Cost-benefit analysis on noise-reducing pavements

Danish Road Institute
Report 146
2005

Road Directorate
Danish Ministry of Transport and Energy

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Contents

Preface

The Road and Hydraulic Institute (DWW) in the Netherlands and the Danish Road Institute of the Danish Road Directorate (DRI) have established cooperation for the period 2004 to 2007 with the title the DRI-DWW Noise Abatement Program [25]. The goal is to carry out joint research and development in issues related to abatement of road traffic noise within the framework of the Dutch Noise Innovation Programme (the IPG program [4]). Seven main themes will be highlighted in this joint DRI-DWW research program on noise abatement which includes the following projects:

- Raveling of porous pavements
- Clogging of porous pavements
- Thin layer pavements
- Modified bitumen used for porous pavements
- CPX noise measurements
- Cost-benefit analysis
- Knowledge transfer

This report presents the Danish input to the project on cost-benefit and as such constitutes the Milestone M3 of this project.

Forord

DWW (The Road and Hydraulic Engineering Institute) i Holland og Vejteknisk Institut, Vejdirektoratet har indgået et samarbejde fra 2004 til 2007, som kaldes “DRI-DWW Noise Abatement Program”. Formålet med projektet er at udføre forskning og udvikling omkring reducering af trafikstøj indenfor det hollandske ”Noise Innovation Programme (the IPG program [4]). Der arbejdes med 7 hovedtemaer i dette forskningsprogram som omhandler følgende projekter:

- Stentab af åbne belægninger
- Tilstopning af åbne belægninger
- Tynde belægninger
- Modificeret bitumen brugt til tynde belægninger
- CPX støjmålinger
- Cost-benefit analyser
- Videnformidling

Denne rapport rummer det danske bidrag til projektet om cost-benefit og udgør som sådan Milestone M3 af dette projekt.

1. Introduction

In most of Europe there is increasing focus on noise from road traffic. However, in spite of 20 years of increasingly strict EU regulation of noise emission from motor vehicles [1], the noise levels along the roads have not decreased. In 2001 further steps to reduce noise were taken through a directive on noise from tires [2], and in 2002, a directive relating to the assessment and management of environmental noise was passed [3].

Whatever the effect of these initiatives may be, there is a need for further means of noise abatement. One of these means is noise-reducing pavements. In Danish and Dutch terminology, noise-reducing pavements are pavements on which noise levels from vehicles are lower than on dense asphalt concrete pavements or similar pavement types. Porous asphalt pavements and thin-layer pavements are the two types of noise reducing pavements in focus in this report. Porous pavements have been known to reduce noise for many years, and especially in the Netherlands this type of pavement is widely used. Thin-layer pavements are new as a means of noise reduction. This type of pavements usually reduces noise less than porous pavements but is also cheaper to lay and maintain. It is therefore relevant when deciding on means of noise abatement to systematically compare the costs and benefits of these two types of pavements and of other types of noise abatement. Such comparisons are the subject of this report, which is a part of the DRI-DWW Noise Abatement Programme.

The project description on cost-benefit analysis (CBA) [5] was finalized by the DRI in July 2004 after a discussion at a meeting in Roskilde/Denmark between members of the IPG staff at DWW and staff from the DRI. At a meeting in February 2005 in Delft/The Netherlands the aim was changed somewhat to direct the focus of the project at comparing Danish and Dutch results of CBA on noise reducing pavements.

Dutch experiences

Porous pavements are, as already mentioned, widely used in the Netherlands, where currently more than half of the motorways are paved with porous asphalt. The aim is to use porous asphalt on all motorways. Much research and development has been done on this type of pavements. One result of such development efforts is two-layer porous pavements, which are mainly used on urban roads, where one-layer porous asphalt tends to clog up and thereby have its noise reducing capacity reduced. On motorways, the cheaper, more durable and technically simpler one-layer porous asphalt is more common. In 2005 test have started in the Netherlands to investigate the possible use of thin layer pavements as a means of noise abatement on highways.

Danish experiences

In Denmark, tests of one-layer porous pavements were started around 1990 on a city street and a highway in a rural area [6, 7]. On the city street, the pavement clogged up and within two years, all noise reduction was gone. On the highway, the noise reduction was maintained throughout the lifetime of the pavement. In 1999, a test section of two-layer porous asphalt was laid on an urban road in Copenhagen [8]. As part of this project, the Øster Søgade project, cost benefit calculations were carried out comparing porous asphalt with noise barriers and facade insulation as means of noise abatement on three cases. The CBA showed the asphalt to be superior to the two alternatives as a means of noise abatement when it comes to cost-effectiveness.

In 2003, a proposal for a national strategy to reduce road traffic noise was presented [9]. As part of the work on this proposal, a socioeconomic comparison of various means of noise abatement was done. This comparison showed noise reducing pavements – both porous and thin-layer asphalt – to be very cost effective, with thin-layer pavements as the most effective of all means.

In 2004, a technical and socioeconomic analysis of the use of noise reducing pavements on the Motorring 3, a freeway in Copenhagen, was performed. The use of one-layer porous asphalt and a thin layer pavement was compared with a basis scenario of using a dense asphalt concrete. The analysis showed thin layer pavements to be the most cost-effective.

The aim of this project

Although there are differences in traffic conditions, society and climate, which may influence the result of socioeconomic evaluations of pavements, the Netherlands and Denmark are quite comparable countries. It is therefore interesting to compare the results of cost-benefit evaluations of using porous asphalt or thin layer pavements to see how and why the results differ. This report presents Danish methods and experiences, which is the Danish input for a later comparison of Dutch and Danish methods and results. The report is milestone M3 of the cost-benefit project in the DRI-DWW noise abatement program.

The contents of the report

Chapter 2 of this note presents the Danish guidelines for socioeconomic assessment of road traffic noise, and chapters 3 to 5 presents the cases from the Øster Søgade project, the national noise strategy and the analysis of using low-noise pavements on the Motorring 3.

2. Danish guidelines on socio-economic assessment

In 1999, the Danish Ministry of Finance published a guide to preparing socioeconomic assessment of consequences [12] of construction works etc. The aim of this is to achieve greater uniformity in socioeconomic assessments of initiatives in the traffic and energy sectors and in relation to investments in administration buildings and investments in the educational sector. The choice of cost-benefit analysis (CBA) or assessment of cost-effectiveness (CEA) depends on the characteristics of the initiative, but CBA is presented as the primary method [12].

The guidelines contain standards and principles for calculation of central parameters in the analyses. Valuation should be based on net present value using a calculation rate of 6 percent and a 20% tax cost factor to account for the costs to society due to financing through taxes. For projects with time horizons of more than 20 years the tax cost factor can be left out if a calculation rate of 7 percent is used.

Valuation of effects should be based on market prices. Noise is valuated by the hedonic method (house prices) based on a study from the 1970's. The values are updated with an index based on house prices. In 1999, the value of noise annoyance is 29.000 Dkk, approx. 3900 €, per NEF[1]. To this, a further 50 percent may be added for costs in relation to headaches, stress, loss of productivity etc. The ministry recommends using only the 29.000 in assessments, as this price in itself is higher than prices found in other studies and other countries. Further, it is argued that the additional effects represented by the 50 percent add-on may be included twice, as they may be included in the differences in house prices on which the 29.000 Dkk are based. This does not seem very likely as house prices are set for the time of the sale, where people have not yet lived in the house. Thus, they may be able to consider the annoyance caused by traffic noise but they will not know the long-time effects.

In 2003, the Ministry of Transport published a manual for socioeconomic analysis based on the above guidelines from the Ministry of Finance [13]. The assessment of noise is based on annoyance at dwellings whereas noise at occupational buildings and institutions is not included. Noise levels below 55 dB ($L_{Aeq,24h}$, free field values in front of the façade) are not included and there is no differentiation between day and night time noise. This relates to the Danish guideline value for road traffic noise at dwellings which is 55 dB ($L_{Aeq,24h}$,). These matters are all mentioned as possible themes for future development and improvement of the method.

