BAH (2000) instead of 0.365 in BAH (1999). This change is related to the use of technical operating speed calculated as an distance-average instead of a time-average speed.

Finland and Sweden all implicitly assume that the only cost driver related to vehicle characteristics is gross tonnes. The speed allowed on the track is sometimes included as explanatory variable, but serves in these cases as an indicator of track quality.

To apply these formulas for cost allocation, one would have to know the actual axle load and speed of each wagon on the network. Data availability with respect to axle loads is expected to be poor. Furthermore, application of the formula to other countries and situations should be done with caution. For these reasons, we propose a simplification.

First of all, since the variable track related costs usually dominate the variable structure costs[69], we propose to allocate the structure-related costs as if they were track-related cost[70].
Secondly, we propose to allocate both track and structure-related costs on the basis of gross tonnes (including vehicle weight). The rationale for proposing this method is as follows.

In cases with limited data availability, actual axle loads will often not be available. An estimate of gross tonnes (including vehicle weight) most probably will be. Therefore we propose to use gross tonnes. This has a disadvantage, though. According to the British formula[71], axle loads have a more than proportional influence on marginal costs (doubling the axle load more than doubles the proportion of costs allocated to the wagon). By using gross tonnes as a proxy, this more than proportional effect cannot be accounted for and passenger trains, which have low axle loads compared to freight trains, are allocated a relative large part of the cost.

This effect is counteracted, however, by not including speed in the cost allocation method. In general, passenger trains travel faster than freight trains. Inclusion of speed would lead to passenger trains being allocated a larger share of the cost. However, they were already allocated a relative large part of the cost due to the approximation of axle load by speed. For networks where speed differences are not too large, these two effects appear to balance reasonably well, see e.g. CE (CE, in progress).

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69 In BAH (1999) 78% of usage-related costs are estimated to be track related, compared to 12% structure-related.

70 Note that this simplification can only be made if in fact structure costs are dominated by track-related costs. If not so, one will have to apply a more complicated approach.

71 As far was we know, this is the only publicly available source of information that tries to derive costs relationships for speed and axle load simultaneously.

Therefore, in practice the difference in cost allocation between a theoretically more correct (and more complicated) cost allocation method and the proposed simplified cost allocation method are expected to be relatively modest[72],[73].

Summarizing, we propose to use the following cost drivers for the allocation of variable maintenance cost:

- Gross tonnes kilometres for cost of track and structures.
- Train kilometres for cost related to signals.
- Electricity consumption for cost related to electrification.
- Number of stops at stations for cost related to stations.

Data on these cost drivers needs to be collected. Allocation to specific users is then relatively straightforward by calculating the share that a specific train represents with respect to the total volume of the respective cost driver. This percentage is to be multiplied with the amount of variable cost in each cost category.

The cost per train for a certain haul can thus be calculated by the following formula:

Cost per train = Σ total maintenance cost per cost category * share of variable cost in cost category * (train performance / Σ train performances on stretch of network)

The term in brackets with respect to train performance relates to the appropriate cost driver for each cost category. For stations, for example, is would be the number of stops at stations of the particular train on this haul divided by the total number of stops in a year on all stations.

9.3 Aviation

Contrary to road and rail transport, infrastructure costs of aviation are already for a large share paid by the infrastructure users, on a usage depend basis. The fact that airports are increasingly privately owned infrastructures with cost-based pricing schemes, plays here an important role.

Infrastructure users of airports usually pay the lion share of the total costs, not just the marginal costs. Therefore, most research on airport infrastructure costs is

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72 Remember that high speed lines and dedicated freight lines are treated separately.

73 An alternative approach would be to introduce equivalence classes as we have done with respect to marginal cost of road infrastructure. There would be two options:

- equivalence classes based on axle load and speed.
- equivalence classes based on gross tonnes.

The former would lead to an indication of costs per wagon, for each train precise information on wagon types, number of wagons and load would have to be taken into account. We do not think this kind of detailed information can be required in a simplified approach.

Equivalence classes based on gross tonnes would not add anything to expressing cost per gross tonne. Using gross tonnes is an approximation for the approach relating costs with axle load and speed. Therefore, speed falls out of the equation when using gross tonnes. Using equivalence classes based on gross tonnes instead of gross tonnes directly would introduce only further disturbances to the calculated costs per train.

focused on *total* costs. As far as we know, there is hardly no research on *marginal* airport infrastructure costs.

In theory, a *marginal* cost approach for airports, could be based on a cost allocation approach, similar to the approach proposed for road transport. The share of total cost that could be labelled as usage depend is probably rather low. The allocation of the total cost to different aircraft could be done by the MTOW[74] or by defining several damage classes. There is no reason to assume that the 4th power rule also holds for airport infrastructure.

However, because of lack of research, a solid marginal cost approach for airports will be very difficult to define. We doubt such an approach would contribute to the current situation. Therefore, at this stage we do not pursue the recommendation of a simplified *marginal* approach for airport infrastructure costs any further.

References:

- (BAH, 1999) *Railway infrastructure cost causation, Report to Office of the Rail Regulator*, Booz Allen & Hamilton, November, 1999
- (BAH, 2000) *Usage costs: issues raised in the Regulator's consultation*, Booz Allen & Hamilton, October 2000
- (CE, in progress) *Onderhoud en beheer van infrastructuur voor goederenvervoer- structuur en hoogte van kosten*, CE-Delft, in progress
- (EU Task Force, 2000) *EU Task Force on Rail Infrastructure charging in the framework of Developing European Railways Committee - Final Report*, 2002

[74] Maximum Take Off Weight.

10 Congestion and scarcity costs

10.1 Calculation methods for a simplified approach for congestion costs of individual transport

One must be aware that congestion development on a transport infrastructure is a complex phenomenon, notably due to possible interactions between the different sections of the infrastructure at hand. Also estimated congestion costs are distributed on a wide range of values[75].

Therefore two types of methodological approach have been envisaged, respectively for simple and complex network situations.

10.1.1 Simple network situation: a single infrastructure link

The hereafter method applies in case of a single link, with no bottleneck at its end and when entering traffic flow does not exceed the link' capacity. It can conveniently be used for stretches of interurban motorways, dual carriageways and trunk roads. It is based on the use of a set of speed-flow curves differentiated according to context and type of road, i.e. the UK COBA.10 curves.

Underlying rationale is as follows:
Considering average time to travel 1 km on the link being concerned (AT), related traffic flow (Q), average speed (S) and average value of time (VOT), total time travelled along 1 km of the link (TTC) is given by:

$$\mathbf{TTC = VOT.Q.AT = VOT.Q.}\ \frac{\mathbf{1}}{\mathbf{S}}$$

Differentiating this and subtracting the average time cost gives:

$$\mathbf{MECC} = \frac{\delta \mathbf{TTC}}{\delta \mathbf{Q}} - \mathbf{VOT.AT = VOT.Q.}\ \frac{\mathbf{-1}}{\mathbf{S}^2} \cdot \frac{\delta \mathbf{S}}{\delta \mathbf{Q}}$$

A linear speed flow curve (constant a, slope –b) gives speed as: S = a – b.Q Thus the marginal external congestion cost is given by:

$$\mathbf{MECC} = \frac{\mathbf{b.VOT.Q}}{\mathbf{S}^2}$$

75 Which is clearly shown by figures in tables 1 and 2 of section 4 (Part 1).

COBA' curves have the form of two linear segments which are defined by:

- S0 : the free flow speed, i.e. the average speed for 0 traffic flow, which is the y coordinate of the beginning of the first segment of the curve.
- Q1 and S1: the traffic flow and speed at junction of the two curve' segments.
- C and S2: the maximum possible traffic flow, i.e. the link capacity, and related speed, which are the x and y coordinates of the end of the second segment.

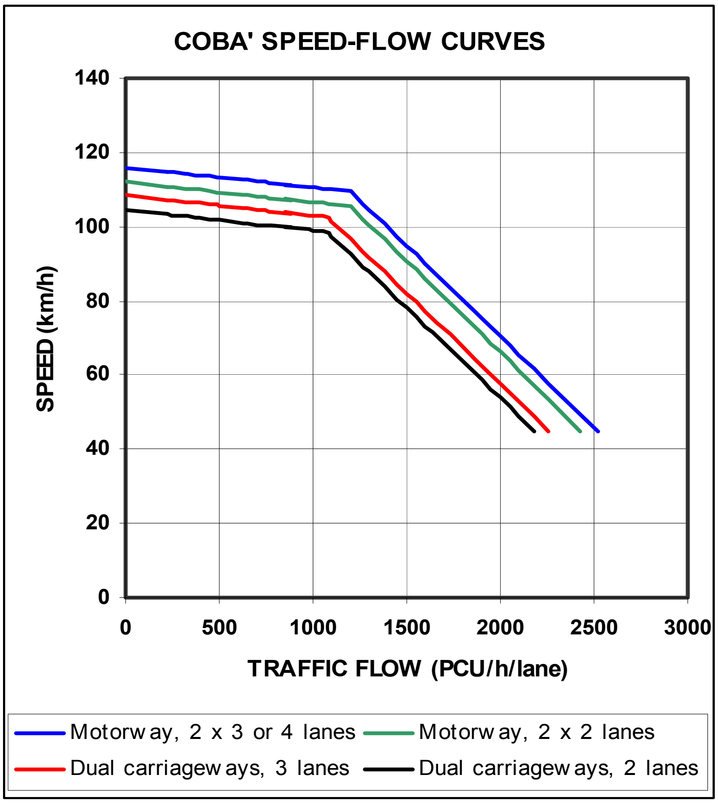
With the traffic flow Q and capacity C being expressed in PCU/h/lane. Appropriate Values of S0, S1, S2, Q1 and C are indicated in Table 14 for 4 examples.

Table 14 COBA speed-flow curves parameters

Context and type of road		S0 (km/h)	S1 (km/h)	S2 (km/h)	F PCU/h/lane	C PCU/h/lane
Rural	Motorway, 2 x 3 or 4 lanes	116	109.5	45	1200	2520
	Motorway, 2x 2 lanes	112	105.5	45	1200	2430
	Dual carriageways, 3 lanes	108.5	102.5	45	1080	2260
	Dual carriageways, 2 lanes	104.5	98.5	45	1080	2180

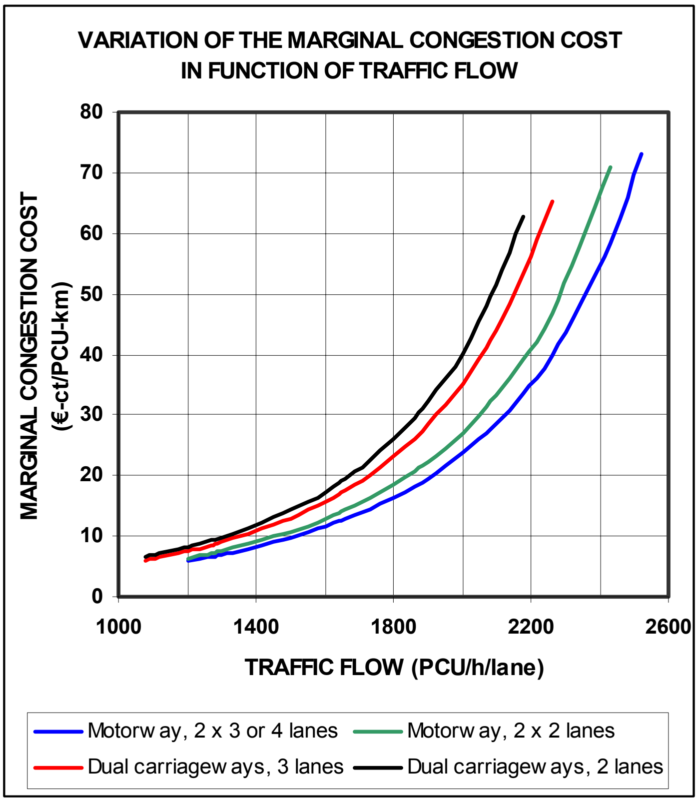
Graph of Figure 13 shows these examples of speed-flow curves.

