Danish Ministry of Transport

External Costs of Transport

3rd Report - Total external costs of road and rail transport in Denmark

July 2004

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1 Introduction

This report is the 3rd Report of the project

"*External Costs of Transport*".

The project is 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 has produced three outputs which are documented in three reports of which this is the second:

1st Report
The 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 have been reviewed. The 1st Report has also compare and critically reviewed the applied methodologies and assumptions in the European studies, and analysed how the results can be adequately applied to 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** 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 have been supplemented with additional sources to the extent necessary. This has primarily been the relevant 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:

- 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. The available information on traffic volumes allows calculations of total external costs for passenger and freight transport for road and rail modes. The results are presented as total costs and average costs per kilometre.

1.2 Report outline

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

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

These are externalities from transport for which methods for monetarisation of the impacts have been developed and actually applied. Congestion was not included in the 3rd Report because it has been assessed that the total costs of congestion in the network is not possible to estimate on the basis of the data which are available today.

Total external costs has not been calculated for air and sea transport because of lack of national figures for vehicle kilometres for these modes. However, this is not considered as critical because main focus has been on freight transport where air and sea modes play a minor role in the domestic traffic. Figures for passenger modes have also been included for road and rail transport.

The next chapter, Chapter 2, will present a few methodological issues and give an overview of the total external costs for each mode and per vehicle kilometre. These figures are simply calculated as the sum over the five individual types of externalities which will subsequently be dealt with in turn in the following Chapters 3 - 7. To keep the presentation condensed, these chapters assume that reader is familiar with the 1st and 2nd Report and will not give any general description of the external effects nor of the methodological approaches for their monetarisation which have been discussed in 1st Report.

2 Total external costs per vehicle km

This chapter presents the results in terms of the total external costs for road and rail transport with a split on modes. Figures are also presented as average costs per vehicle[1] kilometre. In the first section, some methodological aspects and interpretations of terms are discussed. For a more thorough discussion of the methodological framework the reader is referred to the 2nd Report.

2.1 Definition of costs

External costs
In 2nd Report *external* costs were 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 not included in this study. This is assumed to be the case for all vehicle operating costs as well as infrastructure costs for air and sea transport. For road and rail transport infrastructure users are also charges for use of the infrastructure. But for these modes the costs can not be considered as fully and directly paid by the infrastructure user by assumption. The argument is that no financial mechanisms ensure that the full costs, or their structure, are directly reflected in charges in terms of vignette, fuel taxes or railway infrastructure charges. Of course, this aspect has to be taken into account when comparing the external costs across mode and when fixing the structure and level of charges and taxes to be paid by each mode.

With regard to accident costs vehicle insurance payments are assumed to cover the property damage costs of accidents, which are, hence, considered as internalised. But also part of the accident costs related to fatalities and person injuries can be interpreted as internal costs. This study has adopted the approach that the internal costs comprise costs related to an infrastructure users' personal risk of entering into the traffic system. The implication of this approach is elaborated in Chapter 6.

For the last three types of external costs considered in this Report, air pollution, climate change and noise, the external costs are considered to be equal to the social costs because the share of the total costs from these environmental effects from the traffic which relates to the road user generating the effect is insignificant.

Total costs by mode
Calculation of the *total external costs by mode* requires as a first step a more precise definition. First of all, it is reasonable to assume that the different types of external costs are independent so that the total external costs can be achieved by summing across types of externalities. Secondly, for a certain externality it

[1] "Vehicle" refers here and in what follows as a common term for not just road vehicles but also different types of trains, ships and air crafts.

is possible to adopt (at least) two different interpretations of the total external costs of a given *mode*. It could be:

i. the reduction in the total external costs that would take place if all traffic of that mode was removed, *or*

ii. the share of the total external costs which should be allocated to that mode.

These two alternative definitions will only lead to same results if the total external cost function for a given externality is linear in traffic volume of each mode[2] and additive across modes. An alternative formulation of these criteria would be that the marginal costs should be equal to the average costs and that the contribution across modes would be equal apart from an equivalence factor on traffic volumes.

If external costs increase less than proportionately to traffic, so that the cost function is concave, the first definition implies that the sum of total costs of the individual modes will be less than total external costs of all modes, and vice versa if the costs function is convex. The second approach takes, on the other hand, as point of departure an *allocation* of the total costs for all modes so that the sum of the costs for individual modes will by definition equal the total costs of all modes. Therefore, the second of the two approaches is taken in this study. The drawback of this method is that the cost allocation does not necessarily have a very strict theoretical basis in all cases.

Only if the linearity assumption is fulfilled is it possible to calculate the total costs by a "bottom up" approach which simply multiply the marginal cost estimates derived in the 2nd Report with the total national traffic volumes for each mode. This approach has been taken for air pollution and climate change and also for rail accidents. In the latter case this approach was only defendable because the average costs per train kilometre were used as a proxy for the marginal costs in the 2nd Report. A top down approach has been used for noise, road accidents and infrastructure costs starting from national data on noise exposed dwellings, casualties from road accidents and aggregate accounts on yearly infrastructure costs.

An overview of the adopted approach for each type of external cost is presented in Table 2.1 below.

[2] Variations across different types of traffic (vehicle and road types, urbanisation, etc.) are included as long as the external cost function is linear within each of these types of traffic.

Table 2.1 Overview of calculation methods for each externality

Externality	Shape of cost function	Calculation approach
Air pollution	Linear[1)]: MC = AC	"Bottom up"
Climate change	Linear[2)]: MC = AC	"Bottom up"
Noise	Concave: MC < AC	"Top down"
Accidents Road	Concave: MC < AC	"Top down"
Rail	Linear[1)]: MC = AC	"Bottom up"
Infrastructure	Concave[3)]: MC < AC	"Top down"

1) Linear cost function by assumption. In reality the costs functions are not linear.
2) Linearity assumed because Danish transport emission can be considered as marginal changes in comparison with the global emissions.
3) Concavity only due to fixed costs. Variable costs assumed to be linear.

2.2 Results

Table 2.2 below shows that the total external costs of national road and rail transport in Denmark is estimated to about 40 billion DKK for 2000. The majority of these costs, 53%, are infrastructure costs which to some extent are accounted for by various charges for both road and rail transport. Noise and accident are the second and third most important external effect contributing with about 8 and 5 billion DKK (22% and 16%) respectively. Air pollution and climate change accounts for about equal shares of the remaining 10%[3]. Freight transport constitute about 10 billion DKK or 25% of the total external costs.

Table 2.2 Total external costs of road and rail modes. million DKK in 2000.

	Total external costs mill. DKK	
Total	**39,973**	100%
Air pollution	2,090	5%
Climate change	1,467	4%
Noise	8,881	22%
Accidents	6,575	16%
Infrastructure	20,958	53%
Freight (HGV, Van, Freight train)	10,198	26%
Passenger (car, bus, Passenger train)	29,775	74%

[3] For climate change it should be noted that the best estimate in this study is set to 120 DKK per ton CO_2 (with a low and high range from 40 to 1200 DKK) in accordance with the assumptions in behind the Government's Climate Strategy [See *Oplæg til klimastrategi for Danmark*, Finansministeriet 2003. [http://www.fm.dk/1024/visPublikationesForside.asp?artikelID=5354] . In previous analyses 300 DKK per ton has been used. For further details, see 2nd Report Chapter 4.

However, it should be noted that the unit costs applied for the damages are subject to very substantial uncertainties as described and quantified in 2nd Report. Hence, the uncertainties and reservations accentuated in 2nd Report should also be taken duly into account in the interpretation and use of the total amounts as well as the relative shares by type of externality and vehicle type.

Table 2.3 below presents the overall results for the total external costs for each vehicle type. In order to ease interpretation of the results the estimated total costs are also divided by the estimated total traffic volume for the vehicle type to obtain average costs per kilometre. Details about data input and method of calculation are given in the subsequent chapters.

Table 2.3 Overview by mode of total external costs and average external costs per kilometre for road and rail transport. DKK-2000 market prices.

	Road								**Rail**			
Mean of transport	**HGV**		**Van**		**Car**		**Bus**		**Freight**		**Passenger**	
Capacity:	16 t		1,5 t		4 p		40 p		349 t		316 p	
Total costs (million DKK)	**4.738**		**5.086**		**25.450**		**1.846**		**423**		**2.427**	
Air pollution	308		443		818		407		13		100	
Climate change	109		233		997		83		6		39	
Noise	453		1.271		6.496		412		83		166	
Accidents	1.135		1.111		4.033		208		8		81	
Infrastructure	2.733		2.028		13.106		736		313		2.040	
Traffic volumes (million vkm)	1.526		5.452		38.669		629		5		62	
Average costs (DKK per vkm)	**3,10**	100%	**0,93**	100%	**0,66**	100%	**2,94**	100%	**77,99**	100%	**38,85**	100%
Air pollution	0,20	7%	0,08	9%	0,02	3%	0,65	22%	2,38	3%	1,61	4%
Climate change	0,07	2%	0,04	5%	0,03	4%	0,13	4%	1,05	1%	0,63	2%
Noise	0,30	10%	0,23	25%	0,17	26%	0,65	22%	15,26	20%	2,66	7%
Accidents	0,74	24%	0,20	22%	0,10	16%	0,33	11%	1,50	2%	1,30	3%
Infrastructure	1,79	58%	0,37	40%	0,34	51%	1,17	40%	57,80	74%	32,67	84%

Several conclusions can be drawn from the table above from a comparison across modes:

- Passenger cars account for about 70% of total costs but are also the dominant mode in terms of traffic volumes. The costs of noise and accidents are estimated to be much higher than for air pollution and climate change.
- The total external costs of HGVs and Vans are in the same order of magnitude with about 5 billion DKK.
- For HGV the shares for accidents and infrastructure costs are higher than for other road vehicles. Air pollution and noise are relatively less important than for other road vehicles because much of the HGV traffic is in extra-urban areas.
- For buses air pollution is a significant share because a bigger share of the traffic volume is in urban areas.
- For rail traffic, freight and passenger, the total costs are dominated by the high infrastructure costs which constitutes 74% and 85% respectively.

However, a share of these costs is actually paid via rail infrastructure charges.

- Comparing the average costs per vehicle kilometre with the marginal costs presented in 2nd Report Table 2.3 shows that especially for infrastructure costs average costs are much higher than marginal costs. The difference is primarily caused by capital costs which are substantial but only weakly related to the amount of traffic. For noise marginal costs are between two third and three fourth of average costs, while the difference is less for accidents. For air pollution and climate change marginal and average costs are equal by assumptions.

- Comparison of external costs per passenger kilometre and ton kilometre will depend on average load factors but calculation is straight forward from the costs per vehicle kilometre when load factors are available. Comparing costs per passenger or ton kilometre assuming full capacity utilisation is often very problematic. Previous analysis has illustrated that load factors are also very sensitive to the specific conditions which makes it difficult to draw firm conclusions from comparisons across modes.

3 Air pollution

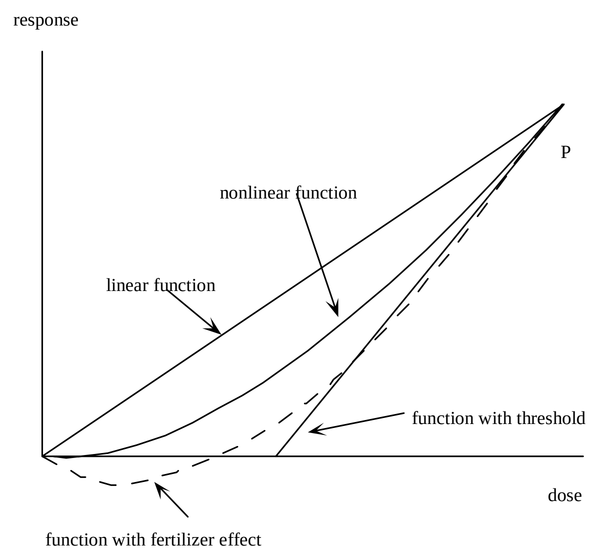
This chapter presents the accounts for the total external costs of air pollution for freight transport in Denmark.

