Value for Money in Road Traffic Noise Abatement

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ABSTRACT

Road traffic noise is a significant environmental problem. The purpose of this work by CEDR Project Group Road Noise 2, has been to provide support to National Road Authorities (NRAs) when developing strategies and plans for future noise abatement in order to reduce noise annoyance. To provide a recommendation on which strategy would be most beneficial to society in general, this project has focused on reduction in noise annoyance and the associated cost of implementing various noise abatement measures.

There are almost 100 million inhabitants in Europe annoyed by road traffic noise. With an investment of EUR 6 billion over a 20 year cycle in a range of different possible noise mitigation measures, it is calculated that the cost of reducing noise annoyance varies from EUR 16 to EUR 4200 per person per year. The findings clearly show that noise reduction at source (quieter vehicles) is much more cost-effective than treating noise at the receiver.

Keywords: Road traffic, noise reduction, cost-effective abatement measures, I-INCE Classification of Subjects Number(s): 52.3,67.1

1. INTRODUCTION

Over the years noise from road traffic has become a significant problem in our society. The increase in noise emissions is mainly due to a constant growth in vehicular traffic and the fact that noise generated by each car and its tyres has not been significantly reduced in the last 20-30 years. Urbanization and new roads also lead to an increase in exposure.

This study compares the effectiveness of different types of noise abatement measures to reduce noise annoyance in relation to the cost of each of these measures. The noise abatement measures investigated are noise barriers, façade insulation façade, quieter road surfaces and development and production of quieter vehicles. Also, tyre noise is considered, but lack of information on tyres has led to a different approach for tyres than for the other measures. Information concerning noise barriers, facade insulation and quieter road surfaces has been gathered and reviewed by the CEDR Project Group Road Noise 2 (CEDR RN2) to give the most updated information.

Noise limits for vehicles has been under discussion in the EU. The European Commission DG Enterprise and Industry ordered a study which was undertaken by TNO Science and Industry on potential new noise limits and their associated effects on noise reduction and costs (7). The TNO report gives the best available data on noise reduction of vehicles and the actual effect alongside roads.

The purpose of this study has been to provide support for strategies, plans and stakeholder positions for future actions for cost effective solutions to reduce adverse noise effects. This way, more noise reduction can be achieved for every euro spent on noise abatement.

2. NOISE EXPOSURE IN EUROPE

Noise exposure data has been obtained from the European Environmental Agency (EEA) and the

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European Topic Centre on Land Use and Spatial Information (ETC LUSI). Data from EEA states that 51 % of inhabitants in agglomerations are exposed to noise above 55 dB L_{den}.

For noise exposure affecting all people in Europe, we have adjusted the distribution of noise exposure of agglomerations to reflect the fact that the total population of Europe is a little less noise exposed compared to people living in agglomerations. This approach is in accordance with a TNO report (7), where it is argued that 44 % of the population is exposed to noise levels above 55 dB L_{den} in total. Some roads have restrictions or very low traffic flow and some dwellings are quite far from the nearest road, therefore, as a consequence approximately 10 % of the population in Europe is hardly exposed to any traffic noise (7). No traffic noise exposure equate to exposure less than 40 dB L_{den}.

