can be given in compensation to those affected by pollution.

Compensation for house price depreciation caused by noise or other environmental impact is a well established policy. House price depreciation does not reflect the full social welfare cost of pollution but compensation may in principle also be paid to cover this - though there are difficulties in deciding what level of compensation this would require. For example, the contingent valuation method which is often advocated as a way of valuing environmental impacts is beset by unresolved doubts about the validity of its estimates of willingness to accept compensation. Willingness to pay for environmental improvements may severely underestimate the compensation required for equal and opposite environmental degradations.

Compensation may be used by people to help defend themselves against environmental impacts - e.g. by installing sound insulation or moving house. Indeed it may be specifically linked to such ends, and given as compensation-in-kind. Alternatively it may be used to purchase other goods to compensate for the loss in welfare brought about by noise. Though social justice may require people who suffer from noise to be compensated, it is debatable whether adopting compensation as a policy instead of noise abatement is socially desirable. It may not be good for society as a whole for people to live in environmentally degraded conditions even if the individuals themselves are satisfied by the compensation payments.

An important aspect of compensation is that in some circumstances the polluter, or the authority making decisions about pollution, may have to pay the compensation themselves. This is particularly so in the planning of new railways, airports and roads where projected compensation payments may be an incentive for the promoting authority to reduce or mitigate environmental impacts.

2.4. Education and information

These activities are important in promoting acceptance of and compliance with noise regulations. They can also be used in their own right to encourage noise abatement. Possibilities include :

- Educating technical staff, decision-makers and elected representatives in the application of noise abatement policy and the importance of noise as a problem.
- Educating the public to gain acceptance of noise abatement policies and promote low-noise behaviour such as choosing quiet vehicles or adopting a low-noise driving style.
- Demonstrating the benefits that improved noise abatement can bring.

3. CONCLUSIONS

Transport noise can be controlled by reducing it at source, limiting its transmission, and reducing it at the reception point (e.g. by insulation or by moving source and receiver further apart). Some techniques have been applied very successfully - e.g. reducing the drive-by noise of heavy goods vehicles from 92 to 80 dB(A) by 1995 - while others have been shown to be effective but have yet to be introduced on a large scale (e.g. porous low-noise road surfaces). Research is continuing to improve our technical ability to reduce transport noise.

To encourage noise reduction techniques to be put into practice, many types of policy are available, and most of them do not appear to have yet been used to maximum effectiveness. For example, the following would all seem to offer the likelihood of improved noise abatement :

- Higher and more widespread aircraft landing charges.

- Road vehicle noise charges linked to taxation and road pricing.
- Tradeable noise permits for both the manufacture and use of vehicles.
- Improved compensation to people who suffer from noise.
- More stringent noise emission regulations.
- In-service testing to encourage proper maintenance. If the testing is coupled with tradeable permits or a noise category tax, it will also encourage users to reduce noise emissions.
- More stringent noise immission regulations
- Improved planning and environmental appraisal tools to allow noise impacts to be better taken into account in decision making
- Supporting all the above by greater investment in research to improve noise control technology.
- Bringing the chosen policies together as a co-ordinated whole, with long term targets being set to reflect a demanding but achievable rate of change.

Many of these activities are covered in the Work Plan of the 5th Environmental Action Programme (EAP) of the CEC, which was approved by the Commission and adopted by the Council in February 1993 [24]. This includes : (i) obtaining an inventory of noise exposure levels in the EC before 1994, (ii) setting up a noise abatement programme before 1995 including further reductions of noise emission from all powered vehicle ; directives to be presented progressively aiming at implementation not later than year 2000, (iii) standardising noise measurement and ratings, (iv) establishing measures to influence behaviour such as driving cars, flight procedures, industrial processes operating at night time, (v) establishing measures related to infrastructure and physical planning such as better zoning around airports, industrial areas, main roads and railways.

Since the policy improvements listed above are in principle fairly straightforward, it would seem that cost and political commitment must be the main factors limiting current noise abatement activities. This suggests that research to establish the size and importance of the noise problem, coupled with projects to demonstrate how noise abatement policy improvements could be introduced, might be the most effective way to promote further improvements in noise abatement. Such action should be an effective support for the Commission of the European Communities objective on noise abatement, as stated in the 5th Environmental Action Programme : "No person should be exposed to noise levels which endanger health and quality of life".

References

[1] P.M. Nelson. Vehicle noise reduction. In: Delanne, Y (ed), The mitigation of traffic noise in urban areas - Reference book. Eurosymposium, 12-15 May 1992, Nantes.

[2] J.W. Tyler. Sources of vehicle noise. In : Nelson, P.M. (ed) Transportation noise reference book. Butterworths, London, 1987.

[3] B. Favre, J.W. Tyler. Quiet vehicle development. In: Nelson, PM (ed) Transportation noise reference book. Butterworths, London, 1987.

[4] B. Favre, J. Lambert, J. Delsey. Perspectives de réduction du bruit des véhicules routiers pour 1985 et 2000 compte tenu des possibilités techniques, de la consommation énergétique et du coût. Rapport EUR 8573, CCE, 1983.

[5] P.M. Nelson. The acoustical characteristics of porous road surfaces. Department of Transport, Transport Research Laboratory Project Report PR/ENV/005/93. Transport Research Laboratory, Crowthorne, 1993.

[6] P. Bar, Y. Delanne. Réduire le bruit pneumatiques-chaussées. Presses de l'ENPC, 1993.

[7] G.R. Watts. Acoustic performance of traffic noise barriers - A state of the art review, Acoustics Bulletin, Vol. 18, No.3 May/June and No. 6 November/December, Institute of Acoustics, St Albans, 1993.

[8] L. Huddard. The use of vegetation for traffic noise screening. Transport Research Laboratory Research Report RR238. Department of Transport, Transport Research Laboratory, Crowthorne, Berkshire, 1990.

[9] Department of Transport. Railway Noise and the Insulation of Dwellings, Department of Transport, HMSO, London, 1991.

[10] M.J.T. Smith & J. Williams. Subsonic aircraft noise. In: Nelson, PM (ed) Transportation noise reference book. Butterworths, London, 1987.

[11] Department of Transport. Review of aircraft noise legislation : announcement of conclusions. Department of Transport, London, 1993.

[12] OECD. Fighting noise in the 1990s. OECD, Paris, 1991.

[13] P. Nelson. Vehicle noise. Paper prepared for the ECMT Ministerial Session of 23 rd november 1989.

[14] Nordic Noise Group - Nordic Council of Ministers. More stringent requirements concerning noise emissions from motors vehicles in the nordic countries. Miljörapport 1988 : 18.

[15] U. Sandberg. Action plan against exterior tyre/road noise. Proceedings of Inter-Noise 93, vol.2, Leuven, Belgium, 1993 August 24 - 26.

[16] OECD. Environmental impact assessment of roads. OECD, Paris, 1994.

[17] A. Alexandre & J.Ph. Barde. The valuation of noise. In Nelson, PM (ed) Transportation noise reference book, Butterworths, London, 1987.

[18] Department of the Environment. Report of the Noise Review Working Party. HMSO London, 1990.

[19] P. Jones, A. Hervik. Restraining car traffic in european cities : an emerging role for road pricing. Transportation research, vol. 26A, n°2, 1992, pp 133 - 145.