Figure 13 Examples of COBA speed-flow curves



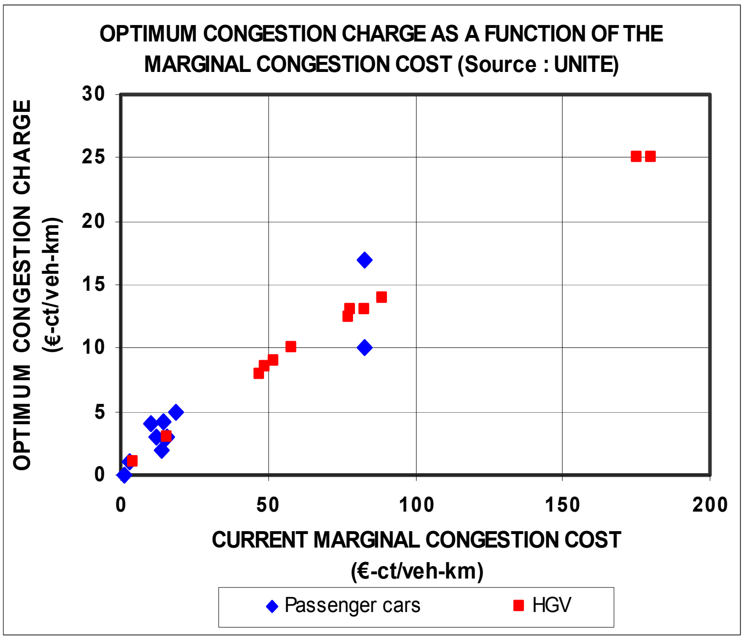
Hereafter Figure 14 shows variations of marginal congestion cost in function of traffic flow for a VOT of 12 €/PCU-h which is a current value for Belgium.

Figure 14 Marginal congestion costs as calculated on the base of the COBA



The following must be emphasized: owing to the sharp increase of the marginal congestion cost in function of the traffic flow, optimum congestion charging can achieve significant reduction of congestion through applying congestion charges of a rather reasonable level. This is shown on graph of figure 15 where optimum congestion charges are plotted in function of related current marginal congestion costs for interurban long distance routes: relationship between optimum congestion charge and marginal congestion cost shows a linear character (at least for HGVs), and there is an average ratio of 1 to 4.6 between them for passenger cars and 1 to 6 for heavy goods vehicles.

Figure 15 Relationship between optimum congestion charge and current marginal congestion costs



10.1.2 An illustration

As an illustration of how to use the COBA curves to calculated congestion cost, we add a fictitious example of an HGV travelling from Hamburg to Munich in Germany.

- The example is typical of the simple network situation wherein the route that is followed by the HGV being concerned is divided into stretches that are considered individually.
- The route assumption was a combination of driving along motorway A7 up to junction with motorway A8, and then motorway A8 up to München; total driving distance is 818 km.
- The route was divided into homogenous stretches considering relevant road characteristics (here the number of lanes[76]).

We have further made assumptions on the traffic flow and share of HGVs per stretch. The latter was used to calculate an average VOT from the VOT of HGVs (assumed to be € 45 per vehicle hour) and the VOT of passenger cars (€ 12 per vehicle hour).

Based on these assumptions, average speed on a stretch can be determined by the use of COBA curves such as shown in Figure 13. From these calculations, the travelling time on the stretch follows.

Next, average marginal congestion cost can be calculated separately for each stretch considered as a single link and assuming that there is not bottleneck at

[76] No detailed information was available to us, we have therefore based the example on fictitious numbers of lanes.

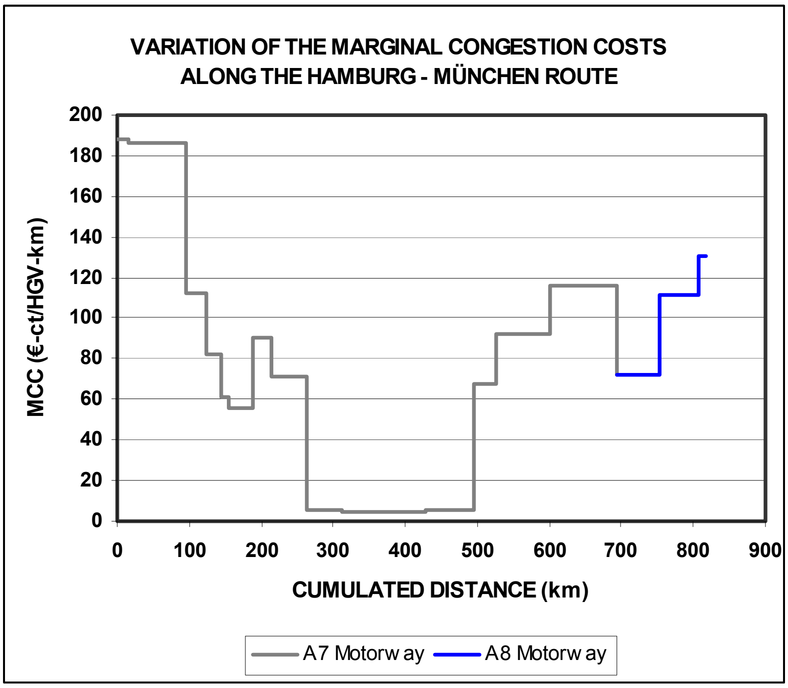
end of any stretch by making use of COBA curves and parameters[77] such as in Figure 14.

Total travel time (not considering possible stops for driver' lunch and rest) is thus calculated at around 8 hours and total marginal congestion cost are estimated at € 408, i.e. an average marginal congestion cost of 50 €cts per HGV kilometre along the route.

It must be understood that data such as number of lanes, traffic flows and share of HGVs are not the actual ones and were only used in order to illustrate the recommended methodology. Related results are thus purely illustrative of the methodological process and should not be interpreted as actual estimates of actual speeds and marginal congestion costs though their values can be seen as plausible ones.

The detail of data that were used and steps of the calculation are shown in Table 15. Graph of Figure 16 shows related variations of the marginal congestion cost along the route.

Figure 16 Variations of the HGV marginal congestion cost along the Hamburg - Munich route



[77] Capacity and traffic flow at junction of the two linear segments composing the COBA' curve (expressed in PCU/h/lane), and speeds at 0 traffic flow, at junction of the two linear segments of the curve and at capacity (expressed in km/h).

Table 15 Example of marginal congestion costs calculation for a route (Hamburg – München) considered as a succession of single links

Road n°	Main sections		Mileage (km)	Type of road	Number of lanes	Traffic flow (PCU/h)	HGVs in % of total vehicles	Average VOT (€/PCU-h)	Average speed (km/h)	Travel time (h)	Current MCC (€-ct/HGV-km)	Current MCC (€)
A7	Hamburg	A1	16	Dualcarriageway	4	7315	21%	15.6	82.5	0.19	163.4	26.14
A7	A1	A27	79	Motorway	3	5165	25%	16.2	95.5	0.83	89.7	70.86
A7	A27	A352	30	Motorway	3	4950	22%	15.8	97.5	0.31	80.4	24.12
A7	A352	A2 (Hannover)	19	Motorway	3	4865	24%	16.1	98.2	0.19	79.4	15.09
A7	A2 (Hannover)	A37	11	Motorway	3	3265	18%	15.2	112.5	0.1	38.3	4.21
A7	A37	A39	34	Motorway	3	2870	18%	15.2	116	0.29	31.7	10.78
A7	A39	N243	24	Motorway	2	2405	21%	15.6	105.4	0.23	33.2	7.97
A7	N243	A388	50	Motorway	2	2505	20%	15.5	104.1	0.48	35.2	17.6
A7	A388	A44 (Kassel)	49	Motorway	2	2730	16%	14.9	101.2	0.48	39.1	19.16
A7	A44 (Kassel)	A4	59	Motorway	2	1830	18%	15.2	110.0	0.54	12.6	7.43
A7	A4	A66	57	Motorway	2	1950	17%	15.1	109.0	0.52	13.5	7.7
A7	A66	A70	68	Motorway	2	2235	15%	14.7	106.8	0.64	15.7	10.68
A7	A70	A3	31	Motorway	2	2480	17%	15.1	104.5	0.3	33.7	10.45
A7	A3	A6	73	Motorway	2	2510	16%	14.9	104.1	0.7	33.9	24.75
A7	A6	A8	94	Motorway	2	2700	20%	15.5	101.6	0.93	39.9	37.51
A8	A7	N2 (Augsburg)	60	Motorway	3	4520	12%	14.3	101.3	0.59	61.6	36.96
A8	N2 (Augsburg)	N471	53	Motorway	3	5930	10%	13.9	88.7	0.6	102.4	54.27
A8	N471	München	11	Dualcarriageway	4	8535	7%	13.4	74.4	0.15	201.4	22.15
Total/average			818						101.4	8.07	49.9	408

10.1.3 Complex network situations: urban, regional networks

Complex network situations cannot be dealt with in such a way without important preparatory work. A simplified method should then consists of referring to values calculated for a certain number of cases so that a satisfactory range of situation can be given at least order of magnitude of the marginal congestion cost. Urban networks are concerned here.

Rationale for estimating these values of the marginal congestion cost is simply the generalization of the principles described here above for a single link wherein total travel time, average travel time, total traffic flow, etc are aggregates estimated at the level of the network being concerned. These values have been calculated through performing simulation work based on different levels of demand, as explained in chapter 4, generally for typical periods of the day : average peak and off peak periods.

Table 16 shows levels of marginal congestion costs observed in various types of urban network situations.

Table 16 Levels of marginal congestion costs observed in various types of urban network situations

Type of urban area	Marginal congestion cost (€ ct/vkm)		
	Passenger car	Bus	HGV
Small size, peak period	6 to 40	12 to 80	15 to 100
Medium size, peak period	25 to 130	50 to 260	65 to 325
Conurbation, inner area, all day	Average : 62	Average : 125	Average : 155
Conurbation, outer area, all day	Average : 34	Average : 70	Average : 85
Metropolis, centre, all day	Average : 126	Average : 255	Average : 315
Metropolis, inner area, all day	Average : 74	Average : 150	Average : 185
Metropolis, outer area, all day	Average : 40	Average : 60	Average : 100

In the average, ratios between marginal congestion costs (MCC) and optimum congestion charges (OCC) vary according to city size are in the range of 3 to 1.2, as shown in Table 17.

Table 17 Ratio of the marginal congestion costs to the optimum congestion charge for roads in inner and outer urban areas

Period of the day and type of urban area	Ratio of MCC to OCC
Peak periods	
Large European cities	3
Medium size cities	2
Small size cities	0 to 1
Intermediate periods between peak and off peak	1.5
Off peak periods	0 to 1.2

10.2 Calculation methods for a simplified approach for congestion costs of public transport operated on their own infrastructure

Development of methods for calculating congestion costs for railway and air transport are still at a research stage, notably considering the complexity of such problem. One of the conclusions of the state of the art review is that approaches for this would be very specific of the case being addressed, considering the driving importance of factors such as network or infrastructure configuration and traffic patterns.

Regarding the **railway side**, studies have been performed in Switzerland and the UK, based on estimated relationships between delays and traffic density. Main results, in terms of estimated marginal congestion costs are summarized in Table 18.

Table 18 Comparison of marginal congestion costs estimated for the Swiss and UK railways

Railway	€/trip		€-ct/p-km		€-ct/train-km	
	Low	High	Low	High	Low	High
Swiss railways	Off peak (1)	Peak (2)	Off peak (1)	Peak (2)	Off peak (1)	Peak (2)
	0.070	0.095	0.074	0.280	3.7	41.9
UK railways	Regional (1)	London (2)	Regional (1)	London (2)	Regional (1)	London (2)
	0.280	0.075	0.280	0.290	14.0	44.0

(1) 50 passengers, 100 km
(2) 150 passengers, 35 km
Source : UNITE

As far as both studies were not based on the same approach, comparison must be made on the Swiss side for peak and off peak periods and on the UK side for train services with low and high density levels. However the differences in the approaches being referred to by the respective authors, there is a remarkable similarity of results for the peak traffic conditions. This might be coincidental to the extent Swiss and UK related assumptions and valuations likely differ from each other, however these figures provide with useful information for setting of pricing schemes and indicate the severity of bottlenecks in time and space.