2.1 The Noise Exposure Factor

The noise exposure factor (NEF – in Danish "Støjbelastningstal", "SBT"), presented in 1989 in a guideline from the Road Directorate [14], is the basis of all Danish cost-benefit analyses of noise from road and rail traffic. It is an expression of the accumulated noise load on all the dwellings in an area. It is calculated as the sum of the

[1] The NEF (Noise Exposure Factor) is described later in this chapter.

weighted noise loads on the individual dwellings in the area, so that dwellings with high noise levels weigh more than dwellings with less noise.

Calculations of the NEF is based on noise in three situations: inside the dwelling, outside the dwelling, and on outdoor areas in connection to the dwelling. The noise level outside the dwelling is calculated as free-field values on the facade and can be interpreted as the noise level to which the inhabitants are subjected when opening windows. The weight assigned to each of these situations depends on whether it is an ordinary dwelling or a weekend cottage. The weights can be seen in Table 2.1.

Table 2.1 Weight assigned to various situations when calculating NEF [14].

	Outside dwelling	Outdoor areas	Inside dwelling
Ordinary dwelling	.2	.2	.6
Weekend cottage etc.	.1	.3	.1

The NEF is based on a dose-response relationship given by:

$$\text{Annoyance factor} = 0.01 * 4.22^{0.1(L_{Aeq}-K)} \qquad (2.1)$$

Where $K = 16$ and $L_{Aeq} \geq 30$ dB for noise inside dwellings
$K = 41$ and $L_{Aeq} \geq 55$ dB for noise outside ordinary dwellings
$K = 36$ and $L_{Aeq} \geq 50$ dB for noise outside weekend cottages etc.

The dose-response relationship for noise outside ordinary dwellings is shown in Figure 2.1.

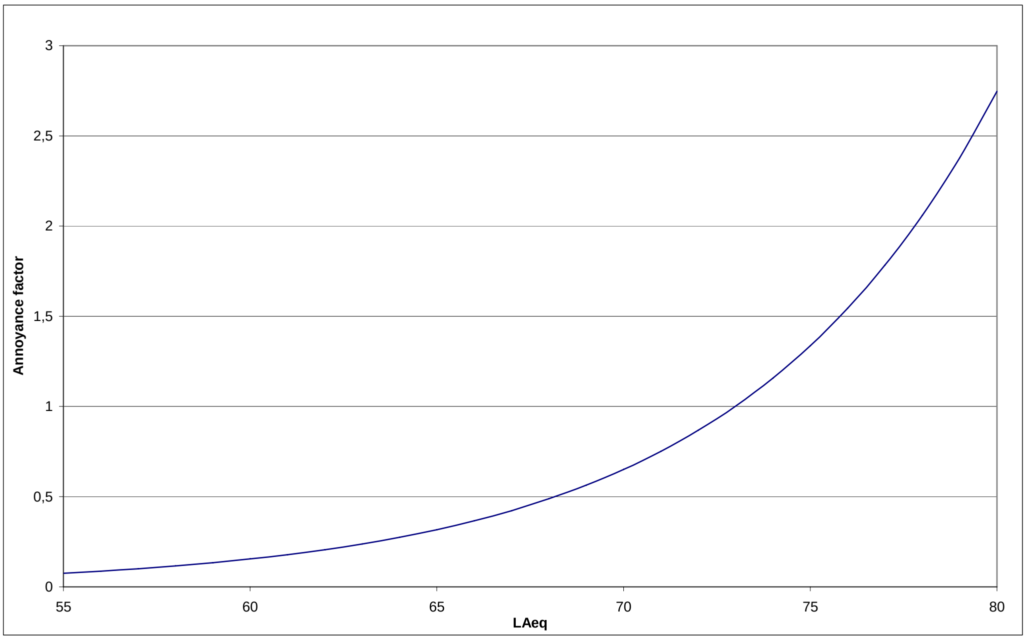

Figure 2.1 The NEF dose-response relationship for noise outside ordinary dwellings. Noise levels are free-field levels on the façade.

The number of dwellings subjected to noise in each of the three situations are calculated in intervals of 5 dB ($L_{Aeq,24h}$, free field values) and multiplied by the corresponding annoyance factor (Table 2.2). The resulting values are summed and multiplied by the corresponding weight from table 1 to give the NEF for the situation for the type of dwelling. Finally the total NEF is calculated by adding the values for each situation and each type of dwelling. A table for calculating the NEF for ordinary dwellings is shown in Table 2.3.

Put into a formula, the NEF can be calculated as:

$$NEF = \sum_k \sum_j w_{jk} \sum_i a_{ijk} N_{ijk}$$

where

k = ord, wec (ordinary dwelling, weekend cottage)
j = od, oa, in (outside dwelling, outdoor areas, onside dwelling)
i = 1, 2, 3, 4, 5, 6 (5-dB intervals starting at 30 dB, 55 dB or 50 dB, see table 2.2)
$w_{jk} = \{0.2, 0.2, 0.6\}_{k=ord}$, $\{0.1, 0.3, 0.1\}_{k=wec}$
a_{ijk} = 0.11, 0.22, 0.45, 0.93, 1.92, 3.94
N_{ijk} is the number of dwellings in the various 5-dB intervals

Table 2.2 Annoyance factor for the individual dwellings [14].

Noise level L_{Aeq}	Type of area			
	Ordinary dwelling		Weekend cottages etc.	
	Indoors	Outside	Indoors	Outside
30.1-35.0	0.11	-	0.11	-
35.1-40.0	0.22	-	0.22	-
40.1-45.0	0.45	-	0.45	-
45.1-50.0	0.93	-	0.93	-
50.1-55.0	1.92	-	1.92	0.11
55.1-60.0	3.94	0.11	3.94	0.22
60.1-65.0	-	0.22	-	0.45
65.1-70.0	-	0.45	-	0.93
70.1-75.0	-	0.93	-	1.92
75.1-80.0	-	1.92	-	3.94

Table 2.3 Example of a calculation of NEF for ordinary dwellings [14].

Outside dwelling			Outdoor areas			Inside dwelling		
L_{od}	No. of dwellings	Annoy. factor	L_{oa}	No. of dwellings	Annoy. factor	L_{in}	No. of dwellings	Annoy. Factor
65-70	163	0.45	65-70	37	0.45	40-45	163	0.45
60-65	207	0.22	60-65	15	0.22	35-40	207	0.22
55-60	123	0.11	55-60	19	0.11	30-35	123	0.11
Weight		0.2	Weight		0.2	Weight		0.6
NEF_{od}		26.5	NEF_{oa}		4.4	NEF_i		79.4
NEF_{ord} = 110.3								

The NEF makes it possible to compare the effects of for example noise reducing pavements and sound insulation in a manner that accounts for the differences in where the noise is reduced. This is an advantage compared to for example using a dB-reduction per dwelling to compare the noise effects of various scenarios. In practical use however, NEF-calculations are usually simplified using only the noise level outside the façade of dwellings and assigning this the weight 1, thus omitting the separate valuation of indoor noise and noise on outdoor areas. For indoor noise this usually will not influence the result significantly, as the facades of ordinary Danish dwellings have insulating effects of just about 25 dB, corresponding to the difference in K-values in (1). Thus, this simplification can be said to assume that the main outdoor areas are at the facade, on which the noise is calculated, so that the noise level outside the dwelling and on the facade are the same, and that the facade of the dwelling is standard, when it comes to sound insulation. Thus, by using this simplification it is not possibly to make a correct evaluation of the effect of establishing façade insulation as a tool for noise abatement, and evaluations of noise barriers may also be misleading due to actual differences in noise levels at the facade and on the outdoor areas.

