Danish Ministry of Transport

# External Costs of Transport

## 1st Report - Review of European Studies

July 2004

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DMU og

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## 1st Report - Review of European Studies

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# 1 Introduction

This report is the 1st Report of the project

"*External Costs of Transport*".

The project has been undertaken by COWI in co-operation with DMU and TetraPlan on behalf of the Danish Ministry of Transport.

## 1.1 Background and purpose

The objective of the project is fourfold:

- To provide an overview of and insight in *European state-of-the-art knowledge* about quantitative assessments of the external costs of transport as background for discussions with the European Commission about the proposed framework directive on the principles for establishing infrastructure charges.

- To provide quantitative estimates of the marginal external costs of transport for all modes, which can serve as basis for evaluating cost based infrastructure charges.

- To recommend a revised matrix of *Danish unit costs for the marginal external costs* of transport which can be used in economic appraisals of infrastructure investments and transport policy initiatives.

- To assess the *total external costs of the freight and passenger traffic in Denmark*, split on modes. The calculations should serve as background for comparison of these costs with the revenues from total payments of charges and taxes in Denmark.

With a view to fulfilment of these objectives the project will produce three outputs which will be documented in three reports of which this is the first:

**1st Report**

This 1st Report deals with the first objective and provides the main basis for the second. The available results from the most important European research projects on external costs of transport will be reviewed. The report will also compare and critically review the applied methodologies and assumptions in the European studies, and analyse how the results can be adequately applied to marginal cost estimation in Denmark.

The key European projects have been identified to be the following five studies, which are here referred to with abbreviations/acronyms (in **bold**):

- **ExternE**, a series of very big research projects funded by the European Commission with primary focus on air pollution costs from energy cycles, including transport.
- **INFRAS/IWW**, published March 2000, an update of a previous study prepared for UIC in 1995, which was the first study presenting comprehensive external costs for all Western European countries. The results had important influence on the EU-Commission's Green book on "*Fair and Efficient Prices*" in 1995.
- **RECORDIT**, a 5th Framework RTD Programme project for DG TREN focusing on estimating the full costs, internal and external, of door-to-door intermodal freight transport in comparison with unimodal road transport
- **UNITE**[1] is also a 5th Framework RTD Programme project for DG TREN aiming at producing support policy-makers in the setting of charges for transport infrastructure use - by providing appropriate methodologies and empirical evidence. A key aspect of the UNITE approach is the recognition that policy considerations behind setting infrastructure charges consists of both efficiency and equity concerns as formulated in the EC White Paper "*Fair payments for infrastructure use*" (CEC1998).
- **TRL**, a consultancy project conducted in 2001 for the European Commission. The project aimed at creating on overview of and consolidating empirical evidence on the external costs of transport in relation to implementing the objectives of the EC white paper "*Fair payment for Infrastructure Use*".

These five main studies has been supplemented with additional sources to the extent necessary in terms of the most important predecessors of the five studies within the field of each of the types of external costs considered.

**2nd Report**

The 2nd Report completes the second objective by setting up comprehensive and detailed matrices of marginal external costs for all major transport modes in Denmark. The matrices provide both a best "estimate" and a "realistic range" for each cost component for each mode.

In the 1st phase of the project the approach was a "top-down" in the sense that the established matrices with estimates were based in expert opinion about what will most likely be the results if state-of-the-art methods were used to calculate revised values of marginal external costs for Denmark. The estimates were generated by a combining three types of information for each type of externality:

[1] Only a limited number of deliverables from the UNITE study were published at the time of the finalisation of the work with the 1st Report of this study. Hence, several UNITE reports have not been available for the review.

- The findings from the critical review of the European state-of-the-art;
- Conclusions about how to apply these methods for Denmark and the likely implications of using the specific Danish conditions as input;
- Critical assessments of and comparisons with existing Danish estimates.

In the 2nd phase of the study, new marginal cost estimates for noise and air pollution have been established based the findings in the 1st Phase. The approach has been thorough "bottom-up" revisions of the existing Danish estimates

**3rd Report**
The 3rd Report deals with the project's fourth objective. An initial step in setting up accounts of the total external costs of freight transport in Denmark was to establish estimates of the traffic volumes for each mode with the relevant subdivisions. This is important to ensure in order to be able to utilise the differentiations provided by the full dimensions of the marginal external cost matrices. A second step has been to clarify whether the total accounts for freight transport should be calculated for given volumes of passenger transport or whether it should be based on full allocation of the total costs for both freight and passenger transport.

## 1.2 Report outline

The project deals with the following six types of external costs:

- Air pollution
- Climate change
- Noise
- Accidents
- Infrastructure (wear and tear)
- Congestion

These are externalities from transport from which methods for monetarisation of the impacts have been developed and actually applied.

The next chapter, Chapter 2, will discuss some general methodological issues and give an overview of the European studies which have been reviewed. Each of the external costs listed above will subsequently be dealt with in turn in the following Chapters 3 - 8.

# 2 Overview and general approach

This chapter aims, firstly, at defining the framework and scope for the project and will, secondly, give a brief overview of the five major studies which are in focus of this review. Chapter 1 explained why these studied have been identified as key sources of European state-of-the-art knowledge about empirical evidence on the external costs of transport. They can all be regarded as exponents of the trend induced by the EC Green Paper "*Toward Fair and Efficient Pricing in Transport"* from 1995. The diverse systems of charging for transport in the individual European countries called for much greater transparency and consistency in the area of infrastructure charging to achieve fair competition in international transport. Therefore, the European Commission convened a *High Level Group* (HLG) of transport specialists to examine the extent to which changes in infrastructure charges along the lines proposed in Green paper might encourage efficient or sustainable use. The HLG completed its first report in June 1998[2], which provided an important input to the Commission's White Paper on "*Fair Payment for Infrastructure Use*", 1998. In the White Paper the economic approach was taken a step further putting a clear case for social marginal cost pricing, explicitly including environmental costs.

In recognition of the lack of solid empirical evidence which could substantiate revised charging schemes, a huge number of research projects have been launched within the European Framework RTD Programmes, such as PETS, QUITS, TRENEN II STRAN and CAPRI from the 4th FP and the RECORDIT and UNITE studies in focus here. Many of these studies are interrelated and with strong overlaps among participating institutions, which has contributed to an emerging consensus harmonisation of results and policy implications.

Consensus among researcher seems to have emerged that *short run marginal costs* are the best point of departure for infrastructure charging to achieve efficient use of the existing infrastructure, but also that the practical barriers, market imperfections and additional objectives imply that pure marginal cost pricing has to be modified to take these issues into account.

At the centre of current research interest is whether multi-part tariffs or other designs of the charging system should be applied as modifications to the "pure" principle of short run marginal cost pricing to take into account the pragmatic issues related to implementation.

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[2] Commission of the European Union: *Calculating Transport Infrastructure Costs, First Report of the Expert Advisors to the High Level Group on Infrastructure Charging,* 1998.

## 2.1 General methodological issues

External costs of transport are relevant as decision support for at least two distinct purposes:

- Basis for decisions on infrastructure pricing, and
- Valuation of effects in relation to Cost Benefit Analysis of infrastructure projects or policy initiatives.

In addition, on could argue that external cost figures can also be used in environmental accounting to evaluate the financial performance in terms of total tax payments across modes.

As it should be clear from Chapter 1 the focus of the present study is primarily on pricing purposes[3]. The classical approach taken by economists is that the aim for setting the optimal prices on infrastructure is to ensure efficient use of the infrastructure. But several additional criteria are important for political acceptability as well.

*Equity* concerns play an important role in two ways:

- First of all, there is the aspect laid down in the first part of the Green Paper title "... *fair and efficient …*" although the concept of fairness is one where there is little consensus. But one interpretation of this equity aspect, which is also reflected (equally vaguely) in the notion the "*polluter-pays-principle*", is that all users of a mode or a certain link in the network should collectively bear the full costs that this mode of transport or link imposes on society[4].
- Secondly, there are income distributional concerns. In principle, these objectives could be pursued more effectively by more direct measures such as the progression of the income tax system. However, given that there are also political restrictions or practical obstacles on the direct income regulating measures these concerns need to be taken into account in pricing decisions. This can for example be the argument for public transport subsidies, assuming that income of public transport users is typically in the low end of the spectre.

Financial viability can also be the criteria for the design of a pricing scheme. Typically, this argument is based on limitations in the available public funding due to budgets constraint on the national or local government. Otherwise, financial viability argument will be very similar to the fairness point of view.

But as mentioned above the general opinion is that the best starting point for infrastructure charging is the *short run marginal costs*. This approach to infrastructure pricing is also advocated by the European Commission in the White Paper "*Fair Payment for infrastructure use*" from 1998. Deviations from this principle could subsequently be argued based on other objectives than the effi-

[3] However, this does not rule out that marginal external cost estimates can be used as valuable inputs to determining the prices to be used in costs benefit analysis.

[4] It should be noted that bearing the full costs of transport might be in contradiction with pure marginal cost pricing to the extent that non-linearities prevail in the external cost functions.

cient use of the existing infrastructure as recommended by the HLG's 2nd Report.

Further, it should be noted that the practical problems, e.g. in terms of monitoring or transaction costs, of pure marginal cost pricing can also lead to deviations from the optimal pricing principle, for example by taxation of fuels or vehicles in stead of driven distances. Even in these situations marginal cost estimates can be used for differentiation and thereby lead to efficiency gains.

It should also be noted that the fixing of optimal infrastructure charging has to take into account the classical optimal taxation problem of behavioural reactions on the price changes: That is, increases (or decreases) in the marginal transport costs will lead to lower transport volumes. Hence, if the demand reactions are substantial this will also change the marginal social costs because the cost curve is typically non-linear.

In the subsections below some important definitions are explained in more detail whereas issues which are specific or most relevant for certain externalities are dealt with in the relevant subsequent chapter.

**Marginal costs**

The notion of *marginal* costs is essentially a rather abstract term which can lead to some confusion in practical applications. A practical definition of marginal costs is given in the 1998 White Paper from the European Commission:

> "Marginal costs are those variable costs that reflect the cost of an additional vehicle or transport unit using the infrastructure. Strictly speaking, they can vary every minute, with different transport users, at different times, in different conditions and in different places. Moreover for the last extra carriage on the train, car on the road, or ship at the sea, marginal costs can often be close to zero. Clearly such a strict definition is of no practical use, and like all other charging arrangements in the commercial world, a degree of approximation and averaging is necessary to develop understandable, practical charging structures. Marginal costs may at times merely reflect an average of variable costs. More usefully, they should reflect infrastructure damage, congestion, and air pollution costs, and so would vary according to factors like unit weight or number of axles, peak times, urban travel, and engine emissions."[5]

**External costs**

In principle, this study only considers *external* costs. These are defined as social costs imposed on others, but not paid for, by the infrastructure user. The part of the social costs which are actually paid are 'internalised' and therefore assumed to be properly reflected in the decisions taken by the infrastructure user. Hence, this study does not consider costs which are fully and directly paid by the user, such as vehicle operating costs and own time use.

Especially, the infrastructure for air transport and short sea shipping is driven under normal market conditions without significant subsidies and the related

[5] EC White Paper "*Fair payment for infrastructure use*" 1998, cited from TRL Vol. 2 p. 10.

costs are therefore considered as fully paid for by the user. Infrastructure costs for these modes are therefore excluded from the analysis, whereas infrastructure costs for road and rail transport are estimated because these costs can not be considered as directly reflected in infrastructure charges which can be both lower and higher than the marginal infrastructure costs. Of course, these aspects have to be taken into account when comparing the external costs across modes and when fixing the structure and level of charges and taxes to be paid by each mode.

The same line of argument holds for vehicle insurance payments which are assumed to cover the property damage costs of accidents.

**Short run vs. long run costs**
*Short* run, as opposed to *long* run, means that the capacity of the infrastructure is regarded as fixed. Hence, the distinction is primarily relevant for infrastructure costs. Neither capital costs of expansion of the network nor maintenance and operating costs which are dependent on the amount of traffic are included in short run marginal costs. Instead the opportunity costs derived from the scarcity aspect of the fixed capacity should be included in terms of congestion.

**Market prices and year of accounting**
Finally, for the sake of consistency the price level has to be settled. In the comparisons between studies the original figures will normally be cited directly and any differences taken into account in the comparative assessment of the figures. But, in the 2nd Report *all costs for Denmark will be presented in market prices as DKK-2000 per vehicle*. Market prices have been chosen because valuation methods for most cost components are primarily based on market prices. Infrastructure costs are based on public accounts which are in factor prices. These costs are converted to market prices using the "netto-afgiftsfaktor" recommended by the Danish Ministry of Finance.

"DKK-2000" is both price *base* year and *reference* year. The first, base year, means that all raw prices are inflated to 2000 price level. However, this is not very important since the level of inflation is low in the relevant period leading to small changes in comparison with the very high degrees of uncertainty in the cost estimates. The second term, reference year, means that the costs are calculated for the actual situation in year 2000, especially with the composition of vehicle fleet and traffic volumes for this year. This is for example important for air pollution where the steadily stricter emission norms over time imply that air pollution costs decreases as the vehicle fleet is replaced. The reference year is more important when more broad categories of vehicles are considered because the sensitivity to the variations over time in vehicle fleet compositions then becomes more severe.

**Comparisons across modes requires load factors**
The unit of measurement for the results of this study will be  or DKK per vehicle kilometre. Hence, comparisons across modes are not directly possible from the results as this will require knowledge about load factors, maximum or average figures or figures for specific transports from an origin to a destination.

In addition access and egress distances for auxiliary modes should be taken into account for modes that do not deliver "from door to door".

## 2.2 UNITE

The UNITE project was launched in January 2000 as a part of the European Commission's 5th Framework RTD Programme. UNITE[6] is carried out for DG TREN by a European wide consortium lead by Institute for Transport Studies, Leeds University. The project was formally finalised by the end of 2002. Major parts of the deliverables from the project was not yet published when the work with this report was finalised

The overall aim of UNITE is to support policy-makers in the setting of charges for transport infrastructure use - by providing appropriate methodologies and empirical evidence. A fundamental aspect of the UNITE approach is the recognition that policy considerations behind setting infrastructure charges consists of both efficiency <u>and</u> equity concerns as formulated in the EC White Paper "Fair payments for infrastructure use" (CEC1998).

- **Efficiency** concerns argue that, in an ideal world, the *marginal* social costs associated with an individual trip on a link of the transport network should reflect the price paid by the individual for that trip.
- **Equity** concerns argue that the total payments of a certain user group should reflect the *total* social costs associated with their transport activities, and that this principle should be applied across modes and user groups to avoid unfair competition.

Further, equity considerations could also apply to the distribution of payments across income groups to avoid unwanted social effects.

This point of departure is reflected in the UNITE distinction between
- the *marginal cost approach*, estimating the extra social costs by a marginal change in traffic volumes; and
- the *accounts approach*, calculating the total costs per mode as well as the payments in terms of charges and taxes.

and thorough methodologies have been developed for both approaches as well as a conceptual analysis of how they can be integrated for policy making[7]. European empirical evidence on marginal costs has been collected for more than 30 case studies covering all modes and all major types of costs and the results will be synthesised in a report (forthcoming). Pilot accounts based existing data have been finalised for Switzerland and Germany (Deliverable 5) and are currently being done for 16 other countries, including Denmark[8].

The UNITE approach is quite comprehensible in terms of types of cost categories as well as modes included, but costs and benefits which are strictly internal

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[6] UNITE = "**UNI**fication of accounts and marginal costs for **T**ransport **E**fficency

[7] See Deliverable 2 (Accounts), Deliverable 3 (Marginal Costs) and Deliverable 4 (Integration).

[8] Undertaken by Prodec as subcontractor to the UNITE partner NEI.

to the individual network user are not considered. The following cost categories are considered in the marginal cost approach:

- Infrastructure costs
- Supplier operating costs (vehicle and service costs for non-individual trips)
- Transport user costs and benefits (congestion, Mohring effect[9])
- Accident costs (split on internal and external costs)
- Environmental costs (air pollution, global warming and noise)

A general strength of UNITE is that the theoretical economic principles for proper marginal cost estimates are carefully considered with distinction between external and internal costs for each cost category. However, the marginal cost methodology report does not seek to demonstrate or elaborate the full calculation process for each cost component but refer to TRENEN-II STRAN and PETS reports which are developed by members of the UNITE consortium.

## 2.3 RECORDIT

The RECORDIT[10] project is also a 5th Framework RTD Programme project for DG TREN. It was initiated in January 2000 and the final report has been submitted to DG TREN for approval and is expected to be released soon.

The main objectives of RECORDIT have been to

- analyse the full costs, i.e. *internal and external* costs and benefits, of door-to-door intermodal freight transport in comparison with unimodal road transport;
- identify any imbalances between actual costs and prices for intermodal as well as road transport;
- formulate recommendations for policies for increasing the competitiveness of intermodal transport in Europe.

Hence, the study considers only freight transport and in order to account for the intermodality it uses the standard EURO load unit as unit of measurement for the cost calculations. It focuses on a bottom-up approach for three selected long-distance corridors:

- The freight freeway:
  (*Patras -) Brindisi - Munich - Hamburg - Gothenburg*
- The tri-modal transport chain:
  *Genova - Basel - Rotterdam - Manchester*
- The door-to-door intermodal chain:
  *Barcelona - Lyon - Torino - Trieste - Ljubliana - Budapest Warsaw*

The chains are selected in order to include all four types of intermodal transport combining rail, short sea shipping, inland waterways and air with feeder trans-

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9 The Mohring effect is the external *benefit* related to an increase in frequency in scheduled public transport induced by increases in demand. (The term refers to an article by Mohring in 1972.

10 **RE**al **CO**st **R**eduction of **D**oor-to-door **I**ntermodal **T**ransport

port by road. Further, the three corridors accounts for substantial variations in vehicle technologies, geo-morphical configuration of the network, population densities etc. to allow investigations in the variations in the external costs under different transport conditions by bottom-up calculations. However, the corridors in their full length are not representative of actual freight flows, but subsections represent important links in the European freight transport network.

Apart from infrastructure and supplier costs, which RECORDIT interpret as (ideally) internal costs, five types of external costs are considered: i) Air pollution, ii) Accidents, iii) Congestion and slot scarcity, iv) Noise and v) Global warming. Generally, the recommendations from the *High Level Group*[11] are adopted, and at the more specific level of actual cost calculations, RECORDIT aims at using as far as possible the same methodologies and monetary values as the parallel running UNITE project.

The quantifications of the external costs are done site-specific wherever possible or reasonable by using the bottom-up *Impact Pathway Approach* developed in the ExternE projects. This means that detailed and comprehensive calculations are made for small sub-sections of each corridor instead of relying on e.g. country specific average unit costs per vehicle kilometre. As a result the calculations are able to reveal very significant variability in the level of each external cost component along the corridors.

A PC-based Decision Support System was developed as part of RECORDIT. Based on the three analysed long-distance corridors the tool allows the user to estimate the external costs for any given corridor taking into account the main factors influencing the cost value (country, urban/inter-urban, vehicle type, load factor).

## 2.4 EXTERNE

The ExternE project originates back to a joint project of the European Commission DGXII and the US Department of Energy. This project was initiated in 1991 as part of the JOULE programme and was reported in a series of six reports in 1995. These reports considered the external costs of electricity generations. However, the methods developed were more widely applicable, and an extension was undertaken under JOULE II & III with three major tasks:

- *ExternE Core*, which comprised update and further development of the methodology (Vol. 7 in 1998), quantification of the global warming effects (Vol. 8) and extension to waste incineration (Vol. 9 in 1999).
- *ExternE National Implementation*, which implemented the methodology of the first part to a wider set of European countries, including Denmark[12].
- *ExternE Transport* which extended the methodology to energy related environmental externalities of transport (Vol. 9 in 1999).

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[11] The "High Level Group on Transport Infrastructure Charging of the European Commission".

[12] See RISØ(1998)

Previous quantifications of the environmental costs of energy production in monetary terms had relied on a "top down" approach from aggregated data. In contrast the ExternE adopted a "bottom up" approach which has become known as the *Impact Pathway Methodology* which is described in Chapter 3. This approach is extremely complicated to apply in practise and the effort laid down in developing the methods to their current state has been very significant. Today more than 50 research teams with a wide range of professional backgrounds from all over Europe have been involved in ExternE. The recognition of the achievements of the project is very high and proven by the extensive use of the ExternE methodology by decision makers in the European Commission and by national and local government in the Member States.

Although ExternE has considered several environmental effects, the dominant contribution is the quantification of the costs of air pollution from combustion of fossil fuels. ExternE transport is limited to quantification of the costs of air pollution and climate change. The latest results from the ExternE Transport research is published in Friedrich and Bickel (ed.) *"Environmental External Costs of Transport"*, 2001.

In addition, the European Commission DG Environment has published the so-called "*BeTa*" (Benefit Tables) study conducted by AEA Technology[13]. This study has generated aggregate air pollution costs for selected pollutants ($PM_{10}$, $NO_x$, $SO_2$, and VOC) for each of the Member States using the impact pathway approach from ExternE. For some aspects The BeTa results deviates from the ExternE approach, especially with regard to valuation of losses in life expectancy.

## 2.5 INFRAS/IWW

The study "External Costs of Transport - Accident, Environmental and Congestion Costs of Transport in Western Europe"[14] by INFRAS and IWW was published March 2000 as an update of a previous study prepared for UIC in 1995[15]. The UIC(1995)-study was the first study presenting external costs for all Western European countries and the results had important influence on the EU-Commission's Green book on "*Fair and Efficient Prices*" in 1995.

Both studies aimed at improving the empirical basis of external costs of transport based on the actual state of the art of cost estimation methodologies. Hence, methodological issues are dealt with by description at the overall level and references to the literature.

As indicated in the title, the INFRAS/IWW-study does not cover infrastructure costs, but otherwise the scope of the study was quite comprehensive and includes:

[13] BeTa: http://europa.eu.int/comm/environment/enveco/air/betaec02aforprinting.pdf

[14] Hereafter referred to as the INFRAS/IWW-study.

[15] "*External Effects of Transport*" by INFRAS/IWW for the International Union of Railways.

- Total and average costs (Year 1995 and 2010) as well as marginal costs (1995);
- For 17 European countries (EU15, Norway and Switzerland);
- Differentiation on all modes, fuel/energy type (cars and railways) urban/interurban (passenger) and short/long distances (freight);
- Specific marginal external cost calculation for four European corridors:
  1. *Paris - Vienna*; 2. *Paris - Brussels;* (passenger),
  3. *Cologne - Milan*; 4. *Rotterdam - Basle;* (freight).
- Estimates of environmental costs include (long run) costs on nature and landscape from provision and utilisation of the infrastructure as well as separation and space availability costs in urban areas;
- Upstream externalities in terms of air pollution and CO2-emissions from vehicle and fuel production as well as nuclear risk for electricity trains.

## 2.6 TRL

In 2001 a consortium[16] led by TRL produced *"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"*[17] for the European Commission DG TREN. The study was launched in order to provide empirical evidence on the social costs of transport in relation to implementing the objectives of the EC white paper "Fair payment for Infrastructure Use". More specifically the study should:

- compile estimates of transport costs for road, rail, air, maritime and inland waterways
- produce cost estimates for case studies to fill in the gaps in current knowledge, especially in relation to ports, short sea shipping, airports and aviation external costs
- develop a pragmatic scenario of "first round" reforms of transport charges

The study explicitly sets out from the guidance in the High Level Group reports and the UNITE approach and considers the same cost components, but the scope is limited to the short run marginal costs.

The first step is to survey the existing literature (Vol. 1) where focus is on:
- All relevant 4th Framework RTD Programme projects;
- INFRAS/IWW(2000);
- Recent Member State cost estimation studies.

The survey presents and comments on a very substantial amount of cost estimates from the recent literature before 5th Framework Programme studies such as UNITE and RECORDIT.

Vol. 2 sets up a "Cost Matrices Handbook" of estimates of the marginal costs of transport based on extracts from the existing literature. A weakness of the ma-

16 TRL, IWW, PTV, NEA, UFSIA,

17 Herafter referred to as the TRL-study.

trices is that no clear description is made of how or why the selected estimates have been preferred to others from the survey.

Vol. 3 consists of two quite separate parts. The first part documents two detailed case studies on maritime transport and aviation. No overall implications from the case studies are drawn up. The second part considers the consequences of a reform of the existing transport charges designed to internalise external costs. The report also gives a useful overview of the existing charging schemes in the individual Member States. Rough estimates of the possible impacts of a charge reform are given based on inference from existing analyses. A concluding summary which generalises the results is also missing for the second part of this volume.

# 3 Air pollution

## 3.1 Definition and scope

Air pollution related to propulsion energy for the transport means by combustion of fossil fuels has since long been recognised and regulated as an environmental burden of transport. Along with accidents it has traditionally been considered as the most severe external cost of transport, especially from road vehicles in urban areas. Consequently almost all studies dealing with quantifying the external costs of transports also consider air pollution.