Estimated rail congestion costs on the Swiss railway network were as follows, using two models considering either all train delays or only delays exceeding 5 min.

Table 19 Model results for rail congestion costs

	Model 1: all delays			Model 2: delays > 5 min only		
	€-ct/trip	€-ct/pas-km	€-ct/train-km (1)	€-ct/trip	€-ct/pas-km	€-ct/train-km (1)
Peak	9.5	0.279	41.85	3.9	0.115	17.25
Off peak	2.5	0.074	3.70	1.0	0.029	0.50
Night	1.5	0.044	1.10	0.6	0.018	0.44
Average	3.2	0.094	9.40	1.3	0.038	3.80

(1) Train occupancy rate considered for conversion : peak : 150; off peak : 50; night : 25.

Source : UNITE

According to model 1 (all delays being considered) estimate, there are congestion externalities of 0.1 € per trip during peak periods and 0.03 € per trip off peak. Model 2 (considering only the delays exceeding 5min) produced congestion externalities estimates at a level of 40% of those produced by model 1.

On the **air transport side**, there doesn't exist any more methods than for the railways. The Madrid airport case study of the UNITE project produced estimates of the additional costs per delayed arrival or departure, and derived costs per trip, passenger, aircraft-km and passenger-km on the base of assumptions regarding frequency of flights delayed by more than 30 min (20%), average number of passengers per flight (130), average travel distance (300 km) and situation at other airports that was assumed to be similar to Madrid. Resulting figures were as follows.

Table 20 Model results for air congestion costs

Average additional delay costs per flight, trip and passenger-km (1)		
Type of cost	July 1999	July 2000
Cost per flight (€)	3 244	2 756
Cost per passenger (€)	24.95	21.20
Cost per aircraft-km (€-ct)	1 081	919
Cost per passenger-km (€-ct)	8.2	7.07

Source : UNITE

These figures are based on very rough assumptions and might easily vary by a factor of 2 or 3 considering other aircraft occupancy rates and travelled distances.

10.3 Scarcity costs

Scarcity costs haven't been to date the object of any operational methodology, either for rail or for air transport.

As far as rail transport is concerned, cost – benefit analysis is recommended by the Strategic Rail Authority for assessment while Directive 2001/14 of the Commission requires rail infrastructure managers to undertake studies in the view of determining the cost of expanding capacity and testing through cost-benefit analysis whether it is justified, but these approaches are far from being simplified. Regarding air transport, there isn't any analytical method that has ever been applied or even tested.

On the other hand there is a concern about efficiency of slot allocation procedures and pricing as far as these are of administrative character and aimed at recovering the infrastructure manager costs instead of priced at operators willingness to pay.

Remedy for inefficiencies of both sectors be under the form of implementing market oriented allocation procedures based on auctioning and trading mechanisms.

As far as railways are concerned, a difficulty arises from the fact that operators are seeking to purchase sets of slots in the view of offering attractive and well balanced services over time. To overcome this problem, allocation of slots is usually performed in successive stages whereby operators introduce their demands, in response to which the infrastructure manager designs packages of slots that are in turn proposed to the operators. Both parties are then entering into negotiations so as to find satisfactory solutions. Prices can be to some extend reflect market values under the form of differentiation between highly trafficked lines and less trafficked ones, between peak and off peak etc, but no strict market mechanism applies to the whole process and there is no strict insurance that the procedure is as efficient as it should be.

On the air transport side, there are also prospects to base allocation procedures on slot auctioning or a combination of auction and secondary trading under the form of bilateral negotiations between airlines. But such a procedure that would enable to have a better knowledge of the costs of slot scarcities is only functioning at present in 4 US major airports fro domestic flights. Secondary trading between airlines is also used at London airports, but this mechanism is not transparent so as to enable negotiated prices to be seen as transferable ones for other European airports. In other words, appropriate slot prices would only result from implementation of market mechanisms evoked above. Even if these would not be quite transparent, they would have the merit to have the slots allocated in accordance with the airlines willingness to pay.

10.4 Common issues

A main common issue is how the charge levels can be differentiated between different Member States. As far as the main "goods" being concerned is the end user time, the problem can easily be solved under conditions each Member State has available appropriate estimates of value of time according to travel purpose and mode of transport.

In case such values are not actually available, values might possibly be derived through ratios of such values to average per capita revenue for Member States where they are available.

11 Marginal external accident costs

11.1 Marginal Costs or Cost Allocation Approach

The first question to be answered is whether the simplified approach should be based on a marginal costs approach or on a cost allocation approach.

The *marginal approach* is theoretically preferable, however as we have seen in part 1 of this study, it has a couple of drawbacks. First, risk elasticity's derived from existing case studies cannot be easily used for general purposes; they're too specific and different case studies lead therefore to different results. Second, the execution of new primarily case studies is costly and time consuming. Third, these studies tend to exclude risk avoidance costs.

The *cost allocation approach*, although theoretically less satisfactory, does have its merits. It's application is much easier, data availability is better, and it is up to now not certain that the results of average cost approaches are substantially different from results from a perfectly done marginal case study - i.e. one that *includes* risk avoidance costs. The reason for this is that low risk elasticity will generally go hand in hand with high risk avoidance costs vice versa.

Therefore we propose to follow the cost allocation approach for the simplified calculation methodology. The generally 'easy to obtain'- average costs will be refined by taking into account factors such as vehicle type (passenger car = low risk and lorry = high risk), location (urban areas = low risk, non-urban areas = high risk), time of day (night = high risk), driver characteristics etc. Naturally, the more refined the approach, the higher the data requirements.

In subsections 3 and 4 we describe the different steps in this cost allocation approach for road, rail and air transport in detail. In the subsection below we first pay attention to some 'more theoretical' items and the assumptions we made on these.

11.2 Discussion points

In a cost allocation approach one first determines the total costs for society of accidents and one subsequently tries to specify them to the different cost drivers.

A specific question (especially in road accidents) is how to allocate victims in multi-party accidents to the parties involved. Approaches followed include allocation on the basis of accident involvement, on the basis of fault, or on the basis of damage done to the other party. Ideally we would like propose to follow the last approach, in line with studies done in the framework of UNITE such as 'External accident costs of heavy goods vehicles' (Lindberg, 2001). However, we are aware that this approach requires quite advanced accident statistics that do not only register the vehicle victims were sitting in, but also the vehicle they collided with (so-called 'conflict tables'). According to our current knowledge the central EU CARE accident database is not that advanced. In this simplified approach we only take into account the vehicle type that causes the accident, so actually in most times on the basis of faults made.

Different valuation internal and external risks?
Another question is whether ‘internal’ and ‘external’ victims should be valued differently. ‘Internal’ victims are those that, for example, drive into a tree. Theoretically it could be questioned whether these victims have faced external costs. However, to date we are not aware of studies that distinguish between these two types of risks. Therefore, we propose not to differentiate between these victims. We think this is a topic that should deserve more attention in European research projects.

Insurance premiums
Insurance premiums can be considered as partly internalisation of external costs. According to economic theory, the premium for self protection should not be deducted, but the premium for third party risks should. We propose not to take these insurance premiums into account as we don’t know too the value of the damage of the vehicles involved in road accidents.

11.3 Approach for road transport

The approach for road transport consists out of five steps:
- Step 1: Determine the valuation of traffic fatalities and injuries.
- Step 2: Collection of statistics on causers of accidents.
- Step 3: Valuation of fatalities and injuries per vehicle kilometre.
- Step 4: Collection of statistics on victims of road accidents.
- Step 5: Determination of correctional factors for cost drivers.

11.3.1 Step 1: Determine the total valuation of traffic fatalities and injuries

We propose to use a Value of Statistical Life (VOSL) of € 1.5 million per fatality[78] (1998 figure) measured as a consumer value (i.e. in market prices). With Public Power Parity-figures this value can be made country-specific.

To have the full value of a fatality the cost of net loss production, medical and ambulance cost should be added, which is approximately 10% of the VOSL. To express it as a factor price[79] (so items are valued without indirect taxes like VAT) the resulting value should be corrected for the indirect taxation level (approximately 20% see chapter on transferability), as illustrated in the formula below.

This resulting value must be multiplied with the total number of fatalities in road transport to calculate the total valuation of all fatalities.

[78] Based on a limited number of well-designed studies UNITE proposes a VOSL of € 1.5 million per fatality.
[79] See chapter 2 for country-specific figures.

Illustration for Belgium:	
Value of Statistical Life (Europe, 1998):	1.50 million €
Cost of net loss production, medical and ambulance cost:	0.15 million €
Inflation Belgium 1998-2003:	9.0%
Public Power Parity figure Belgium:	1.069
Average of indirect taxation on consumer expenditure:	18.9%
Valuation of a traffic fatality in Belgium	1.62 million €
Number of fatalities in Belgium (in 2001)	1,486
Total costs of road fatalities for society	2.40 billion €

The same methodology can be applied for injuries. We propose to valuate severe injuries at 13% and light injuries at 1% of the value of fatalities[80]. Recent information on the amount of serious and light (or slightly) injured persons per country can be obtained from the CARE–database.

The total cost of traffic accidents can be calculated by the following formula:

Cost of traffic accidents = (0.01 * number of light injuries + 0.13 * number of severe injuries + number of casualties) * (1.10 * VOSL * PPP) / (1 + indirect taxation percentage)

11.3.2 Step 2: Collection of statistics on causers of road accidents

In the second step one collects statistics on causers of accidents by vehicle type. So for example the number of fatalities and injuries caused by passenger cars, by people younger than 25 years old etc. However, statistics on causers of road accidents are scarce. Most figures 'concentrate' on the victims of road accidents (distribution per sexe, per day of week etc). For marginal accident costs however one wants to know who or what caused the accident to determine the risk for a specific trip.

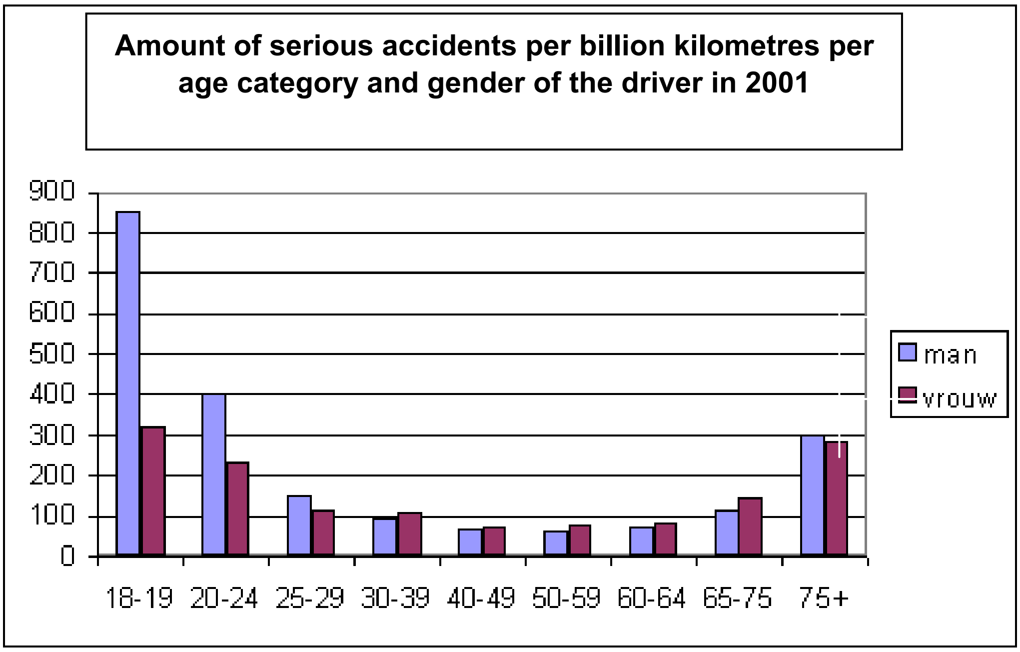
Despite information is scarce we propose to distinguish at least two vehicle types; **heavy goods vehicles** and **non-heavy goods vehicles** as the contribution of heavy goods vehicles (HGV) is disproportionate high relative to their share in traffic. The transport of goods represents some 16% of all vehicle mileages on roads in Europe[81]. By our knowledge there is no European wide database on the involvement of HGV with accidents. However, national statistics give some indication. In Germany in 2000 out of 7,503 traffic deaths in total 1,696 (23%) have been killed in accidents with HGV. The figures for the Netherlands (17% in 2001) and Finland (29% in 1999) are of the same size. In countries as Germany and the Netherlands the share of accidents with HGV involvement is considerably higher than the vehicle mileages share of HGV.