Figure 2.1 shows that an annoyance factor of 1 corresponds to 73 dB. If the annoyance factor up to 73 dB is interpreted as the share of annoyed persons, which is the original intension[2], this opens for a comparison to other dose-response relationships. This is done in Figure 2.2, where the NEF dose-response relationship is compared to a relationship developed by Miedema and Oudshoorn as part of the work on an EU policy on environmental noise [15] and to the results of Larsen, Bendtsen and Mikkelsen from a large Danish survey [16]. The relationship of Miedema and Oudshoorn is based on L_{DEN}. As L_{DEN} along roads with normal traffic distributions is 2–3 dB higher than $L_{Aeq,24h}$, 2.5 dB has been added to the noise levels when calculating the percentage annoyed persons. The relationships of Larsen et al. indicate the percentage, who states being more than slightly annoyed. They have been adapted from second degree equations so that the relationship flattens out at a level corresponding to the lowest value.

Compared to the relationships of Miedema and Oudshoorn and of Larsen et al., the NEF annoyance factor seems to somewhat underestimate the annoyance at low noise levels and overestimate it at high noise levels. The latter may be explained by the fact that it is not an actual dose-response relationship with a natural maximum of 100 % annoyed. The factor used for characterizing the seriousness of the level of exposure should not necessarily have a maximum value of 1.00. All together the factor appears to give a fair representation of the experience of those subjected to the noise.

[2] The original dose-response relationship is not based on a single question of whether or not the respondent is annoyed by the noise. Instead the respondents have stated whether or not they are disturbed in a series of situations (sleeping, reading, at conversations, etc.), and if a respondent was disturbed in at least two situations, he or she was regarded as being annoyed [22].

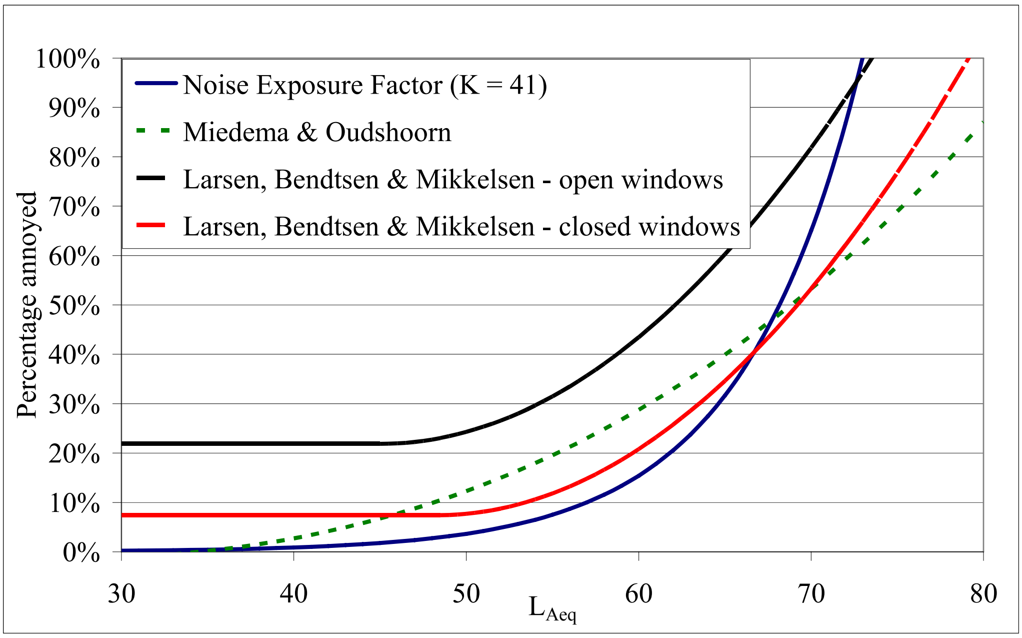

Figure 2.2 Comparison of dose-response relationships [14, 15, 16].

2.2 Key values on noise

In relation to the manual on socioeconomic analysis [13] the Ministry of Transport publishes a catalogue of key values for use in analyzes. In the 2003 version of this catalogue [17], which is the basis for the Motoring 3 analysis, the value put on noise is updated from the same survey as those used in the guide from the Ministry of Finance [12]. The value is 53,090 Dkk (7,126 €[3]) per NEF per year (2001 price level). This covers the annoyance caused by the noise, which is reflected in the house prices, and an additional 50 % (set arbitrarily) for indirect socioeconomic loss due to the negative effects of noise (long term health effects, reduced productivity etc.), which are not considered to be included in the reduced value of real estate.

In the 2004 version of the catalogue [18], the values put on noise are based on a new house price survey (the hedonic method) [19], which was carried out in preparation of the proposal for a Danish strategy to limit road traffic noise [9]. The value put on noise annoyance is 35,853 Dkk (4,812 €) per NEF (2003 price level). 23,018 Dkk (3,090 €) per NEF is added for costs to society due to health effects, which are not included in the reduced house prices. This is also based on studies carried out in preparation of the proposal for a noise strategy [20]. The total value of noise is thus 58,871 Dkk (7,902 €) per NEF.

The assessment of health effects is based on a study of the international literature on the subject. It is concluded that the documentation of actual health effects of noise from road traffic is weak and without clear evidence, and the estimates of costs are therefore done with reservation. There is some evidence of a connection between noise and ischaemic heart disease, although the risk factors related to it are uncertain. A risk factor of 1.09 per 5 dB increase in noise levels is adopted, and it is decided also

[3] 1 € = 7.45 Dkk.

to use this factor for hypertension. Other possible health effects are left out of the assessment of costs.

The assessment of costs is based on the cost-of-illness model. This leads to a conclusion that the direct costs to the health sector are 9.4 (5.5-13.5) million € per year. If all costs, including early deaths, sick leave etc., are included the estimated costs are 80 (40-120) or 456 (242-685) million € per year depending on whether estimates of loss of production through lost life are based on costs or willingness-to-pay. As the general Danish guideline is to use willingness-to-pay when possible [5], the higher estimate of health related costs is selected for the socioeconomic assessment of the various means of abatement.

In a report written for the Ministry of Transport [21] it is concluded from studies of other empirical evidence that the cost of 58,871 Dkk (7,902 €) is likely to be too high, and that considering all the uncertainties involved the correct cost is likely to be found in the interval 16,248 to 47,660 Dkk/NEF (2,181 – 6,397 €/NEF) per year (2003 price level). However, since previous cost-benefit analyses are based on the high costs and because of the uncertainty as to the correct cost, it is recommended to continue using the high cost level. This recommendation is repeated in the 2004 version of the catalogue of key values, but with the addition that sensitivity of the results should be calculated using the lower cost estimates [18]. Prices should be corrected to other price levels using the net price index.

The 2004 version of the catalogue also presents marginal costs of noise from transportation. These costs are originally developed in [21] from the studies in [19] and [20]. The costs per NEF per vehicle kilometer (2003 price level) are .25 Dkk (.0336 €) for HGVs, .17 Dkk (.0228 €) for LGVs[4], .12 Dkk (.0161 €) for cars and .55 Dkk (.0738 €) for buses. The uncertainty on these values is estimated to be minus 50% to plus 100%.

[4] HGV: Heavy Goods Vehicle. LGV: Light Goods Vehicle.

3. Case: The Øster Søgade project

In 1999 three test sections of two-layer porous pavements and a reference section of dense asphalt concrete were laid on Øster Søgade in Copenhagen. [8] An extensive measurement program including noise, surface characteristics and traffic safety is part of the project, which also includes a before-after questionnaire survey on noise annoyance among those living along the road and a socioeconomic comparison of porous asphalt, noise barriers and facade insulation as means of noise abatement. The socioeconomic comparison is presented in English in [27].

The socioeconomic comparison is based on three generalized and therefore somewhat simplified cases with one kilometer long roads, a 50-km/h 2-lane central city street, a 70-km/h 4 lane urban ring road and a 110-km/h 4-lane freeway running through a suburban area. Although simplified in some aspects, the three cases give a fair coverage of the wide span of situations where noise abatement may be necessary. The calculations are done for a 30-year period. Table 3.1 and Figures 3.1 to 3.3 present the results of the analysis.

Table 3.1 Costs (net present value) and effect of the 3 means of noise abatement.[27] The cost/dB/dwelling is based on linear averages of the noise reductions inside the dwellings.

