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The role of monetarization in decision methods for traffic noise abatement measures

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ABSTRACT

Traffic noise, from road, railway and aircraft sources, has a serious impact on people's health. Increased health risks and annoyance lead to a lower state of wellbeing, which, at least partially, translates back to a negative impact on economy. Thankfully, many noise abatement measures exist which reduce the external impact of traffic noise. But they need to be financed and maintained, and they may spoil the scenery (noise barriers) or hinder traffic (speed limits). Decision makers want to weigh all the pros and cons before deciding to invest in a noise barrier, apply rail dampers or alter the flight routes. Many decision methods are based on some form of cost-benefit analysis. Different methods are compared in this paper. Quantification of the health benefits may be done by different monetarization techniques, including the willingness-to- pay. Some benefits or damages, however, cannot or should not be expressed in money. Other decision-making methods such as multi-criteria decision analysis may be able to improve the integral balance of all pros and cons, and may also increase public approval. Simpler methods also exist for simpler cases. The comparison and evaluation of the various decision methods identified are supported by case studies from different European countries.

Keywords: Traffic noise, Cost-benefit, Abatement measures, Legislation
I-INCE Classification of Subjects Number(s): 66.2, 67.1, 67.2, 82

1. INTRODUCTION

Noise abatement is a balance between the costs for prevention and reduction of noise and the benefits of lower environmental noise levels for society. A higher level of environmental protection, with lower noise levels, leads to higher costs for noise abatement. The question whether these costs are justified by the positive effect on the environment and the people in it, arises in various situations.

The balancing between costs and benefits may be performed:

- on a national/international scale: the national government may define legislation and regulations for noise abatement measures, based on an analysis of costs and benefits;
- on a local or project scale: local authorities and infrastructure contractors will decide whether to apply a noise abatement measure for a specific situation, and which particular noise abatement measure it is going to be.

The scale of the situation is important for the cost/benefit analysis. On an (inter)national scale, the question is what should be the general level of protection and how much public money should be spent on the noise problem. Generalizations and averaging are needed. On a project scale, the noise abatement measures will be tailored to the local situation, within the legal boundaries defined nationally. The project scale requires local integration of noise abatement measures. Besides costs and health benefits, other criteria, such as aesthetics and safety or security, may apply. To guarantee fairness and equality for people in different locations, general decision methods for the project scale may be defined nationally.

If the decision method involves a direct economic comparison between costs and benefits, then all benefits must be expressed in monetary units. This process of 'monetarization' is, as we will show, rather difficult for environmental aspects, such as public health and annoyance, and quite impossible

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for the softer or ‘fuzzier’ criteria (1). Monetarization has received much attention from the academic world over the last decades, and has been successfully used in projects and implemented in national legislation. Various methods exist that enable monetarization for environmental aspects, which will be explained further. But alternative decision methods, that do not require monetarization, also exist and are described below.

2. HEALTH IMPACT OF TRAFFIC NOISE

2.1 Definition of health and annoyance

The definition of health most often used is from the World Health Organization, who have defined ‘health’ as being *a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity* (4). The WHO has published a report on the burden of disease from environmental noise (6). In this report, as well as in many other studies, the following negative health impacts (‘endpoints’) are considered as a result of environmental noise:

- annoyance;
- sleep disturbance;
- cardiovascular diseases: high blood pressure, hypertension and coronary heart diseases;
- cognitive impairment in children: decreased learning, mainly around schools.

Tinnitus is also reported, but mainly at very high sound levels seldom found in transportation noise. For each of the other health endpoints, significant dose-effect (or exposure-response) relations have been found for road, rail and/or air traffic noise. These dose-effect relations usually start from a minimum threshold noise level of 55 dB L_{den} or 50 dB L_{night}. For annoyance and sleep disturbance, however, research shows that chances for occurrence of these effects are not negligible for lower values (see Figure 1). Since the number of people exposed to noise levels between 45 and 55 dB, for instance, is much higher, the effect on the total environmental noise impact will still be significant.