[80] Analogue to the UNITE-project and to ECMT-recommendations.
[81] Source: European Transport Report 2002, Prognos, may 2002.

If no detailed information is available one could use a benchmark figure of 25% of the accidents is caused by heavy goods vehicles. This figure could be used too for road injuries, assuming injuries are equally distributed as road fatalities.

Additionally for **non-heavy goods vehicles** we propose to distinguish **age categories and gender** as specific cost drivers. For young persons, especially for young men, the risk on a severe accident is high compared to other age categories. Figure 17 shows the results of Dutch research on the amount of severe accidents (fatalities and serious injuries) per billion kilometres per age category and gender in 2001. As well for men as for women the highest risk is for people in age category between 18 and 24 years old. Especially for young men, who have a (severe) accident risk that is twice as high as women and four times as high as for people between 25 and 65 years old? When people get older the accident risk increases once again. Accident risks between men and women hardly differ for people older than 25 years.

Figure 17 Amount of serious accidents per billion kilometres per age category and gender of the driver in 2001



Source: SWOV

11.3.3 Step 3: Valuation of fatalities and injuries per vehicle kilometre

In the third step the valuation of a fatality per vehicle km is calculated. Ideally one distinguishes for as many as possible road vehicle types but at least for HGV-kilometres and non-HGV-kilometres (the latter split out for age category and gender).

Valuation of HGV-kilometres

For calculating this figure one needs figures on the total amount of vehicle kilometres in a country. For this use can be made of the input figures of the TREMOVE-model (see for more information the section on air pollution) in which figures are shown for all European countries for 19 vehicle types. Another option is to make use of Prognos (2003), *European Transport Report 2002* with figures on vehicle mileages for cars, buses & coaches and freight vehicles for all European countries too. Compared to Prognos the figures in TREMOVE are split out for much more different vehicle types.

Subsequently one divides the results of step 1 by the relevant vehicle kilometrage.

The formula for the cost of traffic accidents (including injuries) for a HGV per kilometre thus becomes:

> Cost of traffic accidents for HGV per kilometre = 0.25 * cost of traffic accidents / vehicle mileage of HGVs

Illustration for Belgium	
Total costs of road fatalities for society	2.40 billion €
Percentage of the accidents caused by HGV	25%
Total costs road fatalities caused by HGV	601 million €
Vehicle mileage of freight transport (in 2002)	9.2 billion vkm
Valuation of fatality by HGV-kilometer	0.065 € /vkm

Valuation of non-HGV-kilometres
In passenger road transport the age and the gender of the driver are important cost drivers. Based on the figure on 'the amount of serious accidents per billion kilometres per age category and gender of the driver in 2001' in step 2 it is possible to derive valuation figures per vehicle kilometre.

This can be done according to the following formula:

> Cost of traffic accidents for passenger cars per kilometre = C_1 * C_2 * C_3 * Σ (cost of injury * number of injuries per billion vkm) / 1,000,000

Where the correction factors *C* are further explained in section 11.3.5, the summation is over the type of injuries (fatal, severe and light) and the cost of a specific injury can be calculated by making use of a straightforward simplification of the formula in section 11.3.1.

Below an illustration is given for the cost of fatalities per kilometre.

Illustration for the Netherlands
In the Netherlands in 1999 about 13,500 serious accidents took place in which 1,090 people (8%) were killed and 12,388 people (92%) were seriously injured. For men of 18 and 19 years old about 800 serious accidents took place per billion vehicle kilometre, so about 64 accidents with fatalities and 336 accidents with serious injuries.

Value of Statistical Life (Europe, 1998)	1.50 million €
Cost of net loss production, medical and ambulance cost:	0.15 million €
Inflation The Netherlands 1998-2003:	16.0%
Public Power Parity figure The Netherlands:	1.090
Average of indirect taxation on consumer expenditure:	21.3%
Valuation of a traffic fatality in Belgium	1.72 million €

Per billion vehicle km for men of 18 or 19 years old 64 fatalities
Valuation of a vehicle Km for men of 18 or 19 years old 0.110 € / km

In the same way figures can be calculated for all age categories, for women and for serious injuries. Table 21 shows Dutch figures for fatalities split out per age categories and per gender.

Table 21 Valuation of a fatality per vehiclekm for men and women per age category

	Man	Woman
18 – 19	0.110	0.041
20 – 24	0.055	0.028
25 – 64	0.014	0.014
> 65	0.041	0.041

Table 21 shows Dutch figures. If no detailed is available one could use these Dutch figures as an estimate for other countries corrected for country-specific figures on Purchasing Power Parity and indirect taxation.

11.3.4 Step 4: Collection of statistics on victims of road accidents

The next step concerns the collection of statistics on victims of road accidents. As statistics on the causers of accidents are scarce, one is forced to collect statistics on victims of accidents. Subsequently one can (optionally) allocate these costs to specific cost drivers.

Based on the EU CARE-database it is possible to specify per EU-country fatalities to:
- Location (Inside or Outside).
- Age categories (<14, 14-17, 18-25, 26-50, 51-65, >65).
- Gender (male, female).
- Person class (driver, passenger, pedestrian other).

- Vehicle group (car or taxi, motor cycle, bus or coach, pedal cycle, agricultural tractor, heavy goods vehicle, lorry under 3.5 tonnes, other).

Table 22 for example shows the distribution of victims for six age categories for the EU-15 countries (source: Community Road Accident Database, most figures are 2001 or 2002).

Table 22 Distribution of victims for six age categories for EU-15 countries

	BE	DK	DE	EL	ES	FR	IE	IT	LU	NL	AT	PT	FI	SE	UK
<14	57	17	178	41	132	221	24	119	2	70	20	56	15	17	131
14-17	52	27	356	57	228	278	21	244	1	66	48	59	18	23	201
18-25	327	75	1667	433	1123	1824	119	1219	17	212	191	321	78	110	755
25-50	610	144	2506	672	2263	2980	150	2173	25	369	342	678	132	185	1291
51-65	184	69	975	275	799	952	45	946	4	144	152	239	74	104	416
>65	248	99	1160	371	818	1310	44	1315	8	229	203	277	98	144	606

Source: Community Road Accident Database, most figures refer to 2001 or 2002

The figures in the table above are collected at the EU-level. Many countries themselves do also collect statistics on road accident victims. In The Netherlands for example figures are available too per month, day of the week, time-of-day and road category (motorways, main roads and remaining roads).

Especially figures on road fatalities are available and only to some extent on road injuries. If no detailed information on road injuries is available we propose to assume the same internal distribution as for road fatalities.

11.3.5 Step 5: Determination of correctional factors for cost drivers

In the fifth and final step one tries to determine 'correctional factors' for specific cost drivers, i.e. the contribution of a specific cost driver to the total. These factors can be applied on the average valuation figures per type of vehicle (i.e. the result of step 3).

By application of the correctional factors, average costs can be specified to different cost drivers. For example specific figures can be derived for younger people making use of roads at night etc. When starting a pricing system based on marginal costs, in this way incentives are implemented in the figures to prevent road accidents.

For many specific cost drivers it should be noticed information out of EU-reports is very scarce. For this reason we have calculated correctional figures on the basis of Dutch figures as an estimate for European figures.

These correctional factors are based on statistics on traffic victims. However ideally, one wants to base the factors on the causers of accidents. As traffic accidents concern huge socio-economic impacts, we think research on the causers of accidents deserves more attention in European research.

All correctional figures are for passenger cars. Again if figures are available on injuries one should use those specific figures, if not we propose to use the same distribution as for road fatalities.

Correctional factors per location type C_1
Generally outside urban areas the risk on a fatality is higher than inside an urban area. Generally spoken speeds outside urban areas are higher and there are more dangerous roads. In the European Union in 2002 (CARE-database) 32% of the road fatalities took place inside urban areas and 68% outside urban areas. Information on the distribution of vehicle km inside urban- and outside urban areas is scarce but Dutch figures show that 55% of the passenger vehicle km are inside urban areas and 45% outside urban areas. These figures form the basis to determine the correctional factors per location type.

Inside urban areas ➔ 32% of road fatalities ➔ 55% of vehicle km ➔ correctional factor of 0.6 (32/55)

Outside urban areas ➔ 68% of road fatalities ➔ 45% of vehicle km ➔ correctional factor of 1.5 (68/45)

Table 23 summarises these correctional factors.

Table 23 Correctional factors for urban and non-urban areas

	Inside urban areas	Outside urban areas
Distribution fatality	32%	68%
Distribution vehicle km	55%	45%
Correctional factor C_1	0.6	1.5

Some countries distinguish besides figures on accidents inside and outside the urban area also figures on accidents on motorways. If available the figures could be used as in general accidents motorways are very safe compared to other rural roads.

Correctional factors per time-of-day C_2
At night more accidents do occur than at day as people are less concentrated. Table 24 (based on Dutch figures) shows the distribution of fatalities and passenger vehicle km during the day and the resulting correctional factors.

Table 24 Correctional factors per time of day

	07 - 09	09 - 12	12 - 16	16 - 18	18 - 22	22 - 07
Distribution fatality	9%	13%	22%	14%	16%	25%
Distribution vehicle km	15%	16%	24%	19%	14%	12%
Correctional factor C_2	0.6	0.8	0.9	0.8	1.2	2.1

If desired Table 24 could be further simplified by regrouping some columns.

Correctional factor per day of week C_3
During days in the weekend more accidents take place that during an 'average' weekday. Table 25 (based on Dutch figures) shows the distribution of fatalities and passenger vehicle km during the days of the week and the resulting correctional factors.

Table 25 Correctional factors per day of week

	MON	TUE	WED	THU	FRI	SAT	SUN
Distribution fatality	15%	11%	12%	13%	16%	17%	15%
Distribution vkm	14%	15%	16%	16%	16%	14%	11%
Correctional factor C_3	1.1	0.8	0.8	0.8	1.0	1.3	1.3

Here too, if desired Table 25 could be further simplified by regrouping of some columns.

Application of correctional figures
The contribution of each cost drivers in the total costs can easy be obtained with this method by multiplying the 'average' valuation per age category and gender with the specific correctional figures.

Illustration for The Netherlands
A young man of 22 years old drives his car at Saturday night outside the city.

'Average' valuation per vehicle km	0.055 € / vkm
Correctional figure location type	1.5
Correctional figure time-of-day	2.1
Correctional figure day of week	1.3
Resulting figure	0.225 €/ vkm

11.4 Approach for rail transport and aviation

If sufficient information on rail and aviation accident drivers would be available, the cost allocation method for road transport could be used. In practice, however, detailed figures on accidents for rail and aviation are scarce or non-existent.

We therefore propose to restrict the methodology for these modes to the following two steps:

- Step 1: Determine the valuation of all traffic fatalities and injuries.
- Step 2: Valuation of fatalities and injuries per vehicle kilometre.

Information on railway (so accidents only involving railways) and aviation fatalities can be derived from Eurostat.

Information on trainkilometres can be derived from TREMOVE and Prognos. For aviation, information on 'vehiclekilometres' is scarce. For this reason it is maybe more easy to use the number of take-offs instead of vehiclekilometres.

Another problem with respect to aviation is that for the majority of flights take off and departure are in different countries. It is not clear to which country accidents should be 'allocated'. The easiest way would be to charge people and cargo from the country of departure.

In this way only average figures can be calculated and used. These figures are not specified for different cost drivers, so the incentive to prevent accidents and to come to a more safe rail transport and aviation is relatively restricted.

