NOISE COSTS OF ROAD TRAFFIC

Hélène Le Maître, Corresponding Author
CEREMA (Centre for Studies and Expertise on Risks, Environment, Mobility, and Urban and Country planning)
110 rue de Paris – 77171 Sourdun – France
Tel: 0033 1 60 52 33 02 ; Fax: 0033 1 60 52 84 97
Email: helene.le-maitre@developpement-durable.gouv.fr

Word count: 4,818 words text + 10 table/figures x 250 words (each) = 7318 words

Submitted August 1st, 2014

ABSTRACT

This paper calculates average and marginal noise costs for road traffic, for both trucks and light vehicles in euro per vehicle kilometer in order to enable noise cost calculations for projects when there is not enough available data to use euros per dB per person exposed in the cost-benefit analysis. It begins with some background on the impacts of noise exposure from transportation projects. Two approaches are used to calculate average costs. First, a top down approach is used to define total noise costs from French noise exposure maps. Then, a method is proposed to calculate exposed population given the settlement density and deduce average costs using noise costs in € per dB per inhabitant. This method allows to better taking into account the settlement density next to the road, instead of using average values for a range of settlement density values. Marginality ratios are calculated using a bottom up approach, combining noise emission and propagation modeling and the use of volume delay functions. The last part of the paper consists in a test of the different approaches on evaluating noise costs of a transportation project.

Keywords: Noise, Marginal cost, Road, Transportation

INTRODUCTION

Since 2004, French national guidelines *(1)* have integrated the evaluation of noise costs in cost-benefit analysis. The recommended method is based on hedonic prices to evaluate noise costs of transportation projects. However most evaluations do not integrate noise costs valuation. This is mainly a consequence of the lack of knowledge on noise levels and populations next to the transportation infrastructures. In the best cases, a noise exposure map of the transportation projects is available but it is not sufficient for the cost-benefit analysis. A complete evaluation requires knowledge on noise levels and exposed population both in the reference and project cases, and the projection of this data during the 50 years of the socio-economic evaluation. However, if the noise costs are given in euro per vehicle kilometer traveled, the evaluation of noise costs of transportation projects would only require knowledge on projected traffic, which is already available when the socio-economic evaluation is conducted. Therefore, this paper aims at testing a methodology providing with marginal and average noise costs in € per vehicle kilometer traveled for roads.

This paper begins with some background on the impacts of noise exposure from transportation projects. Then a top-down approach is used to define average noise costs from national noise exposure maps. The average costs are calculated combining the values in € per dB per exposed person per year from the HEATCO report *(2)*, number of exposed inhabitants per road provided by the noise exposure maps and traffic. Then, a method is proposed to calculate exposed population given the settlement density and deduce average costs using noise costs in € per dB per inhabitant. This method is better to take the settlement density next to the road into account, instead of using average values for a range of settlement density values.

Marginal costs can be deduced from average costs using a marginality ratio. The marginality ratio is calculated using a bottom up approach. Various values are calculated given different types of roads and traffics. The bottom-up approach combines noise emission and propagation modeling and the use of volume delay functions.

The last part of the paper consists in a test of the different approaches on evaluating noise costs of a transportation project. Values from noise exposure maps and €/dB per exposed person per year are compared with the use of marginal costs; the use of the simplified method to calculate the exposed population and €/dB per person exposed per year; and EU marginal costs. All values are of the same range for the project that was tested.

DEFINITION AND USE OF NOISE COSTS IN COST BENEFIT ANALYSIS

Noise indicator

The strength of noise is measured using the sound pressure level in dB. In order to calculate noise costs, a period of time and the time of day must be taken into account. For each period of time an indicator must be determined. The European Commission recommends the use of $L_{A,eq}$ [in dB(A)] which corresponds to the constant noise level that would have been produced by the sum of acoustical energy from all noises happening during the calculation period.

This level is calculated for three periods: « *day* » from 7 am to 7pm, « *evening* » from 7pm to 11 pm and « *night* » from 11pm to 7am. These 3 indicators can be aggregated using formula (1).

$$L_{DEN} = 10 \log\left(\frac{12}{24} * 10^{\frac{LD}{10}} + \frac{4}{24} * 10^{\frac{LE+5}{10}} + \frac{8}{24} * 10^{\frac{LN+10}{10}}\right) \quad (1)$$

where LD, LE and LN the $L_{A,eq}$ are the noise levels calculated for day, evening and night.

Monetary values

The monetary values for transportation noise in France only include the effects on annoyance and health (cardiovascular events). For further description on the impact of noise on health, see *(3), (4)* and *(5)*. The values that are used in France are described in detail in *(1)*. They are based on values provided by HEATCO *(2)* and the transfer from HEATCO to France is described in the following paragraphs.

Annoyance reflects the disturbance which is experienced when exposed to traffic noise. It is monetized based on HEATCO values, corrected for France using the method described in HEATCO-Annex D5. The EU values are based on stated preference studies on road traffic which present willingness to pay in terms of "euro per annoyed person per year" for different annoyance levels (little annoyed, annoyed and highly annoyed): see *(6)*.

Health impacts of noise disturbance are related to the long term exposure to noise, mainly stress related health effects like hypertension and myocardial infarction. Using data from EEA *(5)*, noise impacts on health are taken into account for noise levels lower than the 70 dB level from *(3)*. The values from HEATCO were updated using odds risks from EEA and life statistical value from France *(7)*. This value was determined based on an OCDE meta-analysis *(8)*.