3.1 Approach

The *total external air pollution costs* are calculated by applying a bottom up approach. This means that the *average* external unit costs of air pollution are multiplied with the traffic volume split on modes and other relevant levels of disaggregation. Hence, the approach requires calculation of the average external unit costs of air pollution.

It is assumed that the proposed values of marginal external costs from 2nd Report equals average external costs as this is part of the implicit assumption behind the calculations. As explained in 1st Report this is not necessarily correct. For instance, the dose-response functions may include a threshold as illustrated in the figure below. In such case the marginal costs do not equal the average costs.

Figure 3.1 Possible behaviours of dose-response functions



Another reason that marginal and the average costs are not equal is the chemical reaction between some pollutants, which implies non-linearity between emission reduction and exposure. The most complex situation is regarding ozone because both NO_x and HC contribute to the formation of ozone. Hence, for some NO_x/HC ratios an increase of NO_x emissions first leads to increasing ozone concentrations after passing a "hill" to decreasing ozone formations.

It is, however, beyond the scope of this project to take into account the possible differences between marginal and average costs of air pollution and it is therefore assumed that the marginal external costs equals average external costs.

3.2 Total external costs of air pollution

The calculated total costs of air pollution presented in the table below. The low and high values are obtained by applying the low and high values for the marginal costs, respectively (see 2nd Report Chapter 3). Hence, the uncertainty connected to the traffic volumes is not included in the estimates.

Table 3.1 Total external costs of air pollution from freight traffic, million DKK

		Urban			Extra-urban			Total		
Mode		Low	Central	High	Low	Central	High	Low	Central	High
Road										
HGV	diesel	30	**79**	388	105	**230**	988	135	**308**	1.377
Van	diesel	87	**267**	1.420	54	**136**	635	141	**403**	2.055
	petrol	7	**18**	82	11	**22**	90	18	**40**	172
Car	petrol	130	**324**	1.503	143	**287**	1.126	273	**611**	2.630
	diesel	48	**144**	758	25	**63**	288	74	**207**	1.047
Bus	diesel	126	**356**	1.822	23	**51**	222	149	**407**	2.044
Rail										
Freight	electr.	-	**-**	-	1	**3**	13	1	**3**	13
	diesel	0	**1**	6	4	**9**	39	4	**10**	45
Passenger	electr.	-	**-**	-	7	**17**	76	7	**17**	76
	diesel	6	**18**	90	29	**66**	289	35	**83**	379

For HGVs the total external costs of air pollution are approx. 308 MDKK annually. In comparison the air pollution costs of LGVs (vans) are approx. 443 MDKK annually. It is mainly the diesel vans that contribute to this figure due to the higher emission of particles from diesel vans than petrol vans. Hence, the costs from HGV and LGV are almost the same despite the fact that much more km are driven with LGVs than HGVs.

Rail freight traffic imposes much lower costs - approx. 13 MDKK annually - than freight traffic by road. In comparing these figures it should be kept in mind that the freight volumes transported by rail are much lower than the volumes transported by road.

The passenger transport costs are in general higher because of the higher traffic volumes for these vehicles.

4 Climate Change

This chapter presents the accounts for the total external costs of climate change for freight and passenger transport on roads and railways in Denmark.

4.1 Approach

The *total external climate change costs* are calculated by applying a bottom up approach. This means that the *average* external unit costs of climate change are multiplied with the traffic volume split on modes and other relevant levels of disaggregation. Hence, the approach requires calculation of the average external unit costs of climate change.

It is assumed that the proposed values of marginal external costs from 2nd Report equals average external costs. Given the very wide range of uncertainty in estimating the marginal costs, it is considered of a minor importance that the marginal cost estimate is applied in the assessment.

4.2 Total external costs of climate change

The calculated total costs of climate change for freight transport are presented in the table below. The low and high values are obtained by applying the low and high unit costs for the marginal costs, respectively. Hence, the uncertainty connected to the traffic volumes is not included in the estimates.

The unit costs applied are:

- Low value:	40 DKK per ton
- Central estimate:	120 DKK per ton
- High value:	1200 DKK per ton

as described in the 2nd Report Chapter 4.

Table 4.1 Total external costs of climate change from freight traffic, million DKK per year

		Urban			Extra-urban			Total		
Mode		Low	**Central**	High	Low	**Central**	High	Low	**Central**	High
Road										
HGV	diesel	5	**15**	151	31	**94**	937	36	**109**	1,088
Van	diesel	19	**57**	574	36	**108**	1,078	55	**165**	1,652
	petrol	8	**24**	236	15	**44**	443	23	**68**	679
Car	petrol	135	**404**	6,213	164	**493**	4,927	299	**896**	11,139
	diesel	15	**44**	439	19	**57**	666	34	**101**	1,105
Bus	diesel	19	**58**	582	8	**25**	249	28	**83**	830
Rail										
Freight	electr.	-	**-**	-	1	**3**	33	1	**3**	33
	diesel	0	**0**	1	1	**2**	23	1	**2**	24
Passenger	electr.	-	**0**	0	7	**20**	195	7	**20**	195
	diesel	1	**2**	19	6	**18**	176	7	**20**	195

For HGVs the total external costs of climate change are approx. 109 MDKK annually. In comparison, the clime change costs of LGVs (vans) are approx. 233 MDKK annually, hence twice as much. The main reason is that the LGVs constitute a larger share of traffic than the HGVs.

Freight traffic on rail imposes much lower costs - approx. 5 MDKK annually - than freight traffic by road. When comparing these figures it should be kept in mind that freight volumes transported by rail are much lower than volumes transported by road.

The higher values for passenger transport reflect the higher traffic volumes.

5 Noise

This chapter estimates the total costs of traffic noise from road and rail transport in Denmark and the freight transport share hereof is calculated. Air transport is not considered as no comprehensive mapping of the noise impacts from air traffic is available for Denmark. The noise nuisance from sea transport is considered to be negligible at the overall level. For simplicity independence between the noise costs between the road and rail network is assumed.

5.1 Road

5.1.1 Method

Total costs for road transport are calculated by a "top-down" approach where the total number of noise exposed dwellings is converted to monetary terms by a unit cost of noise. Next, the freight transport share of costs is calculated by using information on differences between noise emissions from vehicle types and allocating costs according to the share of total noise emissions. In practice, traffic volumes for other vehicles are converted into passenger car equivalents.

5.1.2 Noise exposure

The number of dwellings in Denmark exposed to road noise is presently being mapped. The mapping is carried out for the Danish Environmental Agency by TetraPlan, using the mapping software TPNoise. Final results are not available, but preliminary results for selected municipalities have been used in analyses as input to the Danish Noise Strategy 2003. The main mapping is assessed to cover about 65 % of the total number of dwellings exposed to noise over 65 dB, and the preliminary results based on the selected noise areas is assessed to cover about 60 % of such dwellings in Denmark in 2001. In order to reflect the total noise exposure, the selected noise areas have been scaled according to the type of urbanisation and a national number of noise exposed dwellings has been estimated.

The noise mapping is only carried out for urban areas. Therefore these data must be supplemented by data for rural areas. Data on rural areas are available from earlier mapping. The aggregated results are shown in the table below:

Table 5.1: Number of dwellings exposed to noise in Denmark, 200.1

	Total number of dwellings	Urban areas	Extra-urban areas
55-59 dB	342,086	302,399	39,687
60-64 dB	215,916	202,941	12,975
65-69 dB	124,859	121,058	3,801
70-74 dB	22,266	20,854	1,412
>= 75 dB	585	538	47
Total > 55 dB	705,713	647,791	57,922
Total > 65 dB	147,710	142,450	5,260

Source: TP-Noise (uraban areas) and Rambøll Nyvig (extra-urban areas).

As shown in the table, a total number of about 148,000 dwellings are exposed to noise levels above 65 dB, of which more than 95% are located in urban areas and only about 5,300 dwellings in extra-urban areas. A total of 706,000 dwellings are exposed to noises levels above 55 dB, of which about 92% are located in urban areas and about 60,000 dwellings in rural areas.

5.1.3 Total noise costs for road

The total SBT, split on urban and rural areas, can be derived from Table 5.1 , using the SBT formula:

$$\text{SBT-factor per dwelling} = 4.22^{\,0.1*(L-73)}$$

where L = noise level for the dwelling, measured in dB at the facade.

The results are shown in Table 5.2 below.

Table 5.2: Total SBT in Denmark in 2001, split on noise intervals

Noise interval	SBT urban	SBT extra-urban	Total SBT
55-59 dB	33,167	4,384	37,551
60-64 dB	44,827	2,657	47,484
65-69 dB	53,017	1,755	54,771
70-74 dB	16,878	1,150	18,027
>= 75 dB	915	80	995
I alt	148,803	10,026	158,828
> 65 dB	70,809	2,984	73,793

Source: Calculated based on Table 5.1.

As can be seen from the table, there is a total of 158,828 SBT for dwellings over 55 dB. The non-linearity (concavity) of the SBT-curve implies that the concentration of the noise nuisance as measured by SBT in urban areas is even more dominant (94%) than for the number of dwellings.

Next, the total yearly costs for road noise can be calculated by multiplying the figures for total SBT, urban and extra-urban respectively, by the unit cost of 54,350 DKK per year per SBT[4].

When multiplying the 158,828 units of SBT by the unit cost of 54.350 DKK per year per SBT, an estimate of total noise costs of around 8.6 billion DKK can be derived. For urban areas the corresponding figure is 8.1 billion DKK and for extra-urban areas 0.5 billion DKK.

Table 5.3: Total road noises costs (billion DKK)

billion DKK	**Urban**	**Extra-urban**	**Total**
Total road noise costs in Denmark	**8.1**	**0.5**	**8.6**

5.1.4 The freight transport share of total costs

Traffic volumes

The freight transport share of total costs depends on:

- freight transport's share of total traffic volumes
- the distribution of traffic volumes on urban and extra-urban traffic
- noise emission per kilometre for freight transport vehicles as compared to other vehicles.

The traffic volumes by vehicle types and urban/extra-urban traffic are shown in the table below:

Table 5.4: Distribution of traffic volumes. 2000.

mio. vkm **Vehicle type**	**Urban**	**Extra-urban**	**Total**
HGV	166	1,360	1,526
Van	1,936	3,516	5,452
Car	15,161	23,508	38,669
Bus	360	269	629
Total	**17,622**	**28,654**	**46,276**

Source: 2nd Report Appendix A.

[4] For explanation of the unit cost for SBT see 2nd Report Chapter 5.

Emission factors[5]

Emission factors for the individual vehicles are known from the work on the revision of the Nordic noise emission model and were presented in a paper at the Danish transport conference, Ålborg Trafikdage in 2002*: Støjudsendelse fra biler på vejnettet (Noise emissions from vehicles on the road infrastructure),* by Bent Andersen and Hans Bendtsen, Atkins Danmark. The paper describes a project on coordinated, national noise measurement, carried out by the Nordic road directorates in 1999-2000, in relation to an overall Nordic project of revision of the Nordic Emission model running from 1996-2001.