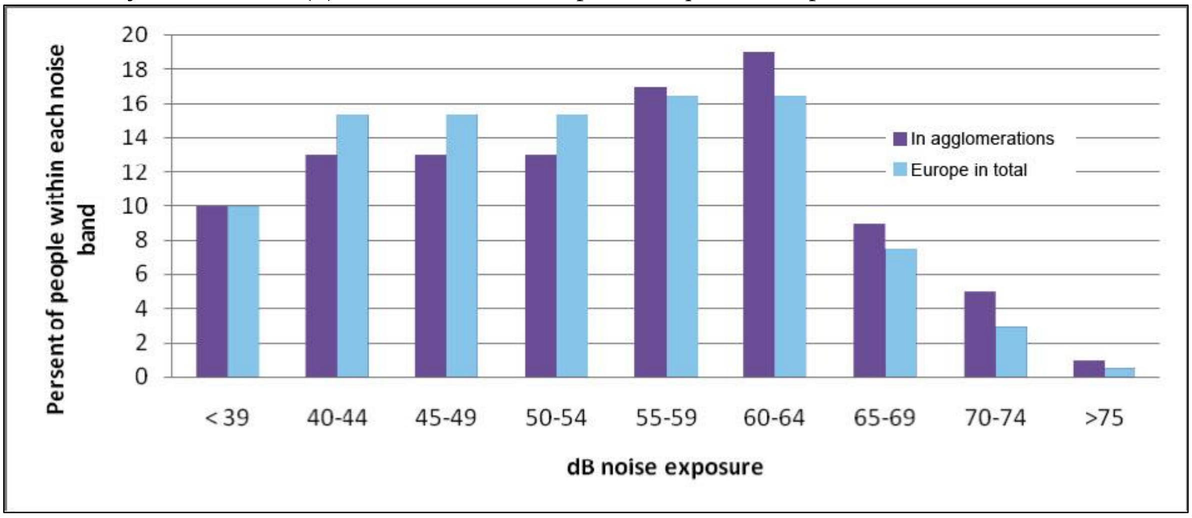

Figure 1 – Distribution of people (in percent) in noise bands inside agglomeration and for Europe in total.

For the calculations in this project the noise exposure distribution (in percent) of people living in agglomerations is used for calculation of measures mainly implemented in agglomerations or densely populated areas. The noise exposure distribution for all people of Europe is used for the calculations of benefits for quieter vehicles. This is because vehicles influence the entire road network and not only people living in agglomerations.

3. ANNOYANCE

It is not easy to find an exact monetary value when calculating the benefit of noise reduction, as it varies a lot between different countries. However, the degree of annoyance is less discussed. According to the World Health Organization, WHO, noise annoyance is widely accepted as an end-point of environmental noise that can be used as a basis for evaluating the impact of noise on the exposed population (9). By choosing annoyance as our measurement for noise impact, we restrict the noise problem to concern only those negatively affected by noise at a given noise level.

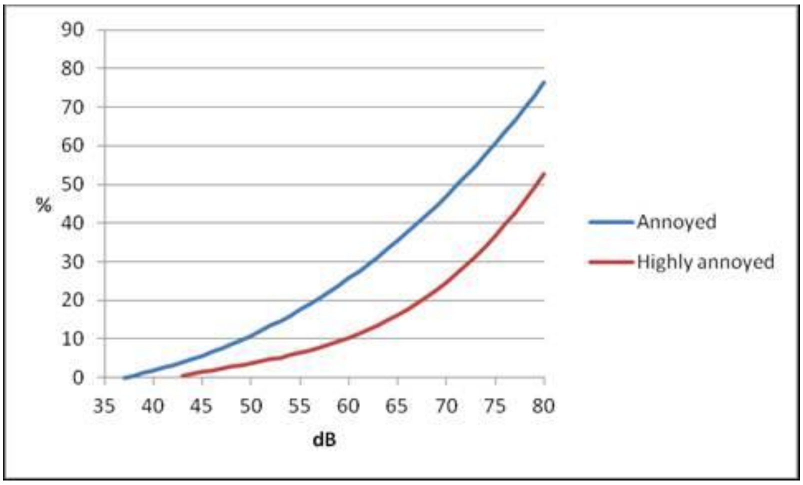

Figure 2 - The likelihood of being annoyed and highly annoyed when exposed to road traffic noise.

Using the exposure distribution given above, and the annoyance equation from Miedema et al (5) we find that out of the 514 million people in Europe in 2010 (EU27 + Switzerland + Norway) there are 98 million people annoyed by road traffic noise.

Both "annoyed" and "highly annoyed" are well accepted indicators. Figure 2 illustrates the difference between "annoyed" and "highly annoyed". For every measure evaluated we have first calculated the number of people affected by the noise reduction, and then the reduction in annoyance per noise band (as given in Figure 1).

4. PEOPLE AFFECTED BY REDUCTION IN ROAD TRAFFIC NOISE

The reduction in calculated annoyance and the corresponding cost effectiveness of a noise barrier or a noise reducing road surface will depend on the number of people affected. This depends further on the type of road in close proximity to where they live. Figure 3 illustrates the variation between different road categories and the number of inhabitants per km alongside each category of road. The numbers of exposed people per km are estimates from noise mapping and demographic data. The data in Figure 3 origin from (7) and is the basis when calculating how many people will be affected by a noise reducing measure.

