Economic analyses of noise reduction packages

Ronny KLÆBOE[1] Sebastian EGGERS[2];

[1]Institute of Transport Economics, Oslo, Norway

[2]Lärmkontor GmbH, Hamburg, Germany

ABSTRACT

Economic analyses are a supplement to noise impact descriptions in the form of noise maps, noise limit exceedances, and aggregated population noise annoyance indicators. The economic performance of noise reduction measures are not intrinsic to the measures themselves, but depends heavily on the context in which the measure is implemented, the deployment strategies, and non-acoustic factors. Noise reduction benefits depend on the number of residents affected, how different areas are utilized, whether some measures have already been implemented and are difficult to improve on. As shown in the ON-AIR project, different countries assess and valuate noise benefits differently, and the economic rankings of noise reduction measures affecting a project area differ between countries and sites due to differences in methodology. When more than one measure is considered, it can be useful to consider whether additional benefits of noise improvements become smaller or come at high cost. In some cases additional benefits could be reaped from plugging protection gaps, and against secondary noise sources that increase in importance. Marginal benefit cost ratios indicate when benefits of extra noise reductions are too small, or come at too high a cost, to be worth-while implementing.

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1. INTRODUCTION

As part of the ON-AIR project, a Guidance Book (1) was developed. It provides an overview of how to manage noise in all stages of road planning and management. The guidance book provides information on a number of noise abatement practices and measures, environmental impact assessments, and how to differentiate between good and bad solutions. It contains chapters on public participation and the benefits of involving the public. The web-site http://on-air.no contains interactive examples. This paper presents some of the content with respect to impact assessments, the economic analysis of one or more measures to reduce noise, and the valuation of noise benefits.

2. ROAD SURFACE MANAGEMENT AND NOISE MEASURES

Noise reduction measures may target the vehicle fleets (engines, powertrains, tires), tire-road surface interactions by means of single or multilayer road pavements, noise barriers and other measures to reduce noise propagation, window and façade insulation projects.

Proper management of road surfaces is not only economically important, but also essential for preserving desirable properties of road surfaces such as maintenance of friction, drivers' comfort, reduced road–tire noise emissions, reduced emissions of greenhouse gases and releases of air and waterways pollutants. The investments, resurfacing and maintenance efforts need to balance different and partially conflicting needs according to traffic, road type, built and natural environments and the use of studded tires.

2.1 Challenges when investing and maintaining a stretch of road

A number of decisions need to be made that have economic consequences, and where engineering approaches may prove inadequate.

- How do we choose between a more durable but also more expensive surface and a less expensive but also a less durable one?

[1] rk@toi.no

[2] s.eggers@laermkontor.de

- When does the additional cost of adding extra noise-abatement elements, higher quality components with better noise reduction or increasing the size of a noise-reducing structure exceed the additional acoustic benefits?

2.2 Challenges for road pavement production

Optimal road management policies need to take the context into account. There is no road pavement that is better on all quality indicators. Instead it is necessary to arrive at useful compromises. Economic analyses can contribute to answer questions concerning:

- Which combination and quality of materials and/or surface treatments is optimal with respect to satisfying the various and partial conflicting requirements for road surface properties (rolling resistance, road friction, low-noise durability, price and ease of deployment)?
- Which type of road surfaces is best suited to different contexts (traffic volume, vehicular fleet, neighborhood, environment, type of road stretch such as acceleration or braking)?

2.3 Challenges when deploying

Many approaches fail to take into account that there is a social cost connected with interrupting and delaying traffic, and too rigid deployment strategies. Questions are:

- What are the savings of motorists and equipment cost per kilometre of reducing the deployment time? Are these higher than the added cost of, for example, paying for more shift work?
- Is it feasible to fine-tune the laying process to fine-tune pavement properties according to the local situation (e.g. thicker surfaces, surface texturing)?

2.4 Principles of economic analyses

Principles of cost effectiveness and cost-benefit analyses (CBA) are as follows (2):

- The impacts of a scheme should be based on the difference between forecasts of the without-scheme and with-scheme cases;
- Impacts should be assessed over a defined appraisal period, capturing the planned period of scheme development and implementation and typically ending 60 years after scheme opening;
- The magnitude of impacts should be interpolated and extrapolated over the appraisal period, drawing on forecasts for at least two future years;
- Values placed on impacts should relate to the perceived costs, factor costs and market prices unit of account, converted as appropriate from factor costs using the indirect tax correction factor;
- Values should be in real prices, in the department's base year, accounting for the effects of inflation;
- Streams of costs and benefits should be given in present values, discounted to the department's base year;
- Results should be presented in the appropriate cost-benefit analysis metrics, normally a benefit-cost ratio (BCR); and
- Sensitivity testing should be undertaken to reflect uncertainty.