[20] W. Rothengatter. Economic aspects. In: Transport policy and the environment. ECMT Ministerial Session, Paris, 1989.

[21] H. Waller. Exchange of information on noise abatement policies : case study on the Netherlands. Report prepared for OECD Environment Directorate, July 1988.

[22] E.R.L. Incentives for low noise vehicles. Report prepared for OECD, 1988.

[23] K. Button. Transport, the environment, and economic policy. Edward Elgar, Aldershot, 1993.

[24] H. Müller. Reflections on the future development of noise policy in the European Commission. Proceedings of Inter-Noise 93, Leuven, Belgium, 1993 August 24 - 26.

PART 5 : ALTERNATIVE SETS OF EC NOISE QUALITY STANDARDS

1. DEFINING THE GOALS

Implementing a European noise policy needs first to define the goals to be achieved. Qualitative targets correspond to sets of noise quality standards (indices and noise exposure limits) called "scenarios".

Targets only reflect the importance that the community and its representative attach to fighting noise pollution and thus have a direct relationship with the effects of noise community wants to avoid or eliminate (see Part 1). This means that for a given goal there is a given noise environment quality.

As an initial approach, three targets can be proposed which correspond to three degrees on commitment in the definition of a noise abatement policy both for existing situations (black spot correction policy) and new situations (prevention policy) for which available technologies provide solutions for the future.

- ***Target 1 : Limit critical noise exposure situations***

The priority is to eliminate existing noise exposure situations which can, over time, impair health. This is the case of extremely high noise levels (daytime Leq > 73 dBA at the facade for road traffic noise). For new situations -i.e. when new infrastructures are created for example, noise will be limited to tolerable annoyance levels.

- ***Target 2 : Provide satisfactory protection to people exposed***

The black spot correction policy aims to eliminate exposure situations which do not only impair health but also are perceived as highly annoying. This corresponds to high levels of noise exposure (daytime Leq > 68 dBA at the facade for road traffic noise). For new situations, exposure levels must reduce annoyance to an acceptable level.

- ***Target 3 : Promote good quality noise environments***

The policy which would enable this target to be attained would eliminate all "black spots" which could lead to high levels of annoyance (daytime Leq > 65 dBA at the facade for road traffic noise). In new situations, the goal would be to limit noise to comfortable levels.

All these targets apply to noise sources for which noise levels can be reduced including road traffic noise, railway noise, aircraft noise and industrial noise. Noise sources like restaurants, stadium, which are difficult to control, are not considered here.

2. DEFINING THE SCENARIOS

2.1. Scenario parameters

All three scenarios detailed below are characterised by a set of noise exposure limit values expressed in L_{Aeq} at the facade (see justification in Part 1). These limit values are not, for the time being, proposals for harmonised limit values but just components of the scenarios to be subjected to cost-benefit analysis (see Part 6).

Given the practices in the various EC member states (see Part 2), noise exposure limit values are based on the following main parameters :

- period of day : daytime, night time ;
- the area concerned : sensitive area (hospital, school ...), residential area, mixed area, industrial area ;
- the type of situation : existing, new ;
- the noise source : road traffic noise, railway noise, aircraft noise, industrial noise.

2.2. Scenario 1 : Limit critical noise exposure situations

In general, this scenario corresponds to recommendations valid in the countries with the lowest noise prevention levels or which have been adopted for over 10 years in the other countries. Priority is given to eliminate existing critical situations and to be quite ambitious for new situations. It is reasonable to expect that this target have been attained by the year 2000.

- ***Road traffic noise***

Table 63 indicates the noise exposure limit values that should be respected in both new and existing situations.

Table 63. **Road traffic noise exposure limit values - Scenario 1**

Area	New road		Existing road	
	Day	Night	Day	Night
Sensitive	60	50	70	62
Residential	63	53	73	65
Mixed (residential and commercial)	67	57	73	65
Industrial and commercial	70	62	75	67

In the case of new roads (or significant modifications to existing roads*), protective or preventive measures must be taken either at the transmission (road surfaces, noise barrier, cuttings etc.), or at reception (insulation of the buildings) if the noise limit values are exceeded. In this latter case, the daytime target is 40 dB(A) inside homes located in residential areas.

* When Leq is expected to increase by more than 2 dB(A).

The application of limiting noise limit values in the case of existing roads leads to the implementation of a black-spot correction programme when daytime noise levels exceed 70/75 dB(A) (critical situations) ; the target level is 65 dB(A) for the daytime period (40 dB(A) indoors).

- ***Railway noise***

Noise exposure limit values are the same as those for road traffic noise corrected by a factor of + 5 dB(A) as railway noise is more acceptable than road traffic noise.

- ***Aircraft noise***

Two noise exposure zones are defined for daytime period :

- Zone 1 : Leq > 73 dB(A)
- Zone 2 : 68 < Leq < 73 dB(A)

In zone 1, building permits are systematically refused whatever the type of building envisaged ; moreover a correction programme is implemented to sound-proof existing homes.

In zone 2, the construction of new buildings is authorised providing that they are sound-proofed.

- ***Industrial noise***

As for the other sources of noise, noise exposure limit values must be respected (table 64) when new industrial installations are built close to existing homes. An insulation programme will be adopted to ensure that noise limit values apply existing buildings.

Table 64. **Industrial noise exposure limit values - Scenario 1**

Area	New installation		Existing installation	
	Day	Night	Day	Night
Sensitive	55	45	60	50
Residential	60	50	65	55
Mixed (residential and commercial)	65	55	70	60
Industrial and commercial	70	60	75	65

2.3. Scenario 2 : Provide satisfactory protection to people exposed

Overall, this scenario corresponds to the standards or recommendations currently valid in the most advanced countries in the field of protection from noise. It should be remembered that the target is to protect population so that they no longer are annoyed by noise (acceptable level). It will probably take at least 10 years (up until 2005) to attain this target.

- ***Road traffic noise***

Table 65 shows the noise exposure limit values that should be respected in both new and existing situations.

Table 65. **Road traffic noise exposure limit values - Scenario 2**

Area	New road		Existing road	
	Day	Night	Day	Night
Sensitive	57	47	65	57
Residential	60	50	68	60
Mixed (residential and commercial)	65	55	68	60
Industrial and commercial	68	58	70	62

In the case of new roads (or significant modifications to existing roads), protective or preventive measures must be taken either at the transmission (road surfaces, noise barrier, cuttings etc.), or at reception (insulation of the buildings) if the noise limit values are exceeded. In this latter case, the daytime target is 37 dB(A) inside homes located in residential areas. The application of limiting noise limit values in the case of existing roads leads to the implementation of a black-spot correction programme when daytime noise levels exceed 65/70 dB(A) (situations with high noise annoyance levels) ; the goal level is 63 dB(A) (an acceptable annoyance level) for the daytime period or 37 dB(A) indoors.

- ***Railway noise***

Noise exposure limit values are the same as those for road traffic noise corrected by a factor of only + 3 dB(A) as railway noise is more acceptable than road traffic noise. However, this is less the case when noise levels not to be exceeded are lower.

- ***Aircraft noise***

Two noise exposure zones are defined for daytime period :

- Zone 1 : Leq > 70 dB(A)
- Zone 2 : 66 < Leq < 70 dB(A)

In zone 1, building permits are systematically refused whatever the type of building envisaged ; moreover a correction programme is implemented to sound-proof existing homes.