Since noise maps provide the number of person who are exposed to a 5 dB range of noise level, the values in Table 1 were used.

TABLE 1 Monetary values of noise in $€_{2010}$ per exposed person and per year.

Lden	Cost
55-60	75,4
60-65	136,2
65-70	248,8
70-75	427,6
75-80	715,2

Total, average and marginal noise costs

The level of noise is a function of traffic volume, distance to the noise emission source, and other factors influencing noise (percentage of trucks, noise barriers, etc.). Total cost of noise is obtained by multiplying the number of individuals in a noise range with the cost of noise in €/dB per exposed person and per year for this range of noise.

$$total\ \cos t = \sum_i \cos t(L_i) \times pop_i \qquad (2)$$

where *cost* is the function of cost per person exposed to a noise level L_i and pop_i the number of person exposed to the noise level L; i is usually a class of noise as noise maps give discreet values of noise level and populations per class of noise level.

The average cost is defined as the total cost of noise from road traffic divided by the traffic in kilometers traveled.

$$average\ \cos t = \sum_i \frac{\cos t_i \times pop_i}{T} \qquad (3)$$

where T is the traffic in vehicle kilometers.

Average cost can therefore be used for a new infrastructure or for transportation project changing considerably the traffic on a road.

The marginal cost is the cost of one additional vehicle on the road. Hence it is used to take into account a limited variation in traffic.

$$marginal\ cost = \frac{\partial(total\ cost)}{\partial T} = \sum_i \frac{\partial(cost(L_i)\times pop_i)}{\partial T} = \sum_i pop_i \frac{\partial(cost)}{\partial L}\frac{\partial L}{\partial T} \qquad (4)$$

$\frac{\partial(L)}{\partial T}$ is the marginal change of noise level.

The marginality ratio is defined as $\frac{\partial L / L}{\partial T / T}$. (5)

If no noise map is available, $pop_i \frac{\partial(cost)}{\partial L}$ cannot be calculated but equation (4) can be approximated using the marginality ratio and the average cost, which are described and calculated in the following parts.

$$marginal\ cost = \sum_i pop_i \frac{\partial(cost)}{\partial L}\frac{\partial L}{\partial T} = \sum_i \frac{\partial L / L}{\partial T / T} pop_i \frac{\partial(cost)}{\partial L} \times \frac{L_i}{T} \qquad (6)$$

Since $\frac{\partial(cost_i)}{\partial L} \approx constant_i$ because $cost_i$ is a constant piecewise function,

$$marginal\ cost \approx \sum_i \frac{\partial L / L}{\partial T / T} \frac{pop_i \times cost_i}{T} \approx \frac{\partial L / L}{\partial T / T} \times average\ cost \qquad (7)$$

In the case of noise impacts, average and marginal cost vastly differ since the perception of noise follows a logarithmic scale. Both average and marginal costs are used in the evaluation of transportation projects. Average costs are used when a new road is built or when the marginality ratio is close to 1.

Use of European values of noise costs

Various methods exist in order to calculate marginal social cost of environmental impacts of transportation projects. For a presentation of these methods see *(9).* Since 2004 a valuation of noise costs has been recommended in France for the evaluation of transportation projects using hedonic prices. However this method asks for a lot of data and cannot be used for every transportation project *(10)*, *(1).* The same problem of systematic applicability occurs with the values from HEATCO reports, and from the European Commission which are in €/dB [*(11), (12), (13), (14)* and *(15)*]. The report from INFRAS *(16)* provides marginal costs for various classes of population density and roads. However, these values cannot be transferred in France since they were calculated for 3 types of roads which are not representative of road type, traffic composition and settlement density in France.

In this paper we aim at providing a simplified method, with costs in € per kilometer traveled. Therefore we used an approach combining the calculation of noise level and marginal change, the population exposed to noise and the use of monetary values in € per dB per exposed person and per year. We first calculated average costs and then marginality ratios in order to get both average and marginal costs in euros per vehicle kilometer.

CALCULATION OF AVERAGE COSTS

This part describes the calculation of average cost of noise for road traffic using noise maps. Noise maps including information on the number of exposed inhabitants will be available for all major roads and cities in the UE as required by the Environmental Noise Directive of the European Commission *(17).* These maps allow calculating average noise cost, and therefore we only need a marginality ratio in order to take into account the effects of a variation in traffic. However, these maps will not exist for every road and transportation project, and rarely cover the whole network affected by the transportation project. This is why we propose an alternate method to calculate average costs for the cases where this data is not available (or is not available for both reference case and project case), which is mostly the case for new transportation projects in France.

Average costs calculated with noise maps

The first approach consists in using available noise maps and calculating average costs that can be transferred to other roads.

Available noise maps are used to calculate average noise cost. Data from these maps include traffic, number of exposed persons for 5dB range and the population density next to the infrastructure was added. Population density is divided into 5 classes and resulting average costs are presented in Table 2.