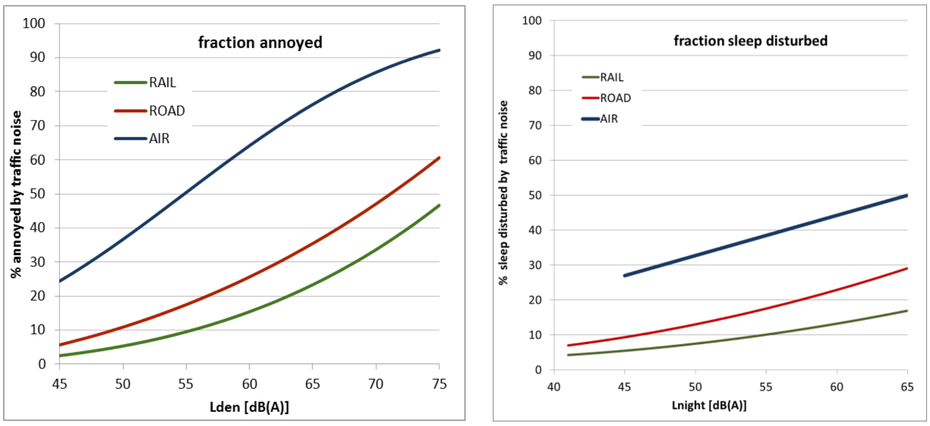

Figure 1 - Fraction of population that is annoyed and sleep disturbed as a function of L_{den} or L_{night}. Graphs are from (2), original data from EU position paper (9), updated with post 1996 findings for aircraft noise.

2.2 Overall impact on EU population

An attempt to map the full impact of traffic noise on the EU33 population was performed by RIVM in 2014 (7), based on the data reported for the 2nd END noise mapping round of 2012. The results indicate that based on the data available, nearly 20 million European people are annoyed by traffic noise levels exceeding 55 dB L_{den}, of which 9 million are severely annoyed. Approximately 8 million Europeans experience moderate or severe sleep disturbance and about 1 million Europeans experience cardiovascular diseases, including hospital admission and mortality as a result of coronary heart diseases and stroke.

The authors report that only part of the required data from major infrastructure and agglomerations has yet been submitted. They have extrapolated the existing data to 100% coverage of the EU population (8). The updated study also extends the noise exposure range to L_{den} levels below 55 dB and L_{night} levels below 50 dB, which is beyond the lower limits set in the END. The conclusions from the update are that the total number of people exposed may be 2 – 3 times higher than reported earlier.

3. COSTS OF NOISE ABATEMENT MEASURES

3.1 Road

For road traffic noise, several types of noise abatement measures exist:

- traffic measures: lowering the speed limit will lead to a lower noise emission, but an effective lowering of road noise would require a substantial lower speed limit;
- low-noise tyres: depending on vehicle speed and road surface type, low-noise tyres may on average have around 3 dB lower noise emission levels;
- low-noise road surfaces: many types of different low-noise surfaces exist, with noise reductions up to 8 dB relative to a standard, non-noise reducing pavement (dense asphalt concrete or SMA11);
- noise barriers: the noise reduction of a barrier depends on its height, relative to the location of the road and the height of the surrounding buildings, but may be up to 15 dB.

The typical costs for these noise abatement measures are given in Figure 2, with their approximate noise reduction on the vertical axis. The costs for these noise abatement measures have been calculated over a life cycle of 30 years and include the direct investment costs as well as the increased maintenance costs over the entire life cycle.

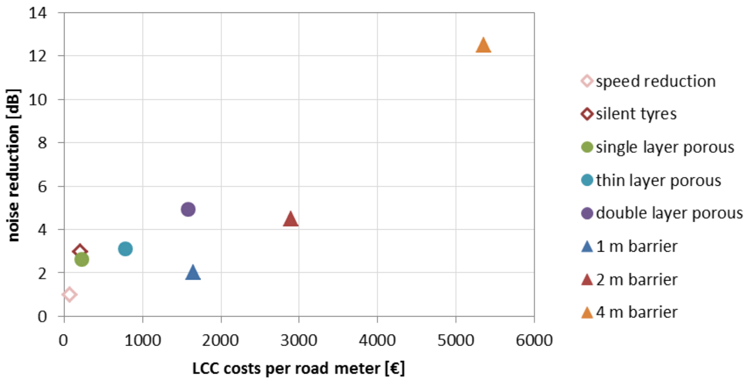

Figure 2 - Noise reduction vs. costs per road meter for various source measures, porous road surfaces and noise barriers; noise reductions for a typical highway situation with mixed traffic (from 10)

3.2 Rail

Typical railway noise abatement measures include:

- vehicle measures: retrofitting K- and LL-type braking blocks for freight wagons;
- track measures: mainly acoustic grinding and tuned absorbers (or ‘rail dampers’);
- propagation measures: noise barriers.

Cost estimates for these noise abatement measures have been studied for instance in the STAIRRS project[2], showing that retrofitting K- and LL-blocks is the most cost effective option.

3.3 Aircraft

For aircraft noise, typical noise abatement measures are:

- reduction at source (quieter aircraft);
- land-use planning and management, including market based instruments (noise charges);
- noise abatement operational procedures, such as continuous descent approach (CDA) and optimization of thrust and flap settings;
- operating restrictions.

A comparison of costs for these different measures is difficult, due to a lack of a common cost estimation method. A description of aircraft noise abatement measures, including several studies that investigate the costs of such measures, can be found in (11).