In zone 2, the construction of new buildings is authorised providing that they are sound-proofed.

- ***Industrial noise***

Maximum noise exposure limit values (table 66) have been lowered by 5 dB(A) vs. scenario 1.

Table 66. **Industrial noise exposure limit values - Scenario 2**

Area	New installation		Existing installation	
	Day	Night	Day	Night
Sensitive	50	40	55	45
Residential	55	45	60	50
Mixed (residential and commercial)	60	50	65	55
Industrial and commercial	65	55	70	60

2.4. Scenario 3 : Promote good quality noise environments

This third scenario requires more commitment. It is a much stronger policy because it aims not only to eliminate all black spots (Leq > 65 dBA) but also to promote a good quality noise environment in new situations through more dynamic planning. To attain this target will require approximately 15 years (2010).

- ***Road traffic noise***

Table 67 shows the noise exposure limit values that should be respected in both new and existing situations.

Table 67. **Road traffic noise exposure limit values - Scenario 3**

Area	New road		Existing road	
	Day	Night	Day	Night
Sensitive	54	44	62	53
Residential	57	47	65	55
Mixed (residential and commercial)	62	52	65	55
Industrial and commercial	65	55	67	57

In the case of new roads (or significant modifications to existing roads), protective or preventive measures must be taken either at the transmission (road surfaces, noise barrier, cuttings etc.), or at reception (insulation of the buildings) if the noise limit values are exceeded. In this latter case, the daytime target is 34 dB(A) inside homes located in residential areas. The application of limiting noise limit values in the case of existing roads leads to the implementation of a black-spot correction programme when daytime noise levels exceed 62/67 dB(A) (situations with significant levels of annoyance) ; the goal level is 60 dB(A) (a low annoyance level) for the daytime period or an indoor noise level of 34 dB(A).

- ***Railway noise***

Noise exposure limit values are identical to those for road traffic noise. No correction factor is applied.

- ***Aircraft noise***

Two noise exposure zones are defined for daytime period :

- Zone 1 : Leq > 68 dB(A)
- Zone 2 : 64 < Leq < 68 dB(A)

In zone 1, building permits are systematically refused whatever the type of building envisaged ; moreover a correction programme is implemented to sound-proof existing homes.

In zone 2, the construction of new buildings is authorised providing that they are sound-proofed.

- ***Industrial noise***

In comparison with scenario 2, the noise exposure limit values to be respected (table 68) have been lowered by 5 dB(A).

Table 68. **Industrial noise exposure limits values - Scenario 3**

Area	New installation		Existing installation	
	Day	Night	Day	Night
Sensitive	45	35	50	40
Residential	50	40	55	45
Mixed (residential and commercial)	55	45	60	50
Industrial and commercial	60	50	65	55

PART 6 : COST-EFFECTIVENESS AND COST-BENEFIT CONSIDERATIONS FOR ALTERNATIVE SETS OF EC NOISE QUALITY CRITERIA

1. COST-BENEFIT ANALYSIS AND ASSESSMENT OF NOISE POLICIES : REVIEW OF THE LITERATURE

1.1. Introduction

Assessment of noise abatement policies raises the question of the definition and evaluation of benefits obtained by implementing these policies.

Two approaches are theoretically possible :

- Cost-benefit analysis, by definition, endeavours to compare costs and benefits in monetary terms. As benefits are defined as the damages which are eliminated or avoided, the principle difficulty is to place a cash value on damage and, more generally, on the social cost of noise.
- The other approach is based on cost-effectiveness analysis, tries to highlight the most effective measures (at the least costs) to attain the given objective ; the difficulty is to make a suitable definition of the effectiveness of a noise abatement project or policy.

There would not appear to be any concrete studies which have tried to apply these methods although this question is central to the evaluation of the benefits and has given rise to many publications, particularly from the OECD [1]. Most frequently, the literature only covers qualitative recommendations for measures to be taken without defining any very accurate basis for assessment.

1.2. How can benefits be evaluated ?

For cost/benefit analysis it is essential to measure the damage that a noise abatement policy can eliminate or prevent (i.e. the benefit) and the costs of the policy. A policy is effective if it produces more benefits than it costs. The higher the cost/benefit ratio, the greater the effectiveness. The policy is optimal if the level of noise abatement attained is such that the marginal advantages are equal to the marginal costs of abatement.

Putting a price to damage caused by noise is an very complicated procedure. Conventionally, three evaluation methods are used [2] :

- the **contingent valuation** method which consists in asking individuals directly (by questionnaire or experimentally) about their willingness to pay for an improved noise environment if it was possible to purchase acoustic comfort (contingent market).
- observation of **a substitution market** (hedonic pricing) in which another commodity is influenced by noise. The property market is relatively suitable for this type of evaluation. It is assumed that some environmental attributes (noise, for example) explain differences in

house prices observed. It represents an willingness to pay for a better quality of the noise environment. This method has been more particularly applied in the field of traffic noise.

- **damages awarded by courts to people** affected by noise can be used to estimate the value placed on annoyance. Courts often distinguish between the reduction in the re-sale value of properties, the loss of amenities and, in some cases, effects on health. Damages awarded vary widely and are not always directly proportional to the noise levels involved.

1.2.1. Contingent evaluation

F. J. Langdon's work on traffic noise in 1976 [3] gives interesting indications about the values people are prepared to pay to reduce road traffic noise to a "reasonable level" - from 0.17 to 1.44 ECU per week and per person, depending on their initial level of dissatisfaction. On average the value of noise reduction is 0.84 ECU per week (approximately 44 ECU per year) (1976). This not only depends on noise levels but also on social and economic variables (particularly income) and psychological variables (sensitivity to noise).

This sum represents 1.6% of annual per capita income which is not significantly lower than the results obtained by Walters [4] for aircraft noise (2 to 7%) and Starkie and Johnson [5] for road traffic noise (5%). However the evaluations used by these authors are based on different methods (costs of soundproofing). However, these results are quite coherent with those obtained in the 1970s by applying the house price depreciation method : i.e. 0.34% per decibel in the 72 to 64 dB(A) L_{10} (i.e. 69 - 61 Leq range).

The most recent results concerning the willingness to pay for a better noise environment are from Germany, which started to evaluate the costs of nuisance and pollution - particularly noise - in 1986 [6 and 7]. Seven thousand people were questioned about their willingness to pay more if they could live in a quieter area. The results show average individual consent to pay per month C = 0.87 ECU per dB(A) when Leq exceeds 43 dB(A), i.e. C = 0.87 * Leq - 37.4 (approximately 10.4 ECU/dB(A) per person and per year). In fact, willingness to pay for quiet increases more quickly than noise levels. It varies from 0.83 ECU for low noise exposure levels to 1.24 ECU for the highest noise exposure levels (Leq > 75 dB(A)). On the basis of these results the annual cost (1989) of traffic noise in Germany was estimated to be 7.8 to 9.6 billion ECU, i.e. :

- road traffic noise : 5.5 to 6.6 billion ECU (70%)
- railway noise : 2.1 to 2.8 billion ECU (28%)
- aircraft noise : 0.16 to 0.21 billion ECU (2%).

These figures should be compared with the annual expenditure of the State and individuals on noise abatement of approximately 1.55 billion ECU (i.e. only 18% of the needs revealed). They should also be compared with the annual cost of the effects of noise on public health (cardio-vascular disease) which has been evaluated from 0.5 to 1.9 billion ECU for road traffic noise and 0.1 billion ECU for aircraft noise.