Road type	Residential urban/ suburban	Residential urban/ suburban	Main roads urban/ suburban	Main roads urban/ suburban	Arterial roads urban/ suburban	Urban motorways urban/ suburban	Rural motorways	Rural roads	Total
Traffic type	inter-mittent	free flow	inter-mittent	free flow	free flow	free flow	free flow	free flow	
Speed range (km/h)	<50	<50	<50	<50	50-70	70-120	80-130	50-100	
Full road length (km)	581 210	1 180 033	49 818	101 146	100 643	5032	95 610	2 918 633	5 032 125
Percentage of total road network	12 %	23 %	1 %	2 %	2 %	0.1 %	2 %	58 %	100 %
Estimated avg. exposed inhabitants (per km)	250	250	500	500	500	1000	40	20	

Figure 3 - Type of roads and how they are categorized

5. NOISE ABATEMENT MEASURES

The most common noise abatement measures for road traffic noise have been investigated. In addition, noise reduction as a consequence of stricter sound limits for type approval of vehicles and tyres have also been considered. The following noise measures are included in this report:

1. Noise barriers
2. Facade insulation of dwellings
3. Porous road surfaces (single and double layer)
4. Thin layer surfaces (dense)
5. Vehicle noise limits for type approval (3 and 5 dB)
6. Tyre noise

The 17 European countries participating in the CEDR RN2 were consulted, using a questionnaire about effects and costs of the different common measures (point 1-4). From the responses received, average or representative values for Europe were chosen. These figures were distributed to the same group for comments and afterward discussed in a CEDR RN2 meeting. From this iterative process, final values where concluded.

Façade insulation can include acoustic glazing, doors, walls, ventilation etc., and it differs from country to country how comprehensive this measure is. As result of the questionnaire process, the most effective and least costly option is used in our calculations: to replace two windows per dwelling.

Data for changes in noise exposure and annoyance caused by reduction in vehicle noise is derived from TNO reports (X15,16). CEDR RN2 has not changed any information given in these TNO reports about vehicle noise reduction. The calculations are based on the first report from 2011 (7), and supplemented with information from the second report (8) when this information became available.

Tyres have a great impact on road traffic noise. Depending on the speed and gear, tyre/road noise can cause higher noise levels than the noise produced from the power train. For light vehicles, tyre/road noise is equal to power unit noise, or dominates, at speeds higher than 30-40 km/h. For heavy vehicles, the tyre/road noise dominates at speeds above 60-70 km/h. Differences in noise properties between different tyres indicate that there could be an important potential to mitigate noise from tyres in a cost effective way.

5.1 People affected

Noise barriers are costly, and mainly used as a local abatement measure to meet legal obligations. They are assumed to be mostly used alongside urban motorways in agglomerations, which, according to Figure 3, amounts to 1000 exposed people per km of road. To protect all these exposed people per km, it is required to have noise barriers on both sides of the road. A noise barrier is in general most effective for dwellings close to the barrier. In the calculations, this is taken into account by assuming that the people living behind a noise barrier are distributed in different noise bands. Those in the highest noise band, closest to the barrier, has a reduction of 8 dB, those in the next noise band (a little further away) have a reduction of 7 dB, then 6 dB, 5 dB etc., until you only have an effect of 1 dB in the lowest noise band (40-44 dB).

Façade insulation is a measure used mainly for the highest noise levels, when other measures, like noise barriers, are not an option. Consequently, only dwellings exposed to noise levels greater than L_{den} 65 dB are included in the calculations. In average, 2.4 persons live in each dwelling (2). Acoustic glazing reduce indoor noise only, and doesn't have any effect on the environmental noise outside, this measure is less likely to reduce the annoyance to the same extent as other measures. It has been assumed a 60% effect on the annoyance reduction (12)

Porous asphalt is expected to be mainly used on urban motorways, which have high speed limits and a high density of inhabitants (1000 per km). For porous asphalt the noise reduction is assumed to be the same for all inhabitants alongside the road, independent of the distance between dwelling and road, as long as the noise level is above 40 dB L_{den}.

Noise reducing thin layer asphalt can be used on city streets where people live very close to the road. Thin layer asphalt is therefore expected to be used on suburban roads, with 500 inhabitants per km.