The starting point for calculations is the existing emission formula from the Nordic noise emission model for heavy and light vehicles. Next, corrections has been made in order to arrive at the emission factors for specific vehicle categories, based on the emission measurements from the above mentioned project.

The existing formulas for emissions from heavy and light vehicles are:

Heavy vehicles: $L_{AE} = 80.5 + 30 \log (v/50)$;

Light vehicles: $L_{AE} = 73.5 + 25 \log (v/50)$.

where v is the speed of the vehicle[6].

The average speed could be expected to be lower in urban areas than in rural areas. For urban areas is assumed an average speed of 50 km/h and for rural areas an average speed of 80 km/h is assumed. The formulas are interpreted as applicable for trucks and cars which are the predominant heavy and light vehicles, respectively. The correction factors for vans as compared to cars and buses as compared trucks are shown in the table below:

Table 5.5: Corrections for emission for van and bus (dB)

Speed	Van as compared to car noise emission	Bus as compared to HGV noise emission
50 km/h	+ 2 ΔdB	- 2½ ΔdB
80 km/h	+ 1 ΔdB	- 2½ ΔdB

Using the emission formulas and the correction factors, the emission factors from the different vehicle categories can be derived, as shown in Table 5.6.

[5] The sections about emission factors and equivalence factors are reproduced from 2nd Report.

[6] Results are only calculated for speeds above 50 km/h.

Table 5.6: Emissions L_{AE} from different types of vehicles (dB)

Speed	HGV	Van	Car	Bus
50 km/h	80.5 dB	75.5 dB	73.5 dB	78.0 dB
80 km/h	86.6 dB	79.6 dB	78.6 dB	84.1 dB

Equivalence factors
Using the *emission* factors, the next step is to calculate equivalence factors, expressing the relative contribution of other types of road vehicles as compared to cars to the total noise *impact*, in terms of noise level at the façade of the dwellings dB level at facade.

In general, the noise contribution from one vehicle of type A equals the noise from $10^{*\,(L_{EA}^{A} - L_{EA}^{B})/10}$ vehicles of type B, where L_{EA}^{A} and L_{EA}^{B} is the noise emission in dB from vehicle A and B, respectively. Thus, if e.g.
$L_{AE}{}^{heavy} - L_{AE}{}^{light} = 8$ dB,
the noise from 1 heavy vehicle will equal the noise from $10^{8/10} = 6.3$ light vehicles.

The difference in noise emissions between vehicle types can be calculated From Table 5.6 for 50 and 80 km/h, taking these speeds as broad indicators for the speeds of urban and rural traffic, respectively. The noise from passenger cars is used as the basis or unit value. The number of car equivalents corresponding to each vehicle type can then be calculated, according to the formula given above.

Table 5.7: Differences in emissions and car equivalence factors

(dB)	HGV	Van	Car	Bus
Difference in emissions as compared to car				
Urban	7.0	2.0	-	4.5
Rural	8.0	1.0	-	5.5
Car equivalents according to formula				
Urban	5.0	1.6	1	2.8
Rural	6.3	1.3	1	3.6

Note: 50 km/h is used as an indicator for average speed in urban areas, and 80 km/h is used as an indicator of average speed in rural areas.

It should be noted that, since noise increases with increasing speeds, it will influence the equivalence factors if one vehicle type typically drives faster than others.

Extra-urban areas comprise various kinds of roads, of which some are motorways, where passenger cars and vans drive faster than trucks, and other roads where the speeds may be more similar. When passenger cars and vans drive faster than trucks, this will increase the noise from cars and vans and decrease the difference between trucks and cars/vans. Thus, if e.g. a truck drives 80 km/h and a car drives 110 km/h, the car equivalent of the truck will decrease from about 6 to about 3. However, since all state roads, including all motorways as well as other high speed roads, accounts for only a minor share of the total noise problem (measured in SBT), it is assessed that in general using the 50 km/h and 80 km/h will be an acceptable rough estimate of speeds in urban and extra-urban areas.

Calculation of share of total costs
If all vehicles had the same emissions, then total costs could be distributed according to the share of traffic. However, since emission factors are not the same, corrections has to be made.

It is assumed that total costs could be distributed between vehicles types according to the total emissions from the different vehicle categories. The total costs for each vehicle category can then be calculated according to the following formula:

$$V_m = \frac{e_m T_m}{\sum_i e_i T_i} TC$$

where

V_m = Total costs for vehicle category m
TC = Total road noise costs
T_m = Traffic volumes for vehicle category *m*
e_m = Emission equivalent for vehicle category *m* (e_m = 1 for *m* = *car*)

The contribution from each vehicle type to the total noise emission is thus calculated and measured in passenger car equivalents. The calculations are done separately for urban and extra-urban areas as shown in the table below.

Table 5.8: Share of total noise emissions measured as passenger car equalents.

dB x mio.Pb-km	**HGV**	**Van**	**Car**	**Bus**	**Total**
Urban	830	3,068	15,161	1,014	20,073
Extra-urban	8,624	4,427	23,508	960	37,519
Relative shares					
Urban	4 %	15 %	76 %	5 %	100 %
Extra-urban	23 %	12 %	63 %	3 %	100 %

Finally, the total noise costs from Table 5.3 can be distributed according to the share of total noise emissions, according to Table 5.8. The results are shown in Table 5.9 below.

Table 5.9: Allocation of total noise costs on vehicle types (mio. DKK)

	HGV	Van	Car	Bus	Total
Urban	326	1,206	6,157	398	8,087
Extra-urban	127	65	339	14	545
Total	460	1,300	6,450	422	8,632

Source: Table 5.3 and Table 5.9.

5.2 Rail

5.2.1 Method

The estimation of the he total costs of rail transport are - similarly to road transport - calculated by multiplying the number of noise exposed dwellings by a unit cost of noise.

A similar method as described for road for distributing total rail noise costs on freight and passenger transport has been investigated. However, noise equivalence factors are not readily available and the data quality not sufficient for providing such equivalence factors comparing the noise from freight and passenger trains. Instead total noise costs have been allocated to passenger and freight traffic according to the marginal noise costs per train km and the traffic volumes.

5.2.2 Noise exposure

The estimated number of rail noise exposed dwellings is showed in the table below:

Table 5.10: Number of dwellings exposed to rail traffic noise in Denmark.

Noise interval	Number of dwellings
60 - 70 dB	12,107
70 - 75 dB	4,727
>= 75 dB	614
Total	17,448

Source: COWI.

A distribution of the number of noise exposed dwellings on urban and extra-urban areas is not available.

5.2.3 Annoyance curve for railway traffic

Railway noise is generally regarded as less annoying than road traffic noise, mainly because of the periodic character of noise. This has been taken into account in the Danish Environmental Agency's noise standards for railway noise where the limit is set at 60 dB as compared to 55 dB for road noise.

Correspondingly, the annoyance curve should be displaced parallel by 5 dB to the right. The formula then changes to:

SBT-factor per dwelling = $4.22^{0.1*(L-78)}$

where L = noise level for the dwelling, measured in dB at the facade.

5.2.4 Total noise costs for rail

From the number of dwellings exposed to railway noise the total SBT can be calculated, similarly to the method used for road traffic, but using the formula from Section 5.2.3 and the unit cost. The results are shown below:

Table 5.11: Total SBT and noise costs from rail way traffic in Denmark.

Noise interval	Total number of dwellings	Noise nuisance SBT	Noise costs mill. DKK per year
60 - 70 dB	12,107	1,863	101
70 - 75 dB	4,727	2,141	116
75 - dB	614	571	31
Total	**17,448**	**4,575**	**249**

Source: COWI

The total railway noise costs amount to about 250 mill. DKK per year. The noise impact from railway noise is thus only a fraction of 3% of the noise impact from road traffic.

No data are available for the distribution of dwellings exposed to railway noise, distributed on urban and extra-urban areas.

5.2.5 The freight transport share of total costs

If all trains had the same emissions per km, then total costs could be distributed according to the share of traffic. However, freight trains typically have higher noise emissions than passenger trains. The costs drivers for railway traffic are in particular:

- Type of train
- Number of stops
- Speed
- Length of train

Freight trains are typically longer and of a more noisy type, but typically they stop less frequently and drive slower. Although these cost drivers pull in different directions, there is all in all a tendency for freight trains to have higher emissions per km than passenger trains. No official figures for the difference in average noise emissions are available. According to rail noise experts, the typical difference in noise emissions between freight trains and passenger trains in Denmark are in the range of 0-4 dB. The low end of the interval refers to situations with stops, typically in urban areas, whereas the high end of the interval refers to smooth driving in extra-urban areas. A rough estimate of the average difference is on this background a 3 dB difference, taking into consideration that most freight trains drive long distance routes.

Applying the general rule of comparing noise from different sources mentioned in chapter 5.1.4 to railway transport, the noise from one freight train (A) equals the noise from $10^{(E_A - E_B)/10}$ passenger trains (B), where E_A - E_B is the difference in noise emission in L_{AE} between freight trains (A) and passenger trains (B). With the assumption of an average difference in noise emissions between freight trains and passenger trains of 3 dB, this means that the noise emission from 1 freight train equals the noise emission about 2 passenger trains.

This value is in line with the ratio of approximately 2 between the marginal costs per km for a freight train metre and a passenger train metre which was derived from the two case study calculations in the 2nd Report[7]. In addition, as for the marginal cost calculations it should be taken into account that freight trains are generally longer than passenger trains. Hence, we use the ratio of the marginal costs per train kilometre for freight and passenger trains as equivalence factor to convert all train kilometres into passenger train kilometre noise equivalents:

Table 5.12 Noise equivalence factors for freight and passenger trains

	Marginal noise costs DKK per train kilometre
Freight trains	35.25
Passenger trains	6.14
Noise equivalence ratio (Freight : Passenger)	**5.74 : 1**

Source: 2nd Report Chapter 5.

On this basis, the total noise costs have been allocated according to the share of total noise emissions, assuming the noise equivalence factor of 5.74 between freight and passenger trains.

[7] See 2nd Report Section 5.5.2.

Table 5.13: Distribution of total costs of railway traffic.

	Freight traffic	Pass. traffic	Total
Traffic volume, mio. train km	5.42	62.46	67.88
Noise contribution, (pass. train km equivalents)	31.15 33%	62.46 67%	93.61 100%
Total noise costs	82 mio. DKK	166 mio. DKK	249 mio. DKK

Source: Table 5.11 and Table 5.12 and Appendix A.

It appears from the table above that the freight trains are estimated to be responsible for about one third of the total railway noise costs.

5.3 Maritime transport

Maritime transport is not included. It is assumed that the external nosts from sea transport is insignificant as compared to other modes.

5.4 Air transport

The freight share of total air transport volumes is assumed to be negligible and therefore the total costs of air freight transport have not been calculated.

5.5 Litterature

Andersen, B., Bendtsen H. (2002): *Støjudsendelse fra biler på vejnettet (Noise emissions from vehicles on the road infrastructure).* Atkins Danmark. Proceeding from Ålborg Trafikdage, 2002.

Andersen, B., Bendtsen H. (2003): *Personal communication.*

Danish Environmental Agency (2003): *National strategi for begrænsning af vejtrafikstøj. Delrapport 2: Støj, gener og sundhed - en sundhedsøkonomisk analyse af udvalgte sygdomsrelationer.* (National strategy for reduction of road noise traffic. Working report 2: Noise, annoyance and health - a health economic analysis of selected diseases.) By COWI in collaboration with the Danish National Institute of Occupational Health and MUUSMANN A/S. Maj 2003.