1.2.2. House price depreciation method

A large number of studies have been carried out over the last 25 years, basically in Anglo-Saxon countries. Cultural differences in noise tolerance, as well as standard of living, are likely to lead to market differences in how much individuals would be willing to pay to reduce noise levels. A non-exhaustive summary of the main quantitative results obtained for road noise are shown in table 69. The decrease in housing values represents the variation in percentage of prices paid for buildings per unit increase in noise and measures the sensitivity to noise of the property market expressed in terms of marginal rates of depreciation per decibel.

If only the studies which give comparable results and which correlate significantly are retained, it can be observed that the rate of depreciation has significantly changed over time.

Table 69. **House price elasticities and road traffic noise**

Study	Year	Noise Index	Elasticity (% per decibel)	Comments
Colony (8)	1967	Distance	0	However estate agents consider that the depreciation exceed 20 to 30 %
Towne (9)	1968	?	negligible	Rent
Diffey (10)	1971	L10	0	
Nelson (11)	1970	LDN	0,88	
Gamble & al. (12)	1969-1971	N.P.L or Leq	0.21 - 0.43 or 0.26 - 0.54	2.2 % for houses located at Bogota (New Jersey)
Anderson & Wise (13)	1971	NPL or Leq	0.25 or 0.31	Mean value for all the sites
Vaughan-Huckins (14)	1972	Daytime Leq	0.41 - 0.80	Non linear depreciation
Hammar (15)	1972	Leq	0.8 - 1.7	Non linear depreciation
Bailey (16)	1977	Leq	0.38	
Hall et al. (17)	1977	Daytime Leq	0.5	Leq > 70 dB(A)
Allen (18)	1980	L10	0.15	
Palmquist (19)	1980	L10	0.08 to 0.48	
Pommerehne (20)	1985	Daytime Leq	1 to 1.4	Rent Non linear depreciation
Soguel (21)	1989	Daytime Leq	0.91	Rent
Streeting (22)	1990	Leq	0.9	Recommendation

Three basic periods can be distinguished :

- the 1960s : the rate of depreciation was negligible or near zero ; but research methods were not very accurate ;
- the 1970s : there was a fall in house value due to noise but results vary. For most studies the rate was approximately 0.3 to 0.8% per decibel ;
- the 1980s (and especially the second half) : the rate of depreciation is approximately 1% per decibel.

Adopting a uniform linear depreciation rate probably underestimates consequences in high exposure zones. On the basis of these depreciation rates, global evaluations of total damages caused by road traffic noise have been undertaken either on the level of a city or on the level of a country. Here are two examples :

- city of Neuchâtel (Switzerland) : 2.9 million ECU per year, i.e. 91 ECU per inhabitant, 161 to 374 ECU per inhabitant exposed to noise levels of over 60 dB(A) ;
- France : 800 millions ECU per year (on the base of 1 % starting from 55 dB(A)) or an average of approximately 30 ECU per inhabitant exposed to over 55 dB(A).

Many authors fix the threshold level at 55 to 65 dB(A) - already a significant difference. If the regulatory level of 65 dB(A) adopted as the annoyance threshold for road construction by Road Authorities in many countries is used, a major fraction of the population affected by annoyance is neglected. In the case of Germany, for example, depending on whether a threshold of 55 or 65 dB(A) is adopted, the estimate for total depreciation of all housing varies by a factor of 3.

Finally, it can be considered that consequences assessed using this method would be lower than consequences actually suffered by owners because it would not take account of the consumer surplus. Does the depreciation of the value of housing reflect consequences caused by long-term noise exposure (effects on sleep and health). In the other hand depreciation could reflect other effects of road traffic (pollution - vibration - visual intrusion etc.) ?

1.2.3. Cases from the Courts. Expert assessments

Some decisions made by administrative tribunals have given cash estimates of the damages caused by transport noise. In France, for example, although few in number, these decisions do provide information on the nature of the consequences considered when calculating damages paid to petitioners. In all cases, the depreciation of the fair market value of property has been considered to be the most important damage (table 70). For the most exposed homes, depreciation of the fair market price was estimated at up to 70% of the cost of the dwelling (the case of the effect of noise caused by the TGV train Paris-Lyon line). In 1992 values, damages paid during the 1980s ranged from 5 000 to 76 000 ECU.

In many cases, these judgements were sought when noise appeared suddenly following the construction of a new infrastructure and not following the gradual rise in the level of noise as in urban zones. This means that the damages paid consider the initial noise environment.

Table 70. **Examples of damages paid for traffic noise in France** (23 and 24)

Date of the decision of the Court	Origin and nature of the noise	Prejudices considered	Damages awarded
May 1980	Noise from the B7 motorway.	Impairment in the use of amenities House price depreciation	1 800 ECU 5 600 ECU 7 400 ECU
November 1981	Disturbance from the A10 motorway.	House price depreciation	4 000 ECU
December 1982	Noise and vibrations from the RER	Impairment in the use of amenities House price depreciation	Total 21 000 ECU
June 1983	Noise from the B7 motorway. Houses located from 10 to 72 m from the road.	Impairment in the use of amenities House price depreciation	5 cases : from 4 700 to 12 000 ECU
July 1983	Noise and pollution from widening the RN 24	Loss of comfort House price depreciation	Total 3 800 ECU
January 1984	Disturbance from the A61 motorway. House located 60 m from the road.	Impairment in the use of amenities House price depreciation	Total 15 200 ECU
October 1984	Noise, loss of view and sunshine caused by the A8 motorway. House located 20 m from the road.	Impairment in the use of amenities House price depreciation	Total 16 200 ECU
November 1984	Disturbance from the B41 motorway. Houses located from 7 to 40 m from the road	Impairment in the use of amenities House price depreciation	12 cases : from 8 000 to 62 000 ECU
October 1985	Noise from the A11 motorway.	House price depreciation	9 100 ECU

October 1985	Noise, pollution, loss of view and sunshine due to the B 52 motorway. Houses located 7.6 m from the road.	Impairment in the use of amenities House price depreciation	Total : 38 000 ECU
February 1992	Noise from the TGV SE	House price depreciation (70% of the value of the home)	30 000 ECU

The analysis of the monetary valuation methods of noise effectively illustrates the diversity and the difficulties of this type of approach. Practice has already taught us that it is difficult to evaluate the social cost of noise. Firstly, the results from these methods can only be considered as relative. In fact estimates are frequently based on very rough hypotheses but also result from calculations which are both complex and impaired by a wide range of uncertainties. This means that the use of monetary valuation, particularly when assessing noise abatement policies, can lead to illogical decisions : the evaluation of social costs is even less obvious if applied to the long term.

This means also that rather than concentrating efforts on finding a way to express annoyance exclusively in monetary terms, it would often appear more reasonable and more realistic to define first decision criteria based on the non-monetary damage function. This means that we should be examining the use of methods of cost/effectiveness analysis.

1.3. How effectiveness be measured ?

There are basically two ways in which to measure the effectiveness of a noise abatement project or, more generally, of a noise abatement policy. It is either possible to consider the number of people for whom noise levels will be reduced or suppressed or, more simply, the variation in the noise exposure of the people concerned by the noise abatement project or policy adopted.