[2] http://www.stairrs.org/

4. DECISION METHODS

4.1 Overview of decision methods

The decision process for noise abatement measures usually involves some kind of *cost/benefit analysis*, although it is not always clearly expressed what is the exact method used. The term ‘cost/benefit analysis’ actually may refer to one method within a family of different methods, each of which have their own characteristics. And each of these methods may actually give different results. The costs for the abatement measure are always an important criterion. The selection of a decision making method is based, therefore, on the question which of the other criteria should be involved. Table 1 gives an overview of five different methods that will be discussed and compared further below.

Table 1 - Overview of decision methods

method	decision criteria	remarks
cost-minimization	cheapest measure that fulfils the target	the output is fixed, to the required noise reduction; costs are then the only variable parameter
cost-effectiveness (CEA)	optimal ratio between noise reduction and costs	for noise, the output parameter is usually the noise reduction (in *dB * persons*)
cost-utility (CUA)	optimal ratio between public health (utility) parameter and costs	the health impact contains various endpoints; the impact is expressed in DALY/QALY units
cost-benefit (CBA)	optimal ratio between multiple, monetarized criteria, summed to a single value, and costs	every benefit is translated to monetary units, e.g. using WTP
multi-design criteria analysis (MDCA)	highest score as a weighted sum over multiple criteria, each on a different arbitrary scale	costs and benefits are scored, then combined on a numeric scale using weighting factors

4.1.1 Cost-minimization and cost-effectiveness

In a *cost-minimization* analysis, the costs are the only variable. In a noise abatement setting, the noise reduction required for a particular situation may be fixed, often based on the noise legislation. Cost minimization can be used to compare different measures that deliver the same result, with the goal of finding the cheapest alternative that fulfills the legal noise limits.

In a *cost-effectiveness analysis (CEA)*, the goal is to optimize the balance between costs on one side and a particular, measurable output quantity on the other side. For noise abatement, the output quantity is often the noise level or noise reduction, or the noise reduction multiplied by the number of people that benefit. In addition to the cost-minimization the objective is not just to find the cheapest solution, but to find an optimal solution, based on the incremental costs vs. incremental returns.

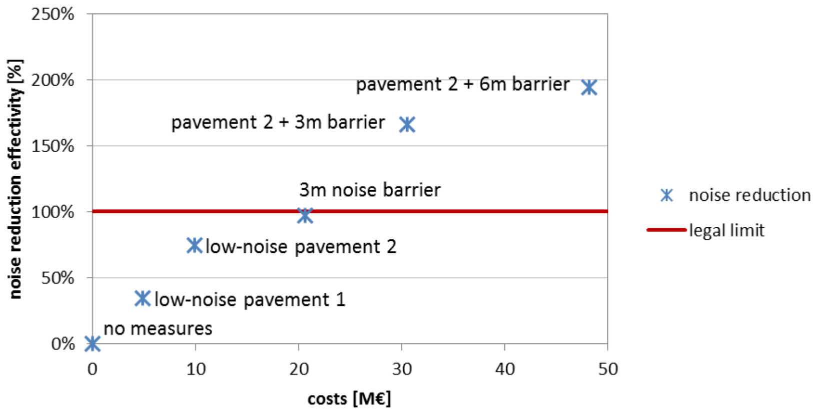

Figure 3 – Example: cost effectiveness of different road traffic noise abatement measures

Figure 3 presents a (hypothetical) example. Six alternative road traffic noise abatement measures are considered for a particular road section. The total LCC costs for each alternative are given on the horizontal axis. The vertical axis indicates the effectivity of the noise measure, in terms of the number of houses for which the noise immission level is brought down below the legal limit. The red line indicates an effectivity of 100%, meaning that the legal requirements are fulfilled for all nearby houses. From a cost minimization perspective, the cheapest alternative that fulfills the requirements is the option ‘pavement 2 + 3m barrier’. However, the option ‘3m noise barrier’ is much more likely to be selected, since it fulfills nearly all legal requirements at 50% lower costs. But from a cost-effectiveness point of view, the ‘low-noise pavement 2’ could be considered a better alternative, since the extra noise reduction of the ‘3m noise barrier’ is just 20%, while costs increase by 100%.

4.1.2 Cost-utility analysis

Cost-utility analysis (CUA) is a method similar to cost-effectiveness, most often used in health research. In a cost-utility analysis, the output parameter is not a single measurable health quantity, such as the life expectancy, but a ‘virtual’ quantity that combines separate health-related quantities in a single unit. Units commonly used are DALY (Disability Adjusted Life Years) or QALY (Quality Adjusted Life Years), both of which aim to estimate the number of ‘healthy life years’. The method for determining the burden of disease in DALY’s is well described in the WHO report (6). To calculate the impact of environmental noise on health, the amount of healthy years lost are calculated for a number of noise-related impacts and diseases, each of which has their own disability weight (DW) factor, and added to the years lost to premature death (which has a DW of 1). Annoyance is included by the WHO as a negative impact of noise on health, albeit with a relatively low DW. Calculations for the different health components are performed using dose-effect relations that have different environmental noise levels as input, such as presented in Figure 1.