As an example, for aviation the formula would be:

Cost of accidents per LTO = Σ number of injuries * cost per type of injury / number of LTO's per year

The cost per type of injury can be determined as described in the formula in section 11.3.1.

12 Air pollution costs

The marginal costs of air pollution depend on the vehicle emissions and on the impact that these emissions have. The impact determines the financial valuation of the emissions. For both parts a simplified approach is needed.

For all three modes the method starts with the valuation of a kilogram or tonne per emission factor. On the basis of emission factors at specific cost drivers (type of fuel, vehicle size).marginal costs are derived.

12.1 Approach for road transport

The approach for road transport consists out of three steps:

- Step 1: Determine the financial valuation of emissions.
- Step 2: Calculate emission factors per vehicle km.
- Step 3: Valuation of emissions per vehicle km.

12.1.1 Step 1: Determine the financial valuation of emissions

The fist step concerns the financial valuation of emissions.

We propose to make use of the BeTA-database[82] containing € per tonne figures for SO_2, NO_2, $PM_{2.5}$ and VOC. The BeTa (the Benefits Table database) has been developed for the European Commission to provide a simple ready reckoner for estimation of the external costs of air pollution[83]. This document could temporally support unit values to be proposed for the main substances, but should be used cautiously, due to the lack of consensus on some values (urban cost for PM and SO_2). The C.A.F.E. C.B.A.[84] will develop further the methodology, and should propose new values by the end of 2004.

The present BeTA-database distinguished figures for marginal costs of emissions in rural areas and in cities.

[82] Eventually results from the ExternE-project (national average values for all substances) or other specific sources on $PM_{2.5}$-emissions (e.g. Friedrich).

[83] For more information see: http://europa.eu.int/comm/environment/enveco/studies2.htm#Marginal%20external%20costs%20air%20pollution.

[84] http://europa.eu.int/comm/environment/air/cafe/activities/cba.htm.

Table 26 Marginal external cost of emissions in rural areas (year 2002 prices, €/tonne)

	SO_2	NO_x	$PM_{2,5}$	VOCs
Austria	7,200	6,800	14,000	1,400
Belgium	7,900	4,700	22,000	3,000
Denmark	3,300	3,300	5,400	7,200
Finland	970	1,500	1,400	490
France	7,400	8,200	15,000	2,000
Germany	6,100	4,100	16,000	2,800
Greece	4,100	6,000	7,800	930
Ireland	2,600	2,800	4,100	1,300
Italy	5,000	7,100	12,000	2,800
Netherlands	7,000	4,000	18,000	2,400
Portugal	3,000	4,100	5,800	1,500
Spain	3,700	4,700	7,900	880
Sweden	1,700	2,600	1,700	680
United Kingdom	4,500	2,600	9,700	1,900
EU-15 average	5,200	4,200	14,000	2,100

Urban results for NO_x and VOCs are taken to be the same as the rural effects, given that quantified impacts are linked to formation of secondary pollutants in the atmosphere (ozone, nitrate aerosols). Given that these take time to be generated in the atmosphere, local variation in population density has little effect on the results.

Urban externalities for $PM_{2,5}$ and SO_2 for cities of different sizes are calculated by multiplying results for a city of 100,000 people by the factors shown below. Results scale linearly to 500,000 people but not beyond. These results are independent of the country in which the city is located. Once results for the cities are calculated, nationally specific rural externalities should be added to account for impacts of long range transport of pollutants.

Table 27 Valuation (year 2000 prices) tonne $PM_{2,5}$ and SO_2 in urban areas

	$PM_{2,5}$	SO_2
100,000 people	33,000	6,000
200,000 people	66,000	12,000
300,000 people	99,000	18,000
400,000 people	132,000	24,000
500,000 people	165,000	30,000
1,000,000 people	247,500	45,000
Several million people	495,000	90,000

12.1.2 Step 2: Calculate emission factors per vehicle km

In the next step emission factors per vehicle km are determined. For this we propose to make use of the TREMOVE-figures.

The (old) TREMOVE model (www.tremove.org) has been developed to support the European policy making process concerning emission standards for vehicles and fuel specifications. TREMOVE was calibrated for nine European countries and calculates for each year from 1996 to 2020 the difference in costs for all transport modes between alternative transport scenarios. The TREMOVE model was developed by the K.U.Leuven in the The Auto-Oil II Cost-Effectiveness Study.

The new TREMOVE-model is under construction since November 2002 by a project team lead by the KU Leuven and Transport & Mobility Leuven in a service contract for DG ENV. TREMOVE is a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector. The model estimates for policies as there are road pricing, public transport pricing, emission standards, subsidies for cleaner cars etc. the transport demand, modal shifts, vehicle stock renewal and scrappage decisions as well as the emissions of air pollutants and the welfare level. The model covers passenger and freight transport in the EU-15 plus Switzerland, Norway, the Czech Republic, Hungary, Poland and Slovenia and covers the period 1995-2030.

TREMOVE 2.3 is expected to be delivered in October 2004. At this moment (May 2004) draft baseline data like emissions factors per vehicle type are already available for all countries. Because of the detailed level information available, including figures on vehicle kilometres, and figures for all European Countries we propose to make use of this database in this simplified approach.

With regard to emissions by road transport TREMOVE distinguishes:
- 10 emission types: CO, NO_x, PM, C_6H_6, VOC, NMVOC, CH_4, SO_2, N_2O, CO_2.
- 19 vehicle types:
  - Small gasoline car -1.5 l, Medium gasoline car 1.5 - 2.0 l, Big gasoline car +2.0 l.
  - Small diesel car -1.5 l, Medium diesel car 1.5-2.0 l, Big diesel car +2.0 l.
  - Light duty vehicle gasoline, Light duty vehicle diesel.
  - Heavy duty vehicle 3.5-7.5 ton, Heavy duty vehicle 7.5-16 ton, Heavy duty vehicle 16-32 ton, Heavy duty vehicle +32 ton.
  - Moped.
  - Motorcycle -50cc, Motorcycle 50-250c, Motorcycle 250-750cc, Motorcycle +750cc.
  - Bus.
  - Coach.

In the TREMOVE-figures the Euro-classes are not explicitly announced, this would be a desired refinement for this method in the near future.

In the available baseline-figures TREMOVE does not present emission factors per vehicle km. However, next to the total pollution per vehicle type, the total vehicle km per vehicle type is shown. So by dividing the total pollution by the total vkm the emission factor per vehicle kilometre can be derived.

Emissions per vkm = emissions per vehicle class / vehicle kilometres of vehicle class

We do not present the actual emission factors derived from TREMOVE here, since this would imply a table of 19 vehicles types, 10 emission types and 15 countries. We refer to TREMOVE. An illustration for NO_x-emission of a small diesel car in Greece:

Illustration for Greece (year 2003) The total NO_x-emissions of small diesel cars amount to 1,845 tonnes. The total vkm of small diesel cars amount to 4.1 billion vkm The average NO_x-figure for a small diesel car in Greece is 0.5 gram per vkm

12.1.3 Step 3: Valuation of emissions per vehicle kilometre

In the last step the valuation of emissions per vehicle kilometre is determined. This takes place by multiplying the emission figure of step 2 by the valuation figures of step 1.

In this methodology emission factors are split out per vehicle type and fuel type. As the valuation for some emissions differs for location types, figures are split-out for urban and non-urban areas.

In addition one could take into account an *ecological sensitivity factor*: for example normally 1, and a higher number when driving closer than 25 km, in or through an ecologically sensitive area like mountainous area (a factor 3).

In a formula:

Cost of air pollution per vkm = C * Σ emission factor per vkm * financial valuation of emission

The cost of air pollution for a specific vehicle per kilometre is equal to the product of the correction factor and the sum of emission factors for that specific vehicle multiplied by the financial valuation of emission. Note that the summation is to be over all the emission types. Furthermore, the financial valuation can depend on the local circumstances as described in section 12.1.1.

Illustration for Greece for a small diesel car (year 2003) The average NO_x-figure for Greece is 0.5 gram per vkm. The financial value of a tonne NO_x is 6,652 € per tonne (corrected for inflation). The valuation of a NO_x-emission per vehicle kilometre is 0.003 € /vkm (0.5 x 6,652/1,000,000) When driving through an ecological sensitive region the valuation figure should be multiplied by a factor 3.

12.2 Approach for rail transport

The approach for road transport consists out of three steps:
- Step 1: Determine the financial valuation of emissions.
- Step 2: Calculate emission factors per vehicle km.
- Step 3: Valuation of emissions per vehicle km.

12.2.1 Step 1: Determine the financial valuation of emissions

Analogue to the methodology for road transport.

12.2.2 Step 2: Calculate emission factors per vehicle km

Analogue to the methodology for road transport. For this just like with road transport we propose to make use of the input in the TREMOVE-database.

With regard to emissions by rail transport TREMOVE distinguishes 8 vehicle types:
- Passenger railcar diesel.
- Passenger railcar electric.
- Passenger locomotive diesel.
- Passenger locomotive electric.
- Passenger high speed train.
- Freight railcar electric.
- Freight locomotive diesel.
- Freight locomotive electric.

TREMOVE distinguishes for rail traffic the same emission factors as for road, so CO, NO_x, PM, C_6H_6, VOC, NMVOC, CH_4, SO_2, N_2O, CO_2.

TREMOVE distinguishes between direct and indirect emissions. Direct emissions concern the emissions of diesel vehicles; indirect emissions concern the emissions for electric vehicles. In the figures the geographical location of power plants and the power plant mix is taken into account.

12.2.3 Step 3: Valuation of emissions per vehicle km

Analogue to the methodology for road transport.

12.3 Approach for air transport

The approach for air transport consists out of three steps:
- Step 1: Determine the financial valuation of emissions.
- Step 2: Calculate emission factors per passenger km.
- Step 3: Valuation of emissions per passenger km.

12.3.1 Step 1: Determine the financial valuation of emissions

Comparable to road transport.

12.3.2 Step 2: Calculate emission factors per passenger km

Analogue to the methodology for road transport. For this just like with road transport we propose to make use of the input in the TREMOVE-database although a lot of specific data is missing on air transport.

With regard to emissions by air transport TREMOVE distinguishes 5 flight types:
- Air transport -500 km.
- Air transport 500-1,000 km.
- Air transport 1,000-1,500 km.
- Air transport 1,500-2,000 km.
- Air transport +2,000 km.

TREMOVE distinguishes total air transport emissions as well landing and take-off emissions as well en route emissions. Contrary to road and rail transport 'only' CO, NO_x and VOC-emissions are distinguished.

No freight data are included in the TREMOVE database. This means that all emissions from aviation are allocated to passenger transport.

In addition TREMOVE 'only' shows total passenger km by plane, no 'vehicle' km by plane. In this way the approach will be based as passenger km for air transport and differs somewhat from the approach on road and rail transport (based on vehicle km).

Illustration for Germany (year 2003) The total VOC-emissions (all flight types) amount to 2,361 tonnes. The total *passenger km* by plane to 58,770 million passenger km The average VOC-emission is 0.04 gram per passenger km

12.3.3 Step 3: Valuation of emissions per passenger km

Analogue to the methodology for road transport.

Illustration for Germany (year 2003) The average VOC-emission is 0.04 gram per passenger km The financial value of a tonne VOC is 2,800 € per tonne. The valuation of a VOC–emission per passenger kilometre is 0.0001125 €/passenger km (= 0.11 € per 1,000 passenger km)

13 Noise costs

13.1 Calculation method for simplified approach

The simplified approach that we propose for noise is a cost allocation approach and consists of the following four steps:

- Step 1: Define the cut-off value (this is the noise level below which the nuisance is regarded as negligible).
- Step 2: Determine *per mode* the number of people/households that are exposed to a certain noise level, do this for several noise level groups (e.g. 56-60 dB(A), 61-65 dB(A), 66-70 dB(A), 71-75 dB(A) and > 75 dB(A)).
- Step 3: Financial valuation per mode and area.
- Step 4: Allocation to vehicle classes within each mode.