1.3.1. The annoyance criterion

A simple method consists in retaining as the indicator of effectiveness E the variation in the number of people annoyed after implementation of one abatement measure or several combined measures. The decision criterion would have the following equation :

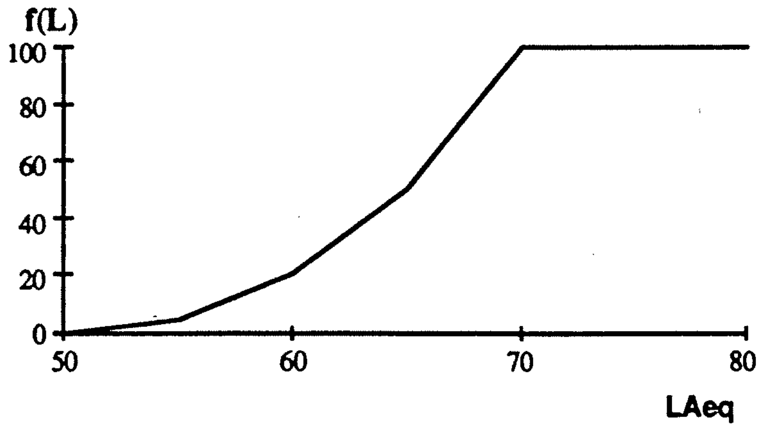
$$N = \frac{E}{C} = \frac{HA_0 - HA_1}{C} = \frac{\Delta HA}{C}$$

in which :

- HA_0 = the number of people highly annoyed by noise before the implementation of the noise abatement measures.
- HA_1 = the number of people highly annoyed by noise after the implementation of the noise abatement measures.
- C = the cost of the noise abatement measures.
- N = the Effectiveness/Cost ratio to be maximised.

The percentage of highly annoyed people can be estimated from the relationship f (L) between the level of noise and the probability that a subject submitted to this noise would be highly annoyed (figure 6). The next step is to apply weighting factor f (L_i) to the number of people P_i located in the different ranges of level of noise L_i. In fact, this is the same as using the probable number of individuals highly annoyed by noise as an indicator for the whole of the population considered. Indicator I is thus : $I = \Sigma P_i f(L_i)$.

Figure 6. **Number of highly annoyed people**



For L < 70 dB(A), function f (L) can also be expressed as k g (L) with $g(L) = 2^{0.1\,L}$ and L = Ln - Lo in which Ln is the exposure level and Lo the reference level [25].

This type of indicator, with coefficients of the following type and as yet little used, has been adopted by the Swedish National Road Administration (1987) and German [26] and Finnish [27] specialists.

LAeq	< 55	55-60	61-65	66-70	≥ 71
f (L) %	0	5	20	50	100

1.3.2. Noise exposure criteria

In this case, it is not the number of highly annoyed people which is used as the effectiveness indicator but only the exposure of the population to noise. This means that the effectiveness of a project will be defined as the variation in exposure to noise. Although relatively close to the previous method, it is different to the extent that the indicator is a combination of variables as it covers the whole of the population concerned. Effectiveness E of a noise abatement project or policy is thus defined as the variation in the exposure of the population to noise following the implementation of a project, i.e. : $E = I_0 - I_1 = \Delta I$, in which I_0 is the value of the noise exposure indicator before protection and I_i the value of the exposure indicator after protection. This indicator will be expressed as : $I_i = P_i\ \phi(L_i)$ in which P_i is the population exposed to a noise level L_i and $\phi(L_i)$ a noise exposure function. This function can have several forms, but the following loudness function is often used :

$$\phi(L_i) = 2^{\frac{L_i - L_s}{10}}$$

This function shows that the subjective impression of noise loudness doubles each time that the noise level increases by 10 dB(A). Ls is a threshold level below which it is considered that annoyance is non-existent (55 dB, for example). This means that the cost-effectiveness indicator N relating to project 1 has the following form :

$$N = \frac{E}{C} = \frac{I_0 - I_1}{C} = \frac{\left[\Sigma P_i \cdot 2^{\frac{L_i - L_s}{10}}\right]_0 - \left[\Sigma P_i \cdot 2^{\frac{L_i - L_s}{10}}\right]_1}{C}$$

The cost-effectiveness of noise abatement projects or policies can be compared with this method. The most effective noise abatement measure to attain a given quality of noise environment will maximise ratio N, i.e. will maximise effectiveness per cash unit spent.

1.4. Results based on the cost/effectiveness analysis

1.4.1. The Norwegian study [28]

This study estimated the costs and effects of different road noise abatement measures to suggest the most effective policies Norway could adopt for the long term.

The reductions in noise which would result from adoption from the measures envisaged are shown in table 71.

Table 71. **Overview of assumed noise reductions of different abatement measures**

Measure	Examples of expected indoor noise reductions (LAeq)	Remarks
Stricter noise regulations for vehicles *	3.8	Year 2000, 10 % heavy vehicles
Local bus requirements	3.1	Year 1990, 10 % buses, 90 % light vehicles
Noise barrier	8	Ground floor, 25 m from road, 2 m high barrier
Noise Insulation :		
- window sealing	3	
- new sound-attenuating windows (3 classes)	7 - 19	Heavy wall (concrete, masonry etc.) and double glazed windows
By-pass tunnel for main urban road	11	Example in Oslo, effect dependent on the local situation
Low noise road surface	2	Main road with speed limit 60-70 km/h or more, 10 % heavy vehicles
Area traffic management :		
- main through roads	-1	Examples from inner-city schemes in Oslo
- local roads	6	

* 75 dB(A) for passenger cars, 80 dB(A) for heavy trucks.

The cost/effectiveness indicator retained is,*"the reduction in the number of very annoyed people per million of ECU invested annually"*. Table 72 indicates the values for this indicator for the different noise abatement measures envisaged. Values depend on the type of area in which the measures are taken.

Table 72. **Reduction in the number of inhabitants very annoyed per million ECU annually spent**

Measure	Type of area				
	Inner parts of large towns	Inner parts of small towns	Large residential areas with multi-storey buildings	Residential areas with detached and semi-detached houses	Ribbon development, low-density
Stricter noise regulations for vehicles	1920 - 6690	840	1090-1670	670	500
Local bus requirements	1170 - 5520	-	-	-	-
Noise barrier (maximum use)	-	-	170-670	85	85-170
Noise insulation, all :					
- dwellings above 35 dB(A) - indoors down to 30 dB(A)	585 - 920	420-750	170-420	250	420-585
By-pass tunnel	330	-	-	-	-
Low noise road surface	-	-	-	1340-2420	170-330
Area traffic management :					
- extensive changes	5430	-	-	-	-
- smaller changes	85 - 1250	-	-	-	330

Analysis of these results leads to the following main conclusions :

1/ The cost/effectiveness ratio for the different traffic noise abatement measures varies significantly with the types of area in which these measures can be applied.

2/ The effects of more stringent vehicle noise emission limits are relatively high whatever the type of area. However, the benefits increase with the density of population.

3/ Measures concerning central areas are likely to be more cost/effective than the same measures taken in other types of area or other smaller cities. This is due to the greater population density, the smaller sizes of dwellings and higher exposure to noise.

4/ Traffic management and the local introduction of quieter buses give a very high cost/effectiveness ratio in areas in which these measures are applicable. Traffic management can be sensibly combined with noise insulation of the buildings located along main streets in which traffic cannot be restricted.