Economic analyses thus take into account that projects have different time profiles, and that costs and benefits which come late in the planning period are more heavily discounted. Increasing the durability of a road surface, thereby increasing its lifetime, thus has two beneficial effects:

1. The production and road surface laying costs per year is reduced
2. Each resurfacing investment is pushed further into the future.

Typically, the heaviest investments are made up-front, after which there is a period of maintenance, resurfacing extending the useful lifetime. The major expenditures are made before the road is opened. Yearly benefits are usually much smaller than the investments, but these benefits are delivered year after year and their accumulated worth thus needs to be calculated.

2.5 Cost benefit analysis

Cost-benefit analysis (CBA) takes a holistic approach including all important impacts for those affected by a measure – both acoustic and non-acoustic. Road surfaces have many properties, each of which are assigned a monetary value. The objective of the CBA is to achieve the best overall performance in money terms, versus the cost.

When considering the cost efficiency of a project, we are interested in the full set of effects. We want to maximize the sum benefits relative to the sum costs. In some cases, a noise- reduction measure can produce multiple benefits and their accumulated worth improves the social efficiency of the project. In others, for example, where a noise screen destroys the visual aesthetics of a landscape, separates one part of a community from another or acts as a noise reflector (if an absorbing barrier is not used instead) so that other groups of people are adversely affected, the overall benefits are reduced.

In the HOSANNA 7th FP measures with low cost such as surface treatments and rows of trees, measures with high acoustic effect, and those both having good acoustic effect and costing little provided high benefit cost ratios when utilized in appropriate contexts (3)

2.6 Differences from simple accounting

Note that socioeconomic analyses differ from simple economic calculations in that it is the societal cost that is important. If a country imposes a fuel tax simply to generate income, the taxation part of the fuel price is not considered a societal cost – it is merely a transfer of money and the society as a whole is considered to be as well off after the transaction as before. In some situations, land may be transferred from local authorities to public road authorities or vice versa. The societal cost is not the transaction prices, since who owns the land is irrelevant to the societal value of the property. However, the opportunity cost does matter -- land claimed for road purposes, may no longer be employed otherwise.

Different European countries apply slightly different accounting principles (4). They differ with respect to the number of years a project is evaluated over, the rate of discounting, whether use of public funding should be associated with taxation cost (i.e. using tax money deprives the public of alternative use of the money and opportunities to profit), how to deal with VAT (value added taxes), fuel tariffs, costs before or after taxation and so on. There could also be differences in the length of the planning horizon, how to deal with residual values (value of the investments at the end of project period, where the infrastructure elements may still be considered to be of value).

3. Valuation of noise changes

In practice, the noise-reduction benefits are assigned a unit value, the size of which depends on the effects that are valued, the methodology used, and state of knowledge. When using a unit value, one assigns an average value to the noise reduction of 1 dB for each person. In some approaches, the value of the noise reduction is assessed through the impact reduction in the form of the reduced number of people that are highly annoyed, moderately annoyed or affected. The impact reduction can be in the form of the number of persons no longer *highly annoyed*, changes in annoyance scores, or other impact indicators.

Valuations of noise reduction or noise impact reduction are usually done by inferring preferences from actual choices and behavior (Revealed preference studies) or by eliciting people’s willingness to pay. These provide a monetary valuation of the most prominent effects affecting the individual.

3.1 Revealed preference studies

Revealed preference studies, such as the hedonic pricing method, are often used to assess the monetary value of local public goods like noise. In the hedonic pricing approach, the price differential when purchasing or renting houses or apartments with different properties, such as the acoustic environment, urban greenery, access to public transport and so on is analyzed. Hedonic pricing studies need to take into account all housing characteristics which are likely to affect the selling price (size, building quality, number of bathrooms, etc.). Based on hedonic-pricing methodology, statistical techniques are used to extract the relative importance of, for example, acoustical quality, vibrations and aesthetics for the valuations. However, the value of such regression analyses depend on the availability of suitable indicators a sufficient number of dwellings (respondents) and sites. Whilst several studies provide unit values for reducing noise by 1 dB, valuation of other factors may be scarce or lacking.