TABLE 2 Average cost of noise in €$_{2010}$/1000 veh-km

Population density *inhabitants/km²*	**Type of road**	**Number of observations**	**Average noise cost** *€$_{2010}$/1000v.km*	**Standard deviation**	**Minimum**	**Maximum**
< 37	Highway	13	0.78	0.59	0.11	2.07
	Other road	40	3.35	4.69	0.00	20.17
37-450	Highway	29	3.14	4.94	0.00	21.81
	Other road	618	7.35	18.53	0.00	260.78
	Communal road	127	35.08	51.82	0.09	398.78
450-1,500	Highway	24	8.99	13.79	0.92	62.36
	Other road	382	9.75	14.39	0.00	165.39
	Communal road	408	48.45	81.81	0.00	850.31
1,500-4,500	Highway	8	13.24	24.51	0.37	73.18
	Other road	207	15.72	24.45	0.00	258.05
	Communal road	672	58.41	95.55	0.00	1342.53
> 4 500	Highway	3	22.40	9.54	11.49	29.21
	Other road	49	28.96	35.30	0.22	209.20
	Communal road	98	66.29	53.80	0.48	291.46

No data was available on the presence of noise barriers and the population density was the population of the city which can explain most of the dispersion in the results.

Method to approximate population exposed to noise with the population density

When no noise map is available, the population exposed to noise can be approximated using hypotheses on the population density. This method allows taking into account the specific settlement density close to the road better than when average costs from Table 2 are used.

Two kind of density were supposed, a homogeneous density, which is assumed to correspond to urban roads, and a linear decrease in density, which is used for rural roads.

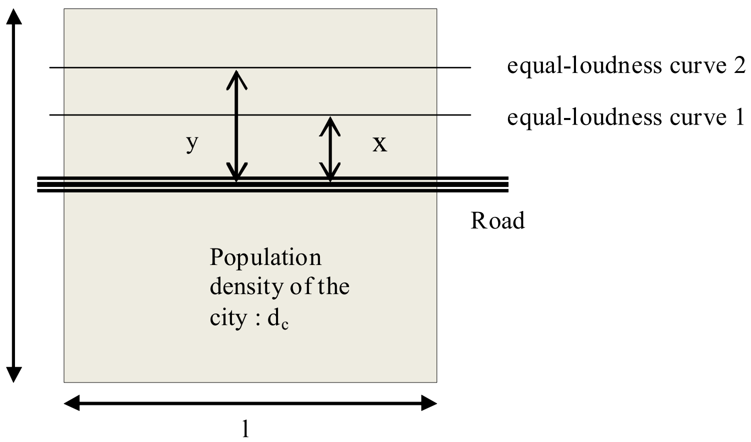

FIGURE 1 Population density and equal-loudness curves.

Population between two equal-loudness curves can be calculated with equation (8).

$$pop_{x,y} = l\int_x^y f\left(d_c, d\right)\partial d \quad (8)$$

where parameters are describes in Figure 1.

The distances between equal-loudness curves and the road are calibrated with the noise maps that were previously used to calculate average noise costs.

TABLE 3 Distances between equal-loudness curves and the road based on noise maps

Equal-loudness curve (class of noise level)	**Distance from to infrastructure for homogeneous density** *(in km)*	**Distance from to infrastructure for linear density** *(in km)*
70-80	0.005	0.01
65-70	0.015	0.015
60-65	0.1	0.1
55-60	0.2	0.2
50-55	0.3	0.36

Resulting distances between equal-loudness curves and the road are presented in Table 3. Using theses distances, the density type and population density of the area traversed by the road and equation (8), populations per class of noise level can be approximated. Finally, average costs can be deduced applying equation (3) and noise values from Table 1.

CALCULATION OF THE MARGINALITY RATIO

Once the average noise cost is known, the marginality ratio must be calculated in order to get the marginal cost of noise. This part describes the noise function, and then calculates the marginal change in noise level for one additional vehicle, which is the derivative of noise level over traffic. Then, marginality ratios, equation (5), are calculated using a bottom up approach, combining noise emission and propagation modeling and the use of vehicle delay functions. Marginal cost of noise can be deduced by multiplying average cost by marginality ratio.

Noise emission and propagation model

The noise level function is determined following the French guidelines *(18)* and *(19)*. These guidelines follow the European recommendations *(17)*. Each road is modeled as a string of punctual sources separated by a distance l_i.

The effect of secondary sources is not taken into account. An example of calculation of noise costs of traffic including the effect of secondary sources can be found in *(21)*.

The first step consists in calculating the noise level L_{eq} at a distance d of the noise source i.

For a road, $$L_{eq\ total} = 10\log\left(\sum_{i=1}^{N} 10^{L_{eq,i}/10}\right) \quad (9)$$

where $L_{eq,i}$ is a function of the noise source i and N is the number of punctual sources.
The level equivalent of noise L_{eq} at a distance d of the noise source i is:

$$L_{eq,i} = 10\log\left(\sum_{j} 10^{L_{j,iH}/10}\right) \quad (10)$$

where $L_{j,i,H}$ is the level of noise for a third octave band j.
The sum of noise levels from two points emitting the noise levels L_1 and L_2 is defined as an acoustical sum:

$$L_1 \oplus L_2 = 10\log(10^{L_1/10} + 10^{L_2/10}) \quad (11)$$

Noise level is usually calculated in two terms (12): the emissions L_{Awi} depend on speed, type of road, composition of traffic, etc. The second part of the equation, L_{AiH} represents the propagation of noise.

$$L_{i,H} = L_{AWi} - A_{iH} \quad (12)$$

where i is the source;
L_{Awi} is the noise level of a source S_i in a third octave band;
A_{iH} is the attenuation due to the propagation of noise from S_i in homogeneous conditions in a third octave band.