5/ Building insulation is most effective when priority is given to the most heavily exposed houses.

6/ The extensive use of noise barriers is not very cost-effective, nor is the construction of new major roads, by-passes and tunnels in urban areas.

7/ Finally, low-noise road surfaces seem to be more cost/effective than noise barriers and often more cost/effective than other solutions when driving speeds exceed some 60 kph.

The costs and the effectiveness of combining these different noise abatement measures on a national level have also been estimated to answer the two basic questions :

- What optimum combination (cost/effectiveness) of measures would enable a reduction in exposure of all homes to the following noise levels by the year 2000 :
    - 35 dB(A) (indoor noise) or 65 dB(A) outside : alternative 1
    - 30 dB(A) (indoor noise) or 60 dB(A) outside : alternative 2
- What these measures cost on a national scale ?

The conclusions of this study are as follows :

1/ Priority should be given to measures in central urban areas, to the reduction and control of vehicle noise levels, to the introduction of quiet buses, to traffic management (particularly on main streets), to low-noise surfaces and to insulation of the most exposed dwellings.

2/ The objective of 35 dB(A) indoor or 65 dB(A) outdoor would require an annual investment of 9 million ECU if the only measure taken consisted in insulating exposed homes. Insulation expenditure would fall to 2.3 million ECU per year if vehicle noise emission limits were lowered. To attain the 30 dB(A) indoor objective, annual expenditure would respectively be 42 to 48 million ECU or 17 to 18 million ECU if vehicle noise emission limits were lowered.

1.4.2. The French study [29]

In 1989 INRETS carried out an economic evaluation of four road noise abatement policies :

- a policy based on existing decisions (trend policy) : protection from noise along new roads or when new buildings are erected + EEC directive 84/424 concerning vehicle noise emission (77 dB(A) for cars, 84 dB(A) for heavy trucks).
- a major extension to this policy for vehicle noise emission levels : 75 dB(A) for cars, 80 dB(A) for heavy trucks (close to EEC directive 92/97).
- a voluntarist policy for local measures : restriction of traffic in city centres combined with the introduction of quiet buses + creation of zones in which traffic is restricted to 30 kph + low-noise surfaces + by-passes for through traffic.
- an "all out" voluntarist policy which combines both the previous policies.

For each of these policies the effects on the noise exposure and the economic consequences were identified. For the purposes of the study INRETS investigated the various technical, financial, human and institutional means required to demonstrate - as far as possible - the benefits which would accrue from these policies, particularly in terms of the noise environment, and to highlight the favourable elements - and the obstacles and difficulties - related to their implementation. This study was a global approach for the evaluation of noise abatement policies

The results of the simulations have shown that, in the hypothesis of a trend policy, the overall situation would improve in 2010 vs. reference year 1985, particularly in zones with high noise levels.

The percentage of the population exposed to over 70 dB(A) would be divided by 3 (from 2.2 million to 720 000 inhabitants). The percentage of the population exposed to noise levels in the 65 to 70 dB(A) range is slightly reduced (by approximately 20%) and falls from 4 million to 3.2 million inhabitants. The population of grey areas (55 to 65 dB(A)) increases from 14 to 15 million inhabitants but this is due to a shift of the population from black spot areas (over 65 dB(A)) to grey areas and not a reduction in populations benefiting from "acoustic comfort" (< 55 dB(A)). The population exposed to < 55 dB(A) grows from 17 to 18.8 million (i.e. an increase of almost 2 million inhabitants).

The investigation shows that a voluntarist "all out" policy would increase the number of people enjoying "acoustic comfort" from 17 to 25 million (i.e. almost 50% in a virtually constant population). This policy would further reduce the number of people who live in grey zones (from 55 to 65 dB(A)) from 14 to 11 million (i.e. a reduction of almost 20%).

Finally, this policy significantly reduces the number of people exposed to high noise levels (between 65 and 70 dB(A)), from 4 to 1.4 million (i.e. 65% fewer) and very high levels (over 70 dB(A)) from 2.2 to 0.2 million (i.e. ten times fewer).

Expenditures that would need to be made annually have been evaluated for all the above policies and distributed by the type of measure envisaged : on the level of the vehicles, buildings and infrastructures particularly and also by the economic agents concerned. Expenditures relating to protecting buildings (new and old) and infrastructures (new and existing), of which a large part is paid for by Public Authorities (84 to 88% of these expenditures), attain, depending on the policy envisaged, from 100 to 118 million ECU per year.

The comparison of costs and effectiveness (in terms of variations in noise exposure - see method in paragraph 1.3.2. above) for the different policies indicates that implementing local measures (in particular traffic management and low-noise road surface) is most cost/effective solution in improving urban noise environments. This comparison also demonstrates that it is interesting to combine the adoption of local and national measures to reduce noise at source.

2. COST-BENEFIT ANALYSIS OF THE ALTERNATIVE SCENARIOS

2.1. Objective and field of evaluation

Costs and benefits of noise abatement strategies which would enable the targets described in Part 5 (i.e. noise exposure levels which should not be exceeded) have been assessed. The objective of this assessment is therefore firstly to show up the combinations of the most cost-effective measures and secondly to evaluate benefits which would accrue from the implementation of these strategies.

This evaluation only applies to land transport (road and rail traffic) and only concerns protective programmes for existing situations in residential areas. Table 73 recalls the noise exposure limits beyond which noise abatement measures should be taken and the targets to attain.

Table 73. **Daytime noise exposure targets (at the facade)**

Scenario/Objective	Abatement measure limit*	Target* Outdoors	Target* Indoors
1 - Limiting critical noise exposure situations	73 dB(A)	65 dB(A)	40 dB(A)
2 - Provide satisfactory protection to people exposed	68 dB(A)	63 dB(A)	37 dB(A)
3 - Promote high quality noise environments	65 dB(A)	60 dB(A)	34 dB(A)

* Daytime Leq

Insofar as the measures envisaged are directly related to the different types of area (city centres, suburbs and rural areas), it is only possible to carry out this assessment in countries in which all the data exists in a sufficiently accurate form to enable the analysis of noise exposure for all of the populations in these different areas. For this reason the evaluation has been limited to France which can be consider as representative of the average exposure of the European population to transport noise.

This evaluation is nevertheless imprecise : a more accurate and finer analysis, wider in scope, still needs to be accomplished. In all probability this work would require the use of a computerised model to simulate the different measures envisaged accurately. The work reported here have a more modest objective and only tries to identify the bases for decisions concerning the definition and the implementation of noise abatement policies.

2.2. Method

The French population is distributed into 3 types of residential areas for all of which the noise exposure is available (see table 74 and figure 7) : city centres (high population density, collective housing, U-shaped roads), suburbs (individual housing and large blocks of flats) and rural areas (low population density and individual houses). The types of measures that are technically possible have been identified for each of these 3 areas. The effectiveness of each measure is defined (reduction of noise in dB) and the unit cost has also been given for each measure (by home or by unit length, for example).

With this data, the number of homes for which protection is required to ensure that they meet the noise quality criteria given in each scenario has been calculated. The level of protection also depends on the initial noise exposure situation (i.e. prior to the protective programme). This method enables evaluation for each scenario of :

- the total number of existing homes requiring protection (due to lack of date, buildings already insulated have not been taken into account) ;
- the total cost of the corrective programmes that need to be implemented.