The damages from transport related air pollution are many and mechanisms through which the impacts are induced are diverse. At the overall level the most important negative impacts are related to:

- *Human health effects* in terms of increased mortality and morbidity by causing or worsening sickness;
- *Lower yields of agriculture and forestry* by reduced plant growth or forest die-back;
- *Blackening and corrosion* of buildings, constructions and historical monuments.

The first component is in general held to be clearly the most significant cost of transport related air pollution. Therefore the description in this chapter focuses on the human health effects. Other less investigated effects are ecological impacts on the amenity value of nature and landscape such as forests, but these effects are normally not included because they are difficult to quantify. The climate change effects from emissions of green house gases are dealt with in Chapter 4.

Some early studies on the environmental costs of air pollution used either a macro-approach estimating the transport-related air pollutions contribution to the overall health problems in the society, while others, including the Danish unit costs, applied an avoidance cost approach.

However, the state of the art is the so-called *Impact Pathway Methodology* which could also be labelled a "bottom up" approach as it seeks to follow the causal links from the traffic to negative impacts and valuation of these. This methodology has been developed by the ExternE research programme, which was initiated in the beginning of the 1990's for electricity production and has continuously improved and expanded to other sectors including transport.

The impact pathway methodology has been generally accepted and all the examined studies refer to various versions of the results from the ExternE project or have performed specific calculations using the models developed by ExternE.

The ExternE results also provided emission data from up- and downstream processes, e.g. from vehicle or fuel production or maintenance of infrastructure. These are relevant for certain questions, such as project appraisals of additional infrastructure which might lead to additional traffic. However, for taxation issues the external costs of these emissions are not relevant. In principle, taxation of these emissions should be levied on the production processes to which they are related. Secondly, emissions from vehicle production etc. are not relevant from a short run marginal cost perspective.

## 3.2 Physical measurement

An overview of the ExternE impact pathway methodology for air pollution is presented below with the effect of $SO_2$ emissions on crop yield as example[18]:

[18] Friedrich and Bickel(2001) Table 2.1 presents a comprehensive list of impact pathways considered in ExternE Transport.

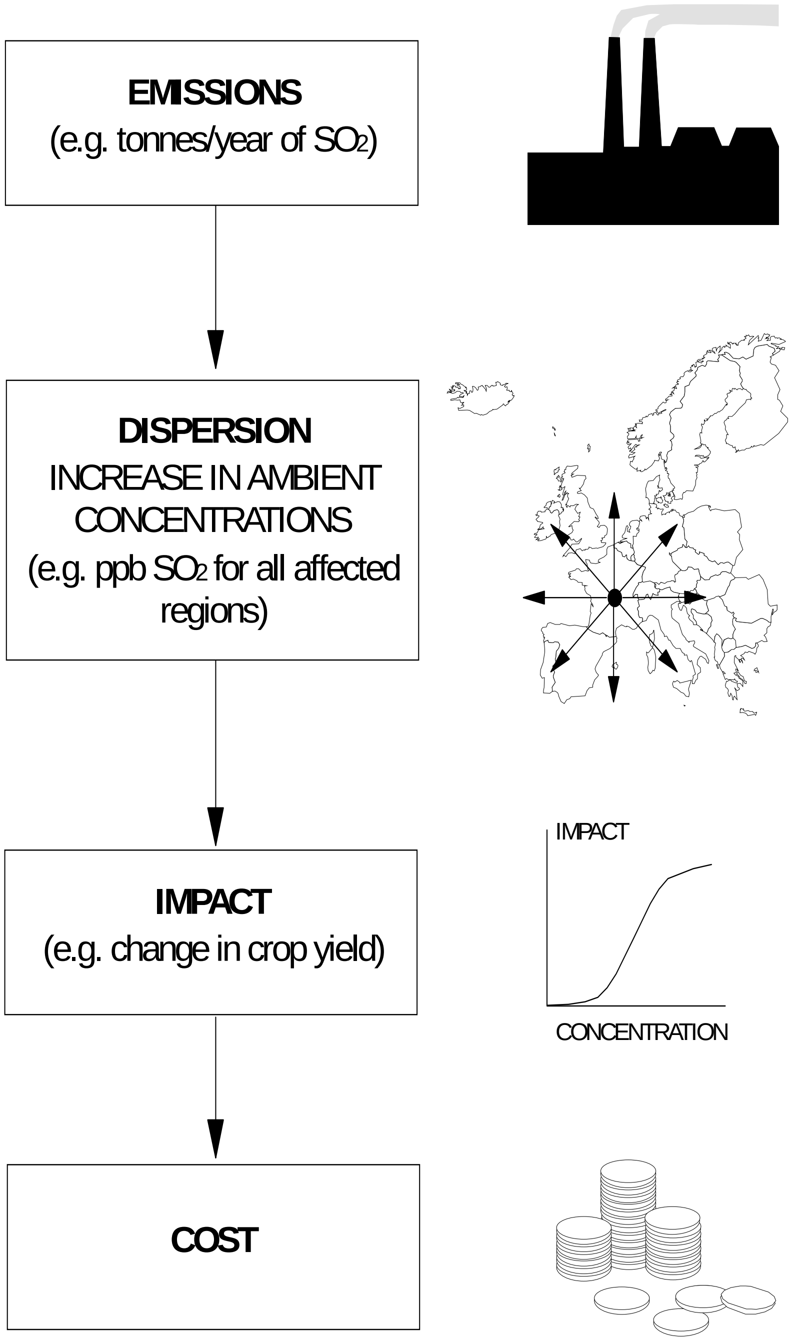


*Figure 3.1 ExternE illustration of the main steps of the impact pathway methodology applied to the effect of $SO_2$ emissions on crop yield*

In the Danish study, TRIP, a somewhat simplified and operational version of the impact pathway has been applied. This is shown in the following figure for health impacts. The description of the impact pathway methodology will take the Danish version as point of departure.

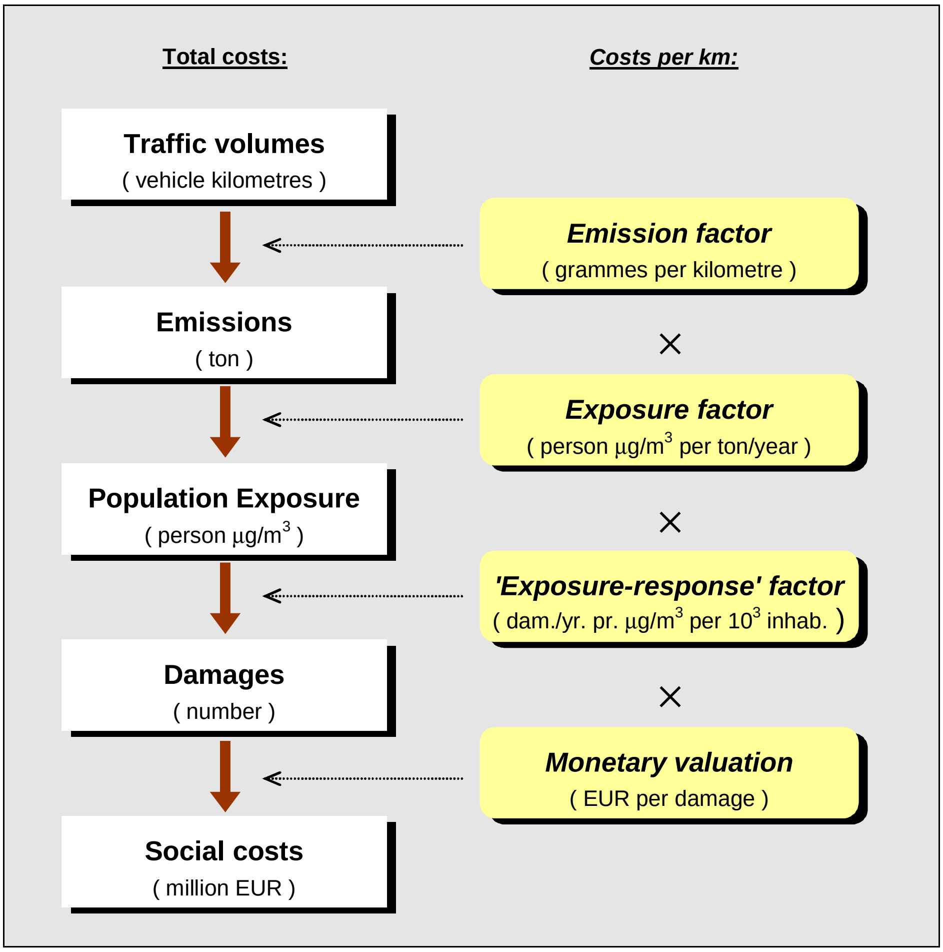


*Figure 3.2 Operational version of the Impact Pathway Methodology for human health effects from air pollution*

The left hand side of Figure 3.2 simply defines the causal relationship in four steps from traffic to the quantitative costs of the damages from traffic related air pollution. The right-hand side of Figure 3.2 represents the simplification made by assuming that the causal chain can be represented by a linear relationship between the four factors: Emission factor, Exposure factor, Exposure-response factor and monetary valuation which are in turn described below.

The assumption of a linear relationship is only a reasonable approximation for marginal changes in the traffic and, hence, in emissions, but this is exactly the scope for calculating the marginal external costs of transport.

### 3.2.1 Emission factors

The emission factors are measured in g/km for the pollutants CO, $SO_2$, $NO_x$, PM, HC/VOC. VOC consists of several hundred single compounds, some of which are relevant for direct health impact (for instance benzene and 1.3-butadiene), and others for global warming or ozone formation.

A large number of laboratory tests have been carried out in the last two decades to determine the emissions of air pollutants at different driving patterns. Emission factors are therefore relatively well-defined even though the relationships are complex and uncertain as they depend on the actual vehicle and driving pattern.

ExternE transport applies primarily emission factors for average driving patterns provided by the 4th Framework Programme project MEET, which will be fully integrated in the COPERT model. For road transport, the vehicles are split on fuel type, size class, and emission standards. The same source was applied in RECORDIT, whereas INFRAS/IWW uses the TRENDS data base system. The TRENDS project was the follow up project of MEET on EU level and the most recent state of the development in emission factors is the ARTEMIS project.

A critical issue is related to particle emissions. In addition to exhaust emissions vehicles also causes particle emissions from wear and tear of infrastructure, tyres, etc. It is heavily debated whether the latter type is equally harmful as the exhaust emissions which are typically smaller and have a more reactive composition. The MEET emission data includes only exhaust emissions whereas the later models include both types.

### 3.2.2 Exposure factors

The exposure factors represent the relationship between emission factors and the population exposure. Exposure factors are site-specific in the sense that the meteorological and topographical conditions of the location where the emission takes place as well as the population distribution will determine the exposure caused by the emissions. The exposure factors are determined in two steps:

- Firstly, dispersion models are applied to determine the emissions' contribution to the concentrations of pollutants in a grid map. This modelling takes into account the meteorological and topographical conditions and the chemical transformations of the emitted compounds in the atmosphere.
- Secondly, the total population exposure per ton of annual emission of the substance is calculated by multiplying the concentration in each grid cell by the population figure in the grid cell and then sum up for the whole geographical area. The unit of the exposure factor thus becomes *person* $\mu g/m^3$ *per ton/year*.

The $SO_2$ and $NO_x$ emissions are transformed to sulphate and nitrate aerosols, also labelled secondary particles, and ozone ($O_3$) is formed in a complex interaction depending on the relative concentrations of $NO_2$ and NMVOC's and climate conditions. Ozone is primarily formed in warmer climate whereas the traffic emissions contribution to the formation of ozone in the Northern parts of Europe can even be negative.

Clearly, these effects are not linear in the levels of traffic in a certain area as the chemical transformations will depend on the ambient concentrations related to emissions from other sources. Hence, the dispersion model results are only valid for marginal changes.

ExternE has developed the EcoSense model which integrates three models specially designed for either local (ROADPOL) or regional (WTM) scale dispersion, and for ozone (SROM) taking into account the interactions between $NO_x$ and NMVOC in the atmosphere. The model has in changing versions been used in several other projects, including QUITS, RECORDIT, UNITE and INFRAS/IWW.

### 3.2.3 Exposure-response factors

The damages to human health are by far the most significant social costs of the transport related air pollution. ExternE results for Greece shows that mortality and morbidity account for more than 95% and 90% in urban and rural areas respectively with mortality about twice the costs of morbidity.

The quantifications of the health damages are based on international epidemiological studies of the relationship between variations in the ambient concentrations of air pollutants and observed indicators of health effects. They are measured as changes in the occurrence rate per person per year per $\mu g/m^3$ for observable symptom indicators.

The primary types of health effects from transport related air pollution[19] are:

- *Cardiopulmonary diseases*, caused by or worsened by $PM_{2.5}$ (including secondary particles).
- *Respiratory diseases*, caused or worsened by $PM_{2.5}$ (including secondary particles), ozone and to some extent $SO_2$ and possibly also $NO_2$ and CO to a minor extent. The health effects also include higher mortality for ill people with reduced respiratory function or weak health general condition.
- *Cancer*, long-termed effects caused by carcinogens: benzene ($C_6H_6$), 1.3-butadiene, PAH on (diesel) particles, benzo-[a]-pyrene.

There is about 15 health effect indicators which can by divided into three main types:

- *increased mortality* (acute as well as chronic, i.e. shortened life expectancy, e.g. higher risk of cancer, due to latency of the impact);
- *increased morbidity*, subdivided into:
    - *hospital treatments* related to respiratory diseases (four types) and cardiovascular diseases;
    - *non-hospitalised symptoms and respiratory diseases* (such as asthma attacks, days with restricted activity, chronic bronchitis etc.).

[19] A complete list of the included quantified exposure-response factors in ExternE transport is presented in Friedrich and Bickel (2001) Table 5.1 and 5.2.

The use of exposure-response factors requires that the results from the epidemiological literature can be generalised for application in a European wide context, i.e. that the geographical variations in the empirical relationships are ignorable. However, the newest knowledge in the field indicates that epidemiological results from the predominantly US studies are not directly transferable to Europe. Especially, the effects of particles seem to be lower in Europe than in the US. Therefore - to the extent possible - European exposure-response functions are applied, but in some cases the US exposure-response factors are scaled down to be representative for Europe.

**Linearity - no thresholds**
A crucial simplification required for consistency of the exposure-response factor is that the relationship is approximately *linear*, also for small concentrations, so that the factor can be summed up across all grid cells weighted by population. Serious uncertainties occur especially, to the extent that the functional relationship includes threshold values. This will imply that local variations within the grid cells (and over time) will undermine the use of average values for population exposure in each grid cell. Further, it is necessary to include contributions to local concentrations from *all* emission sources, and the results will, hence, be influenced by the substantial uncertainties from such approach.

**Particles**
A special comment should be attached to PM because the impact pathway for the health effects of this very important pollutant is not very well understood. Intensive research is currently undertaken in order to enhance the scientific knowledge in this field. The key issue is related to the relative harmfulness of the various size fractions of particles and different chemical compositions.

The epidemiological evidence is most often based on measurements of $PM_{10}$-concentrations and more recently $PM_{2.5}$, i.e. particulate matter with a diameter below 10 µm and 2.5 µm, respectively[20]. Recent research indicates that the smaller fractions are the most harmful.

Evidence to date on the harmfulness of different types of particles is far from conclusive. However, it suggests that, per $\mu g/m^3$ increment in ambient concentrations, the most severe health effects are associated with primary particulate emission and the least severe with nitrates being relatively highly soluble. It may be the case that health effects associated with nitrates are negligible, but many epidemiological studies have shown associations of sulphates with adverse health.

[20] Practically all transport (exhaust) emissions of primary particles are in the "ultra-fine" range, i.e. with diameter <0.1 µm, whereas the secondary particles, nitrates and sulphates, formed in the atmosphere by chemical transformation of $NO_x$- and $SO_2$-emissions are typically in the size-fraction "fine" <2.5 µm.

Friedrich and Bickel (2001) adopted the following conventions for using the epidemiological evidence on exposure-response functions for incremental $\mu g/m^3$ concentrations:

- Primary particles emitted during transport and sulphates are treated as $PM_{2.5}$
- Nitrates is treated as $PM_{10}$ assumed to have a toxicity of 60% of $PM_{2.5}$

### 3.2.4 Economic valuation

As for other environmental externalities the difficulties regarding valuation of damages have to do with the fact that it is difficult to price goods that are not traded at a market, e.g. the case with loss of life due to increased mortality. All studies recommend adopting the willingness to pay (WTP) as fundamental approach. A number of indirect valuation methods have been developed to reveal the willingness to pay for a certain "good".

**Mortality**

For increased mortality ExternE Transport takes as point of departure a meta analysis of existing estimates in the literature for the value of a statistical life (VSL) for accidents. It is concluded that the best estimates is 3.36 million EUR per fatality.

However, the characteristics of the increased mortality from air pollution differ significantly from accidents. More specifically, the acute deaths are almost exclusively elderly people with weak health with a very limited average life expectancy. This is taken into account by converting the VSL from accidents to a value of life year lost (VLYL), which is assuming to be independent of age and health condition. The following formula is used:

$$VSL_a = VLYL \sum_{i=a}^{i=T} P_i^a (1+r)^{(i-a)}$$

where $P_i^a$ is the probability of surviving year $i$ conditional of having survived until the age of $a$ = 40 (the assumed average age for the fatalities behind the VSL) and using a discount rate $r$ = 3% for future life years.

This gives a VLYL of about 150,000 EUR (2000-values). RECORDIT uses the values from UNITE but converted to factor prices. UNITE also recommends to use the VLYL approach, but adopts a smaller VSL of 1.5 million EUR (see Chapter 6) in factor prices. INFRAS/IWW uses unit costs from WHO(1999).

The VLOL estimate is subsequently applied to the average life expectancy for the people affected by the increased mortality due to air pollution. For acute mortality, no empirical evidence is available for this value but ExternE Vol. 7: *Methodology update* (1998) reports a tentative estimate of 0.75 year, which is obviously significantly less than the life expectancy for traffic accidents.

Friedrich and Bickel(2001)/RECORDIT and the BeTa project for DG Environment differ with regard to the treatment of chronic and acute effects. The BeTa approach includes the effects from both estimates of chronic and acute mortality. Where both acute and chronic effects are estimated, ExternE considers including both as double-counting and consequently only includes the chronic effects.

Further, DG Environment (and, hence, also the BeTa project) so far prefers the VSL- rather than the VLYL-approach for valuation of mortality. For chronic and acute mortality values of 490,000 and 1,000,000 EUR are reported.

**Morbidity**
ExternE Transport's valuation of morbidity impacts includes three components:

- *Individual WTP* based on estimates from several Contingent Valuation Surveys
- *Productivity loss* from days off work
- *Health service costs* from hospital treatment etc.

Resulting unit costs for each health effect indicator, including the mortality effects from above, are presented in the table below cited from RECORDIT:

*Table 3.1 Monetary values for health impacts (EU15 average, factor costs, 1998)*

| Impact | per | Monetary value (rounded) |
|---|---|---|
| Year of life lost (chronic effects) | YOLL | 75,000 |
| Year of life lost (acute effects) | YOLL | 130,000 |
| Chronic bronchitis | new case | 138,000 |
| Cerebrovascular hospital admission | case | 14,000 |
| Respiratory hospital admission | case | 3,600 |
| Congestive heart failure | case | 2,700 |
| Chronic cough, children | episode | 200 |
| Restricted Activity day | day | 100 |
| Asthma attack | day | 70 |
| Cough | day | 34 |
| Minor restricted activity day | day | 34 |
| Symptom day | day | 34 |
| Bronchodilator usage | day | 32 |
| Lower respiratory symptom | day | 7 |

Source: RECORDIT D4 p. 20.

For RECORDIT and UNITE all country specific valuations are done by "benefit transfer" based on the above values but adjusted by GDP per capita (at PPP).

Again INFRAS/IWW uses values from the WHO-study for morbidity impacts.

### 3.2.5 Summary of study approaches

Key aspects of the adopted approaches in the reviewed studies are presented in the following table.

*Table 3.2 Overview of key methodological aspects of the reviewed studies*

| | ExternE | RECORDIT | INFRAS/IWW | UNITE | TRL |
|---|---|---|---|---|---|
| Modes | All | Freight | All | All | All |
| Impact pathway approach? | Yes | Yes | Yes | Yes | Yes (meta-analysis) |
| Emission factors | MEET | MEET | TREND | Different national sources | - |
| Exposure factors | EcoSense | EcoSense | EcoSense (generalisations) | EcoSense | - |
| Value of a statistical Life (VSL)[1)] | 3.36 M EUR | 1.5 M EUR | 1.4 M EUR | 1.5 M EUR | - |

1) For ExternE, RECORDIT and UNITE the VSL only serves as a basis for calculating the VLYL.

## 3.3 Cost per physical unit

Firstly, costs per ton of each emitted pollutant are compared in order to ignore differences in emission factors which vary significantly depending on the types of vehicles or vessels, speed, driving pattern etc. Costs per ton pollutant are only available for ExternE and BeTa.

ExternE has performed bottom up calculations for urban and extra-urban case studies in

- Belgium,
- Finland,
- France,
- Germany,
- Greece,
- Netherlands and
- United Kingdom.

Whereas BeTa has produced

- country-specific representative values for rural (extra-urban) areas in each European country plus
- European-wide values for $PM_{2.5}$ and $SO_2$ in urban areas depending (concavely) on the population of the city

An important aspect of the results is the quite substantial geographical variations both for urban and rural areas. For rural areas both ExternE and BeTa shows variations of a factor 4-8 depending on among other things population densities. For urban areas BeTa recommends to use values for $PM_{2.5}$ and $SO_2$

which are 3 and 2 times higher for a city with 100,000 inhabitants and about 40 and 20 times higher for major cities with several million inhabitants.

In order to be able to compare results on a consistent basis the Table below reports ExternE figures for Germany, extra-urban and for Stuttgart with 700,000 inhabitants and BeTa figures for Denmark and Copenhagen to be compared with preliminary Danish results from the TRIP-project which applies a simplified version of the ExternE approach.

*Table 3.3 Comparison of estimates of unit costs of air pollutants. EUR per ton.*

| | Pollutant: | $PM_{2.5}$ | | $NO_x$ | | $SO_2$ | | CO | | HC | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Source** | **City /Country** | **Urban** | **Rural** | **Urban** | **Rural** | **Urban** | **Rural** | **Urban** | **Rural** | **Urban** | **Rural** |
| ExternE | Stuttgart / Germany | 222.746 | 18.909 | 6.264 | 2.914 | 14.506 | 4.523 | 2 | 0 | 1.651 | 1.651 |
| BeTa | Stuttgart / Germany | 214.000 | 16.000 | 4.100 | 4.100 | 42.100 | 6.100 | n.a. | n.a. | 2.800 | 2.800 |
| | Copenh. / Denmark | 252.900 | 5.400 | 3.300 | 3.300 | 48.300 | 3.300 | n.a. | n.a. | 7.200 | 7.200 |
| | EU-15 | | 14.000 | | 4.200 | | 5.200 | n.a. | n.a. | | 2.100 |
| TRIP | Copenh. / Denmark | 104.430 | 27.651 | 8.456 | 7.919 | 11.946 | 6.309 | 3 | 1 | 2.148 | 2.148 |

Note that ExternE and TRIP applies the VLYL approach whereas BeTa applies the VSL approach.

Sources: ExternE: Friedrich and Bickel(2001) p. 205, 2000-values.
BeTa: http://europa.eu.int/comm/environment/enveco/air/betaec02aforprinting.pdf , 2000-values.
TRIP: http://www.akf.dk/TRIP/publications/papers/report35.doc , 2002-values.

The following conclusions can be drawn from the results presented in the table:

- Firstly, comparing the order of magnitude of the different pollutants Table 3.3 shows that particulate matter is causing the highest costs, which is due to the effects on mortality. Further, the PM-effect is much higher in urban areas because of the higher population exposure. $NO_X$ and $SO_2$ are also high in both rural and urban areas, which is mainly due to the atmospheric transformation into aerosols with same health effects as PM over regional distances. $SO_2$ has local health effects leading to higher values for urban areas. The costs of HC are about half[21] of those of $NO_X$ and $SO_2$, whereas CO is practically ignorable.

- Secondly, it also appears from the table that the German values are quite similar for ExternE and BeTa apart from $SO_2$ in urban areas. The similarity can most probably be explained by the use of ExternE results for calibration of BeTa, whereas the difference in $SO_2$ can be explained by the use of the VSL approach giving much higher costs for acute effects than the VLYL approach. The latter implies that the methodological decision regarding whether to apply VSL or VLYL has a big impact. Comparing the

[21] The BeTa-value for HC for Denmark appears very high. It is more than twice the value for the second highest value among the EU-15 countries whereas the Danish value for other pollutants is in the lower end of the range. The authors have been addressed about this and they have verified the value but no explanation has been given for the high value.

rural BeTa values for Denmark, Germany and EU-15 illustrates that Denmark are in the lower range which is due to a relatively low population density and our Northern geographical location i.e. not in the centre of Europe.