6 Accidents

The purpose of this chapter is to estimate the total external accident costs of freight transport modes in Denmark. Estimates are also presented for passenger modes as these estimates follows more or less directly from allocation of the total costs on freight and passenger modes using the same infrastructure. The values split on modes (and other relevant levels of disaggregation) should serve as background for comparison of these costs with the revenues from the total payments of charges and taxes for freight transport in Denmark.

The nature of road transport with many individual vehicles of many different types makes estimation of the *external* costs more complex in practice than for other modes although in principle there is no difference. Road transport's higher complexity as well the substantially higher level of casualties have resulted in a a different and more thorough approach than for other modes. The approach and results for road transport is described first in Section 6.1 whereas the other modes are described subsequently in Section 6.2.

Level of disaggregation

As described in the 1st report accident risk depends on the vehicle type, the infrastructure type, the volume of traffic, the traffic composition, time of day, the road conditions and the driver. Hence, a very detailed disaggregation is desirable, but is however not possible to provide because of lack of data.

It is important to make distinction between different *types of vehicles* involved in accidents. Further, differentiation with respect to location is also important. Hence, the following cost drivers effectively determining the appropriate level of disaggregation for accident costs have been identified:

- Transport mode
- Vehicle type
- Location

For road transport the costs are differentiated with respect to vehicle type and location type (urban/extra urban). For the other modes no further differentiation has been possible based on the available information.

6.1 Road transport

6.1.1 Approach

For road transport a top down approach is applied. The point of departure is the total social costs of road accidents using the unit costs published by the Road Directorate in *Trafikøkonomiske Enhedspriser*. In this approach basically, the total costs are calculated by multiplying the number of casualties (a vector consisting of fatalities, severe injuries and light injuries) with the unit cost per casualty (also a vector consisting of fatalities, severe injuries and light injuries). However, this study focuses on the *external* costs of different modes of transport. Hence, two (interrelated) issues arise from the total social costs:

1) What part of the social costs is external?

2) How should the external costs be allocated on the modes when more than one mode is involved in an accident?

1) External versus internal costs

The degree in which the social costs are internalised depends on the legal and insurance system. In the reviewed studies costs due to property damages are in general 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 internalised. Thus, material damage is not included in this study either.

The costs from accidents which imposed on the society in general are always considered as external costs:

- police and rescue costs;
- medical treatment costs;
- net production loss;

which are not internalised by insurance payments.

However, in line with the recommended approach for calculating the marginal costs (See the 1st report, section 6.3.3.), part of the individual's accident costs are considered as internalised in the first place. It is assumed that the road user internalises in his decision the risk he exposes himself to, valued as his WTP. Hence, when a transport user exposes himself to risk and accidentally becomes *a victim*, only the cost imposed on the general public as described above is considered as external. His own loss is internal. On the other hand, if he is involved in an accident with other road users he also becomes *an injurer*. And all costs that he as an injurer imposes on the counterpart(s), as well as the general public, are external. In reality, the distinction between a victim and injurer can not be made objectively, and therefore both parties in an accident are considered as injurer of their counterpart.[8]

2) Cost allocation

As an example, if a HGV and a car crash the fatalities and injuries in the car are external to the HGV, whereas any fatalities or injuries in the HGV are external to the car. Hence, all costs (except the material costs internalised by the insurance premium) become external costs for either of the parties involved in the

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[8] If a mode is considered collectively one could also argue that costs which the group of road users inflict on each other internally, i.e. in terms of crashes of vehicles of the same mode, are not external for the group as such. However, the exclusion of such "within mode" accident costs would ignore the behavioural aspect of the definition of external costs: that they are all costs not taken into account of the road users in their traffic decisions. In addition, this definition would suffer from the weakness that the total external costs would be less if a more fragmented mode definition was adopted. For example if HGV was subdivided in several weight classes of trucks.

accident. But because the casualties more often to be found in the lightest or softest road user the external costs will be higher for the heavy road user.

If the involved parties belong to the same mode all costs in both vehicles will consequently be external costs of that mode.

Only in the case where the accident involves no counterpart will the individual's welfare loss not be an external cost, but only an internal cost in terms of the accepted risk of entering the traffic flow. This is because the welfare loss is not inflicted by another road user. The costs to the general public, as defined above, will of course still be external.

The above allocation approach follows a similar approach as recommended for calculating marginal costs, which is also the approach used in the UNITE study. However, in other studies (INFRAS/IWW) it is recommended to use a cost allocation mechanism based on a causation principle, which means that the internal and external accident risks are calculated based on information about the legal responsibility for the accident.

In line with the approach for calculating the marginal costs it is expedient to divide the total external accident costs into two categories:

- The accident costs to the rest of the society **(c)** (medical treatment cost, police and rescue cost, net production loss) related to any casualty.
- The accident costs for the casualties of the *other modes of transport*. These costs consist of the costs for the casualty or vehicle user household **(a)** and its relatives and friends **(b)** as expressed by the willingness to pay found from surveys.

The terms, a, b and c follow the definitions given in the 1st and 2nd Report.

To calculate *total external accident costs*, the unit costs of accidents from the Danish Road Directorates "Trafikøkonomiske Enhedspriser" have been used. The unit costs of accidents consists several components as listed below (cost categories in brackets[9]):

- *Loss of human value ("velfærdstabet") (a+b)*
- *Gross production loss*
  - net production loss *(c)*
  - the value of the individuals own lost consumption *(a+b)*
- *Direct public expenditures*
  - police and rescue cost *(c)*
  - medical treatment cost *(c)*
- *Property damage costs (Not included - internalised by insurance)*

Costs of medical treatment, police and rescue costs, net production loss and the property damage costs are all social costs that are not borne by the traffic users

[9] The terms "*a+b*" and "*c*" refers to the theoretical discussions in 1st and 2nd Report.

but by society by large. On the other hand, the costs borne by the individual transport user (and relatives and friends) consist of the loss of human value (willingness to pay for safety) and the value of the individuals own lost consumption

Unit cost of accidents from *Trafikøkonomiske Enhedspriser*
In the table below the unit costs of accidents from *Trafikøkonomiske Enhedspriser* are presented and split on costs for the transport user (a+b) and costs borne by society by large (c).

Table 6.1 Accident unit costs by casualty type and cost categories.

DKK per injury	per fatality	per severely injured	per lightly injured
Costs for the society by large (c)	**1,087,956**	**637,669**	**217,083**
Police and rescue	3,518	4,423	4,895
Medical treatment	27,645	330,740	58,467
Net production loss	1,056,793	302,506	153,721
Costs for the infrastructure user (a+b)	**7,134,708**	**212,556**	**14,472**
Value of individuals lost consumption	1,652,932	-	-
Loss of human value	5,481,776	212,556	14,472
Total	**8,222,664**	**850,225**	**231,556**

Source: Vejdirektoratet, 2002: *Trafikøkonomiske Enhedspriser 2001*

It appears from the table that the total costs for severe injuries are approximately 10% of the costs per fatality whereas the costs for light injuries are about 3% of the costs per fatality. For fatalities the welfare loss for the individual amounts to about 85% of the total unit costs but only 25% and 6% for severe and light injuries.

6.1.2 Total costs for Road transport

Input data
The unit costs from Section Approach have been combined with national statistics on accidents.

The accident data are based on matrices with accidents recorded by mode of victim and mode of counterpart from Statistics Denmark. Unfortunately, recent matrices are not readily available. Therefore, accident matrices from 1990-1994 with the distribution of casualties on modes and counterparts, used in a previous study of accident costs for the Danish Ministry of Transport (Trafikministeriet(1997b), has been used. An average of the number of casualties for the three latest available years (1999-2001) has been coupled with the old distribution from 1990-1994 to scale the 1990-1994 matrices the level of fatalities and injuries of 2000.

In the table below fatalities and severe and light injuries for year 1999-2001 is presented.

Table 6.2 Fatalities and severe and light injuries for year 1999-2001

	1999	*2000*	*2001*	*Average*
Fatalities				
Car	271	235	242	**249**
LGV	27	23	22	**24**
HGV	3	3	2	**3**
Bus	1	6	2	**3**
Tractor	0	0	0	**0**
Motorcycle	26	24	12	**21**
Moped	41	47	43	**44**
Bicycle	59	58	56	**58**
Pedestrian	82	99	49	**77**
Total	**510**	**495**	**428**	**478**
Severe injuries				
Car	1816	1843	1646	**1768**
LGV	231	167	165	**188**
HGV	30	22	26	**26**
Bus	31	24	45	**33**
Tractor	0	0	0	**0**
Motorcycle	252	227	220	**233**
Moped	563	691	696	**650**
Bicycle	792	802	696	**763**
Pedestrian	477	470	442	**463**
Total	**4192**	**4246**	**3936**	**4124**
Light injuries				
Car	2788	2531	2371	**2563**
LGV	240	228	243	**237**
HGV	61	34	38	**44**
Bus	44	53	56	**51**
Tractor	0	0	0	**0**
Motorcycle	126	95	84	**102**
Moped	484	601	573	**553**
Bicycle	1016	890	817	**908**
Pedestrian	369	376	322	**356**
Total	**5128**	**4808**	**4504**	**4813**

Source: Statistics Denmark and own calculations

Note: Police reported accidents

The accident split on urban and extra urban from the detailed data used in the Trafikministeriet(1997b) study has also been assumed. The table below gives an example of one out of the six[10] computed matrices used for the calculation of the total costs.

[10] urban/extra-urban combined with fatalities/severe/light.

Table 6.3 Severe injuries in urban areas, average year 1999-2001, split on mode of victim and mode of counterpart.

	Counterpart											
Fatalities in:	**One element**	**Car**	**LGV**	**HGV**	**Bus**	**Tractor**	**Motor cycle**	**Moped**	**Cycle**	**Pedestr.**	**Obstacle**	**Total**
Car	18	178	89	48	16	6	3	1	6	4	192	**561**
LGV	3	20	4	7	1	1	0	0	1	0	14	**51**
HGV	1	1	1	1	0	0	0	0	0	0	2	**6**
Bus	1	6	2	2	0	0	1	0	0	2	0	**15**
Tractor	0	0	0	0	0	0	0	0	0	0	0	**0**
Motorcycle	11	73	13	4	2	0	2	1	3	3	24	**136**
Moped	54	224	49	21	6	2	4	6	18	9	77	**470**
Bicycle	63	367	67	28	10	2	6	19	33	17	39	**651**
Pedestrian	0	251	42	10	20	2	10	16	52	0	0	**403**
Total	**151**	**1120**	**267**	**122**	**55**	**13**	**25**	**44**	**113**	**35**	**349**	**2294**

Source: Own calculation based on accident data from Statistics Denmark.

Not surprisingly, the table above shows that the "soft" road-users are the most vulnerable. As an example, 251 pedestrians have been severely injured in accidents with cars whereas only 4 car users were severely injured in the same accidents. Similarly, 48 car users have been severely injured in accidents involving HGV whereas only 1 HGV user has been severely injured in these accidents.

This distribution of the injuries will subsequently be reflected in the external costs of road users in accordance with the approach described above. The external costs will constitute the sum of the costs in the columns of that mode plus the costs for the general public (c) for the accidents with "one element" and "obstacle" as counterpart. For example for Car: 1120+18+198 = 1336 fatalities in urban areas[11] of which only the 1120 will get the full costs (a+b+c) whereas the 18+198 will only get the costs to the general public (c), ref. Table 6.1.

Results

The results of the calculation of the total costs are shown in the tables below.

[11] plus the parallel figures in the five other tables.