In the following sections, the calculation of emissions, including speed modeling, and propagation is detailed.

Emission

The noise level of the emissions is an acoustical sum of noise of the emissions from the light vehicles and from the trucks.

$$L_{AWi} = \left[\left(L_{W/m,LV} + 10\log Q_{LV}\right) \oplus \left(L_{W/m,truck} + 10\log Q_{truck}\right)\right] + 10\log l_i + R(j) \quad (13)$$

where l_i is the distance between 2 sources;
$R(j)$ is the road noise spectrum normalized at 0 dB;
Q_{LV} is the hourly traffic flow of light vehicles;
Q_{trucks} is the hourly traffic flow of trucks;

$L_{W/m,LV}$ is the noise strength per meter of source for a traffic flow of 1 light vehicle/h;
$L_{W/m,truck}$ is the noise strength per meter of source for a traffic flow of 1 truck/h.

The noise strength per meter of source for one unit of traffic flow is:

$$L_{W/m,LV} = L_{Amax} - 10\log V - 4{,}4 \qquad (14)$$

where V is the speed, calculated with the speed-flow functions *(22);*
L_{Amax} is the noise level of 1 passing vehicle.

The noise level of one vehicle is an acoustical sum of engine noise and rolling noise.

$$L_{A\max} = L_{rolling} \oplus L_{engine} = \left(a_{rolling} + b_{rolling}\log(V / c_{rollling})\right) \oplus \left(a_{engine} + b_{engine}\log(V / c_{engine})\right) \qquad (15)$$

where a, b and c are constants which depend on the type of road. Values for these parameters can be found in *(18)*;
V is the speed of the vehicle.

Speed as a function of traffic flow

Speed is calculated with French Speed-Flow functions *(22)*, which are based on BPR Speed-Flow Relationships *(23)*.

Travelling times tk_{mLV} for light vehicles and $tk_{m,truck}$ for trucks, in minutes per kilometer, are given by the following equations:

$$tk_{mLV} = tk_{0_V} \times \left[1 + \gamma_{LV} \times \left(\frac{Q_{LV} + e \times Q_{truck}}{\kappa}\right)^{\alpha_{LV}}\right] \qquad (16)$$

$$tk_{m,truck} = tk_{0_{truck}} \times \left[1 + \gamma_{truck} \times \left(\frac{Q_{LV} + e \times Q_{truck}}{\kappa}\right)^{\alpha_{truck}}\right] \qquad (17)$$

where $tk_{0_{LV}}$ and $tk_{0_{truck}}$ are the free flow travelling time of light vehicles and in minutes per kilometer;

γ_{LV} and γ_{truck} are the proportions of time increasing at congestion, are calculated with the equations (18):

$$\gamma_{LV} = \frac{t_{LV}}{tk_{0LV}} - 1 \text{ and } \gamma_{truck} = \frac{t_{truck}}{tk_{0truck}} - 1 \qquad (18)$$

t_{LV} and t_{truck} are the critical times per unit of distance;

e is the equivalent ratio between light vehicles and trucks;

α_{LV} and α_{truck} are the congestion parameters;

Q_{LV} and Q_{truck} are the traffic flow of light vehicles and trucks used for the travel time calculation (in vehicles per hour), are obtained with the concentration factors χ_{LV} and χ_{truck} : $Q_{LV} = x_{Lv} \times \chi_{Lv}$ and $Q_{truck} = x_{truck} \times \chi_{truck}$ where x_{LV} and x_{truck} are assigned light vehicles and trucks traffic flow as AADT/24 (vehicles per hour);

κ is the capacity per traffic unit in either direction.

Propagation: A_{iH}

The propagation effect is divided into 3 terms:

$$A_{i,H} = A_{div} + A_{atm} + A_{front} \quad (19)$$

where A_{div} is the attenuation to the geometric divergence;
A_{atm} is the attenuation due to the atmospheric absorption;
A_{front} is the attenuation due to the ground effect $= f_H(d)$.

Following the guide *Prevision du bruit routier (19),*

$$A_{i,H} = 20 \log d + 11 + \alpha d / 1000 + f_H(d) \quad (20)$$

$$A_{div} = 20 \log d + 11 \text{ and } A_{atm} = \alpha d / 1000 \quad (21)$$

where d is the distance to the source of noise and α is a constant.

Effect of distance on marginal change of noise level

The marginal change of noise level is defined as the derivative of noise level in dB over traffic. As L_{Awi} depends on traffic volume and road characteristics but not on the distance to the noise sources, $\frac{\partial L_{i,H}}{\partial T\, \partial d} = \frac{\partial (L_{AWi} - A_{iH})}{\partial T\, \partial d} = \frac{\partial L_{AWi}}{\partial T\, \partial d} = 0$ (22)

This equations means that distance to the noise source has no effect on marginal change in noise level. Therefore, there is no need to model A_{iH} to calculate marginal change in noise level due to road traffic.

Marginal change in noise level

The final indicator that is used to calculate marginal change in noise level is L_{DEN}. It is calculated using hourly traffic flows in order to get differentiated noise levels for day, evening and night. These noise levels are obtained combining equations (9) to (21).

The marginal change in noise level is calculated as $\frac{\partial L_{DEN}}{\partial T}$ where T is either the truck or light vehicles traffic.