Besides the different output parameter, the cost-utility analysis has a goal similar to the cost-effectiveness analysis, aiming to optimize the balance between cost and health.

4.1.3 Cost-benefit analysis

In a cost-benefit analysis (CBA), not only the costs but also all the benefits are expressed in monetary units. Some benefits are directly related to a monetary value, such as reduced hospital costs due to lower occurrence of diseases. Benefits that are time-related, such as effects on mobility (traveling times, traffic jams) can quite easily be expressed in money. Other benefits, such as the reduction of annoyance or the increase of safety, are not directly expressed in monetary units and need to be ‘monetarized’. Monetarization is quite common for environmental noise issues, although scientific and ethical objections exist. Different techniques are explained and compared in section 5. Monetarization may be quite difficult for more subjective aspects, such as the aesthetic value of noise abatement measures or the perceived positive or negative impact on the landscape.

In cost-benefit analysis, the cost and benefits resulting from a noise abatement measure can be directly compared and combined. The balance between cost and benefits may be optimized by looking at the direct difference between costs and benefits. If the net monetary difference is positive (costs are lower), then the noise abatement measure may be accepted; if it is negative, it may be considered ‘too expensive’. Or, one may look at the ratio of costs over benefits, similar to the cost-effectiveness analysis. The noise abatement measure may be accepted if the C/B ratio is low. Or, one may look at the change in C/B ratio from one measure to another.

4.1.4 Multi-criteria decision analysis (MCDA)

Multi-criteria decision analysis (MCDA) is a form of multi-criteria analysis that combines costs and other decision criteria into a decision evaluation process, which includes attributing a score, on an arbitrary scale, to each of the criteria and assigning weighting factors. Costs are also evaluated on a non-monetary scale. Different options are compared based on their total weighted score. Choosing an option can be done by choosing the option with the highest score. The MCDA requires that weighting factors are derived and assigned for each criterion. It is common to perform a sensitivity analysis to investigate the effect of different weighting factors on the ranking of the different options. A good description and application manual for MCDA methods can be found in (12).

Figure 4 shows the example previously presented in Figure 3, but now analyzed using MCDA. In this example, the noise levels are translated in terms of ‘annoyance’, which is more directly linked to people’s understanding of the noise improvement and therefore better suitable for people to rank the impact of the various alternatives. Other criteria included are the ‘maintainability’, which is worse for the (porous) low-noise surfaces, the ‘aesthetics’ for the road user and the ‘social security’: people living behind a noise barrier may feel more secure if the motorway is separated from their visual environment by the noise barrier.

Three different sets of weighting factors (I, II and III) are applied, to get an idea of the sensitivity of the end result for the chosen weighting factors. In this example, option D (3m noise barrier) is most likely to be chosen although, depending on the weighting factors, the addition of a low-noise pavement may be considered. And if the weighting factors from set III are used, doing nothing also seems a plausible option.

	costs	annoyance	maintainability	roadside aesthetics	social security	score WF I	score WF II	score WF III
A: no noise abatement measures	10.0	0.0	10.0	10	0	20.0	12.0	15.0
B: low-noise surface 1	9.0	1.7	3.8	10	0	17.6	12.7	13.3
C: low-noise surface 2	8.0	5.8	0.8	10	0	19.2	15.8	13.6
D: 3 m noise barrier	5.7	8.3	8.5	2	10	24.3	16.4	15.0
E: low-noise surface 2 + 3 m noise barrier	3.7	10.0	0.0	2	10	19.7	16.1	11.7
F: low-noise surface 2 + 6 m noise barrier	0.0	10.0	0.0	0	10	15.0	12.0	7.5
weighting factors I	100%	100%	50%	50%	50%			
weighting factors II	100%	100%	0%	20%	20%			
weighting factors III	100%	50%	25%	25%	25%			

Figure 4 – MCDA example, with values for costs, annoyance and other criteria for several different measures

4.2 Decision criteria

In sections 2 and 3, we have discussed the two main important decision criteria for noise abatement measures: the positive impact on health and annoyance on one hand and the financial consequences on the other. However, several other criteria exist that may influence the decision for applying a noise abatement measure, or the preference of one particular measure over another:

- technical limitations: some noise abatement measures may not be feasible on a particular location, e.g. a bridge may not be able to carry the weight of double-layer low-noise asphalt surface.
- safety: a noise abatement measure may lead to safety issues. As an example, low-noise tyres may compromise wet grip performance. In the Netherlands, porous road surfaces are not allowed in tunnels because of the increase risk of fire in case of fuel leakage. Such safety issues are usually formulated as ‘knock-out’ criteria, so the noise measure is taken out of the decision process.
- reliability, maintainability and availability: noise abatement measures require increased maintenance efforts. This will lead to additional costs, but may also lead to a lower availability of the network, or increase the risk of full unavailability if something breaks down. Furthermore, some measures, such as rail dampers, may make maintenance more difficult to perform.
- effects on mobility: traffic noise may also be reduced by influencing traffic itself: the amount of traffic, the travelling speed, or the routing. These measures may negatively influence the travelling times for the users, which makes these measures unpopular. Other noise abatement measures are usually considered first, so as to maximize the mobility within the noise limits.
- social, cultural and aesthetic criteria: some noise abatement measures, e.g. noise barriers, are clearly visible and disrupt the visual surroundings. Cultural influences also exist: the cobble stones in the old city center will not be replaced by a low-noise porous asphalt surface.
- research and innovation: innovative and optimized noise abatement measures are continuously being developed and, at some point, need to be tested on a larger scale, for a longer period of time. Innovative noise measures may therefore be stimulated by financial instruments or procurement decisions, thereby influencing the decision process.
- added benefits: noise abatement measures may have secondary functions, which influence the decision making. Examples are noise barriers with solar panels, which may generate financial as well as environmental benefits, or covered with titanium dioxide to improve NOx levels.

4.3 Pros and cons of Cost-Benefit Analysis

Several different decision making methods have been described above. We have distinguished true Cost-Benefit Analysis (CBA) from the other methods; the main characteristic of CBA is that all criteria, both on the cost and benefit side, are expressed in monetary units. In Table 2, we have listed the main advantages and disadvantages of CBA, looking at the method itself (strengths and weaknesses) as well as at the external input, such as costs and data, and the output results (opportunities and threats).

Table 2 – SWOT analysis of CBA

	advantages	disadvantages
internal (methodological)	**Strengths:** • costs and benefits are directly comparable, in the same units • objectivity: independent from expert judgment and policy considerations • consistency and transparency	**Weaknesses:** • requires monetarization: criteria that cannot be monetarized cannot be taken into account • may be inaccurate; accuracy is difficult to assess
external (in- and output)	**Opportunities:** • extensive experience and existing research base with fallback values • easy to understand and explain; people naturally understand monetary units	**Threats:** • monetarization is difficult for some criteria; new studies take time / budget • ethical objections against monetarization of health/environment reduce acceptance of the results

We conclude that most of the advantages and disadvantages of CBA have to do with the monetarization of the criteria. Disadvantages are mainly the time and effort needed for monetarization studies, as well as with the limited accuracy of CBA results. The main advantage, however, also lies in the monetarization, as CBA enables the direct comparison of costs and benefits. The fact that the results are easy to interpret is also a danger in combination with the limited accuracy. It is easy and straightforward to conclude that a noise abatement measure is not a good idea if the costs are higher than the economic benefits. Depending on the monetarization studies used, however, the economic benefits may just as well be multiple times higher or lower, as we will show below. It is recommended, therefore, to always present the CBA results with an indication of the accuracy range.

Compared to the other methods, we find that:

- *Cost minimization* and *cost-effectiveness analysis* are much simpler to perform and to regulate. For many small-scale projects, the decision process for the noise abatement measures will take place within well-defined legal boundaries. Noise abatement measures are designed such that the budget is optimally distributed to solve most of the noise problem for most of the people.
- *Cost utility analysis* is a method suited to find the noise abatement strategy that is optimal in terms of public health and annoyance. CUA is relatively easy to apply, since dose-response relations between road, rail and air traffic noise immission levels and most of the relevant health endpoints can be found in literature and are widely used and accepted. CUA, just as CBA, has limitations with respect to accuracy, mainly in the weighting factors (disability weights) given to each health endpoint. For instance, the weighting factor for annoyance of 0.02 reported by the WHO is proposed with an uncertainty interval from 0.01 to 0.12.
- *Multi-criteria decision analysis* can be a good alternative to CBA, mainly in application on a local or project scale. The main advantages of MCDA over CBA are:
  - any criterion can be added, as long as the experts, stakeholders and/or the public are able to compare and rank the criterion for the different alternatives presented;
  - the ranking of alternatives and the assignment of weighting factors to each criterion enables administrations to increase public involvement and the acceptance of the result. The increased feeling of influence may actually have a decreasing effect on the perceived annoyance (see 13).

Nevertheless, for policy making, CBA is often the only option. At some point, the national authorities need an indication of how much money they could spend on noise abatement. Some calculation of the overall economic benefit, in monetary units, will be needed.

5. MONETARIZATION

5.1 Internal vs. external costs of transport

To quantify the costs of transport, we need to distinguish between *internal* costs, borne by the user (traveler), such as operating and fuel costs paid by the user, and *external* costs or 'social costs' borne by society, such as investment and maintenance of public vehicles and infrastructure. External costs also include environmental costs and the costs for decreased public health and wellbeing, including costs arising from traffic noise.