		City street	Ring road	Freeway
Two-layer porous asphalt	30 year cost	€296,000	€360,000	€477,000
	dB reduction	4	5	6
	NEF reduction	85.7	153.2	179.4
	Cost/dB/dwelling	€111	€180	€183
	Cost/NEF	€3,454	€2,350	€2,659
Noise barriers	30 year cost	–	€1,335,000	€1,590,000
	dB reduction	–	0–12 (average: 3.9)	0–13 (average: 6.2)
	NEF reduction	–	75.5	195.3
	Cost/dB/dwelling	–	€858	€590
	Cost/NEF	–	€17,682	€8,141
Noise insulation	30 year cost	€2,685,000	€1,607,000	€2,890,000
	dB reduction	9	9	9
	NEF reduction	99.0	170.0	123.7
	Cost/dB/dwelling	€449	€448	€738
	Cost/NEF	€27,121	€9,453	€23,363

The assumed noise reductions of 4, 5 and 6 dB are too optimistic. The average reduction of the pavement on Øster Søgade has been 3 dB, and it is therefore more realistic to assume 3, 4 and 5 dB in each of the three cases. This will increase the cost per dB per dwelling to 148, 225 and 220 € for the three cases. Thus, the two-layer porous pavement is still far more cost-effective than the two other means of abatement.

The reductions in NEF have not been recalculated using the lower noise reductions, but as the differences in the original cases were quite big, the noise reducing pavement is still likely to have better cost-benefit relations than noise barriers and sound insulation.

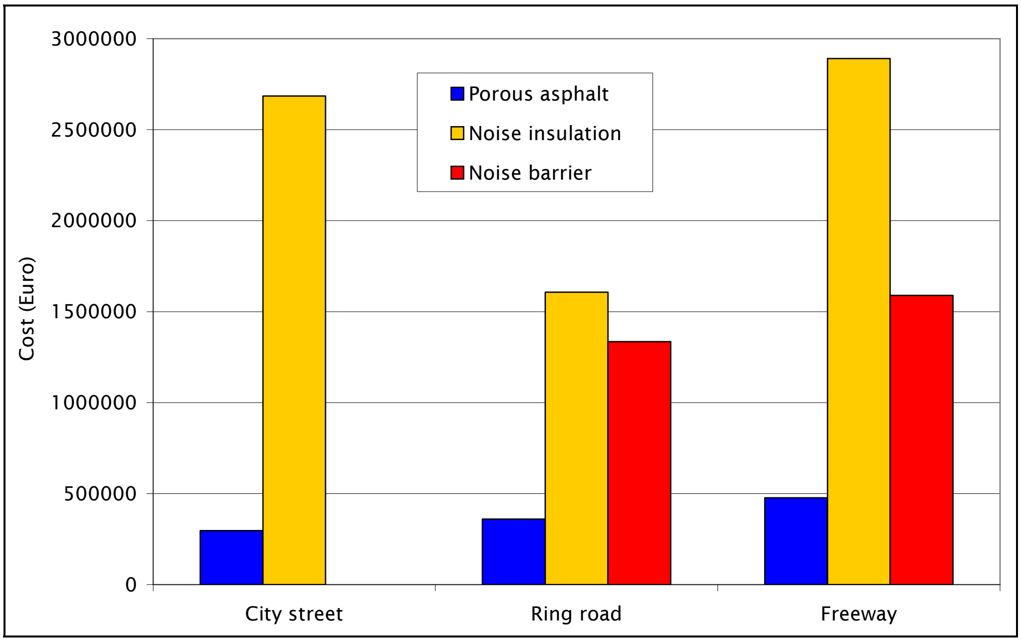

Figure 3.1 The costs of porous asphalt, noise insulation and noise barriers in the three cases. [27]

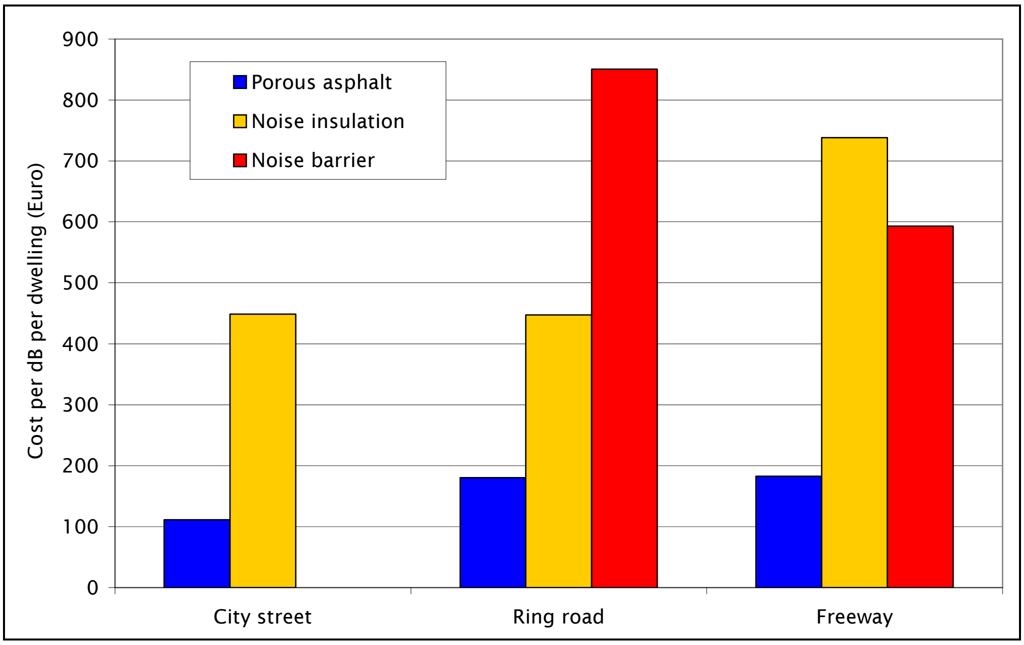

Figure 3.2 Cost per dB per dwelling for porous asphalt, noise insulation and noise barriers for each of the three cases. [27]

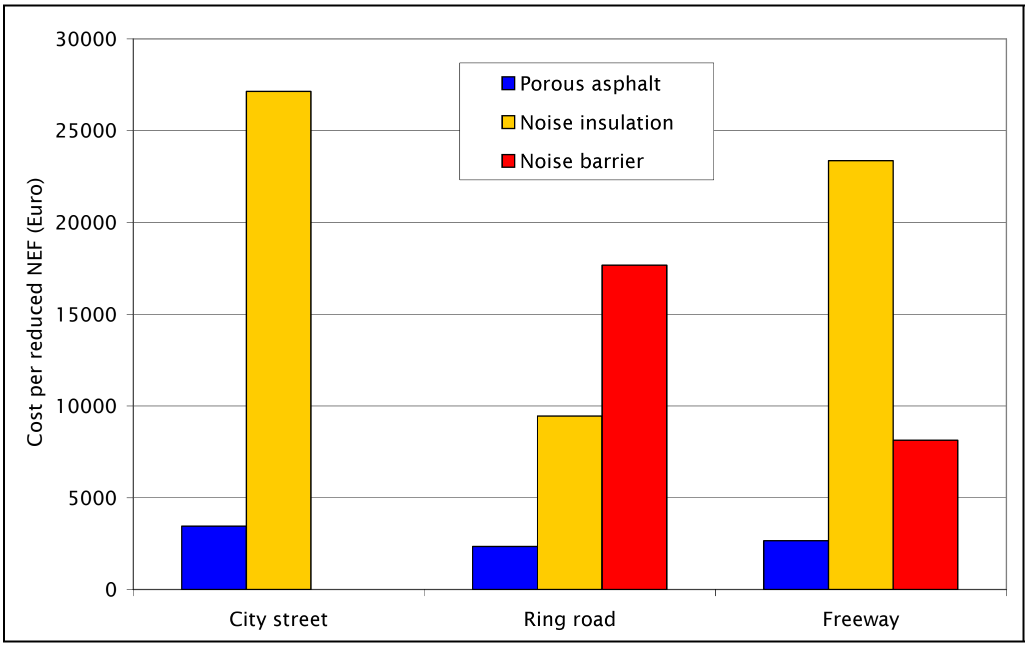

Figure 3.3 Cost per reduced NEF for porous asphalt, noise insulation and noise barriers for each of the three cases. [27]

As already stated, the cases are somewhat simplified. As the cases are thought up examples, all costs are based on general experiences from the Øster Søgade project and from other sources, and costs to drivers due to delays caused by pavement works are not included in the calculations. The latter may seriously influence the cost-benefit relation of the porous pavement.