- Finally, comparison of recent (preliminary) Danish estimates shows somewhat higher values for urban PM-emissions and $NO_x$-emissions and lower values for PM-emissions in urban areas. However, the deviations are not significant in light of the above mentioned big variations and high level of uncertainties of these types of calculations.

## 3.4 Cost per vehicle kilometre

The size of the emissions per vehicle kilometre is different for the pollutants in the table above. For road transport, the total costs per vehicle kilometre are dominated by the $PM_{2.5}$- (urban) and $NO_x$-emissions (rural).

Estimates per vehicle kilometre from the reviewed studies are compared for road vehicles in Table 3.4. Variations are expected to be higher due to variations in the applied emission factors from different sources and because of different definitions of vehicles considered. The purpose of the comparison is primarily to extend the comparison in Table 3.3 to the studies for which unit costs per ton emission is not available.

*Table 3.4 Comparison of estimates of unit costs of air pollution from road vehicles. EUR per 1000 vehicle kilometre.*

| | **Vehicle type:** | **HGV** | | **Petrol car (cat.)** | | **Diesel car** | |
|---|---|---|---|---|---|---|---|
| **Source** | **City /Country** | **Urban** | **Rural** | **Urban** | **Rural** | **Urban** | **Rural** |
| ExternE[1)] | Stuttgart / Germany | 112 | 24 | 3.9 | 0.9 | 12.9 | 2.1 |
| RECORDIT[2)] | Germany | 81 | 44 | n.a. | n.a. | n.a. | n.a. |
| | Copenh. / Denmark | n.a. | 27 | n.a. | n.a. | n.a. | n.a. |
| INFRAS/IWW[3)] | Germany | 408 | 30 - 126 | 9.6 | 1.2 | 24.8 | 2.8 |
| TRL[4)] | Sweden | n.a. | n.a. | 8.8 | 1.8 | 17.6 | 1.8 |
| UNITE[5)] | Stuttgart / Germany | 175 | 39 | 2.5 | 1.2 | 14.5 | 2.6 |
| TRIP[6)] | Copenh. / Denmark | 130 | 70 | 4 | 4 | 13 | 7 |

1) 2000-values. EURO-II vehicles
2) 1998-values in factor costs. EURO-II vehicles.
3) 1995-values. EURO-I vehicles.
4) 1998-values. EURO-I (EURO-II approximately 75% of EURO-I).
5) 1998-values in factor costs. EURO-II vehicles.
6) 2000-values. Average of EURO-I and EURO-II vehicles

Sources: ExternE: Friedrich and Bickel (2001) p. 209, 210, 221., 1998-values for EURO-II
RECORDIT: "Variability of External Costs, vers. 3.0 Draft.
INFRAS/IWW: p. 109.
TRL: Volume 2 p. 47-48.
UNITE: "Environmental Marginal Cost Case Studies", Deliverable 11 vers. 1.0 Draft.
TRIP: http://www.akf.dk/TRIP/publications/papers/report35.doc , 2002-values.

In general the unit costs in Table 3.4 are in the same order of magnitude across studies but of course varying depending on the level of exposure. However, comments should be made regarding two significant differences:

- The INFRAS/IWW-values are significantly higher than ExternE for urban driving although the study applied calculations based on the ExernE models, although in generalised forms. The explanation is most likely differences in exposure in the case situations and that INFRAS/IWW added some effects with evidence for Switzerland, e.g. higher values for building damage and effects on nature and landscape.

- The Danish results from the TRIP project are high in rural area for all modes. This is most likely due to an overestimate of the health damages from the nitrate aerosols.

Unit costs per vehicle kilometre are difficult to compare for other modes than road transport because the size of vehicles and vessels as well as technologies are less uniform across countries.

### 3.5 Summary and critical assessment

The review of the methodologies and results of the European studies with regard to air pollution costs of transport has led to the following conclusion regarding strengths and weaknesses of the current state of the art:

- There is a remarkable degree of consensus with regard to the impact pathway approach as developed by the ExternE project being the preferred methodological approach for calculating the costs of air pollution.

- Health impacts dominate all other effects of the air pollution not considering the climate change effects from $CO_2$-emissions. Therefore, valuation of reduced life expectancy becomes crucial.

- There is a substantial variability in the unit costs per kilometre for all modes depending on the local conditions even when consistent calculation methods are adopted. Regional and local population densities, meteorological and topographic conditions as well as driving patterns have significant influence on the damages.

- Substantial amounts of empirical work have been done. Still, many uncertainties remain which are crucial for size of the air pollution costs remain. Among the most important are:
    - The lack of detailed understanding about which fractions of $PM_{2.5}$ are damaging to human health. If ultra-fine particles (with Ø < 0.1µm) are the main contributor it will increase the traffic's responsibility for the air pollution induced increases in mortality rates substantially. Hence, the costs will increase accordingly since PM-related health effects are the main contributors to the unit costs per kilometre.
    - The economic valuation of lives lost due to air pollution is still under dispute. Even if the value of 1.5 million EUR per statistical life for traffic accidents is accepted the conversion to air pollution related deaths is heavily dependent on he assumptions made because our knowledge about the actual number of life years lost is limited. Therefore the pragmatic methodology for this conversion is not yet settled.

    - No final conclusion can be made about whether all the most important aspects of the impacts of air pollution on human health are included in the currently applied dose-response relations.

- The full-scale use of the ExternE version of impact pathway approach is quite demanding to apply, although very suitable for e.g. project appraisals. Hence, the approaches such as RECORDIT's PC-based Decision Support System and the BeTa data base are very useful for more overall policy oriented purposes. In addition, an ongoing continuation of ExernE, *ExternE* Pol, will provide aggregated figures for policy use.

# 4 Climate Change

## 4.1 Definition and scope

During the past twenty years scientists have found continuously stronger evidence that human activities, especially the use fossil energy sources, affect the climate.

Climate change is a long-term effect caused by several gases which are emitted from both natural sources and human activities. The most important of the "greenhouse gases" are carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) which affect the climate on a global scale. In addition, nitrogen (from aircrafts) and sulphur emissions influence the formation of ozone and sulphate aerosols, which also have, more short-termed, effects on the climate on a regional scale.

Climate change has a very large number of impacts which are extremely complex to predict in a quantitative way. The most significant consequences are sea level rise, extreme weather events, and impacts on human health, agriculture, water resources and ecosystems and changes in energy consumption related to temperature regulation in human environments. Climate Change is a global and long term problem characterised by some irreversibility aspects and large uncertainty.

- *Irreversibility* is a specific characteristic of climate changes. Greenhouse gases have long atmospheric lifetimes and are stock and not flow pollutants. This implies that concentrations respond slowly to changes in emissions and the system is characterised by a great inertia since yearly emission only represent a small fraction of the total global stock.

- *Global*: The consequences of the greenhouse gases on the climate are a global phenomenon affecting the whole earth. However, there are some issues concerning equity and system delimitation in order to establish appropriate values.

- *Long term*: The changes that will affect the climate and the human activities are long term effects.

- *Uncertainty*: The future damages imposed by climate change due to current emissions depend on the future socio-economic conditions and the capacity of adjustment to the impacts of climate change.[22] It is important to

[22] Therefore the Intergovernmental Panel on Climate Change (IPCC) proposed a set of six scenarios up to year 2100 with different factors concerning population, GDP growth, total energy use and use of specific energy sources (nuclear, fossil and renewable).

keep in mind that uncertainties arise at all stages of the analysis. In addition, the most important uncertainties are often more ethical/political than statistical uncertainties.

## 4.2 Physical measurement

A variety of emissions contribute to climate change. Basically two categories can be distinguished:

- gases *directly* contributing to global warming (carbon dioxide ($CO_2$) and with a smaller contributions methane ($CH_4$) and nitrous oxide ($N_2O$). $CO_2$ is dominant as it is directly related to the use of fossil fuels.
- gases *indirectly* affecting the atmosphere via atmospheric chemistry (nitrogen oxides ($NO_x$) and some VOCs - besides $CH_4$ , $SO_2$, and $CH_4$, CO).

There is a convention to report greenhouse impacts as $CO_2$-equivalents, i.e. with reference to concentrations or emissions of carbon dioxide which is clearly the most important contributor. This requires establishing equivalence relations between different greenhouse gases, which is not trivial as the greenhouse gases have different lifetimes in the atmosphere. This is done by complex atmospheric modelling systems.

**ExternE**

In the latest work of ExternE presented in Friedrich and Bickel, (2001) a more exact approach is taken. The atmospheric concentration of each gas is treated separately and the change in the balance between radiation coming into the atmosphere and radiation going out (radiative forcing) is calculated for each year. The advantage of this method is that it avoids arbitrary equivalence, moreover discounting is possible and the marginal damages can be reported separately for each greenhouse gas.

Three models are used to derive the global warming assessment: the Open framework (OF) and two versions of the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model: FUND 1.6 and FUND 2.

From the damage cost results of the model calculations (see Section 4.3.1) with the FUND models one can implicitly calculate the equivalent factors for other greenhouse gases. Based on the central estimates, these equivalence factors are in round figures 20 for methane ($CH_4$) and 300 for Nitrous ($N_2O$) which are not important for transport sector emissions, because they are of relatively small size.

$CH_4$ is an important part of HC-emissions from gas vehicles and petrol cars with catalytic converter, but constitutes only a minor fraction of HC from petrol cars without catalytic converters and diesel vehicles. Friedrich and Bickel(2000) reports percentages of 20-45% for cars with catalytic converters and 4-8% for diesel cars depending on the driving speed. However, methane's contribution to the overall green house effect from the vehicles is insignificant because the emissions are less than 1% of $CO_2$ emissions per vehicle kilometre.

**INFRAS/IWW**

INFRAS/IWW reports emission factors in g $CO_2$ per vehicle km taking into account the country specific fleet composition. But the study calculates an average (overall) shadow price for $CO_2$ which is multiplied with national transport related emissions.

## 4.3 Cost per physical unit

**Damage costs vs. Avoidance costs**

Two main approaches are used to quantify the climate change consequences in economic terms:

- *damage* costs approach, which estimates marginal costs based on changes in the actual physical damages from a marginal reduction in green house gases;
- *avoidance* costs approach, which based on specific emission reduction targets can estimate marginal costs from a cost-effectiveness point of view;

The avoidance cost estimates are typically estimated to be higher than the damage costs since the precautionary principle might lead to higher reduction targets, whereas damage costs only encompasses costs of impacts that are reasonably known. Hence, the impacts covered by the available models are only a fraction (of unknown size) of all climate change impacts.

There are various aspects in estimating avoidance costs. There is an equity, an efficiency and an uncertainty aspect to consider:

- Efficiency would lead to a worldwide equilibrium price per tonne $CO_2$ equivalent. This implies a functioning market system for $CO_2$ certificates. In this case the price is rather low.

- Equity leads to the question which sector should reduce how much in its own country. This approach is arbitrary. If the transport sector should reduce its own emissions according to Kyoto targets, this leads to a different price from the case where the reduction is not tied to the sector.

- Uncertainty: If the Kyoto targets are seen as a political aim, which should be strengthened in the future to meet specific targets, the reduction costs may change (become higher). Hence the costs are dependent on the specific reduction aims. Furthermore, the reduction targets used in the different studies are not (yet) accepted.

ExternE prefers the damage costs approach to be fully consistent with the impact pathway approach. However, ExternE does not exclude other approaches in order to include uncertainty. ExternE's approach is adopted by PETS and QUITS.

Both UNITE, RECORDIT and INFRAS/IWW recommend avoidance costs as a second-best solution due to the high uncertainty of the damage cost results.

TRL is a meta analysis producing some cost matrices comparing figures from different relevant studies and is also more in favour of the avoidance cost approach in light of the state-of -the-art of the damage cost approach.

**Discounting**

Since climate change is a long term problem, the damages to be measured are caused by the actions of one generation and will affect another generation. The higher the discount rate the lower the marginal costs. Therefore discounting is very important issue. Even if the avoidance cost approach is applied for estimating the costs the discounting issue is still relevant to establish the relative effects because the impact duration of the various greenhouse gases differs.

In general, the literature on climate change damage assessment does not provide a clear guidance with rates ranging from 0% up to 5%. In ExternE, the discount rate is the sum of the expected growth rate of consumption per capita and the pure rate of time preference (PRTP). The growth rates vary per region and are based on the IS92a scenario-reference scenario from IPCC[23] 1992a. The latter is set to 0%, 1% and 3% per year with 1% as central estimate. Sensitivity tests show that the unit cost per ton $CO_2$ is a factor 3 higher for 0% as compared to 3%.

### 4.3.1 ExternE

To be consistent with the impact pathway methodology - the fundamental approach in ExternE - ExternE takes on the damage cost approach to estimating the costs of greenhouse gas emissions. Valuation of greenhouse gas emission is treated extensively in ExternE Vol. 8 which focuses only on this issue.

ExternE has opted for Willingness to pay values but this creates problems for global scale effects such as climate change because benefits and costs accrue to people around the world with very different levels of income problems. Equity concerns are addressed by using weighting factors accounting for declining marginal utility of income. Damages are weighted by the inverse of income of each single country.

Based on the results from the Vol. 8, ExternE Vol. 7: *Methodology Update* (1998) recommended using the following estimates for the ExternE National Implementation Studies. It should be noted that these values are now replaced by the values shown in Table 4.2, and that the values in Table 4.2 are based on different assumptions concerning the impacts associated with climate change.

[23] International Panel of Climate Change.

*Table 4.1 ExternE "Methodology Update " recommendations for national implementation studies*

| $EUR_{1995}$ per ton $CO_2$ | **Low** | **High** |
|---|---|---|
| Conservative 95% confidence interval[1)] | 3.8 | 139 |
| Illustrative restricted range[2)] | 18 | 46 |

1) "Conservative" in the sense that the 95% interval could be broader as it is not currently possible to consider all sources of uncertainty. This range varies between the lower end of the 95% confidence interval for a 5% discount rate and the upper end of the 95%condfidence for the 1% discount rate.

2) This range is composed of the base-case estimates for the 1 and 3% discount rates.

Source: ExternE vol. 7, Chapter 6.

Friedrich and Bickel(2001) continues along the same lines using a newer version of the FUND model. The damage costs recommended by Friedrich and Bickel(2001) is 2.4 per ton $CO_2$ (central estimate). This figure and the related confidence intervals in the figures in the table below are based on the central estimate for the pure rate of time preference (PRTP) equal to 1% and the valuation of damages correspond to the world "average" profile[24]. The emissions are in period 2000-2009 and costs are discounted to 2000. The model used is FUND 2.0[25].

Each of the steps of the chain of causality encompasses uncertainty from the emission to the economic valuation of the impacts. When looking at the recommended estimates it is important to keep in mind that they reflect the current best knowledge.

*Table 4.2 Recommended damage cost estimates for greenhouse gases. 2000-values.*

| $_{2000}$ per ton | **Minimum** | **Low** | **Central** | **High** | **Maximum** |
|---|---|---|---|---|---|
| $CO_2$ | 0.1 | 1.4 | **2.4** | 4.1 | 16.4 |
| $N_2O$ | 24.3 | 440.2 | **748.3** | 1272.1 | 5,242.1 |
| $CH_4$ | 1.9 | 28.2 | **44.9** | 71.5 | 257.0 |
| kg N[1)] | -5.5 | 198.2 | **337.0** | 527.9 | 1,270.2 |
| kg S | -35.8 | -16.6 | **-9.8** | -5.8 | 0.0 |

1) High altitude emissions from aircrafts only.

Source: Friedrich and Bickel(2001) p. 136.

[24] "world average" corresponds to the EU impacts with EU values plus impacts in other regions with globally average valued. This alternative argues from a perspective of a benevolent world leader. The respective values for EU only (EU impact only) regional values (with impact in other regions and regional values) and EU values (impact in other regions with EU values) are 0.19 , 1.39 , and 9.59 per ton $CO_2$.

[25] FUND2.0 is currently being peer-reviewed. FUND1.6 reflecting earlier impact literature, may be too pessimistic, whereas FUND2.0 may be too optimistic, reflecting recent literature.

Recognising the severe uncertainties and lack of comprehensiveness in the included effects Friedrich and Bickel(2000) also presents avoidance costs of 19 EUR per ton $CO_2$ for sensitivity analyses.

### 4.3.2 INFRAS/IWW

INFRAS/IWW gives a survey of key literature references for both avoidance and damage costs and gives the following intervals:

- Avoidance costs: 37 - 135 EUR per ton $CO_2$
- Damage costs: 0.05 - 200 EUR per ton $CO_2$

The study ends up recommending the avoidance cost approach based on the lack of sufficient scientific knowledge to justify the damage cost methods. The range is based on two reduction scenarios: The upper bound corresponds to a 50% reduction of European transport $CO_2$ emissions in 2030 compared to 1990 in line with the overall reduction target recommended by IPPC. The lower bound is based on the Kyoto agreement's 8% reduction scenario for EU in the first period (2008-2012) assuming a joint implementation strategy with emission trading. For baseline calculations INFRAS/IWW (2000) uses the high value for avoidance costs of 135 per ton $CO_2$. This avoidance cost is based on a scientific reduction aim of a 50% reduction of the European transport $CO_2$ emissions relative to 1990 until 2030.

### 4.3.3 RECORDIT

RECORDIT also rejects damage cost estimates as not being reliable[26]. Instead the accounting framework (Deliverable 1) follows INFRAS/IWW and recommends the Kyoto 8% EU-target as a lower bound. It is suggested to do sensitivity analysis with the 50% IPPC-target value for the European transport sector and a long term scenario.

### 4.3.4 UNITE

The description of UNITE ideal approach for Global warming is based on a damage cost approach and assume linearity between greenhouse gases and costs. However, the results provided by the damage costs approach are not seen as reliable in line with INFRAS/IWW and RECORDIT. Instead these studies use shadow value (avoidance costs) as a second best approach.

UNITE uses a European average shadow value of 20 per ton $CO_2$ emitted for valuing $CO_2$ emissions[27]. This value has been estimated by Capros and Mantzos(2000)[28] and corresponds to a central estimate of the range of values for

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[26] RECORDIT D1 p. 183 ff.

[27] UNITE Deliverable 11 Environmental Marginal Cost Studies, vers. 2.0 p. 16-17.

[28] They report values in Euro 1990 per tonne of carbon that have been converted in tonne of CO2 by using the conversion factor C/CO2 = 1/3.67. In a full trade flexibility scheme involving all regions of the world a value of 5 per tonne of CO2 is reported and in the case

meeting the Kyoto targets in 2010 for the EU. Low and high values of the range are 5 and 38 EUR per ton $CO_2$. The INFRAS/IWW value of 135 EUR per ton $CO_2$ is also referred mentioning that the 50% target has not yet been politically accepted.

### 4.3.5 TRL

TRL refers the avoidance costs of 135 EUR per ton $CO_2$ from INFRAS/IWW and the ExternE intervals for damage costs presented in Table 4.2. In addition, TRL refers to Sansom et.al.(2001). This study applies DETR's damage cost based recommended range of 7.3-29 £ per ton $CO_2$ with 14.6 £ per ton $CO_2$ as a central estimate.

## 4.4 Cost per vehicle kilometre

The method for calculating the cost per EUR/km basically consists of multiplying the amount of greenhouse gas emitted by a cost factor. For example, the $CO_2$ emissions per unit of transport for marginal costs are multiplied by the unit cost for all modes.

However, there is one exception: air transport. In fact air transport emissions are more critical than other modes (see IPCC 1999) since a major part of them are produced in higher altitude. ExternE suggests unit costs for N- and S-emissions. Alternatively, $CO_2$ emissions could, as a rule of thumb, be multiplied by a factor 2 according to different sources, e.g. Schuhman(1996). However, consensus has not emerged regarding this topic.

## 4.5 Summary and critical assessment

The two types of approaches used for estimating the marginal costs of climate change lead to different ranges where the damage cost estimates tend to be much lower than avoidance cost estimates. This can be explained by the fact that the lack of knowledge makes it impossible to predict damages from climate change in quantitative terms.

On the other hand, the tendency of the figures presented from subsequent analyses within the ExternE framework is clearly decreasing. There is also a tendency to used lower values than the one recommended by INFRAS/IWW (2000), especially in RECORDIT where a lower aim of reduction is recommended.

The quantitative results from the above review is summarised in Table 4.3 below.

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of no trading with countries outside Europe the value rises up to 38    per tonne CO2 avoided.

*Table 4.3 Summary of the $CO_2$ values recommended by the different studies*

| EUR per ton $CO_2$ | | Avoidance costs | Damage costs |
|---|---|---|---|
| **ExternE**<br>Vol. 7 Methodology Update | $EUR_{1995}$ | | **18-46**<br>(3.8 - 139) |
| **ExternE**<br>Friedrich and Bickel(2001) | $EUR_{2000}$ | 19 | **2.4**<br>(1.4 - 4.1) |
| **RECORDIT** | $EUR_{1995}$ | **37**<br>(37 - 135) | |
| **INFRAS/IWW** | $EUR_{1995}$ | **135**<br>(37 - 135) | (0.05 - 200) |
| **UNITE** | $EUR_{2990}$ | **20**<br>(5 - 38) | |
| **TRL** | $EUR_{2000}$ | 135 | 18-46<br>(3.8 - 139) |
| **TRL**<br>Sansom et.al.(2001) | $EUR_{2000}$ | | 20<br>(10 - 40) |

Note: Recommended values in **bold**.

Currently available damage costs are generally considered to be too uncertain. Instead, most of the studies seem to be in favour of adopting the avoidance costs approach. A critical problem with the avoidance cost approach is that the estimates depend very much on politically determined reduction targets.

A special problem relates to the high altitude $NO_x$-emissions from air transport. No clear consensus has yet appeared on how to treat these emissions in the valuation of the climate change effect.

Because of the global aspect of climate change unit costs can easily be transferred from one country to another and especially used the European average for Denmark. Based on benefit transfer of the units costs per ton $CO_2$ and emissions from Denmark a marginal costs for each modes and vehicle types for the different level of disaggregation considered, can easily be computed given that you have decided on the level of the costs per tonne.

# 5 Noise

## 5.1 Definition and scope

### 5.1.1 General features

Noise represents a social cost to society, because noise generates annoyance and health effects on human beings. Annoyance effects include interference with human activities such as speech, listening to radio, reading, etc. Other annoyance effects are concentration problems, learning problems for children, sleep disturbance, etc. When noise increases above certain levels, the consequence can be an increased risk for certain health effects, closely related to stress reactions.

Valuation of noise often reflects these two aspects of the costs of noise. Annoyance is typically valuated by using direct or indirect valuation techniques (hedonic pricing methods). Health costs paid by society such as hospital costs, production loss, etc. - could however not be expected to be fully incorporated in the estimated annoyance costs, although there might be some overlapping.

Road and rail traffic noise is generated primarily from a combination of engine noise and friction noise between the vehicle/train and the road/rail infrastructure. Noise from aircrafts occurs mainly from engine noise from start and landing. Noise from ships is negligible. Noise is local and temporary by nature, and therefore the damage caused by noise depends on the number of people residing or otherwise being relatively close to the noise source[29] and the local environment of importance for the dispersion. Mapping of noise exposure is traditionally carried out by combing noise dispersion models with dwelling maps and counting the number of people or households exposed to noise[30].

The level of sound is a logarithmic function of traffic volumes. This means that the marginal increase in noise from an extra vehicle/train depends on the exist-

[29] However, the effects on humans on continuous noise exposure can accumulate and lead to health effects.
[30] The total exposure during the day is important, and therefore it would be more correct to map the noise exposure for individuals on the various locations during the day. However, no practical solutions have been found to solve this.

ing noise level, which in most cases is dominated by the existing traffic. Noise also depends on speed, as higher speed generates more noise.

For road traffic, noise emissions differ greatly between types of vehicles, such as passenger cars versus HGV. For rail traffic, goods trains have typically higher emissions than passenger train[31].

The disturbance effect of noise depends on the time of day with higher disturbance effects of noise during the night (primarily because of sleep disturbance).

Marginal noise costs are thus mainly determined by:
- the distribution and distance of exposed persons from the source
- the existing noise level (traffic level)
- the time of day

These features of noise mean that marginal noise costs are very variable with respect to local conditions and between day and night. Marginal costs are generally higher at night, due to a combination the higher disturbance effect at night and the lower background noise level.

The logarithmic character of noise pulls in the direction of decreasing marginal costs per km. On the other hand, noise annoyance and health effects are considered to increase exponentially with the noise level, which pulls in the direction increasing marginal costs. The question of the combined effect of these two opposite features and the shape of the total marginal cost curve has not yet been settled.

Due to the periodic character of rail noise (in most cases), the marginal costs may be equal to the average costs. Also, due to the periodic character of rail noise, rail noise is generally assumed to be less annoying than road noise and target levels are often set 5 dB(A) higher that for road traffic. Vibrations may draw in the opposite direction[32].