All people considered to be exposed to road traffic noise in Europe (90 % of the inhabitants) are also considered to be affected by reduction in vehicle noise. The people being exposed to road traffic noise will all have the same reduction in their noise exposure level. This measure takes effect gradually and will only be fully in place when all vehicles are replaced, 12 years after coming into force of the new noise limits (7). The amount of annoyed people are based on the L_{den} levels and the number of exposed people alongside the different road types, Figure 3. A 3.1 dB noise reduction for vehicles will, according to our calculations, give a reduction in annoyance for 19.7 million inhabitants. This is a little less than given in the TNO report itself (24 million). A 5 dB reduction in road traffic noise will affect the same people, and yield an even bigger reduction in annoyance.

6. COST CALCULATIONS

To make the measures easily comparable, our approach has been to look at a total spending of EUR 6 billion in net present value for each type of measure. This amount of money is chosen since the "option 5" in the TNO report (7) on vehicle noise is estimated to cost EUR 5.993 billion (≈ EUR 6 billion). The "option 5" implies stricter noise limits for vehicles, giving an average noise reduction for the vehicle fleet of 3.1 dB when fully implemented. In spring 2011, "option 5" was presented to EU working groups on noise as the recommended suggestions for new type approval limits for vehicles. In December 2011, this option was implemented in Proposal for a Regulation of the European Parliament and of the Council on sound level of motor vehicles, COM(2011) 856 final.

6.1 Costs for quieter tyres

Both the FERHL (4) and TNO (7) have tried to establish the relationship between costs and benefits for less noisy tyres. The FEHRL report concluded that the cost estimate figures the tyre industry, ETRTO, had offered to their investigation were considered to be very significant overestimates. According to the TNO report, the tyre industry claims that the accumulated cost for a 3.1 dB noise reduction for vehicles, would result in a EUR 10.8 billion cost for the tyre industry, since tyre noise influence on the type approval noise level for vehicles. In their conclusions, TNO has highlighted this cost for the tyre industry, but chosen not to take tyre cost into account when calculating the cost-benefit ratio. The authors of this paper assume this is due to skepticism about the cost data. Since there is lack of data for costs connected to less noisy tyres, we have not been able to use the same approach for tyre noise reduction as for the other measures.

6.2 Additional costs for investment and maintenance

In the case of resurfacing roads, only the additional cost of implementing a noise reducing surface, compared to normal asphalt, and the additional cost for maintenance are included in the calculations. The same goes for the other measures, only the additional costs of implementing the noise mitigation measure is compared to the changes in noise level and annoyance.

Maintenance costs are distributed over the 20 years calculation period. The measures without any maintenance costs or need for remaking in a 20 year period, will have all EUR 6 billion spent on the initial investment. This is the case for acoustic glazing. For road surfaces, the cost distribution is calculated with an initial investment, annual maintenance as well as repaving after 13-14 years. For vehicles, it is expected to be a five year research and development period followed by a larger production cost per vehicle when the new technology enters production (7). Due to the large difference in cost profile between different measures, net present value (NPV) is calculated to make them comparable, using a discount rate of 4 %.

Porous asphalt is only used on a large scale on the motorways in the Netherlands. Many countries would probably have to invest in development and test tracks, introduce procedures for testing the acoustic quality, the conformity of production etc., before starting to use porous asphalt on a regular basis. The costs for these adaptations are not taken into consideration.

The costs for vehicles include both R&D and extra production costs due to stricter noise limits.

6.3 Overview of initial investment costs and volume of abatement measure

The initial investment for each measure depends on the spending needed for maintenance, and possibly repaving, to maintain the noise characteristics of the measure in the 20-year period used for comparison. The initial investment available is divided by the cost per unit to implement the measure, giving the total volume of the different measures. A summary of the results is given in Table 1, together with the number of people affected per unit.

Table 1 – The initial investment costs for abatement measures leads to a given amount of noise barriers, new windows etc.

	Initial investment, billion EUR	Cost per unit, EUR	Volume of abatement measure	People affected per unit
Noise barrier	3.627	400 per m^2	2 238 km	500 per km[4]
Façade	6	300 per dwelling	2 mill dwellings	2.4 dwelling
Porous asphalt single layer	2.082	2.14 per m^2	38 825 km	1000 per km
Porous asphalt double layer	1.610	10.45 per m^2	6155 km	1000 per km
Thin layer	4.418	1.5 per m^2	163 632 km	500 per km

[4] 1 km noise barriers cover 0.5 km road (need screens on both sides of the road)

Vehicle (3 dB)	(5.993) 6.995[5]		All vehicles	All people exposed to traffic noise (> 40 dB)
Vehicle (5 dB)	10.2		All vehicles	All people exposed to traffic noise (> 40 dB)

7. RESULTS

Any measure implemented will change the number of annoyed people at a certain cost. By dividing Net Present Value (NPV) of each measure by the change in number of people annoyed, the cost of making one person not annoyed any more is derived. From Table 1, the number of people affected by each type of noise abatement measure can be derived, distributed in noise bands and the reduction in annoyance can be calculated. Table 2 sums up the calculated change in annoyance, and the cost of reducing the annoyance by one. The cost of reducing noise annoyance varies from EUR 16 to EUR 4200 per person per year.