4. Case: The Danish noise strategy

In 2003, the Danish Ministries of the Environment, Finance, Transport, the Interior and Health, Justice and Economic and Business Affairs published a proposal for a strategy to reduce noise from road traffic [9]. In preparation of the proposal, a socio-economic evaluation was done on various means of abatement of road traffic noise, including thin layer and two-layer porous pavements.

The socio-economic assessment of means of abatement is carried out for the means in Table 4.1, which shows the abatement potential, cost-effectiveness and annual net-benefit in 2020 of implementing the means. The year 2020 is chosen because it is the earliest that the full effect of a regulation of vehicles' noise emissions and less noisy tires can be seen.

The actual extent in kilometers of road or number of dwellings of widespread, moderate and limited use of the means in Table 4.1 varies depending on the applicability of the means. For the two types of pavements the extent is the same, so they are directly comparable. The extent of the use of the means is presented below.

Two-layer porous pavements and thin layer pavements:

- Widespread use: 2357 km urban roads, 1272 km major urban roads/highways and 325 km freeways.
- Moderate use: 477 km urban roads, 384 km major urban roads/highways and 4 km freeways.
- Limited use: 209 km urban roads, 102 km major urban roads/highways and 1.5 km freeways.

Noise barriers:

- Widespread use of 3 m or 4 m high noise barriers: Along 712 km roads.[5]
- Limited use of 3 m or 4 m high noise barriers: Along 164 km roads.[6]

Facade insulation:

- Widespread use: 135,000 dwellings (all dwellings with noise levels exceeding 65 dB).
- Moderate use: 19,400 dwellings (all dwellings with noise levels exceeding 70 dB).
- Limited use: 2,250 dwellings (all dwellings with noise levels exceeding 73 dB).

Speed reduction:

- Widespread use: Reduction of 10 km/h on approximately 1690 km roads with speed limits between 50 and 110 km/h.

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[5] It is not clear whether the barriers are to be put up on one or both sides of the road, but it appears to be on only one side.

[6] do.

- Limited use: Reduction of 10 km/h on approximately 164 km roads with speed limits between 50 and 110 km/h.

Regulation of vehicles:
- The full potential using present-day technology is assessed to be 1 dB, which is what the assessment is based on.

Promotion of low-noise tires:
- The full potential using present-day technology is assessed to be 1.3 dB on high speed roads and 0.7 dB on low speed urban roads.

Besides the means in Table 4.1, the report covers ban on heavy vehicles in certain zones at night, transfer of traffic to main roads and change in the use of buildings. These means are not included in the socio-economic assessment, as this has not been possible within the scope of the project.

Table 4.1 Socio-economic net-result of various means of abatement in 2020. [26]

Means of abatement	NEF reduction	Cost-effectiveness € / NEF / year	Mill. € per year
Regulation of vehicles' noise emissions	23,300	3,070	98
Promote use of less noisy tires	19,100	5,020	43
2-layer porous pavements • Widespread use • Moderate use • Limited use	 53,100 33,900 22,100	 2,540 850 460	 253 219 151
Thin layer noise reducing pavements • Widespread use • Moderate use • Limited use	29,200 19,000 12,600	190 50 30	208 137 91
Speed reduction • Widespread use • Limited use	 22,100 15,600	 9,280 4,720	 -44 40
Noise barriers • 3 m – widespread use • 3 m – limited use • 4 m – widespread use • 4 m – limited use	 9,700 6,700 10,600 7,300	 15,180 5,030 16,980 5,620	 -76 15 -102 12
Facade insulation • Widespread use • Moderate use • Limited use	 50,900 12,300 2,200	 1,140 680 440	 165 46 8.5

Table 4.1 shows the 2-layer porous pavement to have a considerably higher annual net-value than the thin layer noise reducing pavements in spite of the fact that the con-

struction and operating costs related to porous pavements are considerably higher than those related to thin layer noise reducing pavements. For thin layer pavements the construction costs are estimated to be 15 percent higher than those of dense asphalt concrete pavements. All operating costs are estimated to be the same for thin layer and dense asphalt concrete pavements.

Compared to this, 2-layer porous pavements involve considerable extra costs for construction, cleaning and winter maintenance, and a shorter expected lifetime (7.5 vs. 15 years) of the top layer. No costs or benefits from positive or negative effects on traffic are included in the analysis. The costs of porous asphalt used in [26] are originally from [8].

The expected noise reducing potentials of the two pavements are 3, 4 and 5 dB for the porous pavement and 1.5, 2 and 2 dB for the thin layer noise reducing pavements at 50, 70 and 110 km/h respectively, compared with dense asphalt concrete.

As it is the case for the noise reducing pavements, facade insulation yields higher values with increasing use, whereas barriers and speed reductions are only cost-effective as means of abatement if the use is limited to the most noise exposed and best suited locations.

Figure 4.1 shows the abatement potential and cost-effectiveness of the various means of abatement. For facade insulation the break-even is 40 percent lower than for the other means of abatement as the noise is only reduced inside the dwelling, and only with closed windows. This reduction is in accordance with the weights used for ordinary dwellings when calculating the NEF (see chapter 2).

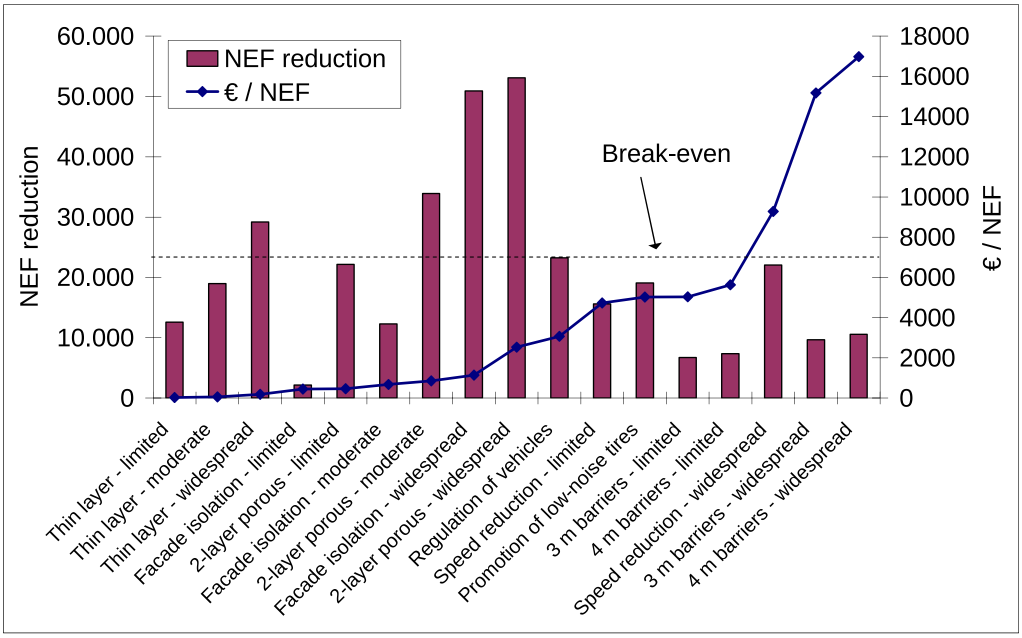

Figure 4.1 Effect and cost-effectiveness of the various means of abatement in 2020. The break-even is 40 % lower for facade insulation than for the other means of abatement. [26]

5. Case: Motorring 3

The Danish case for cost-benefit assessment of noise reducing pavements is based on the enlargement of the Motorring 3 (M3) in Copenhagen. The M3 is a motorway, which functions as a ring road around Copenhagen as well as being part of the E47/E55, which connects the ferries to Sweden in Elsinore with the ferries to Germany in Rødby as well as to the E20, which leads across the Great Belt to Funen and Jutland and across the Sound to Sweden. Being the only ring road around Copenhagen, which is built fully as a motorway, the AADT on the two lanes in each direction is as high as 75,000 vehicles per day. Congestions are therefore frequent, and during rush hours traveling speeds of 25-30 km/h are normal. The alternatives, the Ring 3 and the Ring 4 – which is partly motorway – are also congested, and the drivers therefore have little choice in their selection of a route to drive.