Methodological challenges are whether it is only noise exposure or also other environmental expsores that are valued, whether the housing market is well functioning (which is not always the case), and how to take into account transaction costs.

3.2 Stated preference studies

An alternative economic assessment to hedonic pricing is the stated preference approach. Here, people are asked how much they value different aspects of their environment. One popular method for eliciting such valuations is by choice experiments. In these, people are presented with choice alternatives where the attributes of different alternatives are systematically chosen, allowing statistical analyses of which factors play the greatest roles. This stated choice methodology has the advantage that it is easier to extract valuations of particular aspects of an environment. Disadvantages is that the valuations are often based on relatively few persons, questions that may be have limited validity (How do people assess what a "50%" noise reduction is – and what is the relationship with equivalent noise levels often calculated over a whole year). Many respondents reject the choice experiments because they are politically opposed to having to pay, and a not insignificant number of respondents have problems with the virtual choice experiments requiring disparate factors to be balanced in artificial choice situations.

The extracted values are often given as population averages. When applying the values, it may be useful to consider subpopulations and contextual factors. Noise-sensitive persons may perceive noisy areas to be considerably more annoying than non-sensitive ones.

3.3 Noise control vs soundscape approaches

Most of the valuation methods are undertaken with respect to avoiding excessive noise. However, one should be aware of the emergence of an additional socio-political and economic rationale in urban areas. Promoters of the soundscape approach focus on the value of positive urban environments in attracting people, businesses and economic activity. The idea is that it is not sufficient to limit how bad an area is allowed to become. Politicians and city and road planners need to foster positive urban qualities of areas to attract skilled labor, high-income businesses, tourists and so on. To be successful it is thus necessary to also put a value on restorative areas, benefits of stimulating areas for learning and experiencing etc.This calls for different acoustical indicators, and different types of valuation methods than those that are traditional – and there is a significant lack of empirical studies that address these issues (5).

3.4 European impact assessment and noise costing methods differ

The easiest approach pure exceedance of a noise limit value. In this case, the number of people over a chosen threshold, for example, is summarized. However, the result highly depends on the threshold and rates all exceedances as equal whether they are 1 or 10 dB over the threshold.

Another approach is the weighting of the people exceeding the threshold by the exceedance. This is done e.g. in the LKZ ('LärmKennZiffer') (6) . This methods still depends on a threshold but takes the exceedance into account.

Other methods are based on dose–response relations, based for example on noise annoyance, health effects, depreciation of residential buildings and so on. They can differ substantially on the weighting of high noise levels. Annoyance scores or other indicators that are approximately linear over the range of noise exposure in question, will rank different project alternatives in a similar manner, however the choice of cut-off values may differ, and can when the cut-off functions are sharp (no shoulders) lend disproportionate weight to whether respondents are just below or just above the cut off.

In Denmark, the 'noise exposure factor' (NEF) is the basis of all cost-benefit analyses (CBAs) of noise from road and rail traffic; it is an expression of the accumulated noise load on all the dwellings in an area(7). It is calculated as the sum of the weighted noise loads on the individual dwellings in the area, so that dwellings with high noise levels weigh more than dwellings with less noise'. In the Danish approach, the value of noise reduction thus increases exponentially with the noise level, See Figure 1x: Left panel. The Norwegian Noise Annoyance Index is an alternative approach using the mean annoyance score(8). Here, one not only counts the number of persons who are highly annoyed, but also those who are annoyed and slightly annoyed. Being *'Highly annoyed'* gets an annoyance score that is higher than if a person is merely *'Annoyed'*. The method has the advantage that it takes into account the benefits of noise reductions for those in the population who are exposed to 'normal' noise levels, see Figure 1: Right panel. The linearity of the noise annoyance index simplifies the calculation of noise benefits, since all noise reductions (above the cut-off) are treated as equal irrespective of the baseline level. A counterargument is that the long-term damages are higher at higher noise levels.