The external costs are usually not borne by the transport users and will therefore not be considered by many users in their transport decisions. One of the main objectives of policy makers and researchers is the *internalization* of external costs: how to make the external costs part of the traveling decisions made by the users? Some solutions are of the "command-and-control" type, e.g. low-emission zones in cities. Financial market instruments also exist, such as noise differentiated track access charges (NDTAC) for rail, or noise-dependent access fees for airports.

5.2 Monetarization methods

5.2.1 Top-down vs. bottom-up approach

Two different approaches to the valuation of external transport costs are given in the EU handbook on External Costs of Transport (5):

- In the *top-down* approach, the total noise costs are determined on a large (country) scale, by estimating the number of people exposed to traffic noise (usually in classes: 50 – 55 – 60 – 65 – … dB) multiplied by an average economic value (e.g. Willingness To Pay). The top-down approach results in average noise costs, e.g. per dB and/or per person.
- In the *bottom-up* approach (a.k.a. the Impact Pathway Approach), the starting point is a micro-scale model of the traffic flow for each particular route. Noise immission levels are determined using existing traffic noise models, followed again by an estimation of the economic value. Then, the calculation is repeated for the same situation with one additional vehicle. The result are the marginal noise costs, i.e. the extra costs from the extra vehicle, in € per vehicle-kilometer.

From a theoretical approach, the bottom-up approach is preferred, since it allows to distinguish the influence of traffic density, time of day, location, vehicle type and speed, etc. These specific estimates, however, are not very useful for internalization strategies for environmental noise. An important reason for this is the logarithmic nature of noise: one additional vehicle has less impact when travelling on an already noisy location. Internalization based on the actual environmental impact of a travelling decision would lead to a bundling of traffic on busy routes (see 14).

5.2.2 Willingness To Pay

Common methods for valuation of environmental noise aim at estimating the Willingness-To-Pay (WTP), which expresses the how much money people would be (hypothetically) prepared to pay for a certain improvement to their noise situation. The WTP is usually expressed as a monetary sum per dB, per person or household, per year.

A common reference is the work by Navrud (15) who gives a summary of contingent valuation studies that rate the WTP of road traffic noise between 2 to 99 €/dB/hh/year (price level 2001). Based on this work, the EU Working Group on Health and Socio-Economic Affairs advises a value of 25 €/dB/household/year for road traffic noise between 50 and 75 L_{den} (16).

5.2.3 Revealed Preferences vs. Stated Preferences

The WTP may be determined by using either Stated Preferences (SP) or Revealed Preferences (RP) methods.

In SP methods questionnaires are used to ask people directly how much they would be willing to pay for a particular improvement in the perceived noise levels (Contingent Valuation), or they are asked to choose or rank different alternatives (Choice Experiments, Conjoint Analysis). Most SP studies use Contingent Valuation. For any method, it is important to design the survey well. The reduction in noise level, for instance, should be described in terms that correspond well to the understanding and actual experience of the participants: one should not ask for the WTP for a noise reduction of 3 dB, but for a reduction of annoyance by 30%, or a noise reduction that is equivalent to a situation with half the current traffic flow.

RP methods measure the WTP indirectly by observing their purchases of a certain good, or to relate the price of a certain good to the noise level (Hedonic Pricing). This is most commonly done by relating the developments in real estate prices or rents to the developments in traffic noise levels on that particular relation. The effect is expressed as the Noise Depreciation Index (NDI) or Noise Depreciation Sensitivity Index (NDSI), as a percentage of the property prices or rents. The total economic loss is expressed as:

$$loss = NDI * \sum_i (L_i - L_{th}) * P_i \qquad (1)$$

where L_i is the noise level at dwelling i, L_{th} is a threshold level above which noise depreciation starts and P_i is the price of the dwelling. The WTP is then the average loss per dwelling (household).

RP methods, such as Hedonic Pricing, have the advantage that they measure the actual behavior of the public, which is more objective than asking people directly in surveys. Choices in the analysis method, for instance to separate the effect of noise from other effects that impact the price, have shown to be of great influence on the results, however, and also hinder the translation of the results from one particular RP study to another location or situation.

Other methodological disadvantages of Hedonic Pricing are that the WTP resulting from a HP study only includes the effects that people are actually aware of and consider in their price considerations, and that the method assumes a perfect housing market, in which the buyer actually has information about the noise level when bidding.

5.2.4 Health costs

As stated earlier, monetarization of traffic noise should include both conscious effects (annoyance and self-reported sleep disturbance) and health effects, such as hypertension and coronary heart disease. It is generally assumed that these effects are independent, i.e. the potential long term health risk is not taken into account in people's perceived noise annoyance. SP studies may incorporate questions that involve and explain health effects. But if not, or if RP are used, the health costs should be calculated separately.