Table 6.4 Total external road accident costs per year, split on road user type and urban and extra-urban traffic.

million DKK **Road user type**	**Urban areas**	**Extra-urban areas**	**Total external costs**
Car	2,036	1,997	4,033
Van	492	619	1,111
HGV	354	781	1,135
Bus	120	88	208
Tractor	30	126	156
Motorcycle	78	56	134
Moped	180	63	243
Bicycle	237	42	279
Pedestrian	40	12	52
Total	**3,567**	**3,783**	**7,350**

Note: Average figures for 1999-2001.

Source: Accident data from Statistics Denmark and Table 6.1.

Table 6.4 shows the total costs for each type of road user with a sub-division on urban and extra-urban areas. The total external costs for road traffic amount to 7.3 billion DKK with an about equal split on urban and extra-urban areas. For freight vehicles in total (HGV + van) the external costs are about 2.2 billion DKK. More than half of the costs are due to passenger cars which to a large extent reflect the high traffic volume for this type of vehicle. The costs per vehicle kilometre is higher the heavier the vehicle.

Table 6.5 Total external and internal road accident cost, split on costs to society and individuals and on modes.

mio. DKK	**HGV**	**Van**	**Car**	**Bus**
Costs for society (c)	382	578	2,512	89
Costs for road users (a+b)	753	533	1,521	119
Total external costs	**1,135**	**1,111**	**4,033**	**208**
Internal costs (a+b)	9	99	824	3
Total social costs	1,144	1,209	4,856	211

Note: Average figures for 1999-2001.

Table 6.5 shows the split of the external costs on costs for society (c) and welfare loss for individual road users (a+b) for the main modes. The overall picture is that these two cost components are of the same order of magnitude. In addition the table presents the costs which can not be considered as internal because they solely reflect the individual road users own accident risk (no counterpart in the accident). For the four main modes in total these costs are about 0.9 billion DKK or only about 15% of the external costs. Adding the external and internal costs gives the total social costs[12]. For road transport in total these costs amount to about 8.5 billion DKK.

6.2 Other modes

6.2.1 Approach applied for rail transport, short sea shipping and air transport

The total accident costs for alternative modes were above calculated by a "top-down" approach allocating the costs of the casualties on modes. Alternatively, the total external accident costs can be calculated by a bottom up approach by multiplying an estimate of the average external accident unit cost with the traffic volume for each mode and other relevant dimensions of disaggregation. This approach has been followed for the calculation of the total external accident costs for rail transport, short sea shipping and air transport.

2nd Report presented estimates of marginal external costs, but as explained in 1st report there can be significant differences between *marginal* and *average* external accident costs pr. km. However, recalling the discussion about the marginal external costs for rail transport, short sea shipping and aviation in the 1st Report, it is often simply assumed that proposed values of marginal external costs equals average external costs.

The values proposed for marginal external accident costs in 2nd Report are primarily based on the three studies: INFRAS/IWW, TRL and "*Miljømodel for "Højhastighedstog-modellen*", Trafikministeriet(1997a), which all apply the condition that the estimated marginal costs equals average costs:

- INFRAS/IWW highlights methodological problems and uncertainties of existing studies of risk elasticities and concludes that since the studies do not provide sufficient reliable information of marginal accident risks (e.g. risk elasticity NOT zero), average accident risks is used instead for rail transport, short sea shipping and aviation. This means that average costs are set equal to marginal costs implicitly assuming constant accident risk (risk elasticity of 0)

- The TRL study points out that when adequate data of the risk elasticities are not available indeed only average external costs can be calculated. This approach is then adopted.

- Finally, in Trafikministeriet(1997a) marginal external costs have been estimated for rail, shipping and aviation using the recommended methodology". However, the study *does not* include estimates of *risk elasticities* implicitly assuming risk elasticities equal to zero (or accident elasticity equal to 1) so that marginal costs equals average costs.

[12] Except for material costs internalised through insurance payments which are a significant part of the total accident costs, but not considered at all in this study.

6.2.2 Total costs for other modes

Rail

The total external accident costs for rail transport in Denmark is low compared to road transport. This is due to the fact that only few person are killed[13] in other modes of transport (or pedestrians) in accidents involving trains: Only about 10 fatalities per year in other modes and 1.5 in trains per year as an average over the period from 1986-1995, see Trafikministeriet(1997a).

For rail transport the total external accident costs are calculated from the proposed marginal external unit values from 2nd Report multiplied with the traffic volume, using the assumption that the marginal unit costs equals the average unit costs.

Short sea shipping

For short sea shipping Trafikministeriet(1997a) points out that only 2 accidents with 2 fatalities have been reported in 12 years and therefore it is concluded study that the marginal external costs of shipping are negligible, e.g. practically equal to 0 (for both passenger and freight transport). Hence, the average and total external accident costs for short sea shipping are estimated to zero.

Air transport

The total external accident costs for aviation are generally considered to be low compared to road transport. Only few persons are injured or killed in flight accidents and usually there is no counterpart involved in the accident, which means that the external accident risk is very small. In Trafikministeriet(1997b) the external accident risk is estimated to zero, which means that it is assumed that practically all accidents are internal accidents internalised in the passengers decision to travel. However, although the risks of accidents is in general very small, it is also generally the view that a congested airspace is also generally perceived as leading to higher accident risks. Hence, some of the accident costs from air transport should be considered as external, although small per kilometre. It is therefore instead decided to present the average and total external costs of aviation as "n.a." recognising that further analyses have to be conducted to assess the external costs.

Results

The results for the average and total costs for other modes than road transport are presented in the table below applying traffic volumes from Appendix A.

[13] Fatalities classified as suicides by the police are not included.

Table 6.6 Average and total external accident unit costs for other modes

Mode:	**Average external costs** DKK / vehicle km	**Total external costs** billion DKK
Freight train	1,50	8
Passenger train	1.30	81
Short sea shipping	0	0
Air transport	n.a.	n.a.

Comparing the total external accident costs across modes it is clear that road transport is responsible for by far the major share of the external accident costs. It accounts of app. 95 % of the total external accident costs of all modes (both passenger and freight transport) and HGV account for app. 98% of total external accident costs of freight transport.

6.3 Literature

Trafikministeriet(1997a): *Miljømodel for "Højhastighedstog-modellen"*, COWI for Trafikministeriet.

Trafikministeriet,(1997b): *CO_2-reduktioner i transportsektoren - Samfundsøkonomisk omkostningseffektivitet i transportsektoren*, Arbejdspapir, COWI for Trafikministeriet.

7 Infrastructure

This chapter presents suggestions for total and average infrastructure costs for road and rail transport. For road transport, results are presented as total costs per vehicle kilometre split by vehicle type. Also, methodological issues in the Danish calculation of external road transport costs are presented by comparing the Danish calculations with the 'state-of-the-art' methodology recommended by the DIW(1998) study.

7.1 Approach

Average costs per kilometre for various modes are derived by full allocation of total costs. The average infrastructure costs can be interpreted as *long run* marginal cost of transport. *Short run* marginal costs includes congestion and scarcity as well as variable costs directly related to traffic volumes, whereas long run marginal costs includes fixed costs (for investment) and *all* variable infrastructure costs, including those only vaguely related to traffic volumes, but not congestion costs. The argument is that the capacity of the infrastructure is adapted to the level of traffic. Hence, increased traffic does not lead to additional congestion. See the discussion in Chapter 7.1 of 1st Report.

The Danish approach for calculating the average cost from use and wear of infrastructure has so far been to allocate the total cost of capital, maintenance and operation on the various users of that infrastructure by the type of vehicle used: cars, vans, buses and Heavy Good Vehicles (HGV), according to traffic volumes combined with weight factors. Three different traffic performance or load indicators have been used as weight factors:

- traffic volume,
- vehicle-length corrected traffic volume and
- standard-axle weight factor corrected traffic volume.

These three indicators are used to different extent for the various cost components constituting the total infrastructure costs. A main problem with regard to estimating infrastructure costs is that they are not easily observed even though these costs eventually materialise in expenditures of the infrastructure owner. The point of departure has to be the costs as they can be observed in the accounts of the responsible authority: That is various categories of maintenance and operation costs and investments in new infrastructure.

Considerations about running maintenance and operation costs and the resulting assumption are presented in Section 7.1.1. Possible methodologies for the assessment of capital costs are addressed in Section 7.1.2, while Section 7.2 describes an actual Danish calculation of operation, maintenance and investment costs.

When the total costs are known, allocation of these costs by vehicle type must be addressed. In section 7.3, methodologies from different European countries are shortly described and compared to the Danish allocation methodology, giving advantages and disadvantages, as well as some recommendations for improvement on Danish allocation of costs. The allocation of Danish infrastructure costs on vehicle type is then, finally, described in section 7.4. A summary is found in section 7.5.

7.1.1 Operation and maintenance costs

The total yearly operating and maintenance costs are taken directly from the accounts of the respective road authorities, assuming that these costs are strictly attributable to the traffic of the year where the expenditures are paid. In reality, road authorities have some possibilities to defer or advance expenditures depending on their budget situation in general. This means that looking at a single year can give rise to discrepancies between the long-termed maintenance costs for the infrastructure and the expenditures in the financial accounts of that year.

This is an argument for considering the average over several years instead of the expenditures for just one year. But on the other hand, taking average over a longer period will underestimate the costs if there is a general increasing trend in the size of the network. The conclusion is that this issue is ignored in this study assuming yearly expenditures reflect yearly costs.

7.1.2 Road infrastructure capital costs

Expenditure on new road infrastructure must be considered as an investment, because it creates benefits that last more than one year, and as such, the capital costs are generally not equal to the expenditure on capital.

The annual expenditure for investments in road infrastructure is used in some countries as a proxy for the capital costs of the road infrastructure. This measure is, however, problematic, unless the annual investment exactly equals the annual depreciations plus alternative costs of capital, a condition that is very unlikely to hold. Therefore, a more advanced tool that can address the capital value and depreciations is needed. Three basic methods of the valuation of the road infrastructure capital costs exist:

1) The *Perpetual Inventory model* (PI-model, also known as the indirect method) evaluates the capital stock using historical investments and assumed life expectancy of different stock items.

2) The *synthetic method* (also known as the direct method) evaluates the capital value by addressing the cost of replacing each item of the capital stock.

3) The *business valuation method* describes the commercial value of the road capital.

These three methods are described in detail below, where after the choice of method is discussed. Finally, considerations on the total capital costs are made.

The business valuation method
The business valuation method is based on the commercial value of a piece of road infrastructure. This, in turn, depends on the willingness to pay of the users, as well as country specific taxation issues. Furthermore, the commercial value might also depend on market power if no adequate alternative routes exist. As these factors are irrelevant to an assessment of the external infrastructure costs, this method is not relevant to a study of external infrastructure costs.

The synthetic method
The synthetic method relies on a replacement cost methodology, which requires comprehensive information of the network characteristics and replacement costs. Only a few European countries, namely Austria and Finland, apply the synthetic method in the valuation of the road capital stock. The synthetic method is, however, partly applied in some countries, e.g. in Denmark for the estimation of initial values for the first year in the Perpetual Inventory method.

The Perpetual Inventory model
The Perpetual Inventory model is reason, often used instead of the synthetic method because the data requirements for the synthetic method are very costly. The Perpetual Inventory model relies on long investment time series and assumptions on the life time of the assets. Ideally, the time series starts before the investment in the oldest asset of the capital stock, but when this data is not available, the synthetic method can be used for creating an initial capital value.

The Perpetual Inventory model can be applied using a gross or a net concept:

- The *gross* value comprises the value of all assets which is assumed still to exist in the considered year, e.g. which have not yet exceeded their life expectancy.