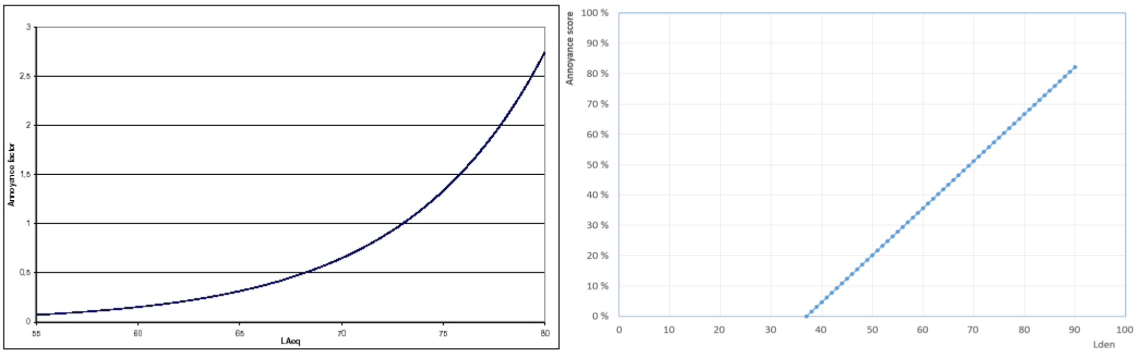

Figure 1 – Two indicators with quite different marginal benefit proviles. The Danish Noise exposure factor (Left panel) and the Norwegian Noise Index.

The NoiseScore (NS) is based on a function which linearly depends on the noise level L_{den} (6). Its increase is lower when under 65 dB than above 65 dB. The value derived from the function is multiplied by the number of affected parties. Since the function does not have a lower limit within its range of validity, the calculations are conducted for all level areas. Therefore, affected individuals with loads up to 65 dB have less influence on the result than those who experience levels higher than 65 dB.

The noise inhabitant level UCE_{DEN} (9) is based on the logarithmic product from the anti-logarithmic conversions of L_{den} and the number of affected parties and it takes some effort to sum up the UCE_{DEN} values determined in that way (for instance, to hectare or building values).

The Bavarian noise evaluation measure is derived from a noise level, a threshold value and the number of affected parties. The evaluation method and the threshold value can be applied in different ways depending on the task. With this function, values are determined only above a threshold which can be selected randomly.

3.5 Health effects

Economic valuation methods may need to be supplemented by methods to take into account health consequences that respondents may be unaware of, are sufficiently distant in time that they are neglected. Some effects of noise are not perceived, and not subjectively taken into account. Respondents also fail to fully take into account economic consequences for others, such as public medical expenses, costs for relatives, and costs for employers (tiredness, absences from work).

In the UK-approach (2), amenity and noise annoyance values are added to the independently derived health values of an increase or decrease of 1 dB. These vary depending on the noise level.

The disability-adjusted life-year (DALY) calculates the burden of disease based on exposure–response relationship, exposure distribution, background prevalence of disease and disability weights of the outcome (10). The excess noise annoyance, sleep disturbances, mortality and morbidity due to living in a noisy environment are assessed and accumulated in one indicator. After assigning a monetary value to one DALY, the results can be converted to monetary terms. However, assigning such a monetary value raises a number of difficult questions concerning the value of life, whether a life in one country is worth the same as in another and so on.

When taking health effects into account, as is done in the UK, the value of reducing noise at high levels with one dB increases – which means that economic calculations will indicate that projects focusing on reducing high-noise situations, ceteris paribus, will 'pay more' than reducing noise levels in medium- and low-level situations. Note that the effects on noise annoyance and sleep disturbances are considered higher than more narrowly defined health impacts.

3.6 Different assessment methods lead to different rankings of projects

Using different indicator methods, scenarios can easily be compared using a single or just a few indicator values. In the example below, three road planning alternatives lead to different numbers of people affected. In one case, the overall number of people affected by 65 dBA is higher; in the other cases, the noise levels are lower in general for most inhabitants, but a few people are affected more intensively by levels of 70 dBA. To make the scenario easier, single values from the bands of the END are used instead of all values e.g. between 60 and 70 dBA.

Table 1: Number of people/dwellings at certain noise levels (no intervals).

Scenario	60 dBA	65 dBA	70 dBA
1	50	120	0
2	100	50	20
3	110	30	30

After calculating the noise resulting noise exposures for the relevant alternatives, and calculating several of the noise impact indicators currently employed, we have the following picture:

Table 2: Number of people/dwellings at certain noise levels (no intervals).

Method		Scenario 1	Scenario 2	Scenario 3
Number of People Affected	> 60 dB	170	170	170
	> 65 dB	120	70	60
	> 70 dB	0	20	30
LKZ	Limit: 60 dB	600	450	450
	Limit: 65 dB	0	100	150
P-Score	Limit: 60 dB	3,181	2,605	2,715
	Limit: 65 dB	0	750	1,125
Noise Annoyance Index		64.8	62.4	62.4
Noise Exposure Factor		31.9	31.0	32.2
VDI 3722-2 (% HA)		24.6	23.4	23.6
WebTAG/Noise Annoyance		41,1	41,2	42,1
UCEDEN		86.3	86.6	87.0
NoiseScore		22,920	124,522	177,516

As can be seen from the ranking of the alternatives according to the different impact indicators, the ranking differs dependent on which indicator is used. For å more comprehensive explanations look up the Guidance Book (1).