Results

Simulation on a highway

Simulations are run for a 4-lane highway with a recent surface course. Parameters for L_{engine} and $L_{rolling}$ for trucks and light vehicles correspond to a constant speed on a flat road. In Figure 2, truck traffic is 200 veh/h when we calculate marginal change in noise level for light vehicles and in Figure 3, light vehicles traffic is 2,000 veh/h when we calculate marginal change in noise level for trucks.

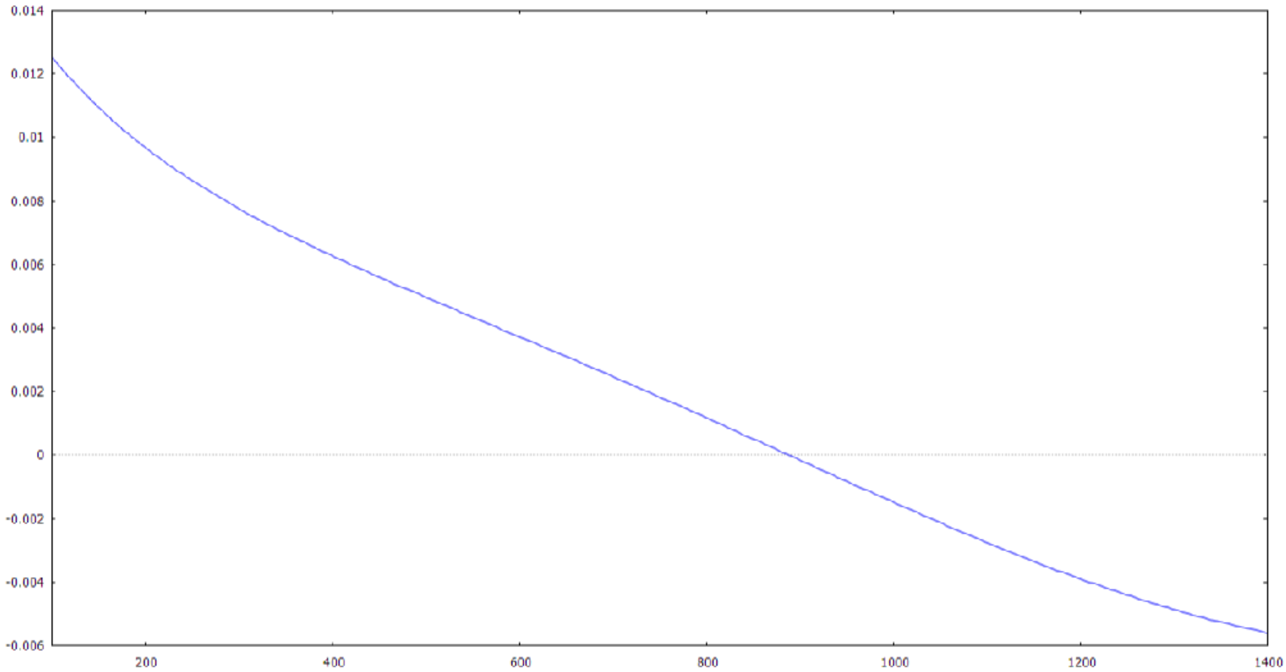

FIGURE 2 Marginal change in noise level due to light vehicles against light vehicles traffic per hour in either direction with a truck traffic of 100 veh/h in either direction