### 5.1.2 The studies

The High Level Group recommends using the Impact Pathway Approach for noise assessment. The marginal external cost should relate to the noise level caused by an additional vehicle, train or plane; a threshold value is assumed (daytime 55 dB(A) and night time 45 dB(A)); the level of sound is a logarithmic function of traffic volume, whereas the cost function is typically of an exponential form; therefore marginal costs may according to the High Level Group increase or decrease with traffic volume.

**INFRAS/IWW**
Considers road, rail and air transport (and inland water transport), but not short sea transport. A top down approach is used for estimating average and total

[31] RECORDIT p. 49.
[32] HLG, p. 25.

costs, and a modeling approach for selected case studies is used for estimating the marginal costs. The study considers annoyance costs as well as health costs, and assumes a linear cost function for the former and an increasing cost function for the latter. A threshold value of 55 dB(A) is assumed for WTP. The study uses a human value (Value of a Statistical Life) to estimate health costs. Marginal costs are recommended for pricing purposes[33].

**RECORDIT**

Uses in general a bottom-up approach, and for noise an impact pathway approach, differentiated for road and rail. Focus is on the marginal costs to be used for optimal pricing purposes[34]. RECORDIT uses country specific noise costs as well as other costs, in line with the UNITE study.

The impact pathway approach is used, consisting of the following steps[35]:

- Sound emission modelling
- Sound propagation and exposure of dwellings
- Quantification of impacts
- Valuation of impacts

The impact pathway is used for a number of "building blocks", which are applied for a number of case studies on other infrastructure sections.

**UNITE**

The UNITE reports have only been briefly reviewed in this draft and specific results are not yet available. The Impacts Pathway Approach is used for marginal costs evaluation, based on the ExternE methodology[36]. Noise impacts are included, and annoyance as well as human health impact is included. Cost drivers are population density, distance from emission source, intensity of transport activities and level of background noise[37].

**Internoise 2002**

As a result of the workshop held in 2002, an article on "External costs of transport noise - a bottom-up approach", published at the 2002 Internoise conference, was provided by the international experts. The results from this paper have been included in the review, since new figures using the bottom-up approach are presented.  The impact Pathway approach is used on a number of urban road transport case studies. The departure is noise exposure modelling and costs are calculated using exposure response functions and hedonic pricing methods.

**TRL**

TRL is a meta-study, based on a literature review. A principal part of the TRL study is developing a cost matrix containing all existing estimates of costs, con-

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[33] INFRAS/WWW p. S-1, S-2.

[34] RECORDIT D1, p. 120

[35] RECORDIT, D4, p 24.

[36] UNITE, D2, p. 41 and D3, ii.

[37] UNITE, D2, p. 32.

sistent with the guidance of the High Level Group and adjusted to the approach used by the UNITE study. Therefore, the cells in the cost matrix in itself has a message, even though there may be no values listed in the cell. For road traffic both WTP for noise disturbance and health costs due to increased cardiovascular diseases are considered.

From an overall point of view it can be concluded that the fundamental approach is very similar in the studies although the level of detail varies. An overview of study approaches is presented in Table 5.1:

*Table 5.1: Overview definition and scope*

| Issue | ExternE | RECORDIT | TRL | UNITE | INFRAS/IWW |
|---|---|---|---|---|---|
| Study type | (Noise not included) | Real costs of inter-modal transport | Overview Cost matrices | Method and calculation | Review Estimates |
| Health costs included | - | Yes | Yes | Yes | Yes |
| Road transport | - | Freight | Pass. and freight | Yes | Car, MC, bus, LGV, HGV |
| Rail transport | - | Freight | Pass. and freight | Yes | Pass. and freight |
| Air transport | - | | Pass. and freight | | Pass. and freight |
| Marginal costs | - | Impact pathway | Review Impact pathway | Impact pathway | Modelling |

## 5.2 Physical measurement

The physical measurements consists of calculation of number of people or household being exposed to various noise levels (exposure) and for some studies number of people experiencing health effects and sleep disturbance (exposure-response).

### 5.2.1 Emissions and exposure

Noise models are often used for transport infrastructure planning in Europe. Typically, a base noise level is measured in dB(A) at a distance to the emission source as a function of traffic volume and traffic mix. Next, corrections are made for speed and geographical characteristics[38].

**INFRAS/IWW**
In INFRAS/IWW, emission-dispersion models for road and rail are used on a number of scenarios which reflect types of land use (rural, suburban, urban), time period (day, night) and traffic (relaxed, dense)[39]. Noise emissions and exposure is calculated for the scenarios and varying with respect to population

[38] HLG p. 18-19.
[39] INFRAS/IWW p. 31.

density, distance to traffic, type of infrastructure, traffic mix and target level in order to reflect typical European situations.

**RECORDIT**

RECORDIT calculates road and rail noise exposure using German emission models[40], RLS90 and Schall03, respectively. The *road* noise model was enhanced with respect to speed calculations and vehicle categories. Since noise emissions increase non-linear with traffic growth, a baseline scenario of the actual traffic on specific road sections/rail line is compared with a marginal scenario of the baseline scenario plus an extra specific vehicle/goods train in a specific time period of the day.

A number of case studies are carried out.

- For *road* three case studies, two motorways and one urban road. The results from the case studies are applied for the other road links. Therefore, local differences with respect to traffic densities, traffic mixes and population distribution may not be fully accounted for.
- For *rail* five case studies were conducted, including for Denmark the rail line Padborg-Kastrup. Specific information on rail traffic volume and the additional train was used. For the receptor distribution (population) "building blocks" from Germany and the UK was applied to the other rail sections. For Denmark, Padborg-Roskilde was classified as "rural, moderate" and Roskilde-Kastrup as urban/suburban.

**Internoise**

The Internoise article uses the same emission models as RECORDIT. Four different urban locations were assessed.

**TRL**

TRL do not make own estimates, but states that noise emissions is a logarithmic function of the level of sound, reflecting traffic volume, the share of HGV's, road structure and speed. Thus, the noise level is decreasingly growing with traffic volume[41]. In TRL the physical measurement of rail noise is not discussed[42].

**Air transport**

TRL and INFRAS/IWW study state that there is a lack of information on emission-dispersion models for airport noise emissions[43].

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[40] See also RECORDIT D1, p 10 and 156.

[41] S. 69.

[42] TRL s. 139-142

[43] TRL, s. 196.

### 5.2.2 Exposure-response[44]

**INFRAS/IWW**

The approach used by INFRAS/IWW includes annoyance as well as health effects. The study states that traffic noise leads to undesired social disturbances and above certain levels nervous stress reactions and risk of cardio-vascular diseases.

With respect to health risks, the study uses two studies by Babisch et al from 1993 and 1994 indicating increased risk of cardiac infarctions of 20 % in the interval 65-75 dB(A) and 70 % for 75-80 dB(A). Values in the INFRAS/IWW report used are set somewhat lower: 20 % for 65-70 dB(A) and 30 % for 70-80 dB(A). It is expected that mainly elderly people would suffer from cardiarc infarctions due to traffic noise.

A sensitivity analysis for a chance in target level from 55 dB(A) to 50 dB(A). It shows that total costs would increase by 58 % and that the noise costs for railway would double[45]. In general it is noted that the more detailed the results are, the more illustrative they should be considered[46], and that noise costs are extremely sensitive to local conditions. Therefore more in-depth local calculations are strongly recommended[47].

**RECORDIT/Internoise**

RECORDIT estimates health costs for the end-points ischaemic heart disease (fatal and non-fatal myocard infarction, angina pectoris and hypertension) and sleep disturbance. The exposure-response functions used are not documented in the RECORDIT study. According the results of the workshop, the methodology is the same as used in the Internoise article. Specific values for the increased risk as a result of traffic noise exposure are indicated. A few examples are presented below:

*Table 5.2 Exposure-response functions for stress-related health effect*

| | |
|---|---|
| **Myocard infarction, fatal (years of life lost)** | 0,084 $L_{den}$ - 5.25 per 1000 adults exposed.<br>Threshold value at 70 dB(A) |
| **Myocard infarction, non-fatal (days in hospital)** | 0,504 $L_{den}$ - 31.5 per 1000 adults exposed.<br>Threshold value at 70 dB(A) |

Source: Internoise 2002: *External costs of transport - a bottom-up approach*, by Stephan Schmid and Rainer Friedrich.

**TRL**

TRL states that chronic stress due to noise leads to enhanced ageing of the heart

[44] The method for estimating annoyance effects by use of the hedonic pricing method is described in the next section.

[45] INFRAS/WWW p. 152

[46] INFRAS/WWW , p. S-13.

[47] INFRAS/WWW p. 103.

and the cardiovascular system. TRL refer to the same studies by Babish, referred above for INFRAS/IWW.

## 5.3 Costs per physical unit

The costs per physical unit for noise comprise the costs of annoyance and the health costs. Costs of road noise disturbance (or annoyance) can be estimated by either hedonic pricing studies or by stated preference surveys. Most studies rely on hedonic studies. Health costs are estimated for the end points identified in the previous section.

**INFRAS/IWW**
For estimating annoyance, a number of European empirical studies using hedonic pricing and revealed preference methods are compared. The gradients are found to be quite similar, and the study arrives at a linear function indicating an increase of WTP per dB(A) of 0.11 % of per capita income. However, the target levels, i.e. the points where the straight line crosses the x-axis, differ. WTP for noise reduction at different noise levels is calculated, using Germany as reference country. These results are extrapolated on the other European countries[48].

With regard to the health costs, national mortality rates for cardiac infarctions are adjusted with the increased risk due to traffic noise, described above.

VSL is used to value this increased mortality. Production losses are neglected with a view to the older age and small number of deceased. No information could be found on external hospital and administrative costs.

**RECORDIT**
Noise effects include annoyance effects as well as health effects[49]. The external noise costs calculated constitutes of three parts:

- Resource costs
- Opportunity costs
- Disutility

where the first two components relate to the Cost-Of -Illness (COI) approach and the latter to the WTP for avoided annoyance.

In RECORDIT the same empirical studies as mentioned under INFRAS/IWW are used[50]. The study by Soguel was used for valuation in RECORDIT. The study gives a NSDI value of 0.91, which is similar to an average derived from a

48 p. 27.
49 RECORDIT D1 p. 10 and 159.
50 RECORDIT, D1 p. 161.

number of European studies. Instead of house prices, a monthly rent net of charges is used[51].

RECORDIT discusses the possible overlap between estimates based on hedonic price studies and COI estimates, and refer to expert judgment that people are generally not aware of definite health risks due to transport noise. Therefore the overlap is assessed to be negligible. Sleep disturbance is on the other hand expected to be included in hedonic price estimates.

Monetary values for health impacts include ischaemic heart disease (fatal and non-fatal myocard infarction, angina pectoris and hypertension). Specific values are presented for a number of countries including Denmark. In D4, Table 7 on p. 26, the specific values used are listed. In the table below are listed the values for Denmark:

*Table 5.3 Monetary values for noise impacts - RECORDIT*

| EURO (1998) | **Average Europe** | **Denmark** |
|---|---|---|
| Fatal myocard infarction (per case) 1) | 522,900 | 624,300 |
| Non-fatal myocard infarction (per case) 1) | 22,600 | 26,980 |
| Angina pectoris (per case) 1 | 14,160 | 16,910 |
| Hypertension (per case) 1 | 3,960 | 4,730 |
| Medical costs sleep disturbance (per year) | 197 | 235 |
| Average net rent (per person per year) | - | 2,565 |

1) Includes medical costs, absentee costs and WTP.

Source: RECORDIT D4, Table 7, p. 26.

RECORDIT argues that noise tends to affect relatively elder people than compared to e.g. accidents. Therefore VLYL instead of VSL is used in the calculations[52].

**TRL**

In general, TRL being a meta-study refers the methodology used by recent studies. TRL suggests that costs of annoyance due to traffic noise can be estimated by either hedonic pricing studies or by stated preference surveys. It is discussed whether the shape of the cost function is exponential or linear[53]. The linear function for noise disturbance combined with the exponential function of the health costs indicates an exponential cost function. On the other hand, the noise function is decreasing function of traffic. These two effects may work oppositely[54]. No conclusion is reached, apart from an observation that recent

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[51] The study by Soguel found that WTP to avoid noise was dependent on the background noise level, which implies a non-linear cost-function. However, a linear function is used in the calculations.

[52] RECORDIT D1 p. 126

[53] TRL Volume 1, p. 69 -71

[54] TRL p. 74.

studies use linear functions. Health costs are estimated using a health risk approach.

It is discussed VSL or VLYL should be used, but no methodological clear answer is reached. VLYL is recommended, but results using VSL are also presented.

## 5.4 Cost per km

### 5.4.1 Road

**INFRAS/IWW**

The marginal noise costs per vehicle km are calculated for the various scenarios and defined as the derivation of the respective total noise cost function by traffic volume times the specific emission factor per vehicle type[55]. Marginal costs are calculated for various vehicle categories, traffic situations, time of day and degree of urbanisation.

Detailed results in terms of marginal costs per vehicle km are presented for these dimensions, i.e. vehicle type - rural/suburban/urban, day/night and thin/dense traffic.

**RECORDIT**

In RECORDIT, the marginal costs for an extra HGV or extra are calculated for the various case studies, using the Impact Pathway Approach. Emission modelling, exposure of dwellings, quantification of impact are used in combination with the unit costs described above to derive at costs per vkm. For motorways, an average of two quite different case study results for motorways in Germany (1.29 EURO-cent/vkm) and Italy (0.48 EURO-cent/vkm) is used. The case studies concern night traffic. For urban roads the marginal costs are based on one case study for Germany (Stuttgart). Marginal costs are derived for day, evening and night and an average calculated. These figures are used as European basis and adjusted by benefit transfer to the various countries. For Denmark the external noise costs amount to 1.06 EURO-cent/vkm for motorway and 51.34 EURO-cent/vkm for urban roads.

Motorway results are considered representative for drives outside built-up areas, with a certain pattern of passing built areas. They have an average speed of 70-90 km/h. Urban areas have average speeds of 20-50 km/h[56].

**Internoise**

In the Internoise article, a marginal scenario is calculated by adding one additional vehicle to a traffic scenario. Daytime results are presented for a number of vehicle categories and four case studies in Germany. No specific figures are presented for marginal costs at night, but it is stated that marginal costs are three times higher during the night due to sleep disturbance. It is stated that

[55] P. 31-32.

[56] RECORDIT D4, task 9.1: Generalisation of real cost calculation. P. 21.

health costs make up 15% during the day, 36% during the evening and 49% during the night.

**TRL**
The marginal road noise costs are expressed in EURO per vkm. TRL finds that the results stated by INFRAS/IWW, PETS and SIKA fulfil the study requirement and estimates are presented in the marginal costs matrices. Results from DETR, based on a number of case studies, are not included, due to inter alia inconsistent disaggregation[57].

**UNITE**
UNITE stresses that noise costs are generally difficult to generalise due to the very local nature and dependence on background noise levels[58].

### 5.4.2 Rail

**INFRAS/IWW**
The marginal noise costs per train km are calculated for the various scenarios and defined as the derivation of the respective total noise cost function by traffic volume times the specific emission factor per train type[59]. Marginal costs are calculated for train categories, traffic situations, time of day and degree of urbanisation.

Detailed results in terms of marginal costs per vehicle km are presented for these dimensions, i.e.:

- train type,
- rural / suburban / urban,
- day / night, and
- thin / dense traffic.

**RECORDIT**
For rail, a similar approach as for road is used, using "building blocks", as described above. The case studies concern night traffic. Specific results for calculated for Denmark and the other case study countries. For other countries, an average for the case studies for used in combination with benefits transfer[60]. Specific data regarding the rail traffic volume was used, such as number, types, length and speed of train. The distribution of settlements along the rail lines was calculated for a number of case studies and transferred to other case studies. For Denmark the case study concerned Padborg-Kastrup, which was categorised as rural from Padborg to Roskilde and urban/suburban from Roskilde to Kastrup. The marginal external costs were calculated to13.2 EURO-cent/trainkm.

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[57] TRL p. 73-75.
[58] UNITE, D3, p. 45.
[59] P. 31-32.
[60] RECORDIT D4, p. 53.

**TRL**
TRL finds that the results for railway noise costs are quite consistent for different studies. Study results estimating the costs per passenger km and ton km are converted to figures per km by using load factor corrections.

### 5.4.3 Maritime transport

No costs estimates are available. The costs are assumed to be negligible.

### 5.4.4 Air transport

According to TRL there is very little information available for calculating the marginal costs of air transport noise. Presently the expected variations according to type of aircraft type, airport characteristics (such as size of the airport and population density) and time of the day could therefore presently not be captured[61]. TRL refers to CSERGE 200 for specific aircraft measures for a specific airport (London) and to INFRAS/IWW for general values (Europe). More research is needed. The average costs in INFRAS/IWW are based on a linear increase of WTP with increasing noise over 55 dB(A). In INFRAS/IWW, because of a lack of emission-dispersion models for airport noise, the study team decided to derive values for marginal noise costs based on a ratio between marginal and average costs for road and rail[62]. It is therefore not consistent with the UNITE and High Level Group guidance[63] and not included in this overview.

### 5.4.5 Comparison

TRL bases their results for noise to a large extent on the INFRAS/IWW results, and therefore these are in line.

The result for RECORDIT and INFRAS/IWW are well in line, which is described in more detail in RECORDIT, D4, Task 9.1, pages 42-44, where results for similar traffic density and population density are compared.

### 5.4.6 Overview of results

In the table below, an overview of the results from the various studies are presented. Estimates from the different sources have been derived for situations which are often not directly comparable. For the sake of comparison, the INFRAS/IWW figures which are differentiated between night and day have been weighted by the factor 16/8 for day and night. For Internoise, only day values are available. RECORDIT figures concerns day/evening/night for urban values, but only night for rural values.

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[61] TRL cost matrix p. 46.
[62] INFRAS/WWW p. 32.
[63] TRL, s. 196.

*Table 5.4: Overview of noise costs (Euro per vehicle km)*

| EURO/vkm | RECORDIT | INFRAS/IWW | TRL[1] | Internoise[2] (UNITE) |
|---|---|---|---|---|
| **Road, urban** | | | | |
| HGV | 0,513 | 0,162 - 0,343 | 0,095 - 0,343 | 0,076- 0,258 |
| Van | n.a. | 0,088 - 0,186 | 0,088 - 0,186 | 0,023 - 0,075 |
| Car | n.a. | 0,018 - 0,037 | 0,006 - 0,037 | 0,003 - 0,015 |
| Bus | n.a. | 0,088 - 0,186 | 0,088 - 0,186 | 0,020 - 0,060 |
| **Road, rural** | | | | |
| HGV | 0,011[3] | 0,002-0,004 | 0,002-0,017 | n.a. |
| Van | n.a. | 0,001 - 0,002 | 0,001 - 0,002 | n.a. |
| Car | n.a. | 0,000 | 0,000-0,001 | n.a. |
| Bus | n.a. | 0,001 - 0,002 | 0,001 - 0,002 | n.a. |
| **Rail, urban** | | | | |
| Passenger | n.a. | 0,390 - 0,474 | 0,390 - 0,474 | n.a. |
| Freight | | 0,569 - 0,825 | 0,569 - 0,825 | n.a. |
| **Rail, rural** | | | | |
| Passenger | n.a. | 0,040 - 0,061 | 0,040 - 0,061 | n.a. |
| Freight | 0,132[4] | 0,043 - 0,065 | 0,043 - 0,065 | n.a. |

1) Builds primarily on INFRAS/IWW data. Where results differ, these results are from SIKA 2000. Results which are not differentiated with regard to urban/rural are not included in the overview.
2) Day values.
3) Only night value available.
4) A mix of rural and urban, but mostly rural. Night values

## 5.5 Critical assessment

The review of the studies has shown that quite similar approaches have been used in the studies with respect to noise costs. Both annoyance and health costs are included. Annoyance costs are estimated by referring to the same hedonic studies and indicating a linear cost function. For health costs it is recognised that noise can lead to various kinds of stress related health problems, such as cardiac infarction and hypertension. RECORDIT includes more health effects than INFRAS/IWW.

It is generally recognised that noise is a very local phenomenon and therefore the best estimates are derived from an impact pathway approach, using local data. It has not been possible to fully use this approach in the studies, because of the large amounts of data required. Instead, estimates and building block approaches are used.

RECORDIT gets closest to relevant data for Denmark, since Denmark is included in the case studies carried out.

Data on car, van and bus come primarily from the INFRAS/IWW study, which are reflected together with a few other, less detailed studies in TRL. Freight transport data from INFRAS/IWW and RECORDIT are according to the comparison above and according RECORDIT's own assessment in line.

The results published in the Internoise article are in line with the INFRAS/IWW study and RECORDIT.

More detailed comparisons taking into account the day/night features of the figures are carried out in 2nd Report.

The number of original data sources is not that many. Differences are due more to the level of detail of the studies than to methodological different approaches.

In Denmark, a hedonic price study has recently been carried out by the Danish Environmental Agency. The study reaches results similar to the international studies, i.e. 0.9-1.5% decrease in house prices per increase dB, but has not yet been published. Denmark has a recently updated mapping of buildings exposed to noise at different noise levels. Health costs are presently estimated by adding 50 % to the WTP estimate. This could be improved, using the inspiration and figures from especially the RECORDIT study and the Internoise article.

Specific marginal costs of adding an extra vehicle or train wagon could be calculated, using the noise mapping model and the updated noise costs.

The shape of the annoyance curve could be discussed, since there seems to be evidence in the literature that it may not be linear. In Denmark a non-linear approach to the shape of the annoyance curve is used for the calculation of unit noise prices, as well as for the allocation of budgets for the physical establishment of noise barriers.

# 6 Accidents

## 6.1 Definition and scope

The social costs include all costs that entail use of social resources or losses in productivity of goods or services. The total social costs comprise of property damage, direct public expenditure (medical treatment, police etc.), indirect cost for the society (loss of production due to illness or death) and human costs for injured and relatives (costs in terms of suffering and grief).

The *marginal* external accident costs are defined as the accident costs imposed on other transport users or society in general of an *additional vehicle km* when using infrastructure. Since accidents give rise to social costs including both internal and external costs, the magnitude depends on the *marginal risk*, the *valuation of accidents* and the *external element* of these costs. Each of these elements are explained further below.

### 6.1.1 Coverage of the modes of transport

The most important mode of transport regarding the external accident costs is road transport since far most accidents happens on roads. According to Rennings et al(1999) as quoted in the RECORDIT study in EU every year app. 48,000 individuals are killed on roads, while only app. 600 fatalities occur in rail transport. Rail transport, air transport and short-sea shipping all have a clear safety advantages per passenger kilometre over road transport.

Therefore, much more emphasis has been invested in accident analysis of road transport than for any modes. For example, valuation of accidents is consistently updated and published for road accidents across European countries, which is not the case for other modes. Only a very small number of studies provide data for air transport and short sea shipping. Also, the *High Level Group report* (WG3 Accidents), which is a key reference for all the reviewed studies, focused on estimating the marginal external cost of road and rail accidents, while very limited attention was given to accident costs of other modes. Consequently, this review mainly revolves around road accident costs.

### 6.1.2 Marginal accident risk

The *marginal accident risk* consists of two effects: the accident risk[64] of one extra vehicle km as well as the increase/decrease in accident risk of all other transport users due to the increase in traffic. The latter effect is often calculated by use of the *risk elasticity*, which is defined as the percentage changes in the accident risk in response to a one percent increase or decrease in traffic volume.

[64] Accident risk is defined as the number of accidents per vehicle kilometre.

(risk elasticity[65]). However, knowledge about the risk elasticities are limited and often this effect is ignored.

### 6.1.3 Valuation of accidents

Basically two different methodological approaches can be used for monetary valuation of accidents:

- A gross output-based (human capital) approach or
- A social welfare (WTP) approach

In both methodologies the accidents costs can be divided into the following social cost categories[66]:

- *Direct public expenditures*
  - police and rescue cost
  - medical treatment cost
- *Indirect costs for society*
  - production loss (net or gross depending on the methodology)
- *Loss of "human value"* (willingness to pay for safety)
- *Property damage costs*

The various cost components are calculated separately for *fatalities*, *severely* and *lightly* injured following the official European classification of accident casualties. However, the property damage is calculated per accident taking account of the repair costs of cars etc. in accidents with no personal damage. The total accident costs for each component are subsequently calculated by multiplying by the relevant number of casualties and accidents with the calculated unit cost. Finally, the accident *unit* cost is to be calculated by dividing with the number of reported accidents.

**The gross output approach**
In Denmark, the methodology used for calculating accident costs is based on the "gross output" approach (also called human capital cost approach). In this approach the costs of death or disablement is calculated on the basis of the future productive potential of the victim. Hereby the expenditure on consumption is included in the calculation of the production loss (gross), which means that at least part of the human costs (covers costs of loss of life expectancy[67],) in terms of the victims own future consumption is included in the production loss.