- The *net* value assumes that annual depreciations reduce the value of existing assets during their assumed life time expectancy. Thus, the net concept summarises the value of all assets net of depreciations.

Regardless of whether the gross or net concept is applied, road assets typically have very different life expectancies. Surface dressing have a rather short life expectancy, typically in the range of 10 to 15 years, whereas e.g. tunnels, bridges and earth work have life expectancies in the range of 70 to 110 years if maintained properly. If the data allows so, it is thus preferable to have time series that distinguishes between investments in assets according to their life expectancy.

When the net concept is used, linear depreciations are often modelled. This means that the value of the asset depreciates totally over its expected life time (T) with an equally large amount (1/T of initial value) for each year. This method is recommended by the System of National Accounts (SNA) for determining general industrial capital costs (although publicly constructed infrastructure is assumed not to depreciate at all).

A more refined approach for modelling depreciation is the introduction of estimated complex survival functions for the different types of infrastructure. On the basis of long time series, mean values and variations for life expectancy can be estimated, and with these, survival functions can be constructed. The estimation of survival functions is, however, somewhat labour and data intensive.

When the PI-model is used, the annual capital costs consist of the depreciations and the interest of the value of the road capital to reflect that these resources could have been used in an alternative way. The DIW study recommends that the chosen interest rate is based on national conventions.

Methodological choice

With the synthetic method, the determination of prices for different types of infrastructure is somewhat problematic. As replacement value may depend on the characteristics of the specific piece of infrastructure (e.g. age, condition, etc.) it seems that the crucial assumptions on prices may be less transparent. The very detailed replacement values needed for the synthetic model may be difficult to derive using actual data, whereas the life time expectancies used in the Perpetual Inventory model can be estimated when sufficient historical data is present.

Although one, in principle, may obtain more correct estimates of the capital value with the synthetic method, the large amount of work as well as the increasing lack of transparency in this process, suggests that the Perpetual Inventory model (where the crucial assumptions concerns only life time expectancy) may be the better choice because the problems with lack of adequate data outweighs the theoretical advantages. The argument for this choice becomes even stronger when the data needs concerning the physical characteristics of the road network are considered.

DIW study concludes that the PI-model represents today's state-of-the-art. This study has followed this implicit recommendation to use the PI-model for estimating the annual infrastructure capital costs.

Although the complex survival functions used in the PI-models of some countries can be considered as 'state-of-the-art' and may give a more precise picture of the development of depreciations, the use of complex survival functions leaves the capital costs less transparent. If infrastructure charging is partly based on the capital costs from the PI-model, the development of the depreciations means that users will contribute differently to the financing of a particular piece infrastructure depending on when[14] they use it (typically, the complex survival function depreciations are larger in the beginning of the asset's life, and accordingly, early users would have to pay more than later ones).

[14] Not yet considering discounting of the payments.

For the precise estimation of the capital values, the use of more accurate survival functions may be desirable if the value of the increased precision is worth the efforts of constructing the survival functions. When the PI-model is used for calculating capital costs for infrastructure charging, questions about the temporal distribution of charging must be considered. This argument speaks for using the net concept with linear depreciation[15]. The recommendation of the DIW study is that the chosen depreciation method is based on national conditions. It is noted, however, that the capital value of the road infrastructure is somewhat more sensitive to the choice of life time than to the method of depreciation chosen.

This study recommends that linear depreciation is used for the estimation of external costs due to depreciation of road infrastructure as this method can be considered both more transparent and fair with respect to the temporal distribution of payments between early and later users. For other purposes, however, the estimation of complex survival functions may be a methodological improvement.

7.2 Danish Road Infrastructure Costs

Data on yearly Danish road expenditure and annual vehicle km is collected by the Danish Road Directorate (Vejdirektoratet) in accordance with the EU-regulation 1108/70. As required by the regulation the expenditures on roads are differentiated on cost and road type:

- National roads (Vejdirektoratet),
  - motorways,
  - trunk roads;
- Regional roads (counties);
- Local roads (municipalities);

which in Denmark coincides with the responsible authority (in brackets). In Table 7.1 below, the expenditure for the three authorities can be seen for 2000. It is also possible to separate national expenditure for new construction on motorways and trunk roads (not shown).

[15] With the gross concept, all depreciation takes place at the end of each asset's life

Table 7.1 Expenditures on Danish roads 2000 (million DKK, market prices)

	National	Regional	Local
Network length (km)	*1,659*	*9,967*	*59,995*
Administration	160	198	1,824
Winter maintenance	54	157	273
Other maintenance	266	419	1,336
Surface renewal	101	541	1,197
New construction	906	460	2,046
Total expenditure	1,487	1,776	6,676

Source: Vejdirektoratet, www.vd.dk and own calculations.

The cost types in the table above are distinguished as operation or maintenance or investment costs as follows:

- Expenditures on administration, winter maintenance and other maintenance expenditures have a service life of less than one year. Following Section 7.1.1 the expenditures are therefore used directly as operation and maintenance costs related to traffic of that year.
- Surface renewal and new construction expenditures have duration of several years and must thus be considered as investments.

Using the assumptions explained above, data on these two expenditure types are available (or can be reconstructed) back to 1950 with the following remarks:

- The value of the Danish infrastructure capital in 1950 has been estimated to 33 billion DKK using the synthetic method.
- From 1993 and onwards, there has been no separate accountancy for the local and regional expenditure on surface renewal. These figures have instead been included in "maintenance except winter maintenance". The surface renewal expenditure share of total investments in the table above has been estimated from the period 1983-1992. Local authorities are thus assumed to use 43 % of operating expenditure on surface renewal, whereas regional authorities are assumed to use 54 % for the same purpose.
- Before 1972, only data on total new construction exists. For the period 1950-1972 an estimate of the split between road types has been made on the basis of investments in 1972-1982. After 1982, the gradual increase in the expenditure on motorways would bias the estimate. Sensitivity analyses have been carried out on this subject, showing that the distinction in this period is only of minor importance.

The existing Danish PI-model[16] is used to calculate the annual capital costs of these investments, which must be considered the true economic costs of the

[16] A complete documentation of the Danish Road Infrastructure Capital Value assessment can be found in "Vejkapitalen", Vejdirektoratet 1999.

road infrastructure capital. Linear depreciation is used in the Danish PI-model, with fixed life time expectancies of the Danish road infrastructure items which appear from Table 7.2. Note that bridges and tunnels are accounted for separately in an item called "large structures", using the synthetic method and the surface area and the construction year of the structures.

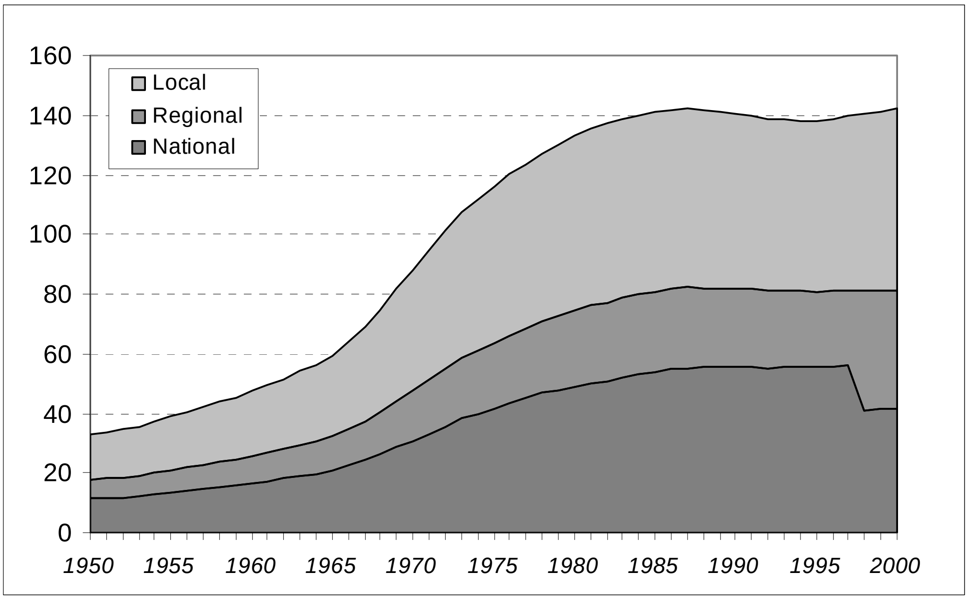
Table 7.2 Assumptions on life expectancy of road infrastructure

	Depreciation rate	Life expectancy
Reinvestment in surface renewal	10 %	10 years
New road investments	2 %	50 years
Investments in large structures	1 %	100 years

Source: "Vejkapitalen", Vejdirektoratet 1999.

Using these life expectancies, the value of the Danish road capital has been calculated to 142 billion DKK in 2000. The development of the road capital value did stagnate in the late 1980'es, but increased investments, especially national, have reversed this development, c.f. Figure 2.

Figure 2 Development in the Danish road capital, 2000 prices



Note: A part of the National road net was transferred to Regional authorities in 1998. Source: Calculations on the Danish Perpetual Inventory model.

The depreciation and interest of the road capital stock and the road surface represent the true economic capital costs, which are shown in Table 7.3, as opposed to the yearly expenditures on surface renewal and new constructions, presented in Table 7.1. The yearly expenditures for administration plus winter and other maintenance are transferred directly to costs as described in Section 7.1.1.

Table 7.3 Infrastructure costs for Danish roads 2000, million DKK, market prices

mill. DKK		National	Regional	Local	Total
Administration		160	198	1,824	2,182
Winter maintenance		54	157	273	484
Other maintenance		266	419	1,336	2,021
Road surface:	interest	132	394	732	1,258
	depreciation	241	1,381	1,357	2,979
Road capital:	interest	2,358	2,000	2,910	7,268
	depreciation	675	722	1,015	2,412
Total expenditure		3,885	5,272	9,447	18,604

Source: Vejdirektoratet, www.vd.dk and own calculations using the PI-model.

7.3 International cost allocation methodologies

To address the cost of different types of road traffic, the total infrastructure costs must be allocated to vehicle types. In DIW et.al.(1998) Section 3.4 a very detailed comparison between the cost allocation procedures of seven European countries is undertaken. In this context, the Danish procedures are rather simple, because only few distinctions on road infrastructure cost exist. In Denmark, these are administration, winter and other maintenance, reconstruction and new investment. In other countries, costs are also differentiated on e.g. bicycle lanes, cleaning, grass cutting, road marking, street lightning and others. The use of few cost factors in Denmark is caused by limited existence of data on these subjects. Four distinctions on so called traffic performance are also made:

- Fixed costs,
- Vehicle kilometres, (vkm)
- Vehicle-length kilometres (PBE), and
- Standard-axle weight factor (Æ10)[17].

Some countries use additional distinctions, such as maximum and gross vehicle weight, pedestrians. With respect to standard-axle weight measures, the Danish Æ10 distinction is relatively coarse[18] including only four categories of vehicles, whereas e.g. Germany and Finland use the American AASHO factors which have very detailed distinctions on weight, number of axles and vehicle types. The purpose of this study is to single out the allocation of infrastructure costs to cars, vans, HGV and busses, and thus the low level of detail in the Æ10 is not a problem here. However, much more detail is needed if fair prices for user charging have to be addressed.

[17] These are updated regularly using continuously collected data from a number of Danish roads. See http://www.vd.dk/wimpdoc.asp?page=document&objno=12950

[18] The reason for the lack of detail is that Æ10 is calculated on the basis of advanced equipment that is capable of determining the axle weight of a vehicle passing the measurement point. Unfortunately, the type of vehicle can only be deducted by the vehicles length. This fact is rather limiting for determining the vehicles type.