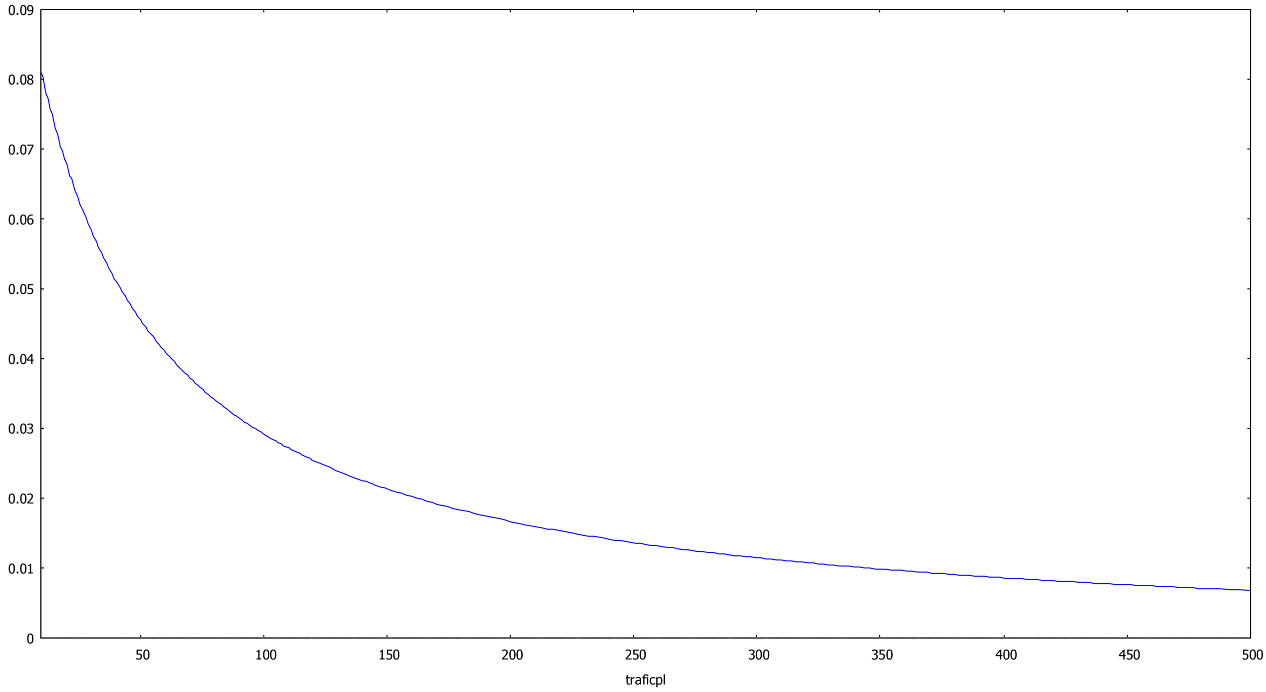

FIGURE 3 Marginal change in noise level due to trucks against truck traffic per hour in either direction with a light vehicles traffic of 1,000 veh/h in either direction

Effect of speed on marginal change in noise level

Figure 2 and Figure 3 show that for light vehicles, above a traffic level limit, marginal change of noise level can be negative. This can be explained by the decrease in speed due to congestion which is modeled by flow-speed equations.

However, when traffic increases and congestion occurs, traffic flow is not constant and vehicles stop and go. Therefore, noise emissions characteristics are altered. Furthermore, speed flow equations may not be in their validity domain. In Figure 2 and Figure 3, until an hourly total traffic flow of 1,200 vehicles in either direction, which corresponds to a speed for light vehicles of 80 km/h, the speed flow equations are in their validity domain.

In order to see the sensitivity of the marginal change in noise level to variations of the engine noise, calculations are run in an acceleration phase with $a_{engine\ LV}$= 68.2, $b_{engine\ LV}$= 38.6 and $c_{engine\ LV}$= 90. These values can be used for a speed between 100 km/h and 130 km/h. A second test is run with values coherent with speed between 20 and 100 km/h: L_{engine}=70 dB. For trucks, the engine noise level is supposed to be the same whether the vehicles accelerate or not *(18)*.

These two tests increase the engine noise which becomes higher than the rolling noise. Therefore, as the engine components increase, the noise emission from the engine is higher than the effect of speed on rolling noise. The marginal change in noise level increases when traffic increases because the relative effect of speed reduction as a result of an additional vehicle decreases.

TABLE 4 Marginal change in noise level due to light vehicles on a 4-lane highway for a trucks traffic of 100 veh/h in either direction

Traffic in either direction	**Light vehicles speed (km/h)**	**Constant speed**	**Acceleration**	**Acceleration, L_{engine}=70**
800	109	0.00117	0.000986	0.00209
900	104	- 0.000157	- 0.0004770	0.00116
1000	98	- 0.00148	- 0.00192	0.000379
1100	92	- 0.00275	- 0.00329	- 0.000162
1200	84	- 0.00389	- 0.00452	- 0.000368

The results in Table 4 show that the increase in the engine component when congestion occurs increases the marginal change in noise level by 15% to 30%. The effect of speed therefore seems preponderant on the effect of the engine component: the marginal change in noise level remains negative for a traffic flow higher than 1,000 vehicles per hour in either direction.

Simulations on a 2-lane road, with an old surface course

Simulations are run for a 2-lane road with an old surface course. Components of L_{engine} and $L_{rolling}$ are chosen for a constant speed on a flat road. These parameters can be used for this type of road for speeds between 20 km/h and 130 km/h at constant speed. In Figure 4, trucks hourly traffic in either direction is 10 veh/h when studying marginal change in noise due to light vehicles traffic and in Figure 5, light vehicles hourly traffic in either direction is 80 veh/h when studying marginal change in noise level due to trucks.