Furthermore we propose to distinguish between the noise cost within urban areas and those outside of urban areas. If statistics on the number of exposed are differentiated with respect to location, this distinction can be accounted for in step 2, if not, this should be incorporated in step 3.

The proposed simplified approach calculates the average transport noise costs (the top-down approach in chapter 7). As indicated before, the calculation of the marginal costs would require a detailed analysis of noise emissions, dose-response relationships and natural geographic features such as hills or building design features (double-glazed windows). These data are often unavailable or incomplete and such an approach is deemed to complicate to serve as a simplified approach. We therefore propose a top-down method to calculate average costs. It should be known though, that the resulting estimates for average costs are generally higher than the marginal costs. Average cost can be 2 (for aviation) up to 6 to 8 (road transport) times higher than marginal cost [CE, 2003a; Verhoef, 1994]. This also holds for densely populated areas.

The approach is identical for all modes, except for the cost allocation to vehicle classes, which we will discuss separately. The other steps are described in a general manner.

13.2 Step 1: Definition of cut-off value (road, rail, air)

The nuisance people experience of noise depends on the source of noise. Rail noise is less annoying than the road noise, because of the low frequency of the sound and it continuous character. On the other hand, aircraft noise is experienced as more annoying than road traffic, because the passage of an aircraft creates fear feelings with people.

The difference in nuisance is the reason that the often cited ‘bonus of 5 dB’ is given to rail. Based on a ‘State-of-the-art in noise valuation’ workshop, organized by DG Environment of the European Commission in 2001 (European

Commission, 2002) and international literature [Navrud, 2002], we propose to use the following cut-off values for noise.

Table 28 Cut-off values for noise in dB(A)

Road	55
Rail	60
Air	55

These cut-off values imply that below these noise levels, no damage cost are taken into account in this simplified approach.

There is, however, some discussion that the cut-off levels should be lower, since below the cut-off values, people can still be annoyed. Also, noise reduction measures can be underestimated with the proposed cut-off value.

As a refinement of the proposed simplified approach, additional noise cut-off values could be defined for night hours. Since people are more sensitive to noise during night hours, it could be argued to set night time cut-off levels five to ten dB(A) lower than the aforementioned cut-off levels.

13.3 Step 2: Determination of number of exposed households / people (road, rail, air)

To determine the total noise cost for a country, estimates for the number of exposed households (or individuals) per noise level group are indispensable. These statistics need to be collected for each country.

Where possible, a distinction can be made between exposed households within urban areas and outside of urban areas.

13.4 Step 3: Financial valuation of noise (road, rail, air)

For the financial valuation of noise emissions, the following methods are most commonly used:

- Revealed preference (RP, based on differences in housing prices that can exclusively be attributed to noise).
- Stated preference (SP, based on questionnaires on the willingness to pay of willingness to accept).

The strength of the RP is that it relies on actual behaviour in the housing market where WTP for noise and other environmental externalities can be observed. A disadvantage of this method is that it is very hard to isolate noise from other environmental problems (e.g. air pollution). Methods based on SP are generally easier to implement. The extents to which SP techniques are capable of providing valid and reliable estimates depend very much on the survey design and analysis. Both methods are generally accepted to use obtaining an estimate for valuation of costs of noise exposure.

The differences between the outcomes of various studies on the valuation of noise are extremely large. This may be caused by:
- Difference in methodological approach.
- Difference in income level.
- Differences in building traditions.
- Difference in initial noise levels.
- Cultural differences.

Although there is some evidence that the WTP for noise reduction increases slightly with the level of existing noise, this change is not statistically significant (ECMT, 1998). We therefore propose to use one value per decibel noise (above the cut-off value), independent of the initial noise level.

Because of these differences, the range in values of the WTP is extremely large. INFRAS/IWW (2000) proposes 0.1% of the GDP per capita, based on stated preference. As an example, this would be € 25 per capita per dB per year for the Netherlands (which is equal to € 58 per *household* per dB per year, 2001 price level). The final report of the EC workshop on 14 December 2001 'State-of-the-art in noise valuation' proposes a valuation between € 5.00 - € 50.00 per household per dB (2001 price level) per year.

For the simplified approach, a first best approach would be to use a valuation which has been especially calculated for the situation of the Member State at hand. As a second best solution, we propose to use the median value from the estimate of the EC workshop, € 23.50 per dB per household per year, or approximately € 10.00 per person.

The noise cost per mode per noise level group can be estimated by multiplying the number of households within a certain noise level groups with the average noise exposure above the cut-off value for this group with the costs of noise per dB per household per year. Total noise costs per mode are obtained by summing the outcomes over the different noise level groups.

Or, in a formula:

Noise cost = 23.5 * Σ number of households in noise level group * (average noise level in group – cut-off value)

To determine the total noise cost within / outside city limits one can either use the distribution of the households in the noise level groups (households within urban areas contribute to total noise cost within urban areas), or in case detailed statistics are unavailable, a default value could be used. For the Netherlands, 80% of noise costs are estimated to fall within urban areas, and 20% outside. Use of these values is a second best option, since clearly the distribution of noise cost in urban and non-urban depends of the urbanisation level of a country and could best be based on the number of households disturbed inside and outside city limits.

13.5 Step 4: Cost allocation

13.5.1 Road and rail

After determining the total noise cost per mode, both inside and outside city limits, the allocation to different vehicle types has to be determined. We distinguish two approaches:
- Allocation based on vehicle kilometres.
- Allocation based on weighted noise vehicle kilometres[85].

An allocation based on vehicle kilometres would pass over the differences in noise emission between vehicles. Clearly an HGV causes more noise than a passenger vehicle, as do freight trains compared to passenger trains.

Unfortunately, no complete set of weighting factors can be found in the international literature. ECMT (1998) and INFRAS/IWW (1995) only provide rather limited overviews. Therefore we support to calculate with weighted noise kilometres, despite the absence of an international scientific foundation.

Despite the lack of internationally agreed set of weights, we propose to take account of the differences in noise emission between vehicles.

If for a Member State, specific weight factors have been determined, use of these would be the first best approach. As a second best approach, we propose to use the weighing factors for road and rail traffic used in a CE (2003b) for the Netherlands. These are presented in table 4.

The weighing factors for rail originally stem from INFRAS/IWW (1995). Weighing factors for road transport were calculated from noise reference values for light, medium heavy and heavy vehicles presented in the Dutch instruction for measuring and calculating road traffic noise [VROM, 2002]. Such reference values can normally be found in governmental instructions for calculating traffic noise, and could be used to determine country specific noise weighing factors (the first best approach).

[85] Weighted noise kilometers are the weight factors of a certain vehicle category multiplied by the vehicle kilometers for this category.

Table 29 Weighing factors for different vehicle classes

Road	Urban (50 km/h)	Other roads (80 km/h of higher)
Passenger car petrol	1,0	1,0
Passenger car diesel	1,2	1,0
Passenger car LPG	1,0	1,0
Moped	9,8	3,0
Motorcycle	13,2	4,2
Bus	9,8	3,3
Van	1,5	1,2
Lorrie solo < 12 ton GVW	9,8	3,0
Lorrie solo > 12 ton GVW	13,2	4,2
Lorrie with trailer	16,6	5,5
Rail		
Passengers train	1	
Freight train	4	

Source: INFRAS/IWW (1995); VROM (2003), mopeds and motorcycles based on own expert guess.

The noise cost per vehicle kilometre can be calculated by the following formula:

Noise cost per vehicle kilometre = noise cost for vehicle category / total vehicle category kilometres

Where:

Noise cost for vehicle category = total noise cost * (vehicle weight factor * total vehicle category kilometres) / Σ (vehicle weight factor * total vehicle category kilometres)

With the summation over all vehicle categories. Depending on the noise cost in an urban area of outside of city limits is being calculated, the total noise cost apply to the total noise cost within urban areas or outside. The appropriate weighing factors should be used.

13.5.2 Air

To allocate noise cost to specific aircraft, the relative performance of aircraft with respect to noise is required. At first sight, the categorisation the noise limits set by ICAO Annex 16 chapter 3 and 4 [ICAO, 2003] appears a good option. However the categorisation and the noise limits set depend on MTOW and the number of engines. So it is possible that a small aircraft belongs to a noisier class than a larger aircraft emitting more noise.

Therefore we need a more sophisticated approach. We propose to allocate the noise cost to aircrafts on the basis of the actual noise **level** (instead of the noise **limit**) they produce according to the instruction in Annex 16 to the ICAO convention, Chapter 3.

These noise levels, measured in EPNdB[86] (EPNdB = dB(A)+13), are known for three different measuring points: take-off, sideline and approach. Based upon these noise levels, weighing factors can be calculated. The weight factor of a B747 for example, with respect to an aircraft of reference, can be calculated as illustrated in the following formula:

Weight factor B747 in comparison with aircraft of reference = $(10^{((EPNdB_{B747}-13)/10)} + 10^{((EPNdB_{B747}-13)/10)} + 10^{(EPNdB_{B747}-13/10)}) / (10^{((EPNdB_{REF}-13)/10)} + 10^{((EPNdB_{REF}-13)/10)} + 10^{((EPNdB_{REF}-13)/10)})$

Weighing factors for a limited number of aircraft are presented in Table 30. The Fokker 100 has been used as the aircraft of reference. From the table below we find that noisy aircrafts (B747-400) produce about 12 times as much noise as the silent Fokker 100. Aircraft with a MTOW of less than 9,000 kg are not taken into account since their contribution to the total noise production is minimal.

86 Aircraft noise is measured in Effective Perceived Noise level (EPNdB).

Table 30 Weighting factors for different aircraft types

Aircraft type	MTOW (in t)	Number of engines	Seating (max.*)	Noise level according to ICAO Annex 16, Chapter 3 (in EPNdB)			Weighing factor
				Take-off	Lateral	Approach	
Jet aircraft							
B 747-400	386	4	524	99,000	98,300	103,300	11,6
MD 11	280	3	410	94,9	95,9	103,8	10,0
A 340-200	254	4	440	94,4	94,8	97,3	3,6
B 777-200	243	2	440	93,3	95,8	99,4	4,7
A 330-300	212	2	440	91,6	97,4	98,6	4,6
B 767-300	185	2	345	93,2	97	100,2	5,6
A 300-600	165	2	375	90	97,2	99,1	4,6
A 310-300	153	2	280	91,5	96	98,6	4,1
B 757-200	109	2	231	84,4	93,1	95	1,8
A 321-100	83	2	220	85,4	94,5	95,4	2,1
Jet							
B 737-500	52	2	132	84	89	97	1,9
Avro RJ 85	44	4	112	84,3	88,4	97,3	2,0
Fokker 100	43	2	109	83,4	89,3	93,1	1,0
Canadair RJ	23	2	50	78,6	82,2	92,1	0,6
Propeller aircraft							
Saab 2000	23	2	58	79,1	86,7	87,9	0,4
Aircraft type	MTOW (in t)	Number of engines	Seating (max.*)	Noise level according to ICAO Annex 16, Chapter 3 (in EPNdB)			Weighing factor
				Take-off	Lateral	Approach	
ATR 72-200	22	2	74	86,5	84,7	94,1	1,1
Fokker	20	2	58	81	85	96,8	1,7
Dash 8-300	19	2	56	85	87,3	98,7	2,7
ATR 42-300	16	2	50	82,6	83,8	96,8	1,7
Dash 8-10	16	2	37	79,8	86,1	97,5	2,0
Dornier	14	2	33	81,7	84	92,7	0,7
Saab 340	12	2	37	77,3	86	90,8	0,5
Embraer	11	2	30	81,2	83,5	92,3	0,7

Fokker 100 is taken as a reference

The cost per LTO of a specific aircraft can be calculated by allocating the total costs on the basis of the number of LTO's and the calculated weighing factors, as in the following formula.

> Noise cost per LTO for specific aircraft = total noise cost * aircraft weight factor / Σ (aircraft weight factor * number of LTO's of aircraft)

The summation in the formula is over all aircraft visiting the airport.

This approach requires detailed information about the aircraft movements (airport dependent) and noise levels of different aircraft. The latter can be derived from the airlines that call in at airports.