However, recognising that the value of a human being comprises of more than just its production value the method often also includes a cost component to take account of the "loss of human value". In Denmark this cost component is

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66 There are minor discrepancies in the cost components included in studies across Europe. However, there is consensus about including the most important components.

67 The loss of life expectancy concerns the loss of well-being of the victim due to the loss of consumption and of leisure time.

called the "welfare loss". However, no strict methodology for calculating the welfare loss exists in the gross output-based approach.

**The social welfare (WTP) approach**

In the social welfare approach the loss of human value is estimated as the willingness to pay for safety (or risk reductions). While it is evident that life is too important to value in monetary terms for en individual, changes in risk can be valued monetarily. People are not ready to trade their life for money but are ready to trade a change in risk for money. However, the willingness to pay for a change in risk can be transformed to a figure that reflects the value of a *statistical* life. For example, if the estimated willingness to pay is EUR 100 for a reduction in the risk of death of 1/10000, the value of a statistical life is estimated at 100*10000, which equals 1 million EUR[68]. Thus, it is not a question of assessing the value of a life in the meaning how high the willingness to pay is to avoid the death of a given person.

Application of the willingness to pay for estimating the loss of human value is consistent with the principles of welfare theory. The fact that we value our life of more reasons than just our future productive potential is captures with a consistent methodology in the social welfare approach by deriving monetary estimates from individual preferences.

### 6.1.4 External accident costs

In most European countries the total social costs of accidents and the unit costs per accident are calculated, because it is the relevant figure to use in cost-benefit analyses of infrastructure projects, which reduces the number of accidents. However, the external costs can be separated out of the social costs by determining which cost components are external.

To calculate the marginal external costs from the social costs, internalised external costs and the internal costs should be excluded.

The direct public expenditures are external costs borne by society in general and imposed by those who cause the accident risk. Also the net production loss is an external cost. In the net production loss, the discounted present value of the victim's future consumption is subtracted from the gross production loss leaving an estimate of the economic impact of the rest of the society due to a person's premature death.

The loss of human value in terms of the willingness to pay for safety (is often considered to be partly internal and partly external. If the general, but disputed, economic theoretical assumption about rational behaviour (*homo oeconomicus*) is accepted, then the road user internalises in his decision to travel the risk he exposes himself to, valued as his WTP. In this case, the external costs are therefore restricted to the WTP of relatives and friends and society for changes in

[68] The example is adapted from ExternE: *Externalities of Energy, Vol. 2: Methodology*. European Commission - DG XII. 1995.

accident risks for all other users of the same transport mode and of all other modes of transport. However, it has been argued that insufficient information lead individuals to not take into account the risk in their decisions to travel. In this case, the external costs are equal to the total loss of human value.

The property damage is covered by private insurance and as such paid by the group of motorists. The costs are at least to some extent internalised by the insurance premiums and the coupled systems of bonuses. However, to what extent the property damage costs are internalised depend on the insurance system.

### 6.1.5 The studies

The **UNITE** study provides useful methodologies discussions. The UNITE project provides detailed description on the full calculation process for each cost component split on an ideal approach and an approach used for pilot account. Further, it applies a consistent framework for distinguishing between external and internal costs (based on the recommendations by the High Level Working Group). Finally, UNITE is also important because a pilot account (of total cost) has been undertaken for Denmark.

**RECORDIT** provides both methodologies recommendations and empirical evidence of the marginal accident costs for freight transport. The RECORDIT study draws heavily on values and valuation conventions from UNITE (subsequently from High Level Working Group) and PETS. RECORDIT does not consider air transport.

The **TRL** study draws together existing estimates of the marginal accidents costs from European studies and provides a cost matrix including accident costs covering all modes and other relevant dimensions. The TRL study uses the definitions and information produced by the High Level Working Groups. However, recognising the importance of consistency with other relevant EC projects, particularly in terms of cost categorisation, the study also draws on the methodology of the UNITE project. Thus, the TRL study has sought to retain consistency with UNITE definitions and cost categories as far as possible without compromising the main objective of the study. In relation to external accident costs, the TRL study also refers frequently to data and information from PETS (1998), INFRAS/IWW (2000), Lindberg (1999 and 2002) and FISCUS (1999).

**INFRAS/IWW** includes external accident cost estimates for all EU member states for all modes of transport. The study is also interesting because it applies a methodological approach, which is different from the approach applied in the other review studies.

**ExternE** does not include transport accidents externalities. It includes relevant methodological considerations of the value of a statistical life, which is however covered by the other reviewed studies.

## 6.2 Physical measurement

*Table 6.1 Overview of the reviewed studies recommendations for the physical measurement of accidents*

| Issue | UNITE | RECORDIT | TRL | INFRAS/IWW |
|---|---|---|---|---|
| **Accident risks** | *All modes*: Emphasise country specific accident statistics | *Road*: IRTAD, 2001 for each country<br>*Rail*: Country statistics on fatalities coupled with detailed German accident data<br>*Short sea shipping*: Negligible - no data | *All modes*: Country statistics on accidents | *Road:* IRTAD, 2001. Accidents distributed according to responsibility of involved parties<br>*Rail*: Risks calculated as average of the years 1991-1997<br>*Aviation*: ICAO data |
| **Risk elasticities** | *All modes:* No specific estimates published yet | *Road and rail:* PETS risk elasticities | *Road:* Average accident risks<br>*Rail:* PETS risk elasticities | *All modes*: Only average accident risks |

Note: ExternE not considered as the it do not include transport accidents externalities

The physical effect is measured as the number of accidents per vehicle kilometre or the *accident risk*. The accident risk depends on the volume of traffic, the traffic composition, the type of vehicle used, the time of day, the road conditions and the driver. Normally, the number of accidents rises with traffic volume. Further, the severity is greater when large vehicles and trucks are involved rather than passenger cars.

*The marginal accident risk*

In order to estimate the marginal external costs it is not enough to just consider the average accident risks. The risk elasticity also has to be taken into account to reflect the marginal accident risk of an extra kilometre. This means that the average accident risk of a vehicle km as well as the increase/decrease in risk of all transport users due to the increase in traffic (the elasticity of accident risk) should be assessed.

On balance the number of accidents rises proportionally with traffic volumes for normal traffic levels in urban areas and more than proportionally with traffic volumes for higher levels of traffic in urban areas. Unfortunately, the empirical evidence regarding the exact relationship is weak.

INFRAS/IWW recommended figures for accident cost are average costs (p. 101). The study discusses the possibilities for estimating the marginal costs and highlights methodological problems and uncertainties of existing studies of risk elasticities. It is concluded that since the studies do not provide sufficient reliable information of marginal accident risks, average accident risks is used instead. However for road transport both marginal and average costs are estimated.

### 6.2.1 Road transport

In RECORDIT, it is stressed that the empirical evidence concerning the relationship between vehicle flow and accident risk is weak. Therefore, estimates of risk elasticities, needed for calculating the *marginal* accident costs, have often been assumed rather than estimated.

New estimates are not developed in RECORDIT. Instead, risk elasticity values proposed in the PETS project are used. This means that an elasticity of 0.5 for the change of risk *for other road users* as the number of heavy goods vehicles increases was used for all road types. For user in the same mode, an elasticity of 0.25 is used for urban roads, while an elasticity of 0 was used for other roads.

It should be stressed that the use of risk elasticities, as opposed to an assumption of constant risk rates, strongly influences the marginal cost estimates.

In RECORDIT, risk values for different road categories are estimated split into fatalities, severe and light injuries and split on occupants and non occupants (important in relation to calculation of the *external* costs). Because of an insufficient level of detail of the risk data, the risk values have primarily been based on information from IRTAD, 2001 about the number of killed persons per billion vkm coupled with detailed information for a few countries (Germany, Switzerland and UK). Table 6.2 below shows the accident risk values used in RECORDIT for Denmark and Germany.

*Table 6.2 The risk of fatalities, severe injuries and light injuries for occupants and non-occupants of lorries per 1 billion vkm - Denmark and Germany*

| | | Fatalities | | Severe injuries | | Light injuries | |
|---|---|---|---|---|---|---|---|
| **Road type** | | r | r' | r | r' | r | r' |
| Motorway | (Denmark) | 3.7 | 14.6 | 39.5 | 81.9 | 69.6 | 214.3 |
| Urban | (Germany) | 5.3 | 48.9 | 42.7 | 326.1 | 130.6 | 1237.0 |
| Extra-urban | (Germany) | 4.8 | 49.8 | 39.4 | 160.5 | 107.1 | 318.6 |
| Motorway | (Germany) | 4.1 | 16.1 | 43.7 | 90.8 | 77.2 | 237.4 |

Source: RECORDIT (D4) - page 32

Note: r = risk for occupant; r' = risk for non-occupants (other road users)

The table shows that the risk a lorry driver imposes on other transport users is far greater than the risk he exposes on himself (r'>>r).

The TRL study distinguishes between accident risk on motorways, country roads and urban roads based on data from INFRAS/IWW, 2000 and Lindberg, 2000. However, the TRL study stresses:

> "Clearly, accident risks have to be assessed for each country separately in order to reflect country differences".

New estimates for the relationship between vehicle flow and accident risk are not developed in the TRL study. Instead, risk elasticity values proposed in other studies (PETS, Lindberg, 2000) are quoted. However, the TRL study questions both the validity of the estimates and the acceptability of transferring risk elasticities between countries.

To calculate the marginal external accident costs the risk elasticities are needed. However, if adequate data of the risk elasticities are not available indeed only average external costs can be calculated. This approach is recommended and used in the TRL study due to the uncertainty of the risk elasticity.

The UNITE study recommends to use the available statistics on accidents from the EC countries for calculation of the accident risk of fatalities, severe and light injuries. However, it is important that risks are corrected for underreporting of accidents, which is considered to be significant in most EC countries.

UNITE also stresses that reliable estimates on the risk elasticity are difficult to find and states:

> "This fact, in particular, makes the estimation of marginal external accident costs more difficult than for the other cost categories. The estimation of the elasticity will be a major problem. When derived from other models, the quality of such elasticities might be questionable".

Further UNITE stresses that the lack of information about risk elasticities set a limit for the desired level of disaggregating of the marginal external cost estimates (e.g. vehicle type, road type, traffic volume etc.).

INFRAS/IWW uses data from The International Road Traffic and Accident Database (IRTAD) to compute the accident risks. The accidents are distributed to transport modes according to the *responsibility* of the involved parties. German data on the national accident risks have been extrapolated and applied on the remaining countries.

### 6.2.2 Rail transport

UNITE, TRL and RECORDIT all state that the empirical evidence regarding the relationship between train frequency and accident risk is very weak.

RECORDIT uses and recommends risk elasticities from PETS. Hence, a risk elasticity of 0 or a constant risk is assumed within the mode goods trains, while a risk elasticity of 0.5 between goods trains and other modes are assumed. These elasticities reflect that the risks for the railway users are limited, while the risk for road users may be significant as the serious consequences almost always falls on the persons outside the train (mostly cars).

The TRL study also quotes the above risk elasticities from PETS.

In RECORDIT, the accident risks for rails have been based on values for Germany for which detailed data about accidents were available coupled with information about the number of fatalities due to good trains per tonne-kilometre. Table 6.3 below shows the accident risk values used in RECORDIT for Denmark Germany.

*Table 6.3 The number of victims of accidents for occupants and non-occupants of goods trains per 1 billion train km - Denmark and Germany*

| | Fatalities | | Severe injuries | | Light injuries | |
|---|---|---|---|---|---|---|
| | r | r' | r | r' | r | r' |
| Denmark | 26.8 | 188.7 | 126.5 | 122.8 | 392.5 | 643.3 |
| Germany | 20.2 | 142.2 | 95.3 | 160.4 | 295.8 | 484.9 |

Source: RECORDIT D4 page 49

Note: r = risk for occupant; r' = risk for non-occupants

In INFRAS/IWW accident risks are calculated as the average of the years 1991-1997 to reduce the uncertainty.

### 6.2.3 Short sea shipping

In RECORDIT the external accident costs for waterborne transport are considered as negligible, since the number of accidents is very low and the amount of tonne kilometres transported per year is very high (RECORDIT, D4, p. 58). Hence, no information on accident risks or risk elasticities is provided.

TRL finds that accidents with fatality or injury in commercial services are rare just as statistics about the accident risks. In the case studies the increased probability of an accident by an extra vessel in ports is calculated.

No explicit recommendations on accident risks for short sea shipping can be found in UNITE. However, in general it is stated that risks should not be generalised as they are easy to collect from country statistics.

Estimates of external accident costs of short sea shipping are not included in INFRAS/IWW.

### 6.2.4 Air transport

TRL stress that there is limited available information of accidents costs for air transport. Hence, only few non-comparable results based on different assumptions are cited. However, air transport accident risks are available from national transport statistics. No information on risk elasticities is available.

In INFRAS/IWW fatality rates are calculated based on information from ICAO, while external costs for injuries are not accounted for because no data on the number of casualties are available for air transport.

## 6.3 Cost per physical unit

*Table 6.4 Overview of the reviewed studies recommendations for calculation of the marginal external costs per accident*

| Issue | INFRAS/IWW | UNITE | RECORDIT | TRL |
|---|---|---|---|---|
| **Definition and scope** | Admin. costs,<br>Medical treatment<br>Property damage<br>Human value | Admin. costs,<br>Medical treatment<br>Property damage<br>Human value | As UNITE | Admin. costs,<br>Medical treatment<br>Property damage<br>Human value<br>Costs of public funds |
| **Calculation approach - direct costs** | Observations of the consequences and market prices | Observations of the consequences and market prices | As UNITE<br>- preferably country specific data | Observations of the consequences and market prices |
| **Valuation approach** | WTP | WTP | WTP | WTP |
| **Value of a statistical life** | European Standard value<br>ECMT, 1998 recommendations injuries<br>No value for friends and relatives | High-quality national values preferred to European value<br>ECMT, 1998 recommendations on injuries<br>No value for friends and relatives | As UNITE | European Standard value<br>ECMT, 1998 recommendations on injuries<br>No value for friends and relatives |
| **Cost allocation and separation of the marginal *external* accident costs** | Top-down approach. Total external costs allocated to modes according to the responsibility<br>Property damage considered internal<br>Payments covered through insurance internal<br>Own risk implicitly included as external costs | External costs allocated on injurer<br>Framework for separating the external marginal costs proposed by the High Level Group.<br>Own risk and property damage considered internal | As UNITE | As UNITE |

Note: ExternE not considered as the it do not include transport accidents externalities

With only minor differences, all the reviewed studies agree on the cost definition and scope of social accident costs. This means that it is recommended to include material costs (administration costs, medical treatment costs, production losses and property damage) as well as non material costs such as injury and suffering of casualties resulting from transport accidents.

The recommendations and approaches applied for calculating the material costs differ only slightly with context across the studies. There is consensus about calculating the direct costs (administration costs, police and rescue costs, medical treatment costs and property damage) from observations of the consequences of accidents and market prices. Since considerable variations exist across countries it is recommended to estimate country specific values rather than transferring estimates from one country to another (RECORDIT, D1, p. 176).

Costs of public funds are included in the TRL study. This means that costs of providing revenue for direct public expenditures such as medical costs and police and rescue cost covered by state or municipalities are calculated and included. By including these costs, the study tries to reflect the true costs for society of public expenditures in relation to accidents, which is consistent with the basic principles of welfare theory. In Denmark, based on recommendations by the Danish Ministry of Finance, the costs of providing public funds are estimated to 20% of the funds needed.

According to TRL (vol.1, page 61) there is no major dissent on the production loss. The production loss can be calculated as:

- *Gross production loss* =
  Loss in future working time * Expected future national income per capita
- *Net production loss* = Gross production loss - Future consumption

Whether the production loss should be included gross or net depends on the methodological approach applied. Thus, if the WTP approach for calculating the lost human value is applied, the net production should be used in order to avoid double-counting the lost consumption of the individual, which is assumed to be part of the WTP estimate for human loss.

### 6.3.1 Recommended methodological approach

There has been a dissent on whether to base estimation of the non material costs on a gross loss (human capital) approach or a WTP approach. However, the High Level Group report favours and recommends the WTP approach as it states:

> "Methods for estimating such costs may be based on "human capital" losses, however these will underestimate the value of suffering and loss. Other methods are more commonly based on a willingness to pay (WTP) to reduce the risk of such accidents. This method is not perfect, and may not always accurately take account of the capacity to pay. However, they provide a useable result in terms of estimates of the value of reduced health, for injuries, and a "value of statistical life" for risks of mortal accidents".

Based on the recommendations of the High Level Group the willingness to pay approach is also recommended and applied in UNITE and RECORDIT. Further, both INFRAS/IWW and TRL proposes estimates of the human value based on meta-analyses of estimates derived from a willingness to pay approach.

### 6.3.2 The value of a statistical life

The loss of human value for fatalities, also called the value of a statistical life (VSL), includes the values for pain, grief and suffering of a transport accident victim. This costs component comprises the main part of the external accident costs (up to 90%).

As stated in UNITE there is broad agreement that the human value should be monetised to reflect individual preferences for risk reductions and that the value should be expressed as the collective willingness to pay for safety improvements. Although the reviewed studies debate the methodological problems associated with the contingent valuation technique all seems to agree that the CV methods is the best approach to estimate the WTP for risk reductions.

During the last 15 years more than 10 CV studies have been made across Europe in order to estimate the human value (TRL, vol. 2, p. 82). The studies show huge variations in the results and consequently no right value can be given. However, several meta-analyses of the estimates have been carried out in order to come up with a best estimate. Using this approach ExternE, 1995 recommended a value of 3.1 mill while ECMT in 1998 found a value of 1.7 mill . On November 13th 2000 a DG Environment workshop for experts was held in Brussels to discuss the subject valuation of a statistical life. On the workshop it was agreed to recommend a lower value of 0.65 mill (based on a study by Jones Lee et al), an upper value of 3.3 mill (based on the ExternE study) and a best estimate of 1.5 mill for the European Standard value.

The best value proposed on the workshop has also been recommended by INFRAS and TRL.

The UNITE study (and consequently RECORDIT as it adopted the UNITE valuation conventions) also finds the European Standard value reliable for EU projects. However, if national values based on well-designed WTP studies are available these values are recommended before applying the European Standard value adjusted in accordance with real per capita income.

*The human value for severe and light injuries*
While the loss of human value are valued using WTP estimates for fatalities, the loss for severe and lightly injured are often estimated on the basis of the value for fatalities. This approach is used in several studies and it appears that no study has attempted to estimate the loss of human value of severe and light injuries explicitly based on a WTP approach.

ECMT, 1998 proposes estimates of human values for severe and light injuries at 13% and 1% respectively of the VSL for fatalities. This recommendation is followed by all the reviewed studies[69].

*The human value for relatives and friends*
It has been discussed if WTP statements of individuals include values for the safety or human loss of relatives and friends. Some studies suggest that values for relatives and friends are included in individuals stated preference (assuming that individuals are altruistic), while other rejects this and suggest that the value

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[69] TRL, vol. 2, p. 84. INFRAS/IWW p. 19. Valuation conventions for UNITE p. 24.

of human loss for a "caring" society are higher than the value in a society of purely self-interested individuals.

A number of the WTP studies aiming at estimating VSL do not include WTP for relatives and friends explicitly, which means that implicit it is assumed that the value is part of the individual WTP. On the other hand, PETS, 1998 suggest that the component might be around 40% of the human value of individuals, however, without stating how this value was derived. In any case, it is difficult to find a solution to this problem since the value for relatives and friends have only received very limited scientific attention

Because of the major uncertainties on this issue none of the reviewed studies include any additional WTP for relatives and friends[70]. By definition this implicit implies that WTP of friends and relatives equals 0 or it is believed that individual WTP are based on altruistic preferences.

### 6.3.3 The marginal external accident costs

*The High Level Group Framework*

Recognising the importance of separating the external accident cost from the total social accident costs UNITE, RECORDIT and TRL all adopt a framework for identifying and valuating the external marginal costs proposed by the High Level Group (Lindberg,1999). The framework for analysing transport accident costs is applicable to all modes of transport.

In the framework the costs of an accident are split in three categories (based on RECORDIT):

(a) Willingness-to-pay (WTP) for safety on part of those travelling in a particular mode exposed to the risk;

(b) WTP on the part of relatives and friends of the person and

(c) Costs on the part of the rest of the society.

It is assumed that the user internalises in his decision the risk he exposes himself to, valued as his WTP.

Moreover, when a transport user becomes a victim, the only externality is the cost imposed on the general public due to his travel decision, the human value is internal. When he is an injurer all costs are external except for costs covered by insurance and bonus systems. Thus, the external marginal cost, consists of three components:

- *System externalities* - the accident costs to the rest of the society (c) (medical treatment cost, police and rescue cost) when the user exposes himself to risk (r) by entering into the traffic flow:

[70] TRL, vol. 2, p. 84. INFRAS/IWW p. 178. RECORDIT, D4, p. 21.

$c\,r$

where r is the risk to become a victim

- *Traffic volume externalities* - the value of risk for all users of the *same mode of transport*, caused by an additional user for the vehicle user/household (a), relatives and friends (b), and costs for the rest of society (c):

  $$(a + b + c)\, r\, E_{rQ}$$

  where $E_{rQ}$ is the risk elasticity.

- *Traffic category externalities* - the value of risk for all users of the *other modes of transport*, caused by an additional user for the vehicle user/household (a), relatives and friends (b), and costs for the rest of society (c):

  $$(a + b + c)\, r' + (a + b + c)\, r'\, E_{r'Q} \;=\; (a + b + c)\, r'\, (1 + E_{r'Q})$$

  where r' is the risk to become an injurer

The risk a transport user exposes on himself ($(a+b)\,r$) is an internal cost and therefore it is not included in the formulas above. Thus, only costs from the *change in risk* (risk elasticity) caused by an additional user for the vehicle user/household ($a$) and relatives and friends ($b$) is included for users of the same mode of transport, whereas the costs from the accident risk of driving ($r$) is not included. For users of the other modes of transport both the costs of the accident risk and the risk elasticity are included.

Finally, defining θ as the share of the total costs of accidents (involving the vehicle type considered) which are related to injuries in the vehicle type considered, the marginal external cost can be expressed as[71]:

$$MC^e = [\theta(1+E_{rQ})\, r + (1-\theta)(1+E_{r'Q})\, r'\,]\,(a + b + c) - \theta r(\mathrm{a} + \mathrm{b})$$

or

$$MC^e = [\theta E_{rQ}\, r + (1-\theta)(1+E_{r'Q})\, r'\,]\,(a + b + c) + \theta r\, c.$$

In the first expression the last term, $\theta r(\mathrm{a} + \mathrm{b})$, is the deduction of the internalised costs from the full marginal costs, MC, to obtain the marginal external costs, $MC^e$.

To which degree social costs are internalised depends on the legal and insurance system[72]. In the studies, in general, costs due to property damages are treated as internalised by vehicle liability insurance payments as it is assumed that all relevant damage costs are repair costs, which are covered either by vehicle liability insurances or directly by the vehicle owners and therefore inter-

[71] following UNITE D3 p. 35.

[72] And also on the degree to which costs to friends and relatives, *b*, are actually taken into account by the road user in the expressed Willingness to pay revealed in the interview surveys.

nalised. Thus, the costs for the rest of society (c) consist of the net production loss, medical treatment costs and administrative costs, which are not internalised by insurance payments[73].

From the framework, it is obvious that the risk elasticities strongly influences the marginal cost estimates. As the number of vehicles increases the number of possible interactions increases with the square. This suggests that the risk should increase with traffic volume. Accident models employed by infrastructure authorities do often assume that the risk is constant when the traffic flow increases; this implies a risk elasticity of zero. However, it is a question which should be settled empirically and the so far sparse research in the field suggest that the risk decreases with traffic volume, i.e. that the risk elasticity is negative (see Section 6.4.1).

Costs are allocated by splitting or calculating separately the accident risk on injurer and victims. The average accident risk split on injurer and victim is calculated from detailed statistics about, the mode of transport and vehicles involved in accidents, the casualties in the modes and vehicles involved (including pedestrians and bicyclist) and total traffic volume (vkm) of all modes and vehicles. In accidents between cars and HGVs, the internal risk on occupants of the car (r) is calculated as the number of casualties in the cars divided by total car kilometres. On the other hand, the external risk on occupants of the HGV (part of r') is calculated as the number of casualties in the HGVs divided by total car kilometres. All intra- and intersystem accidents for each category is calculated and aggregated to the risk per category.

*A top-down approach*
The above framework for calculating the external accident costs is not adopted by INFRAS/IWW. Instead INFRAS/IWW applies a top-down approach where total external costs are calculated and allocated to the modes according to the responsibility for the accident.

The total external costs are calculated by multiplying external unit costs per casualty with the number of fatalities and injuries. INFRAS/IWW computes the external accident unit costs from the social accident unit costs by excluding property damage and subtracting the costs covered by liability insurance systems and gratification payments.

### 6.3.4 Unit costs

Based on the above methodological recommendation and a number of assumptions the studies present monetary values for accidents. The most important assumptions behind the estimates are reflected below the tables.