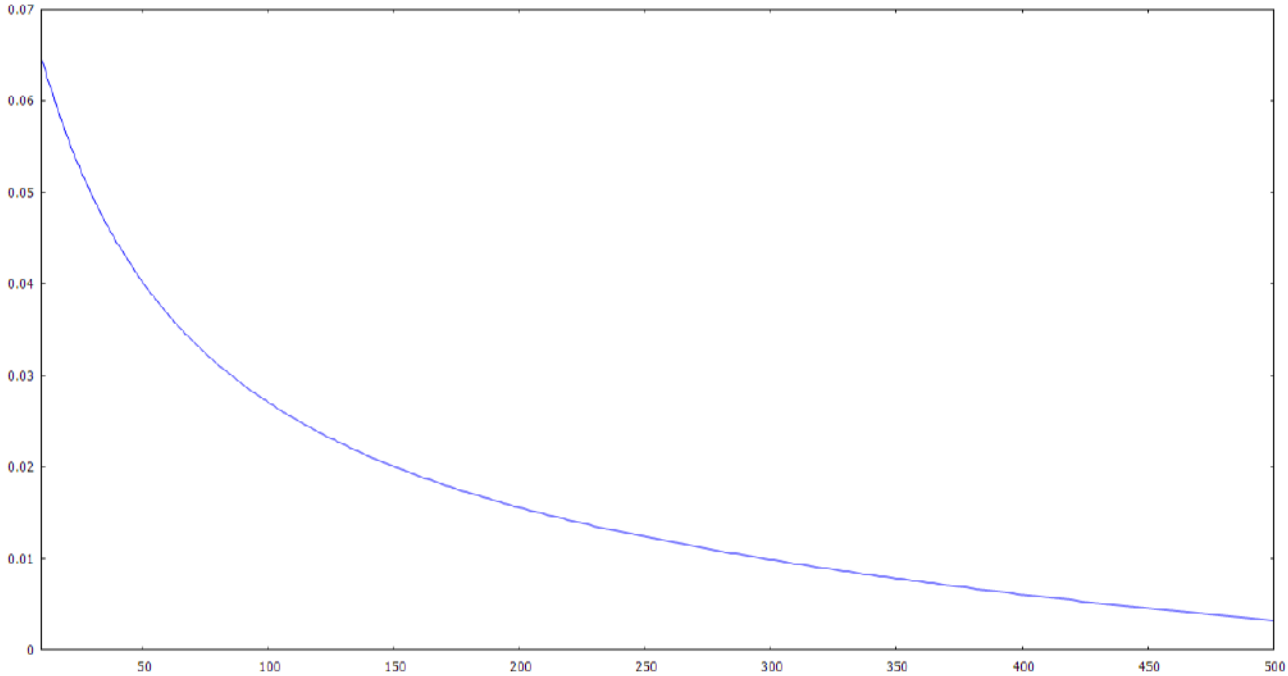

FIGURE 4 Marginal change in noise level due to light vehicles against light vehicles traffic per hour in either direction, with a truck traffic of 10 veh/h

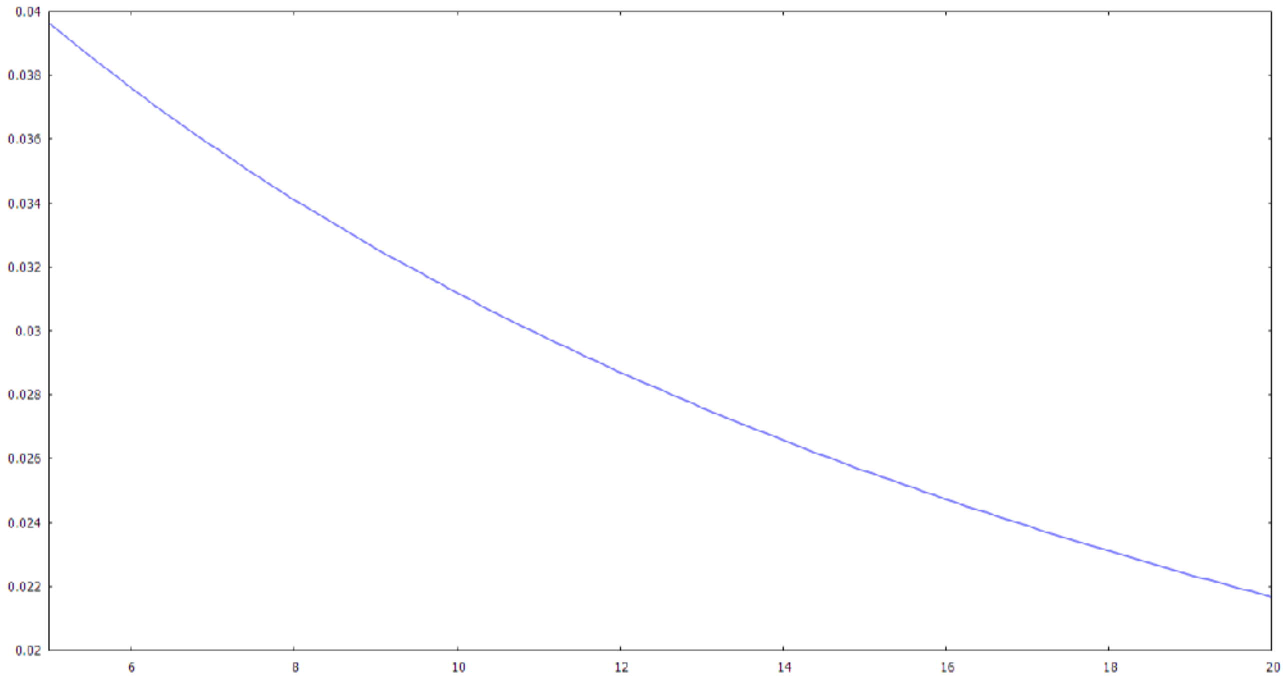

FIGURE 5 Marginal change in noise level due to trucks against truck traffic per hour in either direction, with a light vehicles traffic of 80 veh/h

Figure 4 and Figure 5 show that the marginal change in noise level is higher for a 2-lane road than for the 4-lane highway. Results on the highway and 2-lane road suggest that the marginal change in noise level heavily depend on speed and therefore total traffic.

Calculation of the marginality ratio

Marginality ratios are calculated in Table 5 for a few traffic and road settings, using previous marginal changes in noise levels.