A direct relation between the noise levels and the health-related costs (doctor costs, hospital bills, and costs for decreased productivity) is difficult, since the noise-related effects are not easily separated from related external impacts, e.g. air pollution. A more likely option is to estimate the calculate the burden of disease from traffic noise using the DALY method (section 4.1.2) and then translating the loss of DALY's to an economic loss using the Value of a Statistical Life Year (VSL or VOLY). Values have been established, for instance in the HEATCO and UNITE studies, and more recently in a study by the OECD (17). Country-specific values are recommended, since significant differences between countries exist as a result of difference in demographics and welfare levels. The accuracy of the results may be a problem, however, since the inaccuracies in the VSL estimations add to the inaccuracies in the DALY estimation itself.

6. DECISION AND MONETARIZATION METHODS IN PRACTICE

6.1 Examples of decision methods in legislation

6.1.1 The Netherlands

In Dutch legislation for major roads and railways, a calculation algorithm has been defined to assess the financial effectiveness of a noise abatement alternative. The budget for noise abatement measures is calculated by summing the budget for each dwelling, which is dependent on the noise level (see Figure 5). It is up to the acoustic engineers in the project to come up with different sets of noise abatement measures. Standard cost estimates are gives for low-noise road surfaces, rail dampers, concrete slabs and noise barriers, as a function of dimensions. Costs are based on LCC (investment + 30 years of maintenance) and expressed in 'points', just as for the available budget.

A set of rules is defined to select the most cost-effective measure:

- If a certain set provides enough total noise reduction to bring all noise levels below the limit, then more expensive measures are not to be taken (cost minimization).
- If the entire budget is spent on the noise abatement measures in one alternative, than more expensive measures are not to be taken (cost maximization).
- If a significantly cheaper alternative is available with a total noise reduction that is nearly equal, then the cheaper alternative should be chosen (cost effectiveness). No fixed ratio is defined: it is

left up to the engineers to determine whether the additional noise reduction is worth the extra costs.

Although the Dutch example looks like a CBA method, since both costs and benefits are expressed in the same units, it should actually be considered a cost-effectiveness (CEA) method: the benefit side has a fixed, undefined relation with the noise reduction and does not regard the actual social benefits. It is not directly linked to public health and it does not allow including other benefits, even if they can be monetarized, which should be the case for CBA.

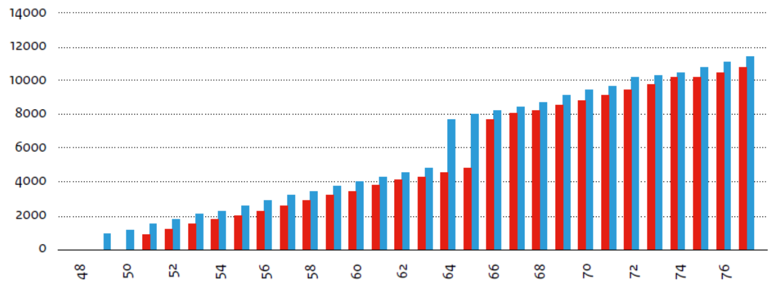

Figure 5 – Budget points for road traffic noise along national roads [28]; red bars are for the national road (highway) network; blue bars are for (sub)urban roads, for which older legislation applies

6.1.2 Switzerland

In Switzerland, a CBA method is prescribed in guidelines by the Bundesamt für Umwelt (BAFU) which prescribe the judgment of an optimal balance between the *effectivity* of a particular set of noise measures and the *efficiency* (cost/benefit ratio) of the noise measures:

- The *effectivity* of the noise measures is expressed as the total noise reduction at all dwelling facades, as a percentage of the total noise reduction needed to bring all noise levels down to the target values: 100% effectivity means the noise immission at all dwellings is below the limits.
- The *efficiency* is expressed as the ratio between the total benefits of the noise measures and the total costs. The benefits are monetarized based on a hedonic pricing method, which is to be applied for each particular location; no predefined values exist. Standard LCC estimates are given for low-noise pavement, noise barriers and noise insulation measures at the dwellings.