In each scenario and for each strategy the average annual cost per person protected is also calculated together with the total cost which takes into account of the probable time of life of the measures envisaged - and the annual average benefits accruing (defined as loss of house value). A very simplified comparison between average annual costs and average annual benefits has been undertaken. More works (and time) would be necessary to make a complete and a more accurate cost-benefit analysis (using annuitized values of costs and benefits).

2.3. Description of the protective measures

Firstly, it is important to distinguish between measures decided at a community level - such as the reduction in vehicle noise emission levels - and local measures such as the erection of noise barriers, building insulation and the construction of low-noise surfaces.

2.3.1. Reduction in vehicle noise emission limits

Three hypotheses have been considered :

- N1 : enforcement of Directive 84/424 EEC (reference situation)
- N2 : enforcement of Directive 92/97 EEC (1996) ;
- N3 : enforcement of a further reduction of vehicle noise emission limits (2000).

Table 74. **Exposure of the French population to land transport noise (daytime LAeq - mid 80' s situation)****

Area	Total * population	Leq ≤ 55	55 - 60	60 - 65	65 - 70	Leq > 70
City centres	14,808	7,087	2,096	1,797	2,047	1,781
Suburbs	21,990	10,003	5,901	3,867	1,839	0,380
Rural area	17,542	10,701	3,325	2,902	0,439	0,175
Total [%]	54,340 [100]	27,791 [51.1]	11,322 [20.8]	8,566 [15.8]	4,325 [8.0]	2,336 [4.3]

* Unit : million

* Data to be published by OECD - State of the environment (1994).

Figure 7. **Exposure of the French population to land transport noise (cumulative percentages)**

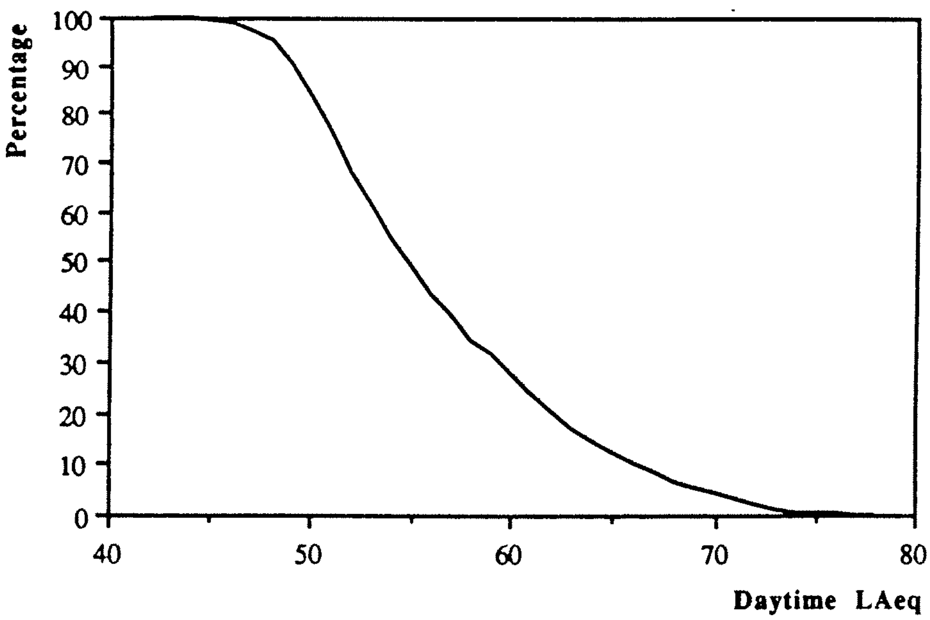


Table 75 below summarises the noise levels that must not be exceeded when vehicles obtain certification for use on roads.

Table 75. **Vehicle noise emission limits**

Type of vehicle	EC Directive 84/424	EC Directive 92/97	Possible further limits
Passenger car	77 dB(A)	74 dB(A)	72 dB(A)
Bus	83 dB(A)	80 dB(A)	78 dB(A)
Heavy truck	84 dB(A)	80 dB(A)	78 dB(A)

2.3.2. Local actions

- City centres

Two types of measures are considered :

- L1 : sound insulation of dwellings

or

- L2 : low-noise road surfaces combined with sound insulation of dwellings.

Other measures - such as traffic restraint in historic centres - could also have been adopted. But it is extremely difficult to evaluate their impact and the cost of implementation.

- Suburbs

As for city centres, two types of measures are considered :

- L3 : sound insulation of dwellings exposed to noise levels exceeding noise exposure limits ;

or

- L4 : use of combined corrective measures : low-noise road surface, noise barriers along roads with very heavy traffic and sound insulation of dwellings.

- Rural areas

Given the low density of housing, the only noise abatement measure applicable is the sound insulation of dwellings (L5). By-passes around small towns are a particularly effective form of noise abatement. However, noise abatement is not usually the main reason why by-passes are built - the decision is more probably taken to increase safety and improve traffic flow.

2.3.3. Simulated strategies

The impact and the cost of 6 protective strategies have been assessed for each scenario :

- the first strategy examines the effect of building insulation when noise levels exceed noise exposure limits, basing vehicle noise emission levels on the EEC Directive 84/424. This strategy therefore includes : N1 + L1 + L3 + L5.

- the second strategy combines different protective measures : building insulation + low-noise surfaces + noise barriers. This strategy therefore includes : N1 + L2 + L4 + L5.

- the third strategy is identical to the first but vehicle noise emission limits are those of the EEC Directive 92/97. This strategy therefore includes : N2 + L1 + L3 + L5.

- the fourth strategy is identical to the second but vehicle noise emission limits are those of the EEC Directive 92/97. This strategy therefore includes : N2 + L2 + L4 + L5.

- the fifth strategy is identical to the first but vehicle noise emission levels are those of a further step in reducing vehicle noise emission limits. This strategy therefore includes : N3 + L1 + L3 + L5.

- the sixth strategy is identical to the second but vehicle noise emission levels are those of a further step in reducing vehicle noise emission limits. This strategy therefore includes : N3 + L2 + L4 + L5.

2.4. Effectiveness and costs of the measures envisaged

2.4.1. Reduction of vehicle noise emission limits

More stringent standards for vehicle noise emission levels (EEC 92/97) should lead, in comparison with existing standards (EEC 84/424) to an average reduction in noise levels of approximately 2 dB(A) in urban areas [30]. In rural areas, where traffic is moving more quickly (speed > 60 kph), there is no noise reduction due to the importance of road/tyre noise emissions. Additional costs of vehicles linked to the enforcement of this Directive are approximately 3% for passenger cars, 2% for buses and 4% for trucks [31].

A further step as described in table 75 should lead to an average reduction in noise exposure of 4 dB(A) in urban area only. Additional costs of vehicles could be of 5 % for passenger cars, 4 % for buses and 7 % for trucks.

2.4.2. Low-noise surface

Given vehicle speeds in urban areas, low-noise surface would enable a reduction of 3 dB(A). The additional cost vs. a conventional road surface is approximately 4.5 ECU/m^2.

2.4.3. Building insulation

The average noise attenuation value of all houses in France is currently approximately 25 dB. Today's insulation products enable soundproofing to 30 to 40 dB on single-glazed windows.