Table 2 – Overview of how an investment of EUR 6 billion will reduce the number of people annoyed by road traffic noise, and the cost of making one person not annoyed anymore.

Measure	Noise reduction (dB)	People affected (million)	Reduction in annoyance	Cost of reducing annoyance by one (per year in EUR)
Noise barrier	8 - 1	1.12	71 500	4200
Façade insulation (60 % effect)	8	4.8	500 000	570
Porous double layer	4	6.2	320 000	940
Porous single layer	2	38.8	1 050 000	290
Thin layer asphalt	2	81.8	2 200 000	136
Vehicle noise (3 dB)	3.1	463.0	19 664 000	18
Vehicle noise (5 dB)	5.2	463.0	31 525 000	16

8. SENSITIVITY ANALYSIS

In order to get a better understanding of the robustness of the results and to get a second opinion of the calculations, an external run of sensitivity analysis was conducted by the Institute of Transport Economics in Norway. Their conclusion is that the calculations appear reasonable and the sensitivity analysis underlines the results in this report.

For running the sensitivity analysis, a web based tool developed in the EU project HOSANNA, has been used. Uncertainty is set at plus and minus 30 % on all costs and benefits. The results of the sensitivity analysis are illustrated in Figure 4. The abscissa axis shows the cost effectiveness results (costs of reducing annoyance by one) and the uncertainty; which are comparable to 90 % confidence intervals (5 % to either side of the simulated point estimate).

[5] TNO updated the cost for vehicle noise reduction from EUR 5.993 billion in their report from 2011(7) to EUR 6.995 billion in a second report in 2012 (8). This adjustment changed the result in Table 4 from EUR 15 to EUR 18 per annoyed per year, but does not influence the other results.