References:

- (Verhoef, 1994) *External Effects and Social Costs of Road Transport*, Erik Verhoef, Transportation Research, Vol. 28A, 1994, p. 286
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14 Examples

14.1 Introduction

The aim of this chapter is to illustrate the simplified approaches presented in the previous chapters. Therefore two examples are presented:

1. Road: HGV travelling from Hamburg to Munich in Germany.
2. Rail: Freight train travelling from Rotterdam to the border with Germany at Venlo.

For both examples all cost types that have been elaborated in this report are calculated using the proposed simplified approaches.

Note that the examples described in this section serve as illustrations. We have used realistic input data if possible, but have not attempted to be exact.

14.2 Example 1: Road HGV travelling from Hamburg to Munich in Germany

In the first example we consider a HGV travelling on the highway from Hamburg to Munich, a distance of approximately 720 kilometres. It’s a Euro 2 vehicle, with 5 axles and GVW 40 tonnes. We assume that the whole trajectory is in non urban areas.

14.2.1 Infrastructure cost

For this example we did not have data on maintenance cost of motorways between Hamburg and Munich. Therefore, this example should be regarded as illustrative making use of fictive figures. However the magnitudes *of the results* of this example are in a ‘normal’ range.

The truck we consider is a truck of damage class G, as defined in section 9.1.3.

If we assume the following parameters for this stretch:

- Total variable infrastructure costs: 13 million €.
- Total variable infrastructure costs for road surface: 10 million €.
- Other variable infrastructure costs: 3 million €.
- Total vehicle kilometres: 2 billion.

The basis for cost allocation are the shares in Table 31, calculated by using the equivalence factors and (fictive) shares in the vehicle kilometres.

Table 31 Share in road damage costs

Class	Equivalence factor	Share in vehicle-km (fictive)	Share in road damage costs
A	0.0001	90%	0.01%
B	0.03	1%	0.03%
C	0.1	1%	0,11%
D	0.5	1%	0.53%
E	1.5	1%	1.59%
F	5	2%	10.62%
G	11	2%	23.37%
H	30	2%	63.74%

In this example, the variable infrastructure costs for a lorry with a GVW of 40 tonnes can be calculated as follows:

- Total costs for damage class G: 23.37%*10 + 2%*3 = 2.4 million.
- Number of vehicle-kilometres per year for damage class G: 2%*2 billion = 40 million.
- Costs per vehicle-km for damage class G: 6 €ct.

So with these (partly fictive) numbers, for a lorry of 40 tonnes driving 720 km from Hamburg to Munich, the total variable infrastructure costs come to € 43.00.

14.2.2 Congestion cost

In this example we do not consider congestion. For an illustrative example of the calculation of congestion costs, we refer to chapter 10.

14.2.3 Accident cost

In Germany about 480,000 people are yearly involved in road accidents. In 2002 6,842 people died in road accidents, 88.382 had severe injuries and 388,031 had light injuries.

The valuation[87] of a traffic fatality amounts to 1.50 million €, a severe injured to 195 thousand € and of a light injured to € 15,000.00.

The total costs for the German society can be estimated at 34.4 billion €. Heavy goods vehicles are involved in about 23% of the road accidents, so total costs of HGV amount to approximately 7.9 billion €.

Heavy goods vehicles in Germany drive about 65 billion vehicle kilometres yearly. As a consequence a total valuation figure of 0.122 € per vehicle kilometre does result.

[87] Including the costs of net loss production, medical and ambulance costs. Figures have been corrected inflation (5.9% in period 1998-2003), public power parity (1.039) and for the average of indirect taxation (17.3%).

Table 32 Accident cost per vehicle km

Type of traffic victim	Valuation figure (€/vkm)
Traffic fatality	0.037
Severe injured	0.063
Light injured	0.021
Total	0.122

Considering a trip from Hamburg to Munich, a distance of approximately 720 kilometres, a total trip cost of € 88.00 does result.

14.2.4 Air pollution cost

In Germany in rural areas the valuation[88] of a tonne SO_2 amounts 6,385 €, of a tonne NO_X to 4,291 €, of a tonne $PM_{2,5}$ € 16,747.00 and of a tonne VOC to € 2,931.00.

Emissions of a heavy goods vehicle (+32 tonnes) amount to 3,490 tonnes SO_2, 161,514 tonnes NO_X, 6,099 tonnes $PM_{2,5}$ and 12,850 tonnes VOC.

Heavy goods vehicles (+32 tonne) in Germany drive together about 16 billion vehicle kilometres yearly.

The below shows the resulting emissions (in gram/vehicle kilometre) and valuation (€/vkm).

Table 33 Emissions and emission cost

Emission type	Emissions (in gram/vkm)	Valuation (in € /vkm)
SO_2	0.22	0.001
NO_X	10.10	0.043
$PM_{2,5}$	0.38	0.006
VOC	0.80	0.002
Total	----	0.053

Taking into account a distance of approximately of 720 km a total trip costs of € 39.00 does result.

14.2.5 Noise cost

We use the proposed cut-off value for road transport, i.e. 55 dB. For the purpose of this example, we use (dated) information from INFRAS/IWW (1995) on the number of exposed people for Germany. We have no detailed information with respect to the number of people exposed inside and outside urban areas.

88 Corrected for inflation (4.7% in period 2000-2003).

Table 34 Number of people exposed to transport road noise in Germany

	55-60 dB(A)	60-65 dB(A)	65-70 dB(A)	70-75 dB(A)	> 75 dB(A)
Number of exposed (million)	11.89	10.17	5.94	3.10	0.70
Average noise level in excess of cut-off value (dB(A))	2.5	7.5	12.5	17.5	22.5

Source: INFRAS/IWW (1995)

Next, we multiply the number of exposed people in each noise level group with the average excess exposure in each group. For the 55-60 dB(A)-group we find a total of 29.7 million person.dBs. Summing these multiplications for all groups results in 250.25 million person.dBs.
Total noise cost with respect to road is then estimated at € 10.00 per person per dB multiplied with 250 million person dBs, 2.5 billion €.

Since we do not have detailed information with respect to the number of people exposed inside and outside urban areas, we use the second best approach and estimate that 80% of total transport road noise cost takes place in urban areas, and the remaining 20% outside urban areas. Total cost outside of urban areas amounts to 20% of 2.5 billion €, equalling 0.5 billion €.

For the cost allocation information on transport volume is required.

Table 35 Transport volume in Germany

	Passenger cars	Buses	Goods vehicles
Vehicle kilometres (billion)	406.0	3.4	44.6
Urban (percentage)	24%	70%	12%
Urban vehicle kms (billion)	97.44	2.38	5.35
Other roads vehicle kms (billion)	308.56	1.02	39.25

Source: INFRAS/IWW (1995), percentages urban based on own estimates.

We have no information on the distribution of vehicle kilometres over urban and other roads. For the purpose of this example we use the estimates in the third row of Table 36.

Table 36 Noise weighing factors road

	Passenger car	Buses	Goods vehicles
Urban	1	9.8	13.2
Other roads	1	3.3	4.2

By multiplying the transport volume with the relevant noise weighing factor we obtain an estimate of total weighted noise for roads in Germany. This equals

477[89] billion weighted noise kilometres outside urban areas for all vehicles. A trip on the highway from Hamburg to Munich with a goods vehicle equals 4.2 times 720 = 3024 weighted noise kilometres outside of urban areas.

Total noise cost for this trip amount to 3,024 / 477 billion *0.5 billion € = € 3.17.

14.2.6 Overview of the results of example 1

Table 37 gives an overview of the quantitative results of example 1, a lorry travelling from Hamburg to Munich in Germany.

Table 37 Overview of the costs for example 1, derived by simplified approaches

Cost type	Estimation of marginal cost (in €)
Infrastructure	43
Accidents	88
Air pollution	39
Noise	3
Total	**173**

14.3 Example 2: Rail: Freight train travelling from Rotterdam to the border with Germany at Venlo

We consider a freight train travelling in the Netherlands from Rotterdam Kijfhoek to Venlo, a distance of approximately 150 kilometres on the mixed network. Approximately 23% of this route lies in urban areas[90]. The gross tonnage is 800 tonnes (including vehicle weight), with 12 railcars and two locomotives (diesel).

14.3.1 Infrastructure cost

Step 1: Demarcation of network.
The Netherlands are rather flat, so there is no reason to expect highly varying cost per region or stretch. The train uses the mixed network and thus the cost and (gross tonnes) vehicle kilometres of dedicated freight lines[91] are not taken into account.

Step 2: Collection of data for maintenance cost
The second step is to collect data for the relevant cost categories. Since the example considers a freight train on diesel, neither the cost of railway stations nor of electricity apply. For the total cost of the other cost categories we base our calculations on the amounts below.

89 This is calculated as follows: 4.2 * 39.25 + 3.3 * 1.02 + 1 * 308.56 = 477.
90 Source: NEA (2002), Vergelijkingskader modaliteiten, vs 1.2, database, November 2002, NEA Transport research and training.
91 The dedicated freight line 'Betuweroute' is to be opened in 2006.

Table 38 Maintenance cost

Cost category	Total cost (mln €)
Track-related cost	300
Structures-related cost	100
Signals-related cost	60

Step 3: Determination of variable cost
For the structures- and signals related cost the percentages from Table 13 are used, 10% and 1% respectively. For the track related cost, an estimation is made on the base of Figure 12. The length of the mixed network in the Netherlands amounts to approximately 6,500 kilometres. The traffic on the network amounts to about 30,000 million gross tonnes kilometres. On average 30 / 6.5 = 4.6 MGT. This is slightly lower than the British average (5 MGT) and we therefore use a slightly lower estimate for the share of variable track-related cost, 30% instead of 33%. The variable cost follow from the total cost and the shares of total cost that are variable.

Table 39 Infrastructure cost for railways

Cost category	Total cost (mln €)	Share of variable cost	Variable cost (mln €)
Track-related cost	300	0.30	90
Structures-related cost	100	0.10	10
Signals-related cost	60	0.01	0.6

Step 4: Collection of data on cost drivers and Step 5: Allocation to user
Both track- and structure-related cost are allocated on the basis of gross tonnes kilometres. The total traffic on the network amounts to approximately 20,000 million gross tonnes kilometres. The freight train carries in total 800 tonnes over 150 kilometres, 120,000 gross tonnes kilometres.
The variable track- and structure related cost that can be attributed to this particular train are € 600.00.

The signals-related costs are allocated on the basis of train-kilometres. On the Dutch network 130 million train-kilometres are made per year. (150 / 130 million) * € 600,000.00 = € 0.70.

The total variable maintenance cost caused by the particular train amount to approximately € 600.70.

14.3.2 Congestion cost

In this example we do not consider congestion or scarcity. For an illustrative example of the calculation of congestion costs, we refer to chapter 10.

14.3.3 Accident cost

These costs have not been calculated. In the Netherlands accidents only involving trains (so not accidents on crossings) fatalities are very scarce. In recent years on average at most one person yearly dies in railway accidents. If so these fatalities occur mainly in accidents of passenger trains. So costs per freight train vehicle kilometre are assumed to be negligible and are therefore not calculated.

14.3.4 Air pollution cost

We consider a freight train travelling in The Netherlands from Rotterdam to Venlo. Approximately 23% (34.5 km) of this route lies in urban areas and approximately 77% (115.5 km) in rural areas.

The BeTA-database considers different valuation figures for SO_2 and $PM_{2,5}$-emissions in urban and rural areas. Table 40 gives an overview of these valuation figures were calculated.

Table 40 Valuation figures for air pollution for example 2

Emission type	Valuation of a tonne in urban area	Valuation of a tonne in rural area
SO_2	6,703	7,820
NO_X	4,468	4,468
$PM_{2,5}$	36,864	20,108
VOC	2,681	2,681

Emissions of diesel locomotives[92] in The Netherlands amount to 34 tonnes SO_2, 503 tonnes NO_X, 30 tonnes $PM_{2,5}$ and 27 tonnes VOC.

Diesel locomotives in The Netherlands drive together about 2.6 billion vehicle kilometres yearly.

Table 41 shows the resulting emissions (in gram/vkm) and valuation (€/vkm).