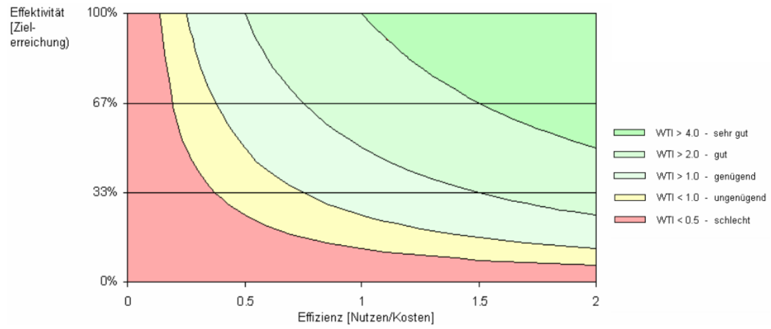

Figure 6 – Effectivity vs. Cost/Benefit efficiency diagram, used in Swiss legislation; colors indicate the “Wirtschaftlicher Tragbarheitsindex” (WTI), a measure for the economic acceptability

6.2 Monetarization examples

6.2.1 Aircraft noise (NL, US)

The Dutch National Institute for Public Health and the Environment (RIVM) has investigated the monetary benefits aircraft noise around airports (18). Their studies mainly contain the application of hedonic pricing for the different noise sources. They observe the effect of noise on house pricing and rents, and also include the effect of noise on (uninhabited) land prices. The NDI value used for air traffic noise is 0.8%, which is higher than the values used for road noise (0.5%) and rail noise (0.25%).

A different Dutch study for aircraft noise in the agglomeration around Amsterdam Airport resulted in a total benefit per household of a 1 dB reduction of € 1500,- which is reported to be equivalent to a marginal benefit of 75€/dB/household/year (19). Compared to the WG HSEA value of 25€/dB/hh/yr for road noise, the value for aircraft noise in this study is three times higher.

CAEP, 8th meeting, has issued a report on the cost-benefit analysis NOx stringency of air traffic, in which the costs of noise are also taken into account. In this report an income related value for WTP is used, based on the work that was published later in (20). The data presented in Figure 7 distinguish between USA and non-USA situations. The WTP refers to an improvement that brings the value from above the significance level of 65 dB(A) L_{den} (or DNL) to a background level of about 55 dB(A). WTP values were based on hedonic pricing studies by others between 1970 and 2007. Other studies on aircraft noise valuation are given in (10), with NDI and WTP values in the same order of magnitude.

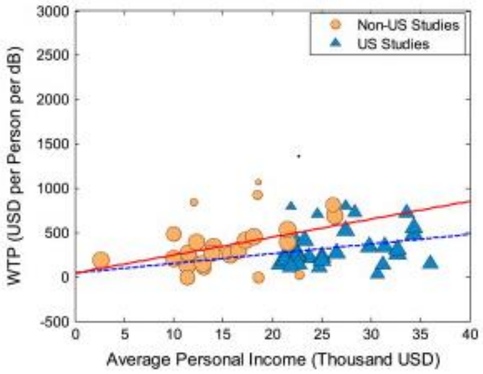

Figure 7 – Yearly WTP for aircraft noise reduction as a function of income per capita (from 20)

6.2.2 Monetarization of health impacts (CH)

An interesting Swiss study (21) addresses the differences between different methods for monetarization of the health impacts due to traffic noise, and the results when applied to the Swiss situation. The report discusses why and how monetarization of traffic noise should be (or should not be) done. The study gives a good overview of CEA and CUA vs. CBA methods, various monetization methods, and difficulties and results from existing studies.

The monetization part focusses on monetarizing the health impairment in DALY and is therefore a combination of cost-utility and cost-benefit, in our definitions. The report follows the approach of estimating the effect of noise on health in DALY (cost-utility), and then monetarizing the DALY's using the value of a statistical life (VSL). The health effect, in this report, is confined to night time sleep disturbance and daytime interference with communication. Multiple methods have been pursued to estimate the VSL. These include SP as well as RP methods, regarding apartment rents but also at the amount people spend on actual medical improvements (e.g. plastic surgery). Values found for the VSL show quite a large range between the various methods, from 42.727 to 250.000 CHF (price level 1996).

7. CONCLUSIONS

Decisions for traffic noise abatement measures are taken often, at many different scales and at many different levels. The direct financial costs for investment and maintenance are always an important parameter in the decision. The criteria considered on the benefit side may be quite different depending on the scope and scale of the noise problem. For policy development and other decisions on large, national scale, Cost-Benefit Analysis (CBA) is often applied and may be the only option. CBA requires monetarization of health and annoyance, as well as for other criteria that one wants to conclude. We have explained and compared various monetarization methods. Examples show that WTP (or NDI) values depend on the traffic type (road, rail or aircraft), but also for one traffic type, values may widely between different methods and different studies. Alternative decision methods exist, which are mainly suitable for noise abatement decisions on a smaller or project scale. If the project is bounded by clear legal limits, then simpler methods such as CEA or even cost minimization may suffice. MCDA is an attractive alternative for specific projects, since it allows an integral consideration of other criteria that may be important to the local community but cannot be easily monetarized. Increased public awareness and involvement are also advantages of MDCA.

An investigation of decision methods implemented in legislation among various European countries is currently being undertaken. As more good and bad examples are added during the coming months, we will be able to derive recommendations for best practices in decision and monetarization methods and application.

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