TABLE 5 Marginality ratio of road traffic

Hourly traffic in either direction	Type of vehicles	Type of road	Marginality ratio for the type of vehicle
500 - 25% of trucks	Light vehicles	4-lane highway	5.7 %
1100 - 10% of trucks	Trucks	4-lane highway	60.0 %
110 - 10% of trucks	Light vehicles	2-lane road	6.2 %
90 - 12% of trucks	Trucks	2-lane road	11.0 %

Noise marginality ratios are between 5% and 60%. Marginality ratios are higher for trucks than for light vehicle, as can be expected, especially in congestion. The values are higher than the 40% ratio (for either light vehicles or trucks) that is indicated in the HEATCO report *(2).*

TESTS ON A REAL PROJECT

Tests of the various methods and costs calculated in this paper are run on an on-site improvement project in France. The project is 18 kilometers long and includes a small town bypass road. AADT is 8,250 vehicles including 17% of trucks for the project case and 6,750 vehicles in the reference case.

The use of the noise map, which was available for this project and marginality ratio, specifically calculated for the project with its total traffic and type of road, resulted in a variation of noise cost for one year around 2.3 k€.

The use of population density and distances between equal-loudness curves from Table 3, and the same marginality ratios as the previous calculation resulted in a cost of 3.45 k€.

The use of average costs from Table 2 and marginality ratio, specifically calculated for the project with its total traffic and type of road, resulted in a variation of noise cost of 1.14 k€.

The use of marginal costs from the report from INFRAS *(16)* resulted in a variation of noise cost around 2.4 k€.

Results from all the methods give the same range of values for this specific case.

CONCLUSION

The various methods tested in this paper allow the calculation of noise costs of roads with various degrees of precision, depending on available data. Average costs were calculated using available noise maps, which allow accounting for more diversity in road types and population density than the use of textbook cases, which are often used to calculate average costs per vehicle kilometer. Also, a more precise method without noise maps, based on population density and type of density can be used as a sensitivity analysis in the calculation of noise costs for a transportation project.

A noise model was used to calculate marginality ratios, which can be combined with average costs to determine marginality costs. This model shows that marginality ratios are very sensitive to speed and therefore to hourly traffic flow, but also to road type and percentage of trucks, as could be expected. This model is simplified since it does not include the effects of secondary sources, but its main advantage is that it allows calculating marginality costs specific to each road included in a transportation model and therefore allows a more precise calculation of noise costs in economic evaluation of transportation projects.

The values that are obtained using these various methods are coherent with other EU values of noise costs.The values that are presented in this report, especially the ones based on noise maps, could be improved if more information is available on the noise maps, especially concerning the presence of noise barriers.

REFERENCES

1. MEDDTL, *Instruction cadre relative aux méthodes d'évaluation économique des grands projets d'infrastructures*. Comité des directeurs transport, French Ministry in charge of Transportation, 2004 (updated in 2005)
2. BICKEL, P. IER, *Derivation of fall-back values for impacts due to noise* – Annex E to HEATCO deliverable 5. 2006.
3. De Kluizenaar Y, van Lenthe FJ, Visschedijk AJ, Zandveld PY, Miedema HM, Mackenbach JP. Road traffic noise, air pollution components and cardiovascular events. *Noise Health*, 2013.
4. WG HSEA EU. *Working group on Health and socio-economic Aspects 'valuation of noise', position paper*, 2003.
5. *Good practice guide on noise exposure and potential health effects*, European Environment Agency, 2010
6. Navrud, S. The economic value of noise within the European Union - A review and analysis of studies. *Mimeo*, 2004.
7. *Cost benefit assessmentof public investments,* report of the mission chaired by Emile Quinet, Commissariat Général à la Stratégie et à la Prospective, 2013
8. OECD, *Mortality Risk Valuation in Environment, Health and Transport Policies*, OECD Publishing, 2012.
9. Florio, M. *Applied welfare economics. Cost-Benefit Analysis of projects and policies*, Routledge, 2014.
10. Day, B., Bateman, I., and Lake, I. Beyond implicit prices: Recovering theoretically consistent and transferable values for noise avoidance from a hedonic property price model. *Environmental and Resource Economics*, 2007.
11. Maibach, M., Schreyer, C., Schneider, C., Herry, M. OCDE, *External costs of transport in Central and Eastern Europe*., 2002.
12. *Deliverable 3: Marginal cost methodology* – UNITE., 2001
13. *Handbook on estimation of external costs in the transport sector* – IMPACT, M. Delft, 2007.
14. European Commission. *White paper - European transport policy for 2010: time to decide*. 2001.
15. *Guide to Cost-Benefit Analysis of Investment Projects*. European Union. 2008.
16. *External costs of transport: update study for 2008*. CE Delft, INFRAS, Fraunhofer, 2011.
17. *Environmental noise directive* European Commission. 2002/49/EG. 2002.
18. SETRA, *Prévision du bruit routier – Calcul des émissions sonores dues au trafic routier. Guide méthodologique*. 2009.
19. SETRA, *Prévision du bruit routier – Méthode de calcul de propagation du bruit incluant les effects météorologiques (NMPB 2008),* 2009.
20. Rothengatter, W. How good is first best? Marginal cost and other pricing principles for user charging in transport, *Transport Policy*, 10(2), 121-130, 2003.
21. Andersson, H., and M. Ögren `Noise Charges in Road Infrastructure: A Pricing Schedule Based on the Marginal Cost Principle'. *Journal of Transportation Engineering* 137(12), 926{933, 2011
22. SETRA, *Fonction temps-débit sur les autoroutes interurbaines – Rénovation des relations entre temps de parcours et débit pour la simulation du trafic*, 2001
23. *Highway Capacity Manual 2000*, Transportation Research Board, 1999