[73] How far these costs are internalised depends on the country and insurance contracts (RECORDIT, D1, p. 174).

*Table 6.5 Monetary values for accident cost component from RECORDIT*

| /case | WTP (a) | | | Costs for society (c) | | |
|---|---|---|---|---|---|---|
| Country | Fatality | Severe Injury | Light Injury | Fatality | Severe Injury | Light Injury |
| **Denmark** | 1,395,000 | 181,300 | 13,900 | 139,500 | 11,000 | 1,130 |
| **Germany** | 1,380,000 | 179,400 | 13,800 | 138,000 | 28,500 | 2,960 |

Source: RECORDIT, D4, p. 23.

Note: Factor prices

A common EU WTP estimate transferred from UNITE (benefit transfer including PPP adjustment). Human values for severe and light injury 13% and 1% of the human value for fatalities. For fatalities the (external) costs to society estimated as 10% of the fatality human value. Costs due to injuries have been taken from EC, 1994 and updated to 1998.

UNITE recommends to use national values first (if of high quality) and secondly to use adjusted common EU figures.

*Table 6.6 Proposed UNITE VOSL by Country and compared to official values (Consumer value - 1998)*

| (million ) **Country** | **Official National values** | **UNITE VOSL** | **UNITE - Official Official** |
|---|---|---|---|
| Denmark | 0.52 | 1.79 | 244% |
| Germany | 0.87 | 1.62 | 87% |

Source: UNITE, Valuation Conventions, p. 6.

Note: UNITE estimates are factor costs. UNITE value 1.5 million common for EU (benefit transfer including PPP adjustment). Official values in use based on Nellthorp, Mackie and Bristow (1998). HICPs for Eurozone has been used to adjust price level to 1998.

UNITE also suggests to use the estimates of human value for severe injuries at 13% and for light injuries at 1% of the human value for fatalities as originally proposed by ECMT, 1998.

INFRAS/IWW provides a broad overview of results of recent studies of human value. From a meta-analysis of these studies human values per casualty are proposed.

*Table 6.7 Proposed EU average human value*

| , 1995 | Fatality | Severe injury | Light Injury |
|---|---|---|---|
| EU average | 1,500,000 | 200,000 | 15,000 |

Source: INFRA/IWW, p. 18

Note: Market prices

INFRAS/IWW also uses the ratios of human value of fatalities for severe and light injuries proposed by ECMT.

*Table 6.8 Total external costs per casualty*

| , 1995 | Fatality | Severe injury | Light Injury |
|---|---|---|---|
| Denmark | 1,817,824 | 236,389 | 20,901 |

Source: INFRA/IWW, p. 180

Note: Factor prices. The EU average human value transferred using PPP and national cost account for other external costs.

A comparison of the unit costs per casualty from the three studies shows that there are only minor variations in the results, which was expected as the studies agree on the value of a statistical life about 1.5 mill. . Differences are due the fact that some prices are expressed in market prices and other in factor prices and due to variations in the benefits transfer using PPP and the calculation year.

**Comparison with existing Danish estimates**

In Denmark, official values of the *social costs* of accidents are provided by the Danish Road Administration as part of "Trafikøkonomiske Enhedspriser". However, the Danish Road Administration provides no recommendation as to which parts of the social costs are external.

The Danish social accident costs are based on the human capital approach. Total costs include the gross production loss, which covers part of the human costs (costs of loss of life expectancy) in terms of the victims own future consumption. However, recognising that the value of human beings comprises of more than just its production value the method also includes a cost component called the "welfare loss" to take account of the "loss of human value". Hence in the Danish methodology the human value equals the welfare loss plus the victims own future consumption. This value is not provided from "Trafikøkonomiske Enhedspriser" and can only be calculated from the results under an assumption own consumption of gross production loss.

*Table 6.9 Human value and other external cost per casualty from the official Danish social accident costs*

| , 2000 | Fatality | Severe injury | Light injury |
|---|---|---|---|
| Human value[1] | 1,015,000 | 27,000 | 1,900 |
| Other external costs[2] | 38,700 | 81,800 | 27,800 |
| Total | 1,053,700 | 108,800 | 29,700 |

1) For fatality 90% of gross production loss assumed own consumption and thus added to the welfare loss. No loss for injured as they still consume.

2) Other external costs: Police and rescue costs, medical treatment costs and net production, i.e. property damage costs are assumed internalised by insurance.

Source: Own calculations based on Vejdirektoratet(2001): *Trafikøkonomiske Enhedspriser* 2000. Factor prices.

The official Danish human value for fatalities is lower than the estimate from the reviewed studies, which is due to different methodological approaches. The human value estimates for severe and light injuries are much lower than the international estimates. On the other hand other external costs are much higher for severe and light injuries.

## 6.4 Cost per vehicle kilometre

All the reviewed studies include methodological discussions on how to compute the marginal external accident costs per vehicle kilometre. However, not all studies present actual cost calculations, which are reflected in the sections below. An overview of the scope of the studies is provided in the table below.

*Table 6.10 The scope of cost estimates of the reviewed studies*

| | UNITE[1)] | RECORDIT | TRL | INFRAS/IWW | ExternE[2)] |
|---|---|---|---|---|---|
| **Road (freight and passenger)** | Case studies from Sweden and Switzerland | External costs for freight transport disaggregated on<br>- countries and<br>- infrastructure type | Estimates from other studies | Marginal cost based on an assumption of constant risk with traffic volume, e.g. equal to average cost | - |
| **Rail (freight and passenger)** | Case study from Sweden | External costs for freight transport disaggregated on<br>- countries | Estimates from other studies | Average cost estimates calculated | - |
| **Short sea shipping (freight and pas.)** | Case study from Sweden and Rhine | No estimates as the costs are considered as negligible | Own case study calculations | Not included | - |
| **Aviation (freight and passenger)** | - | Not included | Estimates from other studies | Average cost estimates calculated | - |

1) UNITE D9.

2) ExternE does not consider accident costs.

As the table shows, only few cost estimates are provided.

### 6.4.1 Road transport

**RECORDIT** presents country specific marginal external costs for road freight transport disaggregated on infrastructure type. The estimates are calculated based on the valuations and risk estimated described above.

*Table 6.11 External costs of road accidents from corridor analysis for HGV*

| per 1000 vkm | **Motorway** | **Extra-urban** | **Urban** |
|---|---|---|---|
| Denmark | 63 | n.a. | n.a. |
| UK (= low) | 20 | 83 | 84 |
| Italy (= high) | 190 | 458 | 652 |

Source: RECORDIT (D4) - WP9, page 19

Figure for UK and Italy are included in the table above to illustrate how much accident risks influence the results. Although the costs per accidents are highest in UK, the external costs of road accidents are much higher per vkm in Italy because the accident risks are much higher (3-10 times the risk in UK). This underlines the fact that accidents costs can not be transferred from one country to another.

**INFRAS/IWW** presents results disaggregated with respect to vehicle type and road type based on the following assumptions:

- Average costs per road and vehicle type set equal to marginal costs implicitly assuming constant accident risk (risk elasticity of 0)
- Applies a WTP approach for valuation
- Cost components included: VSL, Net production loss, other costs
- Applies a top down approach
- The external accident unit costs computed from the social unit costs by subtracting the costs covered by insurance, e.g. the property damage
- All accidents regarded as external, e.g. it is NOT assumed that the user internalises in his decision the risk he exposes himself to, valued as his WTP
- Severe injuries comprise 13% and light injuries 1% of VSL
- Country adjustment of VSL according to PPP

*Table 6.12 Average external accident costs 1998 for Denmark - road (INFRAS/IWW)*

| Euro/1000 vkm | **Car** | **MC** | **Bus** | **LGV** | **HGV** |
|---|---|---|---|---|---|
| Motorways | 15.3 | 69.3 | 17.0 | 11.4 | 5.6 |
| Interurban roads | 68.4 | 260.7 | 60.0 | 33.6 | 28.0 |
| Urban roads | 40.6 | 223.3 | 30.0 | 27.6 | 22.4 |

Source: Own calculations based on costs per pkm and tkm (p. 100) and average load factors (p. 98) from INFRAS/IWW

**TRL** presents reference values from 4 studies:

1. INFRAS/IWW - estimates as above, but only EU average values are cited.

2. PETS - estimates disaggregated on vehicle type for 3 corridors plus for HGV in general on a European level.

*Table 6.13 Marginal external accident costs for the Nordic Triangle Finland (and for HGV at a European level) - road (PETS)*

| Euro/1000 vkm | **Car** | **MC** | **Bus** | **LGV** | **HGV** |
|---|---|---|---|---|---|
| Nordic Triangle Finland | 8.7-22.7 | n.a. | 79.2-90.5 | n.a. | 55.8-64.7 |
| European level | n.a. | n.a. | n.a. | n.a. | 10.6-21.3 |

Source: TRL, vol. 2, p. 39 - Table 27.

3. SIKA, 2000 - estimates disaggregated on vehicle type for rural and urban areas.

*Table 6.14 Marginal external accident costs in Sweden - road (SIKA, 2000)*

| Euro/1000 vkm | **Car** | **MC** | **Bus** | **LGV** | **HGV** |
|---|---|---|---|---|---|
| Motorways | n.a. | n.a. | n.a. | n.a. | n.a. |
| Interurban roads | 9.7 | n.a. | 28.2 | 8.8 | 24.7 |
| Urban roads | 17.6 | n.a. | 32.6 | 11.4 | 43.1 |

Source: TRL, vol. 2, p. 39 - Table 27.

4. DETR, 2001: "*Surface Transport Costs and Charges*", Samson et al. - estimates disaggregated on area type, vehicle type, road type and 2 time periods. The estimates from the DETR study is not included in the TRL marginal cost matrices *due to different and inconsistent disaggregating of the available results.*

5. UNITE made in depth case studies in Sweden (HGV) and Switzerland and the results are presented in the table below.

*Table 6.15 Marginal external accident costs for road traffic in Switzerland and Sweden from the UNITE case studies.*

| Euro/1000 vkm | **Car** | **MC** | **Bus[1)]** | | **LGV** | **HGV** |
|---|---|---|---|---|---|---|
| **Switzerland** | | | | | | |
| All roads | 12 | 80 | 25 | 132 | 14 | 18 |
| Motorways | 3 | 2 | - | 9 | 3 | 3 |
| Extra-urban | 16 | 55 | 39 | 208 | 21 | 27 |
| Urban | 42 | 309 | 47 | 774 | 53 | 107 |
| **Sweden** | | | | | | |
| All vehicles | - | - | | - | - | 8.4 |
| Interval[2)] | | | | | | ÷0.8 - 32 |

1) Urban public transport (left column) and coach (right column).

2) Depending on vehicle size: 12-15 to >31 tons

Source: UNITE D9 p. 13 and p. 21.

A major contribution from UNITE is more in depth investigations into the risk elasticities. Although the evidence is stated to be very weak, and only based on he case studies from Switzerland and Sweden, it clearly indicates that risk elasticities are *negative*, i.e. the number of accidents increases less than the traffic.

The scope of the studies as well as the approaches and assumptions differ, which makes comparison of estimates troublesome. However, estimates of similar cost categorisation vary substantially. For example the estimated accident costs per vkm for HGV, motorways are more than ten times higher in RECORDIT compared to INFRAS/IWW. The huge difference most likely should be attributed to the fundamental difference in the methodology applied, especially whether accident risk elasticities are taken into account. It should also be noted that transfer of unit costs per vehicle is generally not recommended at the current state-of-the-art because of the substantial variations both costs, accident risks and risk elasticities. UNITE has produced a set of recommendations which allow national adjustments of a common European set of values.

### 6.4.2 Rail transport

RECORDIT presents country specific marginal external costs for rail freight transport. The estimates are calculated based on the valuations and risk estimated described above.

*Table 6.16 External costs of rail accidents from corridor analysis*

| **Country** | **per 1000 vkm** |
|---|---|
| Denmark | 516 |

Source: RECORDIT (D4) - WP9, page 19

Several studies with estimates of marginal external accident costs of rail transport have been collected and reviewed in the TRL study. On this basis, results of studies referring to a country (or Europe in general) and studies referring to a corridor or city are cited. The table below presents the results selected for the marginal cost matrices.

*Table 6.17 Marginal external accident costs - rail transport*

| Euro per 1000 vkm | **Source** | **Cost estimate** |
|---|---|---|
| **Passenger trains** | INFRAS/IWW, 2000<br>- European marginal costs (range of countries) | 216<br>(0-240) |
| | PETS, D9, D11<br>- Marginal costs<br>- Corridor results (Finland, Cross Channel)<br>- including internal components | (14-112) |
| | PETS, D12<br>- Optimal charges in 2010 | 500<br>1750-2150[1)] |
| **Freight trains** | INFRAS/IWW, 2000<br>- European marginal costs, (range of countries) | 0<br>(0) |
| | PETS, D10<br>- Marginal external costs | 46-92 |
| | PETS, D9, D10, D11a<br>- Marginal external costs<br>- Corridor results, | (224 - 818) |
| | INFRAS/IWW, 2000<br>- Corridor results | (595 - 1460) |

1) (off-peak)

Source: TRL, vol. 2, p. 40 - Table 29.

UNITE case studies from Sweden estimated marginal external accident costs of 32 per 1000 passages at level crossings with roads. These figures are of course not directly comparable with the figures presented in the tables above.

Again, the scope and specification of the studies differs making comparisons very problematic. The estimates vary substantially, which stresses that the marginal external costs are heavily dependent on the specific area of rail transport. However, again the different methodologies applied (INFRAS/IWW vs. RECORDIT/PETS) probably also influence the results.

As reflected in the table above, the INFRAS/IWW study also includes estimates for rail transport (for Denmark the average cost for passenger transport is 240 per 1000 vkm). The cost is however considered negligible because it is found that 97% of all accidents involving trains are caused by road users. Following the methodology of INFRAS/IWW these costs are therefore the responsibility of road users.

### 6.4.3 Short sea shipping

Studies investigating the marginal external accident costs of short sea shipping are very limited, which is also reflected in the reviewed studies. Hence, in the TRL study it is stated that no estimates for marginal accident costs for Maritime transport are available in the literature (TRL, vol. 2, p. 41). One basic problem seems to be that data needed for estimation of the costs is simple not available (TRL, vol. 1, p. 153).

In the TRL study average cost estimates for the main port of Antwerp for different types of vessels are estimated (TRL, vol. 3, p. 89). However, the calculated costs only include accidents at berth and at storage area and are therefore marginal *port* accident costs rather than accident costs for short sea shipping.

In INFRAS/IWW the marginal external accident costs for waterborne freight transport are 0 as it is found that the accident risks are negligible.

### 6.4.4 Aviation

In the TRL study two general estimates for external accident costs have been identified for air transport:

- IWW/INFRAS (2000): average costs: 0.64 (1998) per 1,000 passenger kilometres (equal to 50 per 1,000 vkm (own calculation using the average number of passenger per flight)). IWW/INFRAS (2000) used the average cost estimate in the absence of any scientific research on marginal accident costs of air transport.
- PETS, D7 (1998): marginal costs: 35 per 1000 vkm.

Both studies' estimates are based on the same cost components, i.e. human costs based on WTP techniques, materiel costs, net lost production, medical care, and administrative costs.

In the TRL study it is stated:

> "On balance, we believe that the result based on the PETS(1998) estimate gives a more reliable picture of marginal external accident costs for this case study as it applies a fatality risk factor for aircraft accidents derived for the UK and the calculation is based on a bottom up approach rather than the top-down approach leading to very average values used from IWW/INFRAS (2000)".

As discussed earlier it is necessary to deduct internal/private costs from the marginal accident costs to derive external marginal accident costs. In PETS (1998) percentages estimated by the Swedish National Road Administration for the amount of costs covered by insurance or the user itself (for road accidents) are applied. This implies that 80% of material losses in fatal and severe accidents and 40% in light accidents have to be covered by the rest of the society and are external costs.

As reflected in the table above, the INFRAS/IWW study also includes estimates for air transport (for Denmark the average cost for passenger transport is 54 per 1000 vkm).

### 6.4.5 Comparison with existing Danish estimates

**Road transport**
In Trafikministeriet(1997) the marginal external accident costs have been estimated for road transport. These estimates are considered to be the best marginal external cost estimates available from Danish studies.

The costs have been estimated with a methodology which in principle follows the approach recommended by HLG. The following setup is used:

- Average risk of injury is for each transport mode split on internal (occupant in same mode) and external risk (occupants in other modes) is calculated;
- Accident costs are allocated on victim and injurer in accordance with the internal and external accident risk;
- The risk a transport user exposes on him self is considered internal;
- A marginal accident elasticity $\alpha = 0.6$ has been applied for all modes based on empirically estimated relationships between the number of accidents (U) and the traffic volume (N) on the form: $U = \beta Q^{\alpha}$.
  An average of 0.6 for different road types was found for $\alpha$. Hence, the risk elasticity $E_r = \alpha - 1 = -0.4$ can be derived;
- Low and high valuation estimates applied. The low estimates based on official values from "*Trafikøkonomiske Enhedspriser*". In the high estimate the human value based on a Danish WTP study, Kidholm(1995);
- Property damage costs were considered as internalised.

The study presents marginal external cost estimates split on vehicle types for urban and rural areas.

*Table 6.18 Marginal external accident costs for road transport in Denmark - split on vehicle type for urban and rural areas (1993)*

| /1000 vkm | Car | LGV | HGV | Bus | Moped |
|---|---|---|---|---|---|
| Rural roads | 5.4 - 14.8 | 10.7 - 29.5 | 38.9 - 114.1 | 18.8 - 53.7 | 10.7 - 14.8 |
| Urban roads | 9.4 - 29.5 | 13.4 - 44.3 | 52.3 - 162.4 | 28.2 - 89.9 | 13.4 - 21.5 |
| Average | 6.7 - 20.1 | 12.1 - 34.9 | 43.0 - 127.5 | 24.2 - 72.5 | 12.1 - 20.1 |

Source: Trafikministeriet(1997)

It should be noted that the study calculated marginal external accident costs from average accident costs as $MC^e = a\ AC = 0.6\ AC$, based on the relationship between marginal and average accident risk: *dr/dQ = a r*. This holds for the marginal accident costs (*MC*), but not for the marginal *external* accident costs ($MC^e$). This is because the internal part increases with the full average costs whereas the external part increases with less than *a AC* because of the accident risk reduction for other vehicles. Hence, the approach taken in the Danish study slightly overestimates the marginal accident costs[74].

The above estimates are comparable to the estimates for road transport from the reviewed studies presented in above. The estimates seem to be in the same order of magnitude as the costs from PETS and SIKA as presented in the TRL study, which are based on a similar approach. The RECORDIT estimate for HGVs (63  /1000vkm for motorways) can not be compared directly as it is only estimated for motorways.

Not surprisingly the estimates from Trafikministeriet(1997) are very different from the estimates presented in INFRAS/IWW. Again, the difference is most likely due to the fundamental difference in the methodology applied, e.g. own risk considered as an external cost and marginal cost equal average cost in INFRAS/IWW.

**Other modes of transport**

In Trafikministeriet(1997a) the marginal external costs have been estimated for rail, shipping and air transport using a methodology similar to the one applied for roads in Trafikministeriet(1997). However, the study *does not* include estimates of *risk elasticities* implicitly assuming risk elasticities equal to zero or marginal costs equal to average costs (or accident elasticity equal to 1).

The marginal external costs for shipping have been estimated as 0 for both passenger and freight transport as only 2 accidents with 2 fatalities have been reported in 12 years. Further, also the marginal external costs of air transport are considered negligible as flight accidents are almost always sole accidents (internal risk) and because it is assumed that risk do not change with the number of flight kilometres. However, this conclusion is questionable as the expected accident costs to the rest of society when the user exposes him self to risk (mainly medical costs) are neglected and might be significant.

The marginal external accident costs for rails have been estimated based on a detailed analysis of accidents involving trains. The internal and external risks of being killed, severely or lightly injured have been calculated and multiplied with the external unit costs for external (a+b+c) and internal (c) accidents to give the marginal external costs per kilometre. The results are presented in the table below.

[74] The degree of over-estimation will differ across modes as it depends on the distribution of the risks and damages on the modes and the share c of costs to society to total costs per accident. Roughly estimated the over-estimation probably amounts to about 20% on average.

*Table 6.19 Marginal external accident costs of rail (high speed train sections)*

| **Rail transport** | DKK per 1000 vkm |
|---|---|
| Passenger | 100 |
| Freight | 30 |

Source: Trafikministeriet(1997): *Miljømodel for "Højhastighedstog-modellen*"
Note: In 1993-prices. Calculated to reflect the costs for high speed trains in year 2010

Unfortunately, the marginal external costs have been calculated to reflect the costs for high speed trains in year 2010, which means that accidents happening in crossings have not been accounted for, as it has been assumed that crossing will not exists on the high speed sections in 2010. This assumption is not appropriate for estimating the external accident costs on rail today. Therefore an alternative calculation has been made including these accidents.

Accidents in crossings actually constitute the vast majority of the total accidents, which is reflected in table below. As for Table 6.19 the calculations are made by allocating accidents on freight and passenger trains according to train kilometres not taking into account differences in accident risks across line sections and time of day. This simplification probably contributes to overestimation of the costs for freight trains because most of the trains run at night when the level of road traffic is low and the risk of accident crossing therefore might be accordingly smaller.

*Table 6.20 Marginal external accident costs of rail.*

| | DKK per 1000 vkm |
|---|---|
| **Passenger trains** | 654 |
| **Freight trains** | 260 |

Source: Own calculation based on Trafikministeriet, 1997: *Miljømodel for "Højhastighedstog-modellen*".
Note: 1993-prices.

## 6.5 Summary: Critical assessment

The marginal external accident costs depend on the *marginal accident risk*, the *valuation* of accidents and the *external element* of the costs. Data exists for each of the three components, but the data are not well developed in all areas. This is reflected in the reviewed studies.

*Table 6.21 Overview of reviewed studies*

| Issue | UNITE | RECORDIT | TRL | INFRAS/IWW |
|---|---|---|---|---|
| **Scope and coverage** | *Passenger and freight*: All modes No estimates published yet | *Passenger*: Not included *Freight*: Road, rail and short sea transport | *Passenger*: All modes *Freight*: All modes | *Passenger*: Road, rail and air *Freight*: Road, rail and air |
| **Recommended overall methodology** | HLG | HLG | HLG | Top-down approach. Total external costs allocated according to responsibility |
| **Accident risk and risk elasticities** | Country statistics on accidents to reflect country differences No specific risk elasticity estimates | Country statistics on accidents to reflect country differences PETS risk elasticities | Country statistics on accidents to reflect country differences PETS risk elasticities | Accidents allocated according to involved parties' responsibility Only average accident risk considered for aviation and rail |
| **Monetary valuation** | WTP | WTP | WTP | WTP |
| **Internal vs. external costs** | Own risk, property damage and other costs covered by insurance considered internal | Own risk, property damage and other costs covered by insurance considered internal | Own risk and property damage considered internal | Property damage and other costs covered by insurance considered internal Own risk implicitly included as external costs |

Note: ExternE not considered as the it do not include transport accidents externalities

Regarding the availability of cost estimates by mode, the literature review shows that there is a big difference between road, rail and air transport and short sea shipping. In general, road transport is by far better investigated than any of the other modes of transport. This is clear from the valuation of accidents, which consistently updated and published for road accidents across European countries, while this is not the case for the other modes of transport. As a consequence often the valuation estimates of accidents developed for road transport victims are used for victims of all other modes.

The literature review shows that for air transport and short sea shipping only a very small number of studies provide data and this data is recommended not to be generalised (TRL, vol. 1, page 22).

### 6.5.1 Strengths and weaknesses of the studies

The table below presents an overview of strengths and weaknesses of reviewed studies. The main criterion for the assessment of strengths and weaknesses of the reviewed studies has been the importance in relation to valuation of Danish marginal external accident costs.

*Table 6.22 Overview of strengths and weaknesses of the studies*

| Issue | UNITE | RECORDIT | TRL | INFRAS/IWW |
|---|---|---|---|---|
| **Strengths** | Include methodological discussions for all modes<br>Recommends consistent overall methodology<br>Consistent valuation approach | Recommends consistent overall methodology<br>Country specific estimates available for road and rail freight transport<br>Consistent valuation approach | Considers all modes for both passenger and freight transport<br>Recommends consistent overall methodology<br>Consistent valuation approach | Considers all modes for both passenger and freight transport<br>Country specific estimates available for all modes<br>Consistent valuation approach |
| **Weaknesses** | No estimates of marginal costs published yet<br>Weak recommendations regarding risk elasticities | Do not consider passenger transport<br>Insufficient evidence of applied risk elasticities | Cost estimate recommendations are unclear<br>Weak recommendations regarding risk elasticities | Inconsistent overall approach.<br>Do not consider own risk as internal.<br>Do not calculate marginal costs for all modes and suggests that marginal equal average cost |

Note: ExternE not considered as the it do not include transport accidents externalities

The issue of calculating the marginal external accident costs is complicated. The risk elasticity approach proposed by the High Level Group and adopted in UNITE, RECORDIT and TRL have several strengths:

- It is applicable to all modes;
- It differentiates between internal and external costs in a consistent manner;
- It allows for differentiation of the risk, e.g. the risk a user imposes on himself, on others using the same mode, and on other modes (which is needed because the external element vary with the risk type);
- The way the risk varies with additional traffic (the risk elasticity) is taken into account.