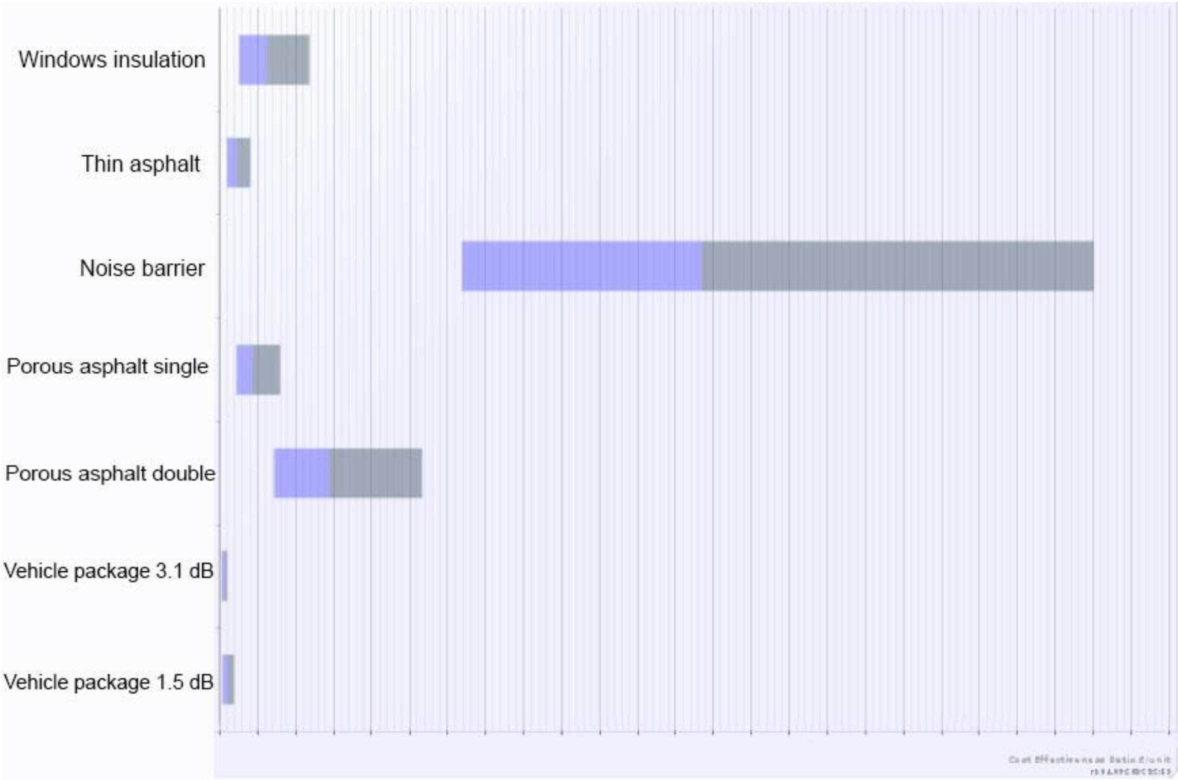

Figure 4 – Overview of simulated cost effectiveness results and uncertainty.

From the sensitivity analysis we can conclude that stricter noise limits for vehicles, reduction of 3.1 dB, will perform economically better than the competing alternatives – given that actual costs and benefits lie within the specified uncertainties. From the vehicle industry it is claimed that real life noise level will not be reduced by 3.1 dB, as stated in the TNO report (7), but only by 1.5 dB. As a worst case scenario, the sensitivity analysis is also performed with only 1.5 dB noise reduction. With a noise reduction of 1.5 dB instead of 3.1 dB, there is a very slight chance that thin layer asphalt could perform economically better than the integrated vehicle package.

9. WHAT ABOUT TYRES?

Since there is very poor information about extra costs connected to less noisy tyres, another method has been used to compare reduction in tyres noise with other noise mitigation measures. We choose to “reverse” the calculations. We turn the question "up-side-down" and ask: If society requires equal cost effectiveness for tyres, as for other measures, how much extra could society (producer and/or consumer) pay per tyre? The following assumptions are made:

- There are about 243 122 000 vehicles in Europe today. If these vehicles change tyres every fourth years, the associated annual sales of tyres will be 243 122 000.
- The average price for one tyre is EUR 80, based on different reports (3,4,6)
- The potential for noise reduction from tyres is assumed to be 1-2 dB (on the road), and calculations are made for 1 dB and for 2 dB.

How to read table 3: Example 1. If tyres can be produced with noise levels 1 dB lower than the average today, and we want tyre noise reduction to be as cost effective as thin-layer asphalt, then we can accept a 5 % increase in tyre price. Example 2. If tyres can be produced with noise levels 2 dB lower than the average today, and we want the tyre noise reduction to be an abatement measure just as cost effective as façade insulations, then the tyre price can be 26 % higher than it is today

As Table 3 illustrates, the society can accept a significant increase in tyre price to reach the same reduction in noise annoyance as façade insulation, noise reducing porous double layer asphalt or noise barriers.

Table 3 How much tyres can increase in price to equal the cost-effectivenss of other noise measures when it comes to reduction in noise annoyance

	Tyres – 1 dB reduction		Tyres – 2 dB reduction	
Measures to be equalized	Extra cost per tyre (EUR)	Percent increase in tyre price	Extra cost per tyre (EUR)	Percent increase in tyre price
Vehicle, 3.1 dB	0.5	0.6 %	0.9	1 %
Thin layer asphalt	3.7	5 %	7.3	9 %
Porous, single-layer asphalt	5.8	7 %	11.3	14 %
Façade insulation	10.7	13 %	21.0	26 %
Porous, double-layer asphalt	25.7	32 %	50.2	63 %
Noise barriers	113	141 %	221.3	277

10. DISCUSSION

Today, approximately 100 million inhabitants in Europe are annoyed by road traffic noise. Because of the elevated and growing costs associated with mitigating severe noise problems, it is important to explore the most cost effective measures that can be used regardless of who is in a position to undertake such measures and who is liable to fund such measures.

10.1 Is EUR 6 billion an unrealistic amount of money?

To establish if EUR 6 billion is an unrealistic amount of money to spend on noise abatement measures, the sum of money was divided among European countries weighted on the number of inhabitants in each country. The length of noise barriers one could get in each country is not unrealistic. Denmark would get 24 km of noise barriers, Estonia 6 km and Ireland 20 km. For bigger and more densely populated countries like Germany and France, the length of noise barriers would be 361 km and 275 km, respectively. Some countries probably spend an amount of money of this magnitude today on noise barriers and façade insulation. Increased awareness of the negative health effects of noise, higher expectations on quality of new roads, stricter regulations etc., can lead to even higher expenses for noise measures in the European countries.