It turns out to be difficult to compare the effect of the allocation methods across countries, both because of the methodological differences, but also because the countries have different traffic volumes. For example, Switzerland has many mountainous roads and a maximum gross weight limit of 28 tonnes. An important conclusion in the DIW study is that cost allocation has to reflect specific national circumstances and data availability, and that no specific general methodology can be recommended.

The methodological differences across the countries are illustrated by an experiment in the DIW study. Traffic volumes for three countries were applied to the cost allocation models for seven countries and the share of costs allocated to HGV was calculated. The experiment showed that the Danish allocation of costs to HGV is moderate, as 13 to 32 % of road infrastructure costs are allocated to HGV with the traffic volumes used, whereas for example the Swedish allocation method gives a much higher share for HGV, between 32 and 41 %.

The differences are mostly caused by differences in the traffic situation, although the share of costs that are allocated by weight-dependent factors has some influence on this result. In general, Germany and Sweden relies on rather high allocation of costs on HGV whereas Switzerland has a much lower HGV cost share. The Netherlands and Denmark has moderate cost shares.

The DIW study recommends that cost should be allocated in a transparent way distinguishing between fixed and variable costs. However, the present Danish cost allocation procedures dates back to 1988, and DIW notes that "the estimation of the (Danish) weight related factors is not very transparent". Thus it seems that there is room for improvement on this issue in Denmark.[19]

7.4 Allocation of Danish Infrastructure costs

In Denmark, infrastructure costs are allocated according to four rough traffic performance measures which reflect the connection to different infrastructure costs. The four performance types are:

a) *Fixed costs* such as planning and administration and some maintenance (e.g. grass cutting or sewage fees), which are not attributable to any kind of traffic volume;

b) *Vehicle-kilometre related costs* (VKM) which are directly related to traffic volume. This could e.g. be costs for policing, to some extent winter maintenance (see also item c below) or collection of waste;

c) *Vehicle-length-kilometre related costs* (PBE) which typically are related to capacity (e.g. automatically regulated crossings), and also to some extent the dimensioning of roads (e.g. number of motorway lanes);

[19] Vejdirektoratet, has informed that new estimations of Æ10 are underway, scheduled for late 2003.

d) *Standard-axle weight factor kilometre costs* (Æ10) which are strongly related to the wear of the surface renewal, but also to the dimensioning of the underlying pavement and earthwork.

The traffic performance figures for different vehicle and performance types are based on the traffic volume of the vehicle type, if necessary corrected with appropriate equivalence factors according to length or weight. The traffic volume shares and equivalence factors are shown in Table 7.4.

Table 7.4 Equivalence factors between volume and traffic performance

	Share of traffic	Fixed costs	VKM	PBE	Æ10
Cars	83.4%	1	1	1	0.00001
Vans (< 6 tonnes)	11.9%	1	1	1.5	0.001
HGV (6-18 tonnes)	0.9%	1	1	3	0.4
Busses	1.4%	1	1	3	0.6
Truck with semi-trailer	0.8%	1	1	3	1.2
HGV with trailer	1.0%	1	1	3	1.5
HGV (>18 tonnes)	0.7%	1	1	3	1.5

Source: *Samfundsøkonomisk omkostningseffektivitet i transportsektoren*, Trafikministeriet 1997 and Statistics Denmark.

In Denmark, fixed costs are distributed proportional to traffic volume, although they could have been allocated using the number of registered vehicles or other performance indicators as well.[20]

A conclusion of the DIW study is that "for cost allocation to vehicle types a transparent method should be applied which divides costs into fixed costs allocated according to vehicle kilometres and/or specific equivalence factors, and variable costs allocated by vehicle kilometres and standard-axle kilometres", and that "the equivalence factors and the standard-axles have to be defined by considering the national conditions". Thus, the Danish cost allocation matrix as presented in Table 7.5 is in accordance with the DIW recommendations (not considering the issues regarding the Æ10 factors mentioned in Section 7.3).

The five types of costs mentioned in section 7.2 are allocated to vehicle types by the vehicle types' share of traffic performance that can be calculated from the equivalence factors described above. The costs are allocated using the cost allocation factors stated in Table 7.5 below.

[20] Seemingly, no Danish discussion of this issue exists.

Table 7.5 Cost allocation factors of Danish cost types on traffic performance

Cost type	Authority	Fixed costs	VKM	PBE	Æ10
Administration	National	70%	30%	0%	0%
	Regional	80%	20%	0%	0%
Winter maintenance	National	50%	30%	20%	0%
	Regional	50%	30%	20%	0%
Other maintenance	National	70%	20%	10%	0%
	Regional	70%	20%	10%	0%
Surface renewal	National	30%	0%	25%	45%
	Regional	50%	0%	10%	40%
Road capital	National	0%	45%	40%	15%
	Regional	0%	80%	15%	5%

Source: *Subsidiering af godstransport*, Transportrådet 1995.

With the cost allocation factors, the costs are allocated to traffic performance types. Each vehicle type is then allocated the corresponding shares of each cost type, giving the distribution of infrastructure costs by vehicle and cost type. This is shown in Table 7.6. It can be seen that cars, due to their high traffic volume, bears a major part of the infrastructure costs.

Table 7.6 Traffic cost by vehicle and cost type 2000 (million DKK)

	Cars	Vans	HGV	Busses	All
Administration	1,820	260	73	30	2,182
Winter maintenance	393	61	21	9	484
Other maintenance	1,663	247	78	32	2,021
Surface renewal	2,053	323	1,507	354	4,237
New construction	7,177	1,137	1,054	312	9,680
Total cost	**13,106**	**2,028**	**2,733**	**736**	**18,604**

Note: It is assumed that traffic volumes on national and regional roads have the same composition of vehicle types.

Source: Calculations using Table 7.3, Table 7.4 and Table 7.5.

In Table 7.7, the distribution by performance category can be seen. It is very clear that HGV, and to some extent busses, has the overwhelming part of the weight related costs. Also, the reliance of traffic volume for the allocation of fixed costs can be seen here, as cars are allocated the main part of these costs. This underlines the sensitivity with respect to the construction of the cost allocation matrix presented in Table 7.5.

Table 7.7 Traffic cost by vehicle and performance category 2000 (million DKK)

	Cars	Vans	HGV	Busses	All
Fixed	4,528	647	181	75	5,430
VKM	6,408	915	256	106	7,684
PBE	2,170	457	256	105	2,989
Æ10	1	10	2,040	450	2,501

Note: It is assumed that traffic volumes on national and regional roads have the same composition of vehicle types. Source: Calculations using Table 7.3, Table 7.4 and Table 7.5.

Comparing the infrastructure costs with the traffic volume by vehicle type it can be seen that cars have 84 % of the traffic volume but bears only 71 % of the costs, whereas HGV have 3 % of the traffic volume, but is allocated 14 % of the total infrastructure costs, c.f. Table 7.8.

Table 7.8 Total land average infrastructure costs by vehicle type

	Cars	Vans	HGV	Busses	All
	---------------- million vehicle kilometres ----------------				
Traffic volume	38,669	5,452	1,526	629	46,277
	------------------ relative distribution --------------------				
Traffic volume	84%	12%	3%	1%	100%
Total infrastructure cost	70%	11%	15%	4%	100%
	------------ DKK / vehicle kilometre -------------				
Average infrastructure cost	0.34	0.37	1.79	1.17	0.41

Source: Traffic volumes from Vejdirektoratet and Table 7.6.

In this table, the infrastructure cost per vehicle kilometre is also presented. The lowest cost is 0.34 DKK per vehicle km. for cars, whereas HGV have the highest cost at 1.79 DKK per vehicle km. The weighted average cost is 0.41 DKK per km. HGV are allocated 14% of total infrastructure costs. This result is similar to that of other countries presented in the DIW study.

7.5 Summary

The DIW study concluded that the Perpetual Inventory model is the state of the art for the valuation of the road infrastructure capital. This method is used in the assessment of the Danish road infrastructure capital value and costs.

The Danish PI-model uses simple linear depreciation based on assumed average life times of the road assets. Although more sophisticated methods for assessment of the road capital depreciation exists, it is debatable whether such methods are adequate if the purpose of the modelling is to address pricing questions for user charging. Thus, in this type of study, a tentative recommendation is to use linear depreciation for estimating total annual costs. But more complex survival function for the value of the assets could be considered In the future.

Another pivotal point in the assessment of infrastructure costs by vehicle type is the factors used for allocating different cost types to vehicle types through the use of traffic performance indicators such as traffic volume possibly weighted by vehicle weight or length. The DIW study launched moderate criticisms on the transparency of Danish weight related equivalence factors, and the cost allocation factors dates back to the late 1980'es. A review of these is recommendable.

Finally, the Danish average road infrastructure cost by vehicle type has been calculated. The calculations show that HGV are allocated 14 % of total infrastructure costs, a figure which is similar to the figure found by studies in other European countries.

7.6 Rail

The calculation of the total infrastructure costs for railway transport follows the approach applied for roads. The total infrastructure costs consist of

- depreciation of the railway network capital value;
- 6% interest of the total capital value;
- the total maintenance and operating costs.

The total infrastructure costs have to be allocated on freight and passenger traffic. The allocation is based on the conclusions in "*1. udgave af fuldt fordelt regnskab, DSB (prognose 1990)*" (Internal note from Banestyrelsen, then DSB):

Table 7.9 Allocation of cost items on freight and passenger traffic in year 2000.

Cost items	Allocation key	Freight	Passenger
Capital costs and interests:	Key figures[1)]	16.5%	83.5%
Operation and maintenance costs:	Train kilometres[)]	9.6%	90.4%

1) "*1. udgave af fuldt fordelt regnskab, DSB (prognose 1990)*" (Internal note from Banestyrelsen, then DSB)
2) Statistiske Efterretninger 2002:28 http://www.dst.dk/2148

Practically all freight transport by railway takes place on the Banestyrelsen's network. For passenger rail transport the average costs per train kilometre at Banestyrelsen's tracks are assumed to apply also to the rest of the network (Privatbanerne). Finally, for the sake of completeness, the infrastructure costs are allocated equally on electric and diesel propulsion according to train kilometres.

The Danish Railway Agency (Banestyrelsen) calculates the value of (their part) of the railway network and related material assets using the perpetual inventory approach. According to the Banestyrelsen's Annual Report 2000 the total material asset value amounted to 11.5 bill. DKK (primo) and the depreciations during the year to 584 mill. DKK. The operation and maintenance costs were 2,534 mill. DKK that year.

The resulting total infrastructure costs and their allocation on freight and passenger traffic are presented in the table below:

mill. DKK in 2000	Total	Freight	Passenger
Capital value	11,531	-	-
Depreciation	584	96	488
Interest	692	114	578
Operation and maintenance	1,078	103	975
Total costs	**2,354**	**313**	**2,040**
Traffic volumes (mill. train km)	60.776	5.805	54.971
Average costs (DKK per train km)	**39**	**54**	**37**
Total costs incl. private railways	**2,354**	**313**	**2,218**

7.7 References

Banestyrelsen: *1. udgave af fuldt fordelt regnskab, DSB (prognose 1990)* (Internal note from Banestyrelsen, formerly DSB)

Banestyrelsen: Virksomhedsregnskab 2000.

DIW, INFRAS, Max Herry and NERA (1998): Infrastructure Capital, Maintenance and Road Damage Cost for Different Heavy Goods Vehicles in the EU, Final Report. DIW, Berlin.

Trafikministeriet(1997): Samfundsøkonomisk omkostningseffektivitet i transportsektoren. Copenhagen.

Transportrådet(1995): Subsidiering af godstransport. Copenhagen.