The accident risk differs between different vehicle categories and, even more important, the proportion of person injured within the vehicle to persons injured outside the vehicle will be dependent on vehicle type. The lighter vehicle types, as motorcycles, generate the highest risk to the occupants themselves (r) while the heavy vehicle types, as buses, generate the main risk for non-occupants (r'). Thus, it is very important to apply a methodological framework which differentiates between the risks for different vehicle categories and provides a sound estimate of the internal risk of transport users.

By applying a top-down approach where costs are allocated according to the responsibility of the involved parties, the INFRAS/IWW approach does not take account of the fact that the user internalises in his decision the risk he exposes himself to. The approach entails that even though the risk that motorcyclist's imposes on other transport users is small the external costs are very high, since motorcyclists are often involved and responsible for accidents.

Accepting the judgment behind the general welfare economic assumption about rationality of agents, the INFRAS/IWW approach will overestimate the external accident costs, especially for motorcycles and cars where the risk on occupants themselves are high.

### 6.5.2 Transferability of results to DK

Due to huge differences in the accident risks for European countries, it is recommended *not to transfer* EU average estimates or country/corridor specific marginal external accident costs per vehicle kilometre to other countries. Furthermore, some variations of the external material costs (e.g. administrative costs, medical costs, production loss) can be observed between the countries. This is also a reason for country specific calculations of marginal external accident costs.

This recommendation is in line with the recommendations of the reviewed studies, e.g. RECORDIT, D1, p. 178:

> "It is widely accepted, that relevant accident externality charges should be estimated for each Member State using accident risk data and accident cost figures in its components".

The reviewed studies include estimates, which have been calculated specifically for Denmark. However, often the accident risks as well as the valuation of accidents have been partly based on generic EU data or on rough assumptions about the conditions in Denmark. Therefore, it is recommended only to adopt these figures after a thorough critical review.

**An ideal approach**
Instead of transferring EU average estimates or country/corridor specific estimates directly to Denmark an ideal approach of estimating the marginal external cost per vehicle kilometre has been outlined. The ideal approach is founded in the methodological framework proposed by HLG, which has also been adopted by RECORDIT (and UNITE). The ideal approach outlined below is based on recommendations from RECORDIT.

*Country specific risk data:*

- Risk (r) per vehicle kilometre for user of the specific mode
- Risk (r') per vehicle kilometre for users of other modes
- Elasticity of the risk ($E_r$) for user of the specific mode
- Elasticity of the risk ($E_{r'}$) for user of other modes

*Country specific cost data:*

- External material costs per accident (administrative costs, medical treatment costs and net production loss)
    - for road accidents

- for rail accidents
- for short sea shipping accidents
- for air transport

- The human value (based on the WTP approach)

If the information needed is not readily available for a specific country a more pragmatic approach have to be applied, in which issues are *generalised* by adapting information from other studies. However, there are some aspects where generalisation can not be recommended. Following UNITE (D3, p. 42) it is recommended *not* to transfer accident risk rates and economic input values of non-human/damage related costs.

### 6.5.3 Pragmatic approach for estimating the Danish costs

The reviewed studies do *not* support to generalise EU marginal external cost estimates basing Danish estimates of cost per vehicle km *completely* on estimates for other countries. However, it is acceptable to base Danish estimates *partially* on data from European studies in a pragmatic approach of estimating costs.

With only few minor differences the method used for calculating marginal external accident costs in Trafikministeriet(1997) is similar to the method proposed by the HLG. It is proposed to correct the methodology to fully reflect the recommendations of the HLG and to update the input data in the calculations. This implies that all data specified above is needed. However, it is foreseen that data for this can be made available Denmark based on the high quality Danish accident statistics.

**Risk elasticities**
A very broad estimate of the risk elasticity, 0.6 - 1 = -0.4, is available for Denmark and has been used in the existing estimates. However, elasticities of risk for users of the specific mode and other modes are not available for Denmark and estimates for other countries are scarce. Further, there seems to be consensus only to transfer estimates with great care because it relies on the critical assumption that road conditions and behaviour are very similar across countries. Nevertheless, as the empirical evidence is limited, all the reviewed studies except UNITE transfer risk elasticities from other studies.

The HLG report on accidents draws conclusions in relation to accident elasticities based on comprehensive literature survey. It is found that single-vehicle accidents probably have negative risk elasticity while multi-vehicle accidents show, on average, limited positive risk elasticity. On balance, it is concluded that it seems reasonable to assume that the risk elasticity is zero on interurban road links at low to moderate flow levels. This conclusion is supported by the practice among Road authorities, which usually employ zero risk elasticity on road-links (UK COBA, Swedish EVA). Further, it is stated that at high and even congested traffic flows the risk elasticity may still be positive. However, the recent UNITE case studies indicate negative risk elasticities.

**Human value**

An estimate of the human value for Denmark is available from Kidholm(1995). However, it has been found that the study probably overestimate the value due to a number of methodological problems, Vejdirektoratet(2002). Therefore it is proposed to use the European Standard value adjusted in accordance with real per capita income using PPP.

# 7 Infrastructure

## 7.1 Definition and scope

As opposed to the other types of external costs considered in this study infrastructure costs are characterised by being observable directly in monetary units, typically as accounted in budgets and accounts from road organisations responsible for the network. Hence, the problem of estimation of the marginal external infrastructure costs is not a matter of valuation of costs but rather of defining correctly the relevant cost categories and assessing the various vehicle types' contribution to these costs.

Another issue relates to the definition of *external* costs, which means costs which are not explicitly paid for and therefore not taken into account of the infrastructure users. For modes where the infrastructure is privately owned or by principle financed fully by user fees the infrastructure costs can be considered as fully *internalised*[75]. In this study this is assumed to be the case for air and sea transport. Rail and road transport also pay charges or taxes which can be considered as among other things payment for use of the infrastructure. But so far these charges and taxes are not calculated so as to reflect the actual infrastructure costs and we therefore regard these costs as external costs. Consequently the present structure of the charges and taxes has to be taken into account when establishing infrastructure charges so as to optimally internalise in an optimal way the full social cost of each mode of transport.

Two aspects of the nature of transport infrastructure give rise to crucial problems in relation to estimating the marginal infrastructure costs:

- Transport infrastructure involves substantial capital costs and has a typical service life of several decades;
- Transport infrastructure is typically used by several modes, vehicle types or operators (e.g. freight and passenger) leading to a need for allocation of the infrastructure costs.

### 7.1.1 Short run versus long run marginal infrastructure costs

The long service life of transport infrastructure means that the distinction between short and long run perspective is important with respect to assessing the marginal costs.

[75] This is in line with the costs of other products which are sold on a market, such as tyres or tomatoes, where the price is assumed to reflect the full social costs of their production and consumption. However, market imperfections such as monopoly can invalidate this viewpoint but this aspect is here considered to be out of the scope for assessing the external costs.

- **In the short term** the infrastructure is given and the capital costs laid down in the construction of the infrastructure can be considered as fixed, i.e. 'sunk costs' which are unavoidable. Hence, only costs related to repair, maintenance and operation of the infrastructure are variable in the short run. Further, some of these costs are necessary irrespectively of the level of traffic so that even only some of the variable costs are marginal in the meaning depending on change in the amount of traffic.

  Hence, two sub-categories should be distinguished among the variable costs:

  - Variable costs only vaguely related to traffic volume (lighting, snow clearance).
  - Variable cost directly varying with the level of traffic and can be attributed to vehicles (e.g. surface renewal).

  Only the second category is relevant for estimating the short run marginal costs of infrastructure use. These costs can be classified under broader categories such as maintenance and repairs, operation and some services.

- **In the long term**, it is possible to dimension the capacity of the infrastructure to the amount of traffic, historically by expanding the network along with the traffic growth. Hence, the capital costs are not fixed in the long run and should be included in the variable and marginal costs of infrastructure use. The long run marginal cost principle would therefore be charging the costs imposed by the extra traffic if the infrastructure is optimally adjusted to the new traffic level. But the other hand, this will lower the marginal congestion costs as the purpose of the expansion of the infrastructure is to reduce capacity problems.

From a theoretical point of view it could be argued that in an optimal situation short run marginal infrastructure costs, including scarcity and congestion costs, should equal the long run marginal infrastructure costs, including capital costs. However, for practical purposes it will be problematic to assume that a situation with long run optimal level of infrastructure is prevailing.

*Table 7.1: Short term vs. long term marginal costs*

| | **Short run marginal costs** | **Long run marginal costs** |
|---|---|---|
| Fixed cost (e.g. construction) | | ✓ |
| Variable costs only vaguely related to traffic | | ✓ |
| Variable costs varying with the level of traffic | ✓ | ✓ |
| Congestion and scarcity | ✓ | |

*The approach advocated by the White Papers of the European Commission is short run marginal cost pricing,* which is also the general recommendation from economic theory for an optimal ('first best') solution[76]. However, there is continuous debate and criticism toward this approach as it does not take into account (political) restrictions on financing possibilities for new infrastructure which gives substantial weight to the argument of full cost recovery charges.

Another problem is that short run marginal pricing in modes with publicly owned infrastructure (road and rail) creates a competitive advantage as compared to privately owned infrastructure (air and sea) which must charge long run marginal costs in other to finance the capital costs.

### 7.1.2 Delimitation of infrastructure costs

The HLG-report defines transport infrastructure as "the physical and organisational network, which allows movements between different locations", to which a basic service package is associated. This includes:

- the traffic network (road, tracks, etc)
- the traffic organisation and the control units

The main focus in the HLG-report is on the methodological principles and primarily for road and rail infrastructures. The marginal costs for infrastructure include the damage to infrastructure (such as maintenance of road surfaces and tracks and some repairs to bridges, noise walls and technical facilities) as well as the cost of services or other infrastructure operations. These typically differ between modes and depend on institutional backgrounds and organisation of the transport chain, e.g. the provision of electric energy for rail transport or parking facilities. About rail transport it is stated that rail infrastructure costs it is difficult to distinguish between the costs of tracks in the narrow sense and those related to other facilities such as stations and freight terminals[77]. Energy provision is specific to the railways and the HLG suggests that if energy is provided by the infrastructure operator, the costs should be included as short run marginal costs.

Traditionally, national studies of infrastructure costs have put more emphasis into allocation of all variable costs on vehicle types, i.e. an average costs rather than a marginal cost approach. The first step in relation to estimation of marginal infrastructure costs is, however, to determine what part of the costs which actually depend on the amount of traffic.

Most (recent) marginal cost estimations have come to the conclusion primarily repair and renewal costs which are relevant. Winter maintenance, police costs etc. are less correlated with traffic volumes and should therefore only be allo-

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[76] That is: efficient use of the given infrastructure provided that the optimal prices can actually be charged and that any equity objectives in terms of fair payments from groups of infrastructure users can be obtained by other means (see Chapter 2).

[77] In relation to the cost recovery issue the HLG recommends using a Two Part Tariffs with a fixed rate for "entry" or annual use and a variable charge based on marginal costs.

cated on vehicles in average costs accounts. This has significant influence on the relative size of the marginal costs of various vehicle types.

According to HLG, the short-run marginal costs should be derived from actual occurring costs rather than modelling approaches. This will of course lead to some arbitrariness as the annual costs are also influenced by available budgets which in turn are determined by political priorities. If maintenance is neglected marginal infrastructure costs based on actual maintenance costs will be too low which justifies modification of maintenance costs derived from budgets. It is therefore more robust to look at the average yearly costs over a longer period of time.

### 7.1.3 Cost allocation and cost drivers

At the general level, the following costs drivers, and the proxy indicators to be used if data is not available, appear from the HLG (rail- and road-transport) and UNITE (rail-, road-, maritime-, air-transport) conclusions.

*Table 7.2 Main costs drivers and proxy by mode*

| Mode | Main determinant cost drivers | Proxy indicator |
|---|---|---|
| **Road transport** | • Axle weight | • Vehicle type categories |
| **Rail transport** | • Train weight<br>• Speed | • Freight/passenger/wagon load/combined transport/high speed/inter-city/regional/urban |
| **Air transport** | • Passenger/Freight<br>• Maximum take-off weight (MTOW)<br>• Maximum landing weight (MLW)<br>• Type of infrastructure elements<br>• Climate conditions | |
| **Maritime Transport** | • Geometry of the basin and its construction | |

Cost allocation on vehicle types is in fact a very sensitive issue. It often contains a somewhat arbitrary aspect in actual applications and is clearly an important source of uncertainty for the derived marginal costs.

DIWet.al.(1998) commissioned by EU DG-VII surveyed national calculations of average and marginal infrastructure costs in European countries. For road transport it is common to apply three types of indicators in the allocation of costs to vehicles:

- *Vehicle kilometres* with equal weight to all vehicle types;
- *PCU kilometres* (passenger car unit) with weights depending on the size of the vehicles; and
- *Axle -load kilometres*, e.g. based on the AASHO-factors ($4^{th}$ power rule)[78].

Concerning wear and tear of rail infrastructure some studies indicate a rise in the damage of third power in axle load as opposed to the factor 4 for road surfaces.

## 7.2 Cost per vehicle kilometre

For infrastructure, the categories that have different costs are road type (motorway, national, state, regional roads, and urban streets) and track speed and formation (e.g. number of sleepers per 100m) or existing rail categories (main/minor lines, electrified, single/double), airport type (national, international), port type (main, national, regional).

A distinction between urban and rural is not relevant as this is more adequately encompassed in the type of infrastructure. There is no significant difference between peak/off-peak, i.e. the curve is believed to be approximately linear in traffic volumes leading to constant marginal costs.

**EXTERNE and INFRAS/IWW**
Neither ExternE nor INFRAS/IWW considers infrastructure costs.

**TRL**
For road transport the TRL study refers primarily to the DIW et.al.(1998) for the European Commission which is widely recognised as the first study developing a common framework for infrastructure cost calculations for Heavy Goods Vehicles, and it is still considered as a key source regarding infrastructure costs. The study compiled data for and presented values for all EU-15 countries for marginal as well as average infrastructure costs. The estimates for HGV are presented in Figure 7.1 below.

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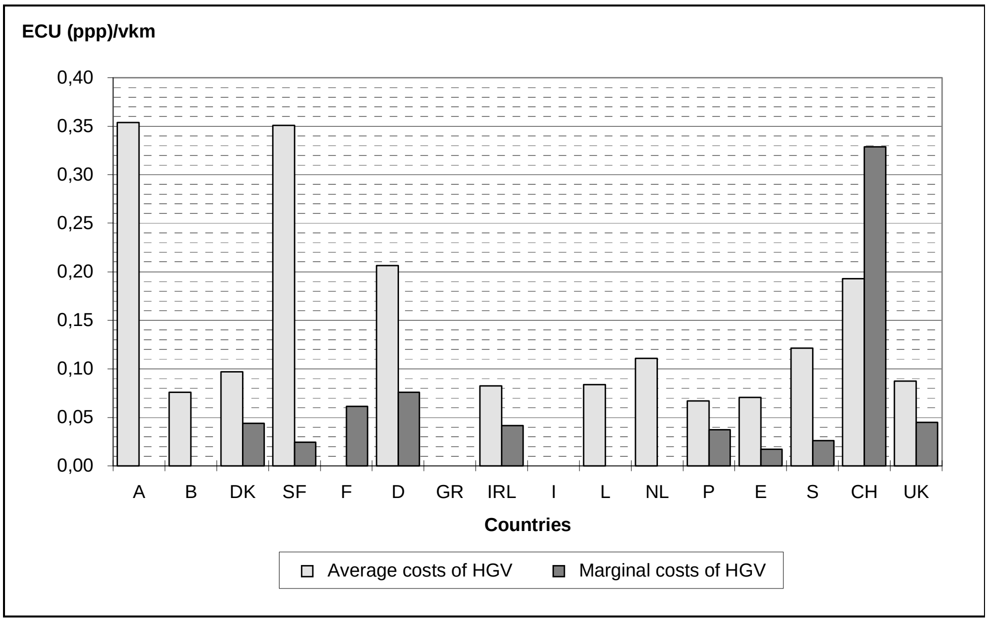
[78] American Association of State Highways Officials.

*Figure 7.1 Average and marginal costs of HGV for roads in Europe 1994*




Source: DIW et.al. (1998) Chapter 4, Figure 18.

The table demonstrates that marginal costs are significantly lower than average costs because only a fraction of the costs depends on the actual traffic on the roads. Further, it appears that variations across countries are very wide, which is considered to be partly due to differences in the methods applied and partly to differences in topographic and weather conditions along with different maintenance strategies across road administrations in the countries. The marginal infrastructure costs calculated for Denmark are about the middle of the range looking apart from the extreme value for Switzerland.

The DIW-study also estimated these costs per kilometre for other road modes. An overview of the range of values across European countries is reproduced from the TRL-study in Table 3.1 below. In addition to the DIW-values it also compares with British values from the recent study Sansom et.al.(2001).

*Table 7.3 Review of marginal road infrastructure costs in 1998 EURO-cent/vkm*

| **Vehicle Type** | **EU** DIW at al (1998) | **UK** Sansom et.al. (2001) |
|---|---|---|
| Passenger cars | 0.02 – 0.14 | 0.074 - 0.103 |
| Buses | 0.17 – 5.07 | 7.691 -10.0 |
| Light Goods vehicles (<3.5 t GVW) | 0.02 – 0.17 | 0.088 - 0.118 |
| Heavy Goods vehicles (>3.5 t GVW) | 1.73 – 5.24 | 11.103 - 14.441 |

Source: TRL(2001) vol. 2 p. 17, cited from DIW et.al. (1998) and Sansom et al.(2001).

The British estimates are somewhat higher than DIW for HGVs and Buses but encompassed in the DIW-interval for passenger cars and LGVs.

TRL values for rail is based on IWW calculations of long run marginal maintenance and operation costs, i.e. including renewal but not investments in extensions or improvements of the network. The figures obviously do not include costs of propulsion power for electric trains as the figures are identical for diesel and electric trains. The IWW-estimates are compared with figures from Sansom et.al.(2001).

*Table 7.4 Review of marginal rail infrastructure costs in Euro 1998/train-km*

| | **Operation Type** | **IWW[1)]** | | **UK** |
|---|---|---|---|---|
| | | per gross-tkm | per trainkm | per trainkm |
| **Passenger** | High speed | 0,0029 | 2.70 | 1.641 |
| | Fast train | 0,0029 | 1.45 | - |
| | Regional train | 0,0025 | 0.95 | 0.219 |
| | Local train | 0,0023 | 0.35 | 0.597 [2)] |
| **Freight** | Light, low speed | 0,0026 | 0.91 | - |
| | Heavy, express | 0,0035 | 3.50 | - |
| | Bulk | | - | 2.632 |

1) IWW calculations based on long term marginal maintenance and operation costs as wear and tear costs are extremely variable for rail transport.

2) Sansom et.al.(2001).

3) London commuter train.

The main cost driver is gross ton kilometres which for marginal rail infrastructure costs. The IWW-results in Table 7.4 indicates that these values do not vary much across train types whereas the costs per train kilometre vary due to variations in the typical weight of different train types. The British and IWW figures are in the same order of magnitude.

**RECORDIT**

Following the recommendations of the HLG-report, RECORDIT focus on short run marginal cost and exclude capital costs for new investment, overhead costs).

Originally, infrastructure costs were not considered as a priority topic in RECORDIT. Estimates were produced based on the DIW-study and the continuation in Link et.al.(1999). The costs of intermodal freight terminals etc. are analysed in RECORDIT. RECORDIT D6 presented the marginal costs per load unit FEU for intermodal transports using combinations of road, rail, inland waterways or sea. Different weights of loading units or different weights of the same loading unit were not taken into account. As acknowledge by RECORDIT this does not give an accurate picture of the wear and tear of the infrastructure, since wear and tear is very dependent on the weight of the vehicle. In addition, some of the estimates, including the Danish figures[79], were found to be much too high as compared with the rest of the countries.

Concerning the DIW-study's estimate for Denmark the values for articulated trucks and lorries with trailers are very high whereas the value for rigid trucks is very small. However, the latter includes all vehicles above 3 tons which includes practically all light good vehicles <3.5 ton in Denmark. Hence, considering that the Danish average value for all trucks is about average (see Figure 7.1) it seems that the main reason is related to confusion about definitions of truck types with regard to weight which is crucial to the strong non-linearity in the axel weight wear functions.

In light of the very deviating figure for certain countries RECORDIT produced corrected values based on comparison with the other countries using now values per vehicle kilometre for rigid trucks (10 t) and articulated trucks (40 t). As a general rule the following criteria have been used:

- The marginal costs of articulated vehicles have been estimated to be about twice the costs of rigid vehicles.
- The marginal costs for other roads have been estimated to be in the range of about twice the costs of motorways.

The estimated values for Denmark which are close to the average of the available values for other EU-countries, are presented in Table 7.5.

*Table 7.5 RECORDIT estimates for marginal infrastructure costs for HGV. EURO-cents per vehicle kilometre. 2000.*

| EURO-cents per vkm<br>**Road type** | **Rigid trucks**<br>(10 ton) | **Articulated trucks**<br>(40 ton) |
|---|---|---|
| Motorways | 3 | 5 |
| All roads/other roads | 6 | 10 |

Source: Information from TetraPlan.

**UNITE**

UNITE covers the same scope as the HLG report. To produce marginal infrastructure cost estimates UNITE applied two different methodological approaches:

- *The engineering approach* is a "bottom-up approach", which has traditionally been the approach to estimate infrastructure costs and also the one used in the DIW-study presented above. Annual marginal infrastructure costs are taken from road administrations accounts of cost items which are arguably dependent on the traffic volumes. These costs are allocated to vehicle types according to several indicators, most importantly axel load kilometres.

- *The econometric approach* is a "top down approach", where observed total maintenance and operation costs are the dependent variable and observed

[79] Also the figures for Switzerland and Austria were very high.

transport outputs (e.g. train km) are among the independent variables in a statistical analysis of the cost drivers of the infrastructure costs. Parameters can be derived from cross sectional analysis of cost data split in lines and line sections or time series analysis of more aggregate cost data or a combination (panel data). The parameters related to traffic volumes can be directly interpreted as marginal costs, or used to construct the total cost function. In this case the cost allocation is in principle straightforward if different vehicle types etc. have been included as parameters in the estimations. However, in actual applications multi-collinearity between vehicle types makes transformation input data into axel-load kilometres necessary. The main barrier for using this approach is that very good and detailed cost data are needed which are often not available at the required level of detail.

One purpose of the UNITE case studies are to evaluate the comparative advantages and disadvantages of the two approaches, which are both considered valid for infrastructure costs although the econometric method is preferred in principle. The econometric approach has rarely been applied other than for rail in the past. Purely marginal infrastructure costs have been investigated by Johansson and Nilsson(1998) for Swedish railways and Herry et al.(1993) for Austrian roads.

The econometric approach was applied to case studies in Germany, Switzerland, and Austria for roads, and in Sweden and Finland for rail. The engineering approach was only applied to roads in Sweden.

Preliminary results from UNITE case studies seems to indicate that the case studies estimating marginal road infrastructure costs by using an econometric approach clearly have to be seen as a first step showing somewhat contradictory results. Therefore, it is not recommended to transfer the results to other countries in general until additional research has been undertaken. The results appear from the table below:

*Table 7.6 Marginal cost estimates for road and rail infrastructure costs*

| Mode | Country | Mean | Trucks | Car |
|---|---|---|---|---|
| **Road** -cents/vkm | Germany[1)] | - | 0.05 - 2.70[a)] | - |
| | Austria[2)] | 0.16 | 2.17[b)] | 0.07[b)] |
| | Switzerland[3)] | 0.67 - 1.15 | 3.62 - 5.17 | 0.42 - 0.50 |
| | Sweden[4)] | - | 0.77 - 1.86 | - |
| | | **Mean** | **Main lines** | **Side lines** |
| **Rail** -cents/gross-tkm | Sweden[5)] | 0.013 | 0.0088 | 0.097 |
| | Finland[5)] | 0.017 | 0.029[c)] | 0.045[d)] |

1) Marginal renewal costs.
2) Marginal costs of maintenance and renewals.
3) Marginal costs of maintenance (operational and constructional) and upgrades & renewals. Calculated from the minimum and maximum values for all cost categories.
4) Marginal costs of renewals.
5) Marginal maintenance costs.
a) Marginal costs obtained from a model with the ratio between trucks and passenger cars where the AADT of passenger cars was fixed at the minimum and maximum observed value in the sample.
b) Based on log-linear regression model with vehicles-km of 2 vehicles classes. The model was statistically insignificant.
c) Refers to electrified lines.
d) Refers to non-electrified lines.
*Source*: UNITE D10 p. 69

The most successful applications of the econometric approach in UNITE has been to railways, Although it is not recommended to transfer cost estimates across countries because of significant country specific variations cost elasticities, i.e. MC/AC the ratio between marginal and average maintenance costs appear to be more consistent. The results indicate that less than 20% of rail track maintenance and renewal costs are variable with traffic levels. Similar results are obtained by the engineering approach in other countries.