[92] The figures concern direct emissions, there are no indirect emissions.

Table 41 Emissions and costs of emissions

Emission type	Emissions (in gram/vkm)	Valuation in urban area (in € /vkm)	Valuation in rural area (in € /vkm)
SO_2	13.08	0.088	0.102
NO_X	193.46	0.864	0.864
$PM_{2,5}$	11.54	0.425	0.232
VOC	10.38	0.028	0.028
Total	----	1.405	1.227

Taking into account the distance of approximately 150 km and 2 locomotives a total trip cost of 380 € does result.

14.3.5 Noise cost

The cut-off value for noise by railroads is 60 dB(A). The number of exposed people in each noise level group is:

Table 42 Number of people exposed to transport rail noise in the Netherlands

	60-65 dB(A)	65-70 dB(A)	70-75 dB(A)	> 75 dB(A)
Number of exposed (million)	0.333	0.105	0.031	0.011
Average noise level in excess of cut-off value (dB(A))	2.5	7.5	12.5	17.5

Source: CE (2004)

This leads to 2,2 million person-dB, valued at 22 million €. 80% of these cost are perceived within urban areas: 17,6 million €, and 20% outside urban areas: 4,4 million €.

Data on transport volume is given in Table 43.

Table 43 Transport volume rail in the Netherlands

	Passenger trains	Freight traffic
Vehicle kms (million)	120	10

Source: Rough indication

For both passenger trains and freight traffic, approximately 24% of the vehicle kilometres are travelled within urban areas. This also holds for the route from Rotterdam to Venlo.

The total number of weighted noise kilometres within urban areas equals 0.24 *120 *1 + 0.24 *10 * 4 = 38.4 million. Outside urban areas a total of 0.76 * 120 * 1 + 0.76 * 10 * 4 = 121.6 weighted noise vehicle kilometres.

A freight train travelling 150 kilometres from Rotterdam to Venlo amounts to 0.24 * 150 * 4 = 144 and 0.76 * 150 *4 = 456 weighted noise kilometres within and outside urban areas respectively.

Noise cost for this train inside urban areas equals 144 / 38.4 million * 17.6 million = € 66. Outside urban areas: 456 / 121.6 million * 4.4 million = € 16.5. The total noise cost for this train on this particular stretch amount to approximately € 83.

14.3.6 Overview of the results of example 2

Table 44 gives an overview of the quantitative results of example 1, a freight train travelling from Rotterdam to the border with Germany at Venlo.

Table 44 Overview of the costs for example 2, derived by simplified approaches

Cost type	Estimation of marginal cost (in €)
Infrastructure	601
Accidents	negligible
Air pollution	380
Noise	83
Total	**1,064**

14.4 Conclusion

The two examples in this chapter make clear that the simplified approaches proposed in part 2 of this report can be applied easily. In cases where more sophisticated approaches are available, we recommend to apply these approaches. However, in cases where these sophisticated approaches are either not available or too complicated to apply, e.g. because of lack of data, the simplified approaches presented in this report can yield satisfying estimations of the marginal costs of infrastructure use.

Glossary

Accident Cost	Cost mainly related to vehicle repair and medical cost and the cost of 'suffering' associated with accidents.
Accident insurance	Voluntary or mandated insurance against the risks of accidents (property and health). The premia serve to (partly) internalise external costs.
Accident rate	Accident rates describe the probability of an accident per 1'000 vehicle kilometres.
Average costs	Total costs in a period, divided by the quantity (output) produced/consumed in that period. Long term average costs include a share of fixed costs (e.g. costs associated with expansion of existing infra-structure).
Commercial transport	On-demand transport services offered by non-official transport suppliers. It is a business activity where the final users are considered as the operator's customers getting charges the full range of operation costs recorded by business accounts.
Contingent valuation method	Valuation technique which asks people directly how much they are willing to pay/to accept for improving/deteriorating environmental quality. Method is based on the stated preference approach; it is the only method that allows the estimation of existence value. The values obtained are compared with other opportunities, in order to make visible a budget restriction.
Cost category	Category within the cost has the same characteristics, or in other words is attributed to the appropriate network.
Cost coverage	Cost coverage is the ration between revenues and costs. It answers the question whether the costs are covered by the (respective) revenues.
Cost driver	A variable which denotes the (key) cause of various transport costs.
Cost-effectiveness	Seeks to minimise the costs of achieving a given (e.g. environmental) objective/target. This principle is a 'second-best' efficiency criterion, often used when a full cost-benefit analysis is not feasible.

CO_2	Carbon dioxide is a major greenhouse gas i.e. it contributes to the climate change.
Decibel	(dB(A)) Decibel (dB) is a measure for the intensity of sound energy. According to the characteristic of human ears the relationship between sound energy and dB is logarithmic. Several filters have been defined to achieve a better adaptation of dB measurements and the loudness impression of human beings. The most commonly used type of filter is the (A) filter.
Defensive expenditures	Valuation technique wherein a value for environmental quality is inferred from people's (voluntary) expenditures aimed at improving their situation.
Dose-response-functions	Functions showing the connection between a specific concentration and its specific effects. They are especially used for the measurements of air pollution impacts. For example health: Impacts on mortality due to specific air pollution concentrations.
Efficiency	Refers to the efficient allocation of scarce resources. At the margin, resources should be used by the individual who is willing to pay the most for them (i.e. where marginal social cost equals marginal social benefit).
Elasticity	Proportional change in demand in response to a price increase or decrease (price elasticity); or reaction in total demand after an increase/decrease in income (income elasticity).
Existence value	Economic value which people attribute to something purely for its existence (no consumption is fore-seen); can only be estimated via the → contingent valuation method.
Exposure-Response Function	Functional relationship relating changes in human health, material corrosion, crop yields etc. to unit changes in ambient concentrations of pollutants. Used more or less synonymously with dose-response function.
Externality (external effect)	The consequences not normally taken into account in markets and in the decisions made by market players. The external costs are the economic valuation of an external effect.

Fixed cost	Cost which are not depending on the traffic volume (in the short run).
Fourth power law	This rule relates the road deterioration to axle weight. If the load is doubled the road damages increases by a factor 16 (=2^4).
Free-flow situation	Traffic situation without congestion, used as a reference level. Usually an Off-Peak-Situation can be used for urban traffic.
Hedonic pricing	Valuation technique, which infers a value for environmental quality from rent or property price differentials.
HGV	Heavy goods vehicles.
Impact Pathway Approach	Methodology for externality quantification developed in the ExternE project series. It follows the chain of causal relationships from pollutant emissions via dispersion, leading to changes in ambient air concentrations from which impacts can be quantified using exposure-response functions. Damages are then calculated using monetary values based on the willingness-to-pay approach.
Individual transport	Transport performed on the own account of users with their own vehicle for private reasons.
Injurer	In a collision accident the injurer is the user that is not hurt in the accident. The injurer does not have to be guilty of the accident.
Internalisation	Incorporation of an externality into the market decision making process through pricing or regulatory intervention. In the narrow sense internalisation is implemented by charging the polluters with the damage costs of the pollution generated by them, the corresponding damage costs resp. according to the polluter pays principle.
Marginal costs	Costs related to a small increment in demand (e.g. an extra vehicle-kilometre driven). Long-term marginal costs include the capacity expansion needed to service increased traffic demands.
Opportunity costs	Costs which arise when a particular project restricts alternative uses of a scarce resource (e.g. land-use of infrastructure prevents an alternative use, such as recreation). The size of an opportunity cost is the value of a resource in its most productive alternative use.

PCU	(= Passenger Car Units) PCU is used in order to standardise vehicles in relation to a passenger car. Speed and lengths differentials are most common. Within this study they are used for the allocation of different costs (e.g. nature and landscape, urban effects, congestion).
PKM	Passenger kilometre (see VKM).
Polluter-pays-principle	Political/economic principle which stipulates that the user should pay the full social cost (including environmental costs) of his/her activity.
Prevention approach	Valuation technique for estimating externalities whereby the costs of preventing damage are used as a proxy for the cost of the damage itself for society.
Private marginal cost	The cost the user perceives as an extra cost due to his decision.
Public good	Good/service for which property rights are not defined. Without government intervention, environmental goods (e.g. clean air) are usually treated as public.
Public transport	Public (or scheduled) transport subsumes all services that are supplied according to a pre-defined timetable in passenger and freight transport. The final user here pays an average fare. Typical public transport is rail, bus, air and ferry services.
Purchasing power parity	(= PPP) The purchasing power parity describes the amount of goods or services which can be bought in a particular country compared to a reference country. The PPP necessarily must be expressed relative to a particular currency.
Receptor	Person, animal and plant or building exposed to an environmental burden.
Revealed preference	Valuation technique wherein consumers' choices are revealed in the marketplace (e.g. by the purchase of a good).
Risk approach	Valuation technique for estimating externalities whereby external costs inferred from premia for risk factors (e.g. the cost of insurance, or of risk diversification).
Risk avoiding behaviour	When a user perceives that the risk increases he changes his behaviour and searches for safer alternatives. This means that the observed change in risk due to increased traffic may be an underestimation

	of the cost; in addition to the cost of accidents the users also have cost of protection.
Risk elasticity	Percentage changes in the accident risk in response to a one percent increase or decrease in the traffic volume.
Risk value	Monetary value for pain, grief and suffering of an average transport victim, mainly used for the estimation of accident fatalities.
Shadow Prices	Shadow price is the marginal opportunity cost of the use of a resource (i.e. the loss of benefits caused if this resource cannot be used the next best purpose).
Social costs	The sum total of internal and external costs.
Social cost benefit analysis	Systematic estimation of all costs and benefits of a project that are relevant to society. Includes both technological externalities and pecuniary externalities, as long as the latter are not merely redistribution of income.
Social marginal cost pricing	A pricing scheme, which charges marginal costs.
SO_2	Sulphur dioxide contributes to the formation of sulphate aerosols and is the primary pollutant in the formation of acid rain. It can also cause respiratory system damage in humans.
Speed-flow function	A mathematical or graphical relationship between the flow on a particular road, and the speed of that traffic flow. As traffic flows increase, traffic speeds eventually fall.
Stated preference	Valuation technique wherein monetary estimates are derived from hypothetical statements by individuals about their preferences. The typical method used is a questionnaire approach (e.g. contingent valuation method).
System externalities (accidents)	The expected accident cost to the rest of society when the user exposes himself to risk by entering into the traffic flow; mainly medical and hospital costs.
Technological Externality	External effect that is not actively or voluntarily processed through markets, which results in economic inefficiencies. This occurs when some firm or individual uses an asset without paying for it. Technically they occur where one productive activity changes the amount of output or welfare which can be

	produced by some other activity using any given amount of resources. Negative technological externalities reduce the amount of output or welfare which an economy can produce with any given allocation of inputs.
TKM	Tonne kilometre.
Traffic mode	Category of means of transport (road, rail, aviation, shipping, etc.).
Traffic volume	Measure for traffic activity which can be expressed in vehicle-kilometres, or in passenger/tonne kilometres.
Unit costs	Costs per unit of service or goods provided (e.g. traffic volume).
(User) charge	Charge imposed on the user of a good (e.g. road infrastructure), often linked to the costs generated by his or her use.
Utility (Private)	Private benefit received by an individual due to his/her consumption of a good or service, or by the existence of that good/service.
Utility (Social)	The aggregate of private utilities in an economy.
Valuation	Process of estimating the economic value of a certain quantity of a transport good/service; generally expressed in monetary terms.
Value of statistical life (=VOSL)	The value of statistical life is a methodology to find a monetary pendant to a killed or injured human being. VSL is the opportunity costs of a saved human life.
Variable costs	Full costs can be subdivided into fixed costs and variable costs. Fixed costs remain constant with varying use of a transport system (e.g. supplier- or capital costs for road and rail networks or administrative costs).
VKM, Vehicle-kilometre	One kilometre travelled by a single vehicle.
Victim	The user that is hurt in an accident.
Willingness to pay (= WTP).	The willingness (or ability) of people to pay for the abolishment, reduction or reception of a particular matter can be estimated by two ways: (1) by stated preference surveys and by hedonic pricing methods.