Vejdirektoratet(1999): Vejkapitalen. Copenhagen.

Appendix A Traffic volumes for road and rail transport in 2000

(In Danish)

Trafikarbejdet i 2000

En opgørelse af det nationale trafikarbejde skal benyttes til to formål i dette projekt:

1. Det *samlede* trafikarbejde fordelt på de kategorier som hver transportform er opdelt på, skal benyttes opgørelse af de *totale* eksterne omkostninger for godstransporten i 3rd Report.

2. Den *relative* fordeling af trafikarbejdet på disse kategorier skal benyttes til at sammenveje de *marginale* eksterne omkostninger til repræsentative værdier for hver transportform, jf. 2nd Report.

Vejtrafikken

I "Transportsektorens energiforbrug og emissioner", Vejdirektoratet (2002), omtales varebiler over 2 tons som kilde til godstransportarbejde, mens varebiler under 2 tons betragtes som persontransportarbejde. Vejtrafikarbejdet er opgjort af Vejdirektoratet og kan ses i TabelA1.1.

TabelA1.1 Vejtrafikarbejdet 2000 (mio. vognkilometer)

(mio. vkm)	**Trafikarbejde**
Personbiler, hyrevogne og MC under 2 tons	38.669
Varebiler 2-3 tons	2.904
Lastbiler 3-6 tons	2.548
Lastbiler over 6 tons[1)]	1.526
By- og turistbusser	629
I alt	46.276

1) inkl. påhængs- og sættevogne samt renovationskørsel

Kilde: Vejdirektoratets hjemmeside, www.vd.dk

Som det kan ses af tabellen, ligger grænsen mellem vare- og lastbiler ligger ved 3 tons totalvægt i Vejdirektoratets opgørelse. I mange opgørelser som involverer sondring mellem vare- og lastbiler ligger grænsen ved 3,5 tons, fordi der kræves særligt kørekort til køretøjer over 3,5 tons. Denne undersøgelse benytter denne definition.

I Danmark var der i 2000 indregistreret 102.109 biler med en totalvægt mellem 3 og 3,5 tons, mens der kun var indregistreret 4899 køretøjer med en totalvægt mellem 3,5 og tons.[21] Det må således forventes at den langt overvejende andel

[21] Jf. Statistiske Efterretninger, Transport 2003:10, tabel 3 og 4.

af trafikarbejdet for køretøjer mellem 3 og 6 tons foretages af varebiler hvortil der kan anvendes almindeligt kørekort.

Alle lastbiler mellem 3,5 og 6 tons er derfor regnet som varebiler og fejlen herved vurderes at være ubetydelig. Således opgøres trafikarbejdet for varebiler i denne undersøgelse 5.452 mio. vognkilometer for 2000.

Lastbiler (over 6 tons) kørte 1.526 mio. vognkilometer, altså knap en tredjedel af varebilernes trafikarbejde, selv om lastbilerne står for langt den overvejende del af det indenlandske godstransportarbejde. Turist- og bybusser tilsammen kørte 629 mio. vognkilometer.

Der er ikke opdaterede data for luftfartstrafikken, men godstransportarbejdet med fly er ubetydeligt i det samlede indenlandske billede opgjort i tonkm. For skibstrafikken viser statistikken, at 2794 coastere anløb danske havne i 2000, mens det tilsvarende tal for containerskibe er 1728. Der findes kun tal for anløb, men ikke transportarbejde. Der er ikke på basis heraf foretaget en vurdering af fordelingen af trafikarbejdet ud fra antallet af anløb, da usikkerheden herved vil være for stor.

Togtrafikken
I følge opgørelser fra DSB blev der i 2000 kørt 62,5 mio. togkilometer med passagertog, mens trafikarbejdet med godstog var 5.4 mio. togkilometer. Fordelingen heraf på el- og dieseldrivkraft ses i TabelA1.2.

TabelA1.2 Fordelingen af trafikarbejdet med tog på drivmiddel og type 2000

	Trafikarbejde mio. togkm[1)]	El	Diesel	Total
Godstransport	5,4	4,7 %	3,3 %	8,0 %
Persontransport	62,5	33,3 %	58,7 %	92,0 %
Total	67,9	38,0 %	62,0 %	100 %

1) Eksklusiv transittrafik
Kilde: Oplysninger fra DSB og Danmarks Statistik

Vejtrafikarbejdets fordeling mellem land og by

Trafikkens påvirkninger er forskellige på landet og i byerne. Der er for eksempel flere uheld i byerne, og støj og forurening er også et større problem her, da befolkningstætheden er større. Derfor er det interessant at kende fordelingen af trafikarbejdet mellem land og by. Som det vil vise sig er det dog ikke helt entydigt hvordan denne skelnen kan og bør foretages.

Data om fordelingen af trafikarbejde mellem land og by fordelt på køretøjer kan belyses ved hjælp af data fra Trafikministeriets Rejsevaneundersøgelser, TU. TU data er en stikprøveundersøgelse hvor et tilfældigt valgt udsnit af befolkningen udspørges om deres transportadfærd. Fordelingen af persontransportarbejdet på by og land ud fra TU data ses i nedenstående tabel:

TabelA1.3 Fordelingen af persontransportarbejde på visse køretøjer og by/landdistrikt i TU data (pct.)

	Helt by	Mest by	Ligeligt	Mest land	Helt land	Total
MC, cykel og knallert	56,7%	10,2%	7,5%	20,7%	4,9%	100%
Personbil	14,9%	4,7%	13,2%	65,1%	8,0%	100%
Bus	33,9%	10,4%	10,4%	41,1%	4,2%	100%
Vare/lastbil	9,2%	4,7%	13,2%	65,1%	7,9%	100%

Kilde: TU data.

I TU data spørges for erhvervsrejser ikke til turens fordeling mellem by og land, hvorfor tabellen kun omfatter private rejser. Endvidere er tælleenheden personkilometer, mens den relevante opdeling for fordelingen af trafikkens eksterne omkostninger er køretøjskilometer.

TU data fremkommer på baggrund af telefoninterview angående respondentens rejseaktivitet en given dag. Hvad angår køretøjer[22] kan respondenten vælge mellem flere mulige, herunder samtlige de nævnte i tabellen. At lastbil og varevogn alligevel er slået sammen skyldes DTF og Vejdirektoratets præsentationsmæssige valg, som ikke kan omgøres uden adgang til grunddata.

Hvad angår fordelingen af turen på by og land[23] spørges respondenten: "Foregik turen hovedsagelig i byområde eller i landområde?" og kan herefter vælge mellem 5 muligheder: "Helt i byområde", "Mest i byområde", "Ligeligt i by- og landområde", "Mest i landområde" og "Helt i landområde". Disse svar kan naturligvis ikke give en eksakt fordeling, og opdelingen på transportarbejdet på by og land vil derfor være behæftet med nogen usikkerhed.

For **cykler og knallerter** er det oplagt at persontransportarbejdet og trafikarbejdet i store træk er ens, og at det i øvrigt er svært at forestille sig at eventuelle forskelle skulle samvariere med turens fordeling på by og land.

For **MC** er der muligvis en lidt større forskel mellem trafik- og persontransportarbejde, men her gør sig også gældende at der ikke umiddelbart er grund til at tro at denne skulle hænge sammen med fordelingen af turen på ny og land.

For **personbiler** er anvendt transportarbejdet for personbilfører, som må være stort set ækvivalent med trafikarbejdet med personbil.

For **bus** er vurderingen noget vanskeligere, idet belægningsprocenterne kan variere ganske meget. I "TEMA 2000, Teknisk rapport" (Trafikministeriet maj 2000) er det opgjort at bybusser kører med gennemsnitligt 12,6 passagerer, regionalbusser med 9,4, fjernbusser med 10,3 og turistbusser med 27 (sidstnævnte kører godt halvdelen af bussernes trafikarbejde). Turistbusserne er således væsentligt forskellige fra øvrige busser, men det er ikke umiddelbart til at vur-

[22] Se http://130.226.153.65/tu/VARIABLE/TUR/maxmid/variabelbeskrivelse.htm
[23] Se http://130.226.153.65/tu/VARIABLE/TUR/byland/variabelbeskrivelse.htm

dere om disse kører væsentligt anderledes i forhold til by/land end andre busser. Derfor antages det at forholdet for transportarbejde mellem by og land også kan anvendes til trafikarbejdet.[24]

For **varebiler** vurderes fordelingen af kørslen på by/land i TU data at være repræsentativ for den faktiske kørsel. En stor del af vare/lastbil-kørslen foregår i følge TU mest på landet, hvilket muligvis kan være en overvurdering for varebiler, idet lastbiler må tænkes at køre endnu mere på landet (hoved- og motorveje).

Datagrundlaget for **lastbiler** i TU data vurderes at være for spinkelt og næppe repræsentativt. Derfor er der i stedet taget udgangspunkt i Danmarks Statistiks tal for transport med lastbiler over 6 ton[25]. Her er trafikarbejdet opgjort på turlængder. For lastbiler må det antages at lange ture primært køres mellem byer, dvs. på hoved- og motorveje som for langt den største del ligger på landet. En stor del af de korte ture (mindre end 15 km) må imidlertid antages at være i bymæssig bebyggelse.

Jo længere turen er, jo mindre en del må antages at foregå i by. Dog må det forventet at langt de fleste ture starter og slutter i by. Det kan altså med rimelighed antages at nogle få kilometer af turen i gennemsnit som hovedregel vil foregå i bymæssig bebyggelse. I TabelA1.4 er opregnet et over- og underkants- samt et middelskøn over andelen af lastbilernes trafikarbejde i by.

TabelA1.4 Følsomhedsanalyser for bykørsel-andelen for lastbiler

	Underkants-skøn	**Middel-skøn**	Overkants-skøn
Minimum bykørsel	2 km	**4 km**	8 km
Turlængde (km) < 15	40%	**80%**	100%
15 - 29	10%	**40%**	50%
30 - 49	3%	**10%**	20%
50 <	0,5%	**1%**	4%
Samlet bykørsel (% af alle ture)	**5%**	**11%**	**20%**

Følsomhedsanalyserne viser at bykørslen for lastbiler formentlig udgør mellem 5 og 20 procent. De valgte parametre til middelskønnet giver at knap 11 procent af det nationale trafikarbejde med danske lastbiler over 6 tons foregår i by. Dette resultat afviger en del fra TEMA 2000, hvor det blev antaget at 27 pro-

[24] Af TabelA1.3 fremgår at der er en pukkel af transportarbejde "mest på landet", som kan tænkes at være turistbusser (som kører passagerer fra by til by, fx. skiturisme og éndagsture). Hvis dette er korrekt vil de gjorte antagelser overvurdere andelen af trafikarbejdet på landet for busser.

[25] Statistiske Efterretninger, Transport 2002:32.

cent af trafikarbejdet med lastbiler foregik i by. Det må understreges at det foreliggende statistiske grundlag er stærkt begrænset.

Fordelingen af trafikarbejdet mellem land og by for forskellige transportmidler er sammenfattet i TabelA1.5 på baggrund af de ovenfor fremlagte oplysninger. I opgørelsen er det for tallene med baggrund i TU data er det antaget at "Mest by" svarer til 75 procent af trafikarbejdet i by, 50 procent for "Ligeligt", og 25 procent for "Mest land".

TabelA1.5 Fordelingen af trafikarbejdet på by/land

	Trafikarbejde i by	Trafikarbejde på land
MC, cykel og knallert	73%	27%
Personbil	41%	59%
Bus	57%	43%
Varebil	36%	64%
Lastbil	11%	89%