In order to improve the traffic situation, it has been decided to widen the M3 from four to six lanes. As part of the planning of the extension, an environmental impact assessment (EIA) has been carried out, including noise mappings and planning of noise abatement measures. The Road Directorate, who is responsible for the extension, has made a great effort to inform and hear the neighbors of the road. Together with the natural interest of the neighbors, this has lead to public focus on the traffic noise situation after the extension, and following this to considerations in the Road Directorate and to public demands in the media for supplementing the planned noise barriers with low-noise road surfaces. As a result, the Danish Road Institute has carried out a technical and socioeconomic assessment of using one-layer porous asphalt or thin layer pavements as means of noise abatement on the M3 [23].

A two-layer porous pavement was also considered. Based on Dutch recommendations [7] considering the more complicated laying procedure and maintenance, the result of the technical survey was a recommendation not to use such a pavement on the M3. Two-layer porous pavements are therefore not considered in the cost-benefit analysis.

5.1 Basis of the cost-benefit analysis

The basis for the cost-benefit assessment of the choice of pavement is the M3 after the extension. Therefore, the socioeconomic assessment only includes differences in costs and benefits related to the construction and maintenance of the pavements and not possible savings from using lower noise barriers. Likewise all costs which are independent of the choice of pavement, such as air pollution and time savings due to less congestion on the widened road, are omitted from the calculations.

The analysis is based on data prepared for a socioeconomic assessment of highway projects in the Greater Copenhagen area [24] adjusted according to the guidelines in [13]. The assessment is based on net present value (NPV) in the opening year 2009 calculated in 2002 price level. Calculations are done for a 30-year period using an interest rate of 6 percent and including a 20 % dead-weight loss from financing through

[7] Gebert van Bochove, Heijmans Infrastructuur.

taxes. From 2020 onwards calculations are based on constant positive and negative effects. In practice this means that traffic levels on the M3 are considered to be constant from this time. From 2009 to 2020 an annual increase of 1.5 percent in traffic levels is expected. An exchange rate of 1 € = 7.45 Dkk is used for the conversion of costs and benefits from Danish kroner into Euro.

Costs and benefits are assessed for:
- laying of pavement
- change of pavement
- establishing special winter maintenance and traffic management system in the case with porous pavement
- special alert and readiness in case of glaze and snowfall in the case with porous pavement
- cleaning of porous pavement
- extra delays to drivers due to road works
- benefits to those living along the road from reduced noise levels.

Initial investments in pavements, winter maintenance, etc. are set for 2008. Later pavement changes and renewal of equipment for winter maintenance are calculated as part of the service costs. All other effects are calculated for a thirty-year period from 2009 to 2038. After 30 years the remaining value of the pavements are calculated based on the remaining lifetime. The lifetime of a pavement is defined as the period in which the pavement meets all essential demands to its functionality, that is, both the physical lifetime and in relation to noise reduction.

5.2 Pavement costs

Calculations of pavement costs are based on laying and changing surface courses on the full 575,000 m^2 of carriageways and ramps, including on the 100,000 m^2 of the emergency lanes[8]. Due to problems with durability, porous pavements are not used on ramps, but the noise reducing effect of the pavement decreases accordingly, so both costs and benefits are reduced. It is assumed that these reductions are of the same magnitude and therefore will not affect the result of the CBA.

The construction costs and the costs of renewal of the surface courses are presented in Table 5.1. The renewals are assumed to take ten weeks distributed on two five week periods in two consecutive years. The costs of renewal include establishing work places, preparatory work and road marking. On the porous pavement surface dressing of the emergency lane is also included.

[8] The main part of [23] states the total area of the M3 to be 575,000 m^2 including emergency lanes and ramps. This is the area used for calculations of the pavement costs. In the appendix on the need for special winter maintenance of porous pavements, however, the calculations are based on an assessed area of 500,000 m^2 including emergency lanes and ramps. This is the basis for the calculation of the costs of winter maintenance.

Table 5.1 Construction costs and costs of renewal of pavements on M3 [23].

	Expected lifetime	Construction costs per m^2	Year of construction	Renewal of surface course per m^2	Year of renewal
Dense asphalt concrete	15 years	45 Dkk 6.0 €	2008	70 Dkk 9.4 €	2023 / 2024
Thin layer pavement	12 years	50 Dkk 6.7 €	2008	75 Dkk 10.1 €	2020 / 2021 2032 / 2033
One-layer porous asphalt	9 years	60 Dkk 8.1 €	2008	90 Dkk 12.1 €	2017 / 2018 2026 / 2027 2035 / 2036

The expected lifetimes of the surface courses of the thin-layer and porous pavements are assessed on the basis of international experiences and considerations of the Danish winter weather. On the porous pavement it is considered that there locally may be places where water remains in the pavement and freezes, thus speeding up the breaking down of the pavement. It is also considered that the pavement may clog up and thus loose its noise reducing characteristics, which will necessitate a renewal of the surface course. All together this leads to an expected lifetime of 9 years for the porous pavement, although Dutch experiences according to [23] indicate a lifetime of 12 years.

Table 5.2 presents the total extra construction costs and costs of renewal of the surface courses of the thin layer and the porous pavement over the 30-year period. The necessary renewal of the dense asphalt concrete pavement in 2038/2039 is disregarded when calculating the remaining values.

Table 5.2 Net present value in 2009 of difference in construction costs, costs of renewal of surface course and remaining value after 30 years between the noise reducing pavements and the stone mastic of the main project.[9]

Mill. Dkk / Mill. € (2002 price level)	Construction costs	Costs of renewal of surface course	Remaining value in 2039	Total extra costs over 30 years
Thin layer pavement	3.7 / .50	18.9 / 2.54	4.1 / .55	18.4 / 2.47
One-layer porous asphalt	11.0 / 1.48	52.8 / 7.09	6.6 / .89	57.2 / 7.68

It is clear that the shorter expected lifetime of the noise reducing pavements – especially the porous pavement – contributes significantly to the overall costs of the pavements due to the more frequent renewals of the surface course. The pavement renewals are regarded as service costs in the following.

[9] The figures are reconstructed based on the figures in Table 5.1 with the aid of TetraPlan, who did the original socioeconomic calculations.

5.3 Costs of winter maintenance

The cost of winter maintenance of the thin layer pavement is the same as for the stone mastic pavement of the main project. On the porous pavement there are significant extra costs because such pavements are more exposed to drops in air temperature, and because the porous structure leads water and with it also salt away from the road surface[10].

Due to the larger surface area, the surface temperature of porous pavements will drop below 0 °C faster than on dense surfaces when air temperature drops. This calls for shorter response time for salting. The porous pavement stays cold for longer time, partly because it during the cooling process reaches a lower temperature than the dense pavements and partly because the pores often will contain water, which delays the warming up. The fast cooling and lower general temperature of the porous pavement leads to more shifts across the freezing point than on dense pavements. This is of great importance in Denmark, where temperatures during winter often are close to 0°C. This leads to a greater demand for personnel and equipment for salting.

In situations with snow or freezing rain the ability of porous pavements to lead away water makes preventive salting difficult. In the case of snow there is also a risk of creating a freezing mixture in the pores of the pavement, so that the pavement temperature is reduced further. Problems with both snow and freezing rain may to some extent be mitigated by closing lanes so that traffic is concentrated on one lane in each direction. In any case, both snow and freezing rain will require more personnel and equipment for salting than dense pavements do.