3.7 Marginal improvements

Many measures to reduce noise affect a whole population of dwelling. In the case of surface treatments in the form of brick lattices the largest effects[3] are gained at the more distant locations, see

[3] . This is due to the acoustic properties of these devices

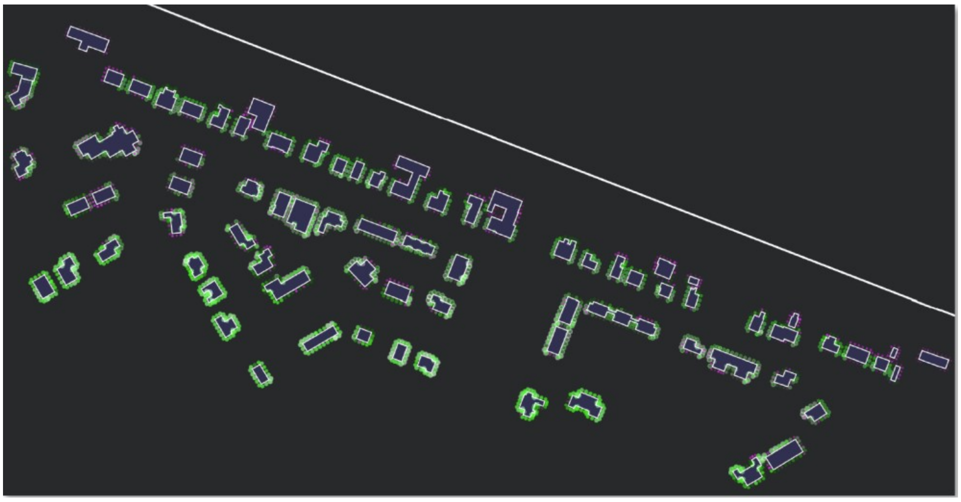

Figure 2 – A community benefiting from noise reducing brick lattices between lanes, and along the proximal road side. Calculated values.

When considering how large the additional benefits of low noise surfaces, traffic speed reduction or other measures, it is important to realize that average benefit diminishes as a function of the number of dBA the noise is reduce. Other noise outdoor and indoor noise sources increase in prominence as noise from the previous main noise source is reduced. For each additional dBA noise reduction more and more dwellings are below a cut-off of say 35 dBA where it is no longer reasonable to take into account the noise reduction(3). As a result the marginal monetary benefit of each additional dBA is reduced, see Figure 3.

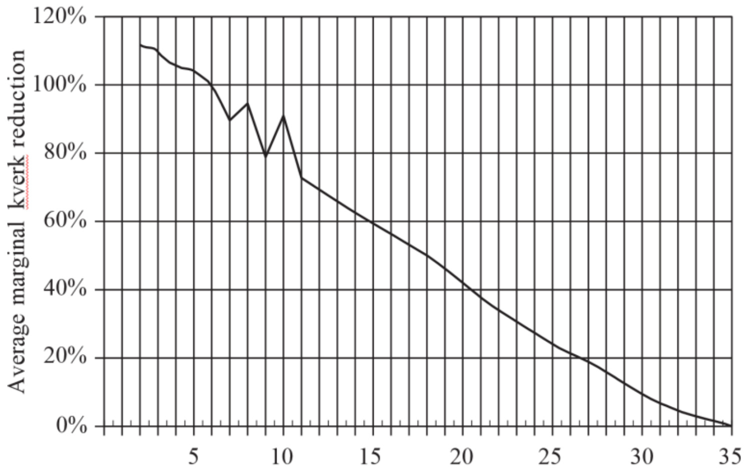

Figure 3 – Marginal benefits from each additional dBA are reduced as more and more dwellings are exposed to noise levels below the cut-off value.

4. CONCLUSIONS

Tere is a wide variety of monetary values for noise, and a wide variety of noise impact assessment methodologies currently employed. However, economic valuations can be an important addition to other noise impact assessment tools. They can help prioritize and rank projects and initiatives. Economic analyses can also be helpful when considering where to draw the line when additional benefits are not worth the extra cost, and where funds might be more usefully employed elsewhere.

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