Although the econometric approach is generally preferred the data difficulties are very often very problematic. Adequate sample size generally requires disaggregation of cost data on individual road or railway line sections which is typically not very reliable with today's available information. For both roads and rail the econometric approach shows a cost elasticity (ratio of marginal to average cost) less than one, which is in contrast with a cost elasticity of one from a full cost allocation approach.

### 7.2.2 Comparison with existing Danish estimates

The most recent analysis of the marginal infrastructure costs per vehicle kilometre is Trafikministeriet(1997). However, this study only considers road transport. It applies the method from Transportrådet(1995) which included both rail and road transport, both on the other hand only looked at freight transport. DØRS(1996) is referring to these two sources but has no figures for infrastructure costs for rail.

Both these, rather old, studies were concerned with *long run* rather than the *short run* marginal costs which is the prevailing recommendation for pricing purposes as discussed in Section 7.1.1. Hence, the Danish figures, which can be considered as "average costs" in the DIW terminology, should be significantly higher than the short run marginal cost estimates from the surveyed literature.

However, since COWI conducted the Trafikministeriet(1996) study it has been possible to extract from the spreadsheet which are more in line with the marginal short run costs per vehicle kilometre for road transport reported by DIW et.al.(1998) and RECORDIT. In accordance with the description of short run marginal costs in Trafikministeriet(1997) the following adjustments have been made to the existing figures:

- Only surface costs are dependent on traffic volumes;
- 40% of these are invariant to marginal traffic increases;
- 11% are added to adjust for inflation from 1993 to 1998.

The results are compared with the original figures as well as the DIW-figures reported in the TRL study:

*Table 7.7 Comparison of Danish and European estimates of marginal road infrastructure costs. 1998 EURO-cent/vkm*

| EURO-cents/vkm | **DK** Trafikministeriet(1997) | | **EU** DIW at al (1998) |
|---|---|---|---|
| **Vehicle Type** | Variable costs | Marginal costs | Marginal costs |
| Passenger cars | 2.5 | 0.15 | 0.02 – 0.14 |
| Buses | 6.4 | 0.82 | 0.17 – 5.07 |
| Light Goods vehicles | 3.3 | 0.16 | 0.02 – 0.17 |
| Heavy Goods vehicles | 9.6 | 2.96 | 1.73 – 5.24 |

Source: TRL(2001) vol. 2 p. 17, [Table 7.3].
Own calculations based on data behind Trafikministeriet(1997) p. 34.

Two findings about the Danish figures appear from the table above. Firstly, the short run marginal costs' share of the variable infrastructure costs varies from 5% for passenger cars to about one third for HGV. Secondly, the Danish figures are more or less within the range of the EU estimates with light vehicles being at the high end and the heavy vehicles well inside the range.

Finally, comparison with the RECORDIT estimates for HGVs for Denmark in Table 7.5 it seems that the estimate of approximately 3 EURO-cents per vehicle kilometre from Table 7.7 is somewhat lower. An overall average would be about 6 EURO-cent per vkm, roughly estimated.

## 7.3 Summary: Critical assessment

### 7.3.1 Overview of strengths and weaknesses of the studies

Compared to the other external costs estimation of marginal infrastructure costs should have the advantage that the issue of monetarisation is straight forward here because the damage costs appear directly in the operating and maintenance costs of the infrastructure supplier.

In spite of this current estimates of marginal infrastructure costs still seem to be subject to great uncertainties. The significant variations of values from actual applications in different countries seem to be primarily a matter of lack of consensus about which costs are actually allocated to traffic as marginal costs and of the functional form (the elasticities) for their dependency of traffic volumes.

The major obstacle for improvement of the knowledge about the marginal infrastructure costs appears to be the quality of the data which can be extracted from the available data sources. The accounts of infrastructure suppliers have traditionally not been focused on providing this kind of information for specific parts of the network at a sufficiently detailed level. Further, even if this is improved there will still be the problem that expenditures on maintenance and renewal to some extent lag several years behind the traffic that caused it. However, this problem should be possible to solve over time and the politically determined structural changes toward cost based infrastructure charges should facilitate this process.

This is in line with the HLG recommends that the approach should be based on actual costs adjusting these figures to certain circumstances and to use the possible approaches in parallel:

- In the short run, the pragmatic top-down approach should be used in order to estimate a cost figure
- Parallel to the pragmatic approach more work on cost function is required

Even if higher quality of cost data from infrastructure providers' accounts will be available the essential question remains how to allocate costs to heavy goods vehicles and other vehicles. The approach chosen here will be crucial for the results.

Because of the above mentioned reasons great uncertainties appear to be present in marginal cost estimates. There are significant variations across countries in the types of costs included and the allocation of costs on modes are not fully substantiated. Further, the pragmatic top-down approach assumes linear cost functions. In other word the marginal costs are constant, which is not supported by the available empirical evidence.

A substantial scope for methodological and empirical development of marginal infrastructure costs exists, as top-down and bottom up approaches have been rarely applied for the estimation road and rail. For airports and waterborne transport, relevant studies are non-existent (partly due to the limited ratio of marginal cost categories in overall costs).

### 7.3.2 Transferability of results to Denmark

Existing studies on infrastructure costs are difficult to transfer to other countries as there is a high dependency on the institutional background (level of privatisation in the infrastructure sector, financing principles, general transport policy). Further, because infrastructure costs as opposed to other external cost categories considered do not have to make use of estimated unit costs, figures from national accounts of infrastructure maintenance and operations is the natural first best starting point from estimating the marginal infrastructure costs.

However, knowledge about the relative importance of different vehicle categories' contribution to the wear of the infrastructure, should be transferable, - and has indeed been in the past. Also, due care has to be taken for the possible postponement of maintenance and renewal costs due to political priorities so that account do not reflect the actual accounts in the short run.

Further, for heavy good vehicles it is very important to take into account any differences in the definition of trucks, i.e. the weight classes included, and also differences in the composition of the vehicle fleet across countries.

# 8 Congestion

Congestion in transport occurs when the demand for transport in a given area at a specific time exceeds the supplied transport in the form of capacity of the infrastructure. The congestion takes different forms depending on the type of transport, i.e. the transport is scheduled or non-scheduled. No matter what type of transport the main effects of congestion are longer travel times and increased operation costs.

## 8.1 Definition and scope

With the above description of congestion the main costs associated with congestion are delay costs due to longer travel time and additional operating cost depending on speed and additional time. Other costs may origin from changes in emissions and accidents. None of these effects are included under congestion in the reviewed studies, but the effects of increasing traffic on accidents are included under section 6 of Accidents.

For congestion it is important to distinguish between internal and external costs. The distinguishing of the different effects depends on the mode of transport or rather if the transport is scheduled or non-scheduled. As an example of this INFRAS/IWW (2000) states that

> "External congestion costs are defined as the dead weight loss according to economic welfare theory. … This welfare-theoretical definition of external congestion costs implies that those means of transport, where the allocation of infrastructure is planned centrally are free of congestion. This means that congestion costs are only computed for road transport."

In other words, for those modes where a common authority assigns slots of infrastructure to different users there are no congestion costs. This applies to rail, air and waterborne modes. Instead one may speak of scarcity costs, which describe the lack of slots at specific times. E.g. RECORDIT (2000) describes how the scarcity costs of slots can be determined through auctioning or negotiations. These costs are assumed internalised through the payment for the slots. UNITE (UNITE D7, 2003) reports some values of time and a few delay values for some of these modes.

Consequently, only road traffic where the single driver chooses the time of departure himself may observe congestion costs. Another important discussion in relation to congestion costs is whether to use total, average or marginal costs. RECORDIT has summarised the differences as

> "Total congestion costs arise from an inefficient use of the existing infrastructure. They can only appear on means of transport where single users decide on the use of infrastructure. …
>
> Average congestion costs are equal to the difference between the value of the generalised costs of the actual speed in the situation of congestion and the value of the generalised costs of the reference free flow speed.
>
> Marginal congestion costs are equal to the extra money plus time costs imposed on all other vehicles by an addition of an extra vehicle to traffic flow. …
>
> The ratio of marginal to average costs strongly increases with the growing traffic density."

All studies agree on this definition and approach.

In Table 8.1 the types of congestion costs and the dimensions for the costs in the reviewed studies are reported.

*Table 8.1 Types of congestion cost and dimensions in the reviewed studies*

| | **INFRAS/IWW** | **RECORDIT** | **UNITE** |
|---|---|---|---|
| **Total** | country<br>vehicle type | | country |
| **Average** | country<br>vehicle type | | country<br>vehicle type<br>type of road<br>level of traffic |
| **Marginal** | vehicle type<br>type of road<br>level of traffic | vehicle type<br>type of road<br>level of traffic | vehicle type<br>type of road<br>level of traffic |

The differences in average and marginal costs are of special importance for congestion, since the external marginal congestion costs are rather small until the traffic reaches the capacity limit of the road. In this case, the external marginal congestion costs increase dramatically.

All studies agree on the approach to evaluate the effects of congestion however there are minor differences as to the details in the approach. In general the relation between amount of traffic and travel time is determined by using speed-flow curves for different types of road. This is described in more detail in section 8.2. The resulting delays are then transferred into congestion costs using values of time, which are described in section 8.3. The final costs are reported and compared in section 8.4. Finally, a critical assessment of the studies is carried out in section 8.5.

## 8.2 Physical measurement

The physical measurement includes a description of the methodology used to achieve the effects of congestion. In all, the effects can be summarised by time effects and cost effects. The time effects describe the additional travel time due to congestion whereas cost effects describe the additional operating costs due to congestion.

The High Level Group (1999)[80] describes that the ideal approach to measure the physical effects of congestion is a bottom-up approach based on a model, which is able to include delays on specific roads through speed-flow relationships as well as changes in behaviour due to congestion. These changes can e.g. be choice of another route or another departure time. The second best approach is to evaluate the speed-flow curves either for single roads or for selected areas without including the effects of changes in demand.

INFRAS/IWW and RECORDIT use such a bottom-up approach using the same speed-flow curves. In addition INFRAS/IWW includes the demand effects for inter-urban traffic through the VACLAV traffic model. UNITE takes on different approaches depending on the type of congestion cost. For the marginal congestion costs UNITE applies the same bottom-up approach as INFRAS/IWW and RECORDIT including demand effects.

In Table 8.2 some of the general assumptions of the different studies are gathered for an overview. Afterwards, the main principles of the almost identical approaches of the three studies are presented.

*Table 8.2 Types of congestion cost and dimensions in the reviewed studies*

| | INFRAS/IWW | RECORDIT | UNITE |
|---|---|---|---|
| Time effect | German speed-flow curve | German speed-flow curve | German speed-flow curve |
| Cost effect | indirectly | yes | yes |
| Traffic above capacity | marginal costs are constant | marginal costs are constant | marginal costs are constant |
| Marginal effect | MSC - PC | MSC - PC | MSC - MPC |
| Includes demand effects | yes | no | yes |

msc is short for marginal social cost, whereas pc is short for personal cost and mpc is short for marginal personal cost.

The approach for calculating physical effects is based on speed-flow curves. As INFRAS/IWW states

> "The shape of the speed-flow curves applied is strongly influencing marginal cost functions and consequently the resulting total congestion costs."

[80] Also referred to as Nash and Sansom (1999)

Despite this introductory remark all studies agree on using common speed-flow curves presented in the German investment plans[81] and in the High Level Group (1999). The chosen speed-flow curves have the form

$$V = c_0 + c_1 \cdot \exp\left(c_2 \cdot \left(Q_p + 2 * Q_G\right)\right)$$

where $Q_p$ and $Q_G$ are the amounts of passenger cars and heavy goods vehicles respectively. A factor of 2 PCU per heavy goods vehicle is applied. The constants $c_0$, $c_1$ and $c_2$ all depend on the type of road.

The problem with these curves is that they only apply until the capacity limit of the road is reached, and it is the situation just around this limit that is of interest to congestion costs. This is described in INFRAS/IWW as

> "When traffic demand is exceeding the road's capacity limit flows remain constant … Accordingly, marginal costs become zero under congested road conditions and hence the application of the social welfare theory is no longer possible. … It is decided to keep the external marginal costs constant when traffic flows exceed the maximum capacity."

The same assumption is applied in RECORDIT and UNITE.

Based on the speed flow curves the marginal and total additional time due to congestion are derived for different levels of traffic and for different types of roads. INFRAS/IWW uses the American LOS measure from Highway Capacity Manual to distinguish the different levels of traffic (with levels D, E and F having constant marginal congestion costs). In the end this is transferred into three levels of traffic named 'relaxed traffic', 'dense traffic' and 'congestion'. RECORDIT applies the same denomination and in this way it should be possible to compare the results of the different studies.

An important difference between INFRAS/IWW and RECORDIT is that INFRAS/IWW includes effects of changes in demand, e.g. change of route and departure time through the German traffic model VACLAV, whereas RECORDIT do not include these effects. Consequently, the effects of congestion and thereby the congestion costs may be higher in INFRAS/IWW than in RECORDIT. This will be discussed further in section 8.4.

The physical effects of congestion do also include additional operation costs. When described, the approach for these costs is very much in line with the approach for time costs. Instead of a speed-flow curve the calculation of effects are based on e.g. fuel cost curves.

[81] EWS (1997)

## 8.3 Cost per physical unit

The second part of deriving congestion costs is to transfer the physical effects measured in time into costs through values of time, which is the cost per physical unit for congestion.

The reviewed studies present a lot of different values of time for both passengers/tonnes of freight and vehicles. When evaluating congestion costs the additional time is measured per vehicle and it is therefore important to have values of time per vehicle. If these are not available values of time per passenger or per tonne of freight have to be recalculated based on average occupancy rate for the vehicles in the specific area or on the specific type of road.

For the purpose of calculating congestion costs it may be relevant to have values of time per vehicle hour differing by country, purpose and type of vehicle. In some cases the value of time is also differing for different levels of traffic, i.e. different values of time for 'normal' traffic and for 'congested' traffic. Where these numbers are found in the reviewed studies, the numbers are presented in Table 8.3. The actual costs per vehicle km will of course depend on the assumed occupancy rates for passenger vehicles. For freight vehicles values do not include time values for the freight but only for the vehicle and driver[82].

*Table 8.3 Values of time reported in studies compared to applied Danish values (all values measured in 1998 /vehicle hour)*

| EUR per vehicle hour | **INFRAS/ IWW** | | **UNITE** | | **Danish values[83]** |
|---|---|---|---|---|---|
| | EU | DK | EU | DK | DK |
| **Car** | **15.31** | **17.96** | **13.29** | **15.27** | **9.56** |
| - business | | | 26.54 | 30.49 | 29.44 |
| - commute | | | 7.79 | 8.95 | 7.90 |
| - leisure | | | 6.62 | 7.61 | 5.99 |
| **Motorcycle** | **6.70** | **8.29** | **12.20** | **14.02** | |
| - business | | | 25.34 | 29.12 | |
| - commute | | | 7.24 | 8.32 | |
| - leisure | | | 4.83 | 5.55 | |
| **Bus** | **102.90** | **131.81** | | | |
| - business | | | | | |
| - commute | | | | | |
| - leisure | | | | | |
| **LGV** | **21.26** | **27.85** | **45.96** | **52.81** | **24.68** |
| **HGV** | **39.22** | **51.56** | **49.41** | **56.77** | **34.79** |

[82] Some countries, e.g. Sweden and France, have estimated values of time for different commodity groups. The values typically increase with the average value of the goods.
[83] Recommended Danish values of time according to the Danish Road Directorate

No values of time are presented for RECORDIT, since they only present values of time per person-hour and no occupancy rates. However, when the reported numbers for Denmark are compared to the officially recommended values of time per person-hour, the values in RECORDIT are 10-25% lower than the recommended values. In UNITE(2001) the general values for EU are transferred to single countries according to the ratio of GDP per capita, which is adjusted for differences in purchasing power. For Denmark this ratio is 1.149, so the average value of time for car is 13.29   /veh.hour in EU and 15.27   /veh.hour in Denmark.

For the passengers UNITE is the study which is most in line with the officially recommended Danish values. For an average car the value of time per vehicle-hour is 60% higher in UNITE. The primary reason for this is that the assumed distribution on purposes in UNITE is much different from the assumed distribution in the Danish numbers.

For freight it is INFRAS/IWW, which is closest to the officially recommended Danish values of time. The values of time in INFRAS/IWW are in the same order as the recommended Danish values, whereas the values for UNITE is twice as high.

Finally, UNITE (2001) includes higher values of time for time spend in congested situations. The conservative methodology applied is that the congestion values of time for car, motorcycle and bus are 1.5 times the values of time reported in Table 8.3.

## 8.4 Cost per vehicle kilometre

Based on the results in 8.2 and 8.3, the congestion cost measured as cost per vehicle km is obtained by multiplying the physical effects by the value of time.

As presented in Table 8.1 some studies present average congestion costs and some present marginal congestion costs. Since it is the marginal congestion costs that are of interest in relation to EU, it is those costs that are reported in the tables below.

The physical effects differed for type of vehicle, level of congestion and type of road and so will the resulting marginal congestion costs presented here. INFRAS/IWW and RECORDIT agree that external marginal congestion costs for motorcycles, buses, LGV and HGV can be obtained by scaling the external marginal congestion costs for cars. The applied scales are different from those scales traditionally used to scale vehicles to Passenger Car Units (PCU). The applied scaling is presented in Table 8.4.

*Table 8.4 Scaling of costs for different types of vehicles*

| | INFRAS/ IWW | RECORDIT | UNITE | Ext.costs of Transport | Congestion |
|---|---|---|---|---|---|
| Motorcycle | 0.5 | n.a. | n.a. | n.a. | n.a. |
| Bus | 2.0 | n.a. | n.a. | 3.0 | n.a. |
| LGV | 1.5 | 1.5 | n.a. | 1.5 | n.a. |
| HGV | 2.5 | 2.5 | n.a. | 3.0 | n.a. |

The results of *External costs of Transport* are presented in COWI (1997), while the results of *Congestion* are presented in COWI et al. (2002).

The table shows that when scaling is reported RECORDIT agrees with INFRAS/IWW. Accordingly, it is sufficient to present the external marginal congestion costs for cars, since the remaining costs can be obtained from the scaling. When INFRAS/IWW reports marginal congestion costs for cars in the congested situation of 2.16 per vkm, the similar numbers for HGVs are 5.40 per vkm.

When external marginal congestion costs are reported in the three studies, INFRAS/IWW, RECORDIT and UNITE, they all refer to the three levels of traffic 'Relaxed', 'Dense' and 'Congested'. However, numbers in INFRAS/IWW are based on traffic in London, Paris, Brussels and Cologne, which are all heavily congested cities, while RECORDIT are based on inter-urban traffic primarily outside peak hours. For UNITE the case studies cover both congested cities e.g. Brussels and inter-urban traffic. Consequently, there may be differences in the levels of external marginal congestion costs for the different traffic levels even though they have a common denomination.

*Table 8.5 External marginal congestion costs for cars on motorways (1998 per vkm)*

| Traffic level | INFRAS/ IWW | RECORDIT | UNITE | Ext.costs of Transport | Congestion |
|---|---|---|---|---|---|
| Relaxed | 0.01 | 0.00 | 0.00 | | |
| Dense | 2.10 | 0.08 | | | |
| Congested | 2.16 | 0.20 | 0,14 | 0.02 | 0.24 |

The numbers from UNITE is presented in UNITE D7(2003).

Table 8.5 shows significant differences in the levels of congestion costs for the different studies. In general the numbers from INFRAS/IWW are higher than the numbers in RECORDIT and UNITE, but this might be expected from the geographical areas. Other explanations may be that INFRAS/IWW and UNITE include effects of changes in demand, which RECORDIT do not include. Also, INFRAS/IWW in general applies higher values of time than RECORDIT and UNITE. However, UNITE reports external marginal congestion costs for Brussels of 0.22 per vehicle km. This is much lower than the numbers reported in INFRAS/IWW even though Brussels is part of INFRAS/IWW and both studies include demand effects.

The last two columns in the table present some Danish results. The first number is based on a top-down approach, which generates much lower costs than INFRAS/IWW and RECORDIT. The second number is based on observed speed-flow curves for a Danish motorway. This value is in the same order as RECORDIT and UNITE but still much lower than INFRAS/IWW.

*Table 8.6 Marginal congestion costs for rural roads (1998 per vkm)*

| Traffic level | INFRAS/ IWW | RECORDIT | UNITE | Ext.costs of Transport | Congestion |
|---|---|---|---|---|---|
| Relaxed | 0.04 | 0.00 | 0.00 | | |
| Dense | 1.33 | 0.00 | | | |
| Congested | 2.07 | 0.03 | 0.16 | 0.02 | |

For rural roads the differences between INFRAS/IWW and RECORDIT are even larger than for motorways. Also, the values for congested traffic is much higher in UNITE compared to RECORDIT. The Danish studies only include a number from the top-down approach, which is expected to be much lower than the other numbers reported.

*Table 8.7 Marginal congestion costs for urban roads (1998 per vkm)*

| Traffic level | INFRAS/ IWW | RECORDIT | UNITE | Ext.costs of Transport | Congestion |
|---|---|---|---|---|---|
| Relaxed | 0.03 | 0.00 | | | |
| Dense | 2.88 | 0.06 | | | |
| Congested | 3.29 | 0.18 | 0.34-0.90 | 0.02 | 0.27-0.67 |

In Table 8.7 concerning urban roads the difference between INFRAS/IWW and RECORDIT is in the same order as for motorways. An important difference compared with the other results is that the numbers for INFRAS/IWW are not obtained by the VACLAV traffic model and therefore do not include all the demand effects in form of rerouting and change of departure time. It is not described in the available reports if e.g. demand elasticities are used instead. The UNITE case studies include a number of different case studies for urban roads, and the marginal congestion costs obtained in these studies vary significantly from city to city. Consequently, the numbers for UNITE is an interval raging from 0.34 per vkm reported for Brussels to 0.90 per vkm reported for Stuttgart. A number of other cities are included in the study, but no ranges for marginal external congestion costs are reported for these cities.

The general conclusion from these three tables is that there are significant differences in the level of congestion costs in INFRAS/IWW, RECORDIT and UNITE. Some of these differences may be explained by the geographical area and the number of effects included. RECORDIT only includes effects of the speed-flow curves whereas INFRAS/IWW and UNITE also includes effects of changes in demand. Another explanation for may be that INFRAS/IWW in general applies higher values of time than RECORDIT and UNITE.

With respect to Danish external marginal congestion costs, the numbers from COWI et.al.(2002) are in the same order as the numbers reported by RECORDIT and UNITE but much lower than the numbers in INFRAS/IWW, which are based on traffic in London, Paris, Brussels and Cologne.

## 8.5 Summary: Critical assessment

In the above four sections the methodology and results of some European studies concerning congestion costs have been reported. All of the reviewed studies agree on using a bottom-up approach to evaluate external marginal congestion costs. However, there are minor differences as reported in the different tables.

Even though INFRAS/IWW, RECORDIT and UNITE apply the same approach in general terms they obtain significantly different results with respect to marginal congestion costs for different types of roads, vehicle types and levels of congestion. Some of the difference may be explained by the extent to which demand effects are included and by differences in the values of time applied. Another part may be explained by the geographical areas and possible lack of consistence in the use of the terms 'relaxed', 'dense' and 'congested' traffic. These terms might have been defined relative to the traffic density on the road, but this does not seem likely.

All studies agree to use German speed flow curves throughout all countries in Europe even though INFRAS/IWW states that

> "The shape of the speed-flow curves applied is strongly influencing marginal cost functions and consequently the resulting total congestion costs."

It might be an excuse that it is a very time consuming task to apply local speed-flow curves to all roads or areas but it is a subject for evaluation with respect to the transferability of results from one area to another.

Furthermore, the studies assume that the external marginal congestion costs are constant when the amount of traffic exceeds the capacity of the road. The question regarding speed-flow curves around the capacity limit of the road is not an easy task to solve, but this question is the primary issue regarding conditions of congestion. Consequently, a correct description of these conditions is of major importance to the resulting external marginal congestion costs.

Finally, the comparison of results from the European studies and the existing Danish studies show significant differences in the levels of marginal congestion costs. However, the most recent Danish results are in the same order as the marginal congestion costs reported in RECORDIT and UNITE.

The Danish numbers may be updated applying relations from the European studies, whereas the level may be based on the experience from the most recent Danish study. This study is still ongoing and further results may be applied when available.

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