The assessment of the need for extra salting is based on the principle that the use of porous pavements may not lead to serious accidents which could have been avoided by different planning. The calculations are therefore always done "on the safe side". All in all the disadvantages related to winter maintenance of a porous pavement on the M3 can be summarized as follows:

- The number of situations where preventive salting is necessary can be expected to increase by fifty percent – from 80 to 120 times per year.
- Because the periods where salting is necessary will be longer and occur faster and at other times than on dense pavements, snowplows and salt spreaders need shorter reaction times. This increases the need for maintenance equipment. The need also increases because it will be necessary to spread fifty percent more salt in each drive-through.
- The problems in relation to snow means that the plows need to run at shorter intervals.
- Equipment is needed to warn drivers of freezing rain and maybe also to decrease the number of active lanes.
- It may be expected that the whole road section will have to be closed for a short period once or twice every year.

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[10] This section on the need for winter maintenance on porous pavements is based on Appendix 1 in [23].

Today the whole section[11] and a little extra at one end is maintained by two salt spreaders and four snowplows. In addition to this 12 ramps are maintained by equipment in service on other routes. This need for equipment and personnel is expected to be doubled on a
widened M3 with porous asphalt. Of the extra equipment one plow can be ascribed to the widened road. The remaining extra equipment is due to the use of porous asphalt.

The amount of salt used is expected to increase due to a fifty percent increase in the number of times salting is needed and a fifty percent increase in the amount of salt spread in each drive-through. It will also be necessary to spread salt on the emergency lane. All together this results in use of 810 tons of extra salt.

It is judged that there is a need for two extra road weather stations along the M3, and that intensive use of a road surface monitoring vehicle will be necessary before the first season. The need is estimated to ten runs with the monitoring vehicle. This should be supplemented by extra runs every year. In addition to this it is estimated that there is a need for patrolling the section the first five years until experience with winter maintenance on the new pavement has been attained. After this the extent of patrolling will decrease.

20 electronic information boards – one at each end of the section and one at each drive-on ramp – is necessary to warn drivers of glazing and inform them about special speed limits and limitations in the use of lanes.

The unit costs of equipment and service for winter maintenance are shown in Table 5.3. Table 5.4 presents the overall extra costs of the winter maintenance throughout the 30 year period.

[11] The road is 16 km. long and at present has a total area of approximately 400.000 m^2. This is assumed to increase to approximately 500.000 m^2.

Table 5.3 Unit costs of equipment and service for extra winter maintenance [23].

	Number	Unit price (Dkk / €)	Lifetime (years)	Years of expense
Equipment:				
- salt spreader	4[12]	400,000 / 54,000	12[13]	2008, 2020, 2032
- snowplow	3	120,000 / 16,000	12	2008, 2020, 2032
Service costs to contractor:				
- annual fee, salting	2	50,000 / 6,700		Annually
- annual fee, snow clearing	3	50,000 / 6,700		Annually
- fee per call, salting	320	2,500 / 340		Annually
- hourly fee , snow clearing	360	650 / 87		Annually
Salt:				
- purchase	810 tons	300 / 40		Annually[14]
- processing and storing		10,000 / 1,300		Annually
Road weather stations:				
- purchase	2	150,000 / 20,000	12[15]	2008, 2020, 2032
- service	2	20,000 / 2,700		Annually
Electronic information boards:				
- purchase	20	50,000 / 6,700	12[16]	2008, 2020, 2032
- service	20	5,000 / 670		Annually
Patrolling		100,000 / 13,000		Annually[17]
Road surface monitoring vehicle	10	10,000 / 1,300		Annually[18]

[12] The appendix of [23] states a need for 2 extra salt spreaders, but the socioeconomic calculations are based on 4. This is compensate for the use of 12 years expected lifetime for all equipment in order to simplify the socioeconomic calculations.

[13] The appendix of [23] states the lifetime to be 8 years, but the socioeconomic calculations are based on 12 years.

[14] The socioeconomic calculations are based on an annual expense of 234,000 Dkk instead of 243,000 Dkk. This expense corresponds to use of 780 tons or to a price of 289 Dkk / 39 € per ton.

[15] The appendix of [23] states the lifetime to be 10 years, but the socioeconomic calculations are based on 12 years.

[16] do.

[17] The appendix of [23] assesses patrolling to be necessary at the stated extent for the first five years. The socioeconomic calculations, however, are based on the same extent throughout the 30-year calculation period.

[18] The appendix of [23] assesses patrolling to be necessary 10 times before the first season and to some extent in the following years. The socioeconomic calculations, however, are based on 10 times annually throughout the 30-year calculation period.

Table 5.4 Net present value in 2009 of establishing and service costs of extra winter maintenance in the case of using porous pavements.[19]

Mill. Dkk / Mill. € (2002 price level)	Establishing costs	Service costs	Remaining value in 2039	Total extra costs over 30 years
Thin layer pavement	-	-	-	-
One-layer porous asphalt	4.1 / .55	35.1 / 4.71	.2 / .03	39.0 / 5.24[20]

The extra costs of winter maintenance of porous asphalt are significant under conditions like the Danish winter. This contributes significantly to making the NPV of porous pavements lower than that of thin layer pavements.

However, two-layer porous pavements have been used on an urban road (speed limit 50 km/h) in Copenhagen since 1999 without special winter maintenance. This has not led to any problems. This may be because the speed is lower. This means less risk of loosing traction if the road is glazed, and it also reduces the severity of accidents, if any occur. The safety margin on such a road is therefore likely to be lower than on a freeway. It may, however, also indicate that the premises for the assessment of winter maintenance on the M3 with a porous pavement overestimate the problems regarding snow and freezing rain.

5.4 Costs of cleaning of the porous pavement

In order to keep the pores open the porous pavement needs to be cleaned. According to Dutch experiences with porous pavements on freeways cleaning is only necessary in the emergency lane, because pumping from the tires in wet weather cleans the ordinary lanes. However, with a cost of a cleaning which is assessed to be Dkk 400,000 / € 53,700 per year and a cleaning cost per square meter of approximately 1 Dkk / .13 €, the M3 analysis is based on cleaning of the entire surface. Including dead-weight loss the cost is Dkk 480,000 / € 64,400, which sums up to total service costs with a NPV of Dkk -7,000,000 / € 940,000 for the 30 year period.

5.5 Effects on traffic

Effects on traffic are delays due to renewal of pavements. For the porous pavement delays due to periods with reduced service caused by snow or freezing rain are not included as it was deemed to difficult to assess the likely number and duration of such occurrences. Instead the maximum number of such occurrences was calculated if the net present value still was to be positive. Increased capacity in wet weather in the case with porous asphalt is disregarded in the socioeconomic analyzes as this is considered too difficult to estimate.

[19] The figures are reconstructed based on the figures in Table 5.1 with the aid of TetraPlan, who did the original socioeconomic calculations.

[20] If the socioeconomic calculations are carried out according to the figures and estimated lifetimes of the appendix to [23], that is, without the simplifications, the NPV is Dkk -36.7 mill. / € -4.93 mill.

The values of time for vehicles used for calculating the costs of delays are presented in Table 5.5. In the calculations the values are set to increase by 1.8 percent per year corresponding to the growth in the Danish gross national product.

Table 5.5 Values of time for various types of vehicles and trip purposes [17].

	Costs	
	Dkk / hour	€ / hour
Passenger car		
• commuter	62	8.3
• occupational	269.1	36.1
• other	48	6.4
Light goods vehicles	198	26.6
Heavy goods vehicles	279	37.4

The calculations are based on predictions of traffic levels in 2010. Pavement works are set to take 10 weeks evenly distributed on two consecutive summer holiday periods. During these two periods there will be four lanes open with a speed limit of 80 km/h as opposed to 6 lanes and 90-110 km/h normally.

The NPV of the extra costs to road users due to the more frequent renewals of the two noise reducing pavements as compared with a SMA pavement are Dkk -35.8 mill. / € -4.81 mill. for the thin layer pavement and Dkk -71.7 mill. / € -9.62 mill. for the one-layer porous pavement.