10.2 Difference between annoyed and highly annoyed

As illustrated in Figure 2, there are less people highly annoyed than annoyed for a given noise level. The project also included a calculation for highly annoyed, and the measures were in general doubled in cost. The relative difference between the costs was least for façade insulation and biggest for vehicle noise. Still, the same order of cost effectiveness was achieved for the annoyed and highly annoyed.

10.3 Variations in cost in European countries

The cost for noise abatement measures varies significantly between member states. The costs chosen in our calculations are assumed to be representative as European averages when the measures are in common use. For many countries, porous asphalt is not an alternative within their normal road surfaces, and therefore, the cost per m^2 is significantly higher, making this measure more costly than shown in our calculations. Material and building costs also vary, and the CEDR members gave values from EUR 100 (Ireland) to EUR 1000 (Finland) per m^2 for noise barriers. By assessing each measure individually, CEDR RN2 has managed to agree upon representative values, which are used in the calculations of costs.

10.4 Other limitations of the survey

In this report, each noise measure is evaluated separately and combined effects are not considered. Further, other topics than noise are not considered. Traffic safety, climate and aesthetics are elements which can influence the choice of noise abatement measure, but such elements are not taken into account in our evaluation of preferred noise abatement measures. An example is porous asphalt which gives better traffic handling and reduces risk of aquaplaning. This is positive for traffic safety, and a factor one could also put a value on.

There might be legal obligations to reduce the noise to a certain noise level, i.e. when building a new road. In situations where low noise pavements do not deliver sufficient reductions in noise levels in specific local situations, then member states should consider the use of noise barriers and façade insulation as more effective solutions. Demand for a significant noise reduction and local circumstances might alter the costs and benefits for each possible measure substantially. This study does not give further guidance related to these specific cases.

It should be stressed that assumptions have been made to simplify the calculations. Sensitivity analysis has therefore been performed to assess the veracity of the results. The findings are robust and the uncertainties, simplifications and limitations are not enough to invalidate the conclusions.

11. CONCLUSIONS AND RECOMMENDATIONS

When the purpose is to reduce noise annoyance for as many people as possible for a given sum of money, or reduce the number of people annoyed by a certain number as economically as possible, this report concludes:

- Measures taken at the noise source are in general the most cost effective measures and result in the best reduction in respects of noise exposed people and noise annoyance.
- Stricter noise limits for vehicles are in particular the most cost-effective measures to reduce noise annoyance.
- To reduce noise annoyance, noise barriers are the most expensive measure included in this study.
- A significant increase in tyre price can be accepted for low noise tyres in order to make tyres an alternative to traditional noise abatement measures.

The CEDR RN2 recommendation is to have a strategy for encouraging the exploitation of the most cost-effective actions to mitigate noise, and this could involve the following:

A. *International regulations on noise sources* - Advice national governments to have positions on proposals for new regulations or revision of existing regulations concerning sound levels from vehicles and tyres. More specific this might include:

- Stricter noise limits for cars and heavy vehicles,
- A "not-to-exceed" maximum noise limit for all vehicles of 90 dB, for highly intrusive peak noise levels, such as when an engine is revved,
- Stricter noise limits for all tyres and promotion of low noise tyres,
- Paying particular attention to tyres for heavy vehicles, as these tyres had the most lenient noise limit reduction in 2009, and include re-treaded tyres in the Regulation (EC) No 661/2009.

B. *Liaise with other stakeholders* - Work with vehicle and tyre manufacturers to agree better methods of noise control addressing the vehicles, traffic management (including ITS) and where relevant the infrastructure. Liaise closely with interested parties such as the vehicle and tyre manufactures to formulate a combination of measures that are appropriate for the treatment of road traffic noise.

C. *National measures to be fulfilled by road administrations* - At a national level, NRAs should consider the following:

- Use thin layer asphalt, where appropriate, as the preferred measure to reduce general noise annoyance,
- Porous double layer asphalt is probably more suitable as a local measure than a measure to reduce the general noise annoyance,
- Continue research and testing in order to develop safer and more durable high quality noise reducing pavements which give greater value for money

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