The calculations of the maximum number of occurrences of especially problematic periods of freezing rain or snowfalls if the NPV for the porous pavement is still to be positive are based on periods of 6 hours starting at the beginning of a peak hour where it is necessary to reduce traffic to one lane in each direction at a speed of 50 km/h. All other roads – without porous pavements – are expected to be as passable as they usually are.

If the noise reducing effect of the pavement is 3 dB, the maximum number of such occurrences is 2 times per year. If the effect is 4 dB, the NPV is still positive in the case of 4 occurrences per year.

It is evident that the socioeconomic benefit of using noise reducing pavements on roads with traffic loads close to the total capacity is highly dependable on the lifetime of the pavements, not only because of the extra costs for laying pavements but also because of the delays such asphalt works cause to road users.

5.6 Noise benefits

The thin layer pavement is expected to reduce noise by 2 dB compared to the reference pavement, and the porous pavement is expected to reduce noise by 3 dB. In the analysis it is considered that the noise reduction of the thin layer pavement may only be 1 dB, and that the reduction of the porous pavement may be as high as 4 dB.

The economic benefits from using noise reducing pavements are calculated based on the NEF. The calculations are done for noise reductions of 1-4 dB. The results of the NEF calculations are presented in Table 5.6, and Table 5.7 presents the economic benefit of the noise reductions. The background for these calculations is a noise mapping of all the homes affected by noise levels from the freeway exceeding 55 dB in the initial situation after the enlargement of the freeway with a standard pavement (SMA with 11 mm aggregate)

Table 5.6 Results of using noise reducing pavements on the noise exposure along the M3. The results are given as the number of dwellings exposed to different noise levels and the corresponding noise exposure factor (NEF). [23]

Scenario	No. of noise exposed dwellings and weekend cottages				Total	NEF	ΔNEF
	55-59	60-64	65-69	≥70			
Main	4,343	1,815	292	34	6,484	1,040	0
-1 dB	3,811	1,788	197	34	5,830	933	107
-2 dB	3,285	1,705	196	34	5,220	856	184
-3 dB	3,165	1,376	189	34	4,764	768	272
-4 dB	2,860	1,368	188	34	4,450	732	308

Table 5.7 Value of noise reductions along the M3 expressed as the annual value and the net present value in 2009. [23]

Scenario	ΔNEF	Value of noise reduction (2001 prices)		NPV (2002 prices)	
		Mill. Dkk annual.	Mill. € annually	Mill. Dkk	Mill. €
-1 dB	107	5.7	.77	84.9	11.40
-2 dB	184	9.7	1.30	146.0	19.60
-3 dB	272	14.4	1.93	215.8	28.97
-4 dB	308	16.4	2.20	244.3	32.79

The noise benefit of using the thin layer pavement with a noise reduction of 2 dB is expected to be Dkk 146 mill. / € 19.6 mill. but may only be Dkk 84.9 mill. / € 11.4 mill. if the pavement is less noise reducing than expected (noise reduction only 1 dB). For the one-layer porous pavement with a noise reduction of 3 dB the expected benefit is Dkk 215.8 mill. / € 29.0 mill. but it may be as high as Dkk 244.3 mill. / € 32.8 mill. if the noise reducing effect is higher than expected (noise reduction 4 dB).

5.7 Results of the cost-benefit analysis

The result of the cost-benefit analysis is shown in Table 5.8. The net present value (NPV) for the thin layer pavement with the expected noise reduction of 2 dB is higher than that of the one-layer porous asphalt no mater if the noise reduction is 3 or 4 dB. If, on the other hand, the noise reduction of the thin layer pavement is only 1 dB, the NPV is lower than that of the porous pavement in both cases.

Table 5.8 Results of the cost benefit analysis on the M3. () indicates NPV if the noise reducing effect of the pavements differs from the expected.

Net Present Value (2002 prices)	Thin layer		Porous Pavement	
	Mill. Dkk	Mill. €	Mill. Dkk	Mill. €
Construction costs	**-3.7**	**-.50**	**-15.1**	**-2.03**
• Surface course		-.50	-11.0	-1.48
• Special winter maintenance			-4.1	-.55
Service costs	**-18.9**	**-2.54**	**-94.8**	**-12.72**
• Renewal of surface course	-18.9	-2.54	-52.8	-7.09
• Special winter maintenance			-35.1	-4.71
• Cleaning of pavement			-7.0	-.94
Remaining value	**4.1**	**.55**	**6.8**	**.91**
• Surface course	4.1	.55	6.6	.89
• Winter maintenance			.2	.03
Costs to drivers	**-35.8**	**-4.81**	**-71.7**	**-9.62**
Noise benefit	**146.0** (84.9)	**19.60** (11.40)	**215.8** (244.3)	**28.97** (32.79)
Net present value	**91.7** (30.6)	**12.31** (4.11)	**41.0** (69.5)	**5.50** (9.33)

The expected shorter lifetime of the porous pavement (9 years compared to 12 years for the thin layer pavement and 15 years for the ordinary SMA) has a significant influence on the result of the CBA. Both the costs of renewal of the surface course and the costs to drivers due to delays during periods with road works are significantly higher for the porous pavement than for the thin layer pavement. Porous pavements are more expensive to lay than thin layer pavements, but the main increase in service costs is due to the more frequent renewal of pavements. This is also seen in [23] where the NPV of the porous pavement with a lifetime of 12 years and a noise reduction of 3 dB is shown to be Dkk 101 mill. / € 13.56 mill. This is higher than the NPV of the thin layer pavement which as seen in Table 4.8 is Dkk 91.7 mill. / € 12.31 mill.

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Nr. No.	Titel/Title/Shortcut	Forfatter/Author
128	Viden om drift af veje	Gregers Hildebrand Charles Lykke Hansen SvendKold Johansen Birger Roland Jensen BjarneSchmidt, Jørn Raaberg
129	Crushed concrete from building demolition is a high quality material for road construction	Knud A. Pihl Ole Milvang-Jensen Flemming Berg
130	Ubundne bærelag af knust beton - efter europæiske standarder	Knud A. Pihl Flemming Berg Ole Milvang-Jensen
131	Ubundne bærelag af knust tegl - efter europæiske standarder	Knud A. Pihl Flemming Berg Ole Milvang-Jensen
132	Ubundne bærelag af knust asfalt - efter europæiske standarder	Knud A. Pihl Flemming Berg Ole Milvang-Jensen
133	Bundsikring af forbrændingsslagge - efter europæiske standarder	Knud A. Pihl Flemming Berg Ole Milvang-Jensen
134	Noise emission from 4000 vehicle pass-bys - an Inter-Noise 2004 presentation	Bent Andersen Hans Bendtsen
135	Thin open layers as noise reducing pavements - an Inter-Noise 2004 presentation	Hans Bendtsen Bent Andersen
136	European co-operation in COST 347 - Bringing ALT activities closer together	Gregers Hildebrand Michael E. Nunn
137	Traffic management and noise reducing pavements - Recommendations on additional noise reducing measures	Hans Bendtsen Jürgen Haberl, Johan Litzka Ernst Pucher Ulf Sandberg Greg Watts
138	Mechanistic Design of Semi-Rigid Pavements - An Incremental Approach	Finn Thøgersen Christian Busch Anders Henrichsen
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140	Indbygning af skrivekridt - Et fuldskalaforsøg	Sten Thorsen Poul Panduro Knud A. Pihl
141	Noise reducing pavements - State of the art in Denmark	Hans Bendtsen Bent Andersen
142	Economic assessment of traffic noise in planning – Danish experiences	Lars Ellebjerg Larsen Hans Bendtsen
143	Organising urban noise abatement - New ideas	Hans Bendtsen Lene Nøhr Michelsen Brian Kristensen Lars Ellebjerg Larsen
144	Two-layer porous asphalt - for urban roads	Hans Bendtsen Bent Andersen Jørn Raaberg Lars Ellebjerg Larsen Larsen, Jørgen Kragh
145	Thin noise reducing pavements - Experiences	Hans Bendtsen Bent Andersen
146	Cost-benefit analysis on noise-reducing pavements	Lars Ellebjerg Larsen

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