Insulation of 30/32 dB can be obtained conventionally, i.e. an increase of 5 to 7 dB vs. the average soundproofing quality of old windows.

It is possible to obtain higher levels of soundproofing (up to 45 dB, for example) but this implies the use of double-windows. Strengthening the attenuation values also implies additional costs for good ventilation and solar protection in summer.

The use of these techniques has a significant impact on the cost of existing buildings (table 76).

Table 76. **Costs of insulation of dwellings (existing situation) (ventilation costs included)**

Attenuation value	Cost per dwelling (1992 ECU)	
	Detached or semi-detached house	Flat
° 30 - 32 dB	3 000 to 6 000 ECU	2 000 to 4 000 ECU
° 32 - 35 dB	11 000 to 12 000 ECU	4 000 to 6 000 ECU
° 35 - 40 dB	12 000 to 20 000 ECU	6 000 to 10 000 ECU

2.4.4. Erection of noise barriers

The use of noise barrier enables noise level reductions of from 8 to 12 dB(A). The average unit cost established from works carried out in France over several years is currently approximately 380 ECU/m^2 (table 77).

Table 77. **Average costs of noise barrier (per m^2)**

Type of noise barrier	Cost (1992 ECU)
High (6 to 10 m high)	515 to 700 ECU
Medium (2 to 6 m high)	170 to 515 ECU
Low (< 2 m high)	140 to 210 ECU

For the purposes of these calculations an average cost of protection is calculated to be 19 700 ECU for a detached house and 8 600 ECU for a flat in a block.

2.5. Effects and investments related to the implementation of protective programmes

2.5.1. Scenario 1

The implementation of a correction policy based exclusively on building insulation concerns 283 000 homes i.e. approximately 1.3% of all dwellings or 670 000 people (after figure 7).

Most homes requiring soundproofing are located in urban centres (83%) as that is where noise levels are the highest (table 78).

Table 78. **Distribution of the dwellings to be insulated**

Area	Number of dwellings
City centres	236 000 (83.4 %)
Suburbs	34 500 (12.2 %)
Rural area	12 500 (4.4 %)

The protective programme would involve :

- 116 000 homes requiring soundproofing of between 35 to 40 dB(A), i.e. 10 to 15 dB(A) more than the standard attenuation value ;

- 167 000 requiring soundproofing of between 32 to 35 dB(A), i.e. 7 to 10 dB(A) more than the standard attenuation value.

The total cost of this programme would be approximately 2 billion ECU i.e. 400 million ECU per year if the programme was executed over 5 years.

If, simultaneously, vehicle noise emission limits were lowered (EEC Directive 92/97), this corrective programme would only concern 129 000 homes (0.6% of all homes). Approximately 70% of homes requiring corrective treatment would require additional soundproofing of 32 to 35 dB(A). Total investment would be 840 million ECU i.e. 170 million ECU per year. A further step in lowering vehicle noise emission limits would reduce the cost of this insulation programme to 300 million ECU (60 million per year).

A strategy combining building insulation, the use of low-noise surfaces and noise barriers would limit the number of homes requiring soundproofing to 75 000 (0.35% of the total number of homes) located for 75% in city centres. Total investment would be 940 million ECU i.e. 190 million ECU per year. If, in addition, vehicle noise emission limits were lowered (EEC Directive 92/97), the number of homes to insulate would be limited to 21 000 (0.1% of all homes) located for the most part in rural areas (table 79). Total investment would thus be limited to 610 million ECU i.e. 120 million ECU per year. A further step in lowering vehicle noise emission limits would reduce this programme to 570 million ECU.

Table 79. **Distribution of the dwellings to be insulated**

Area	Number of dwellings
City centres	5 800 (27.6 %)
Suburbs	2 700 (12.9 %)
Rural area	12 500 (59.5 %)

The annual cost of reducing vehicle noise emissions would be approximately :

- 1.2 billion ECU, i.e. 22 ECU per person when EC Directive 92/97 is applied (N2).

- 2 billion ECU, i.e. 38 ECU per person if a further vehicle noise emission reduction were applied (N3).

Table 80 summarises the effects and the costs of applying the various strategies to attain the target. The average annual cost per person protected was calculated to take account of the life of the investments (30 years for building insulation and noise barriers, 10 years for low-noise surfaces).

Table 80. **Cost/effectiveness of noise abatement measures - Scenario 1**

Strategy	Number of people protected	Total investment (million ECU)				Annual cost / people protected** (ECU)
		Insulation	Low noise surface	Noise barrier	Total	
N1+L1+L3+L5	670 000	2013	-	-	2013	100
N2+L1+L3+L5	670 000	840	-	-	840	64
N3+L1+L3+L5	670 000	295	-	-	295	52
N1+L2+L4+L5	670 000	502 (732)*	416 (91)	17 (17)	935 (840)	88 (51)
N2+L2+L4+L5	670 000	190 (253)	416 (91)	6 (6)	612 (350)	94 (49)
N3+L2+L4+L5	670 000	148 (179)	416 (91)	2 (2)	566 (272)	107 (60)

* ( ) : the "low noise surface programme" only concerns city centres.
** reducing vehicle noise emission cost included.

The detailed results of the simulations show that the implementation of a strategy based on a combination of local actions is even more effective if it is applied where population densities are highest (i.e. where the population/roadway length ratio is highest) : if low-noise surfaces were implemented only in city centres, the cost of the protective programme would be reduced by approximately 95 million to 294 million ECU. In this way, the annual cost per person protected of the most cost-effective strategy would be reduced to 49 ECU.

These results confirm first that the implementation of a combination of appropriate measures is more effective than a strategy based only on building insulation and which, for this reason, only enables reduction of noise levels inside homes ; secondly, that a further step in reducing vehicle noise emission levels doesn't seem to provide better results.

2.5.2. Scenario 2

Applying a corrective policy based exclusively on building insulation concerns 1 493 000 homes, i.e. approximately 7% of total homes - 3.6 million people (after figure 7). Most homes requiring soundproofing are located in city centres (72% - table 81).

Table 81. **Distribution of the dwellings to be insulated**

Area	Number of dwellings
City centres	1 076 500 (72.1 %)
Suburbs	292 000 (19.5 %)
Rural area	125 000 (8.4 %)

Soundproofing would involve :

- 463 000 homes which would require insulation in the 35 to 40 dB(A) range i.e. 10 to 15 dB(A) more than the standard attenuation value ;

- 1 031 000 homes which would require insulation in the 32 to 35 dB(A) range i.e. 7 to 10 dB(A) more than the standard attenuation value.

The total cost of this programme would be approximately 11 billion ECU i.e. 1.1 billion ECU per year if the programme was executed over 10 years.

If, simultaneously, vehicle noise emission limits were lowered (EEC Directive 92/97), this corrective programme would only concern 1 044 000 homes (4.9% of all homes). Approximately 68% of homes requiring corrective treatment would require additional soundproofing of 32 to 35 dB(A). Total investment would be 7.4 billion ECU i.e. 740 million ECU per year. A further step in lowering vehicle noise emission limits would reduce the cost of this insulation programme to 4.2 billion ECU (420 million per year).

A strategy which combines building insulation, the use of low-noise surfaces and noise barriers would limit the number of homes requiring soundproofing to 757 000 (3.5% of the total number of homes) 75% of which are located in city centres. Total investment would be 6.1 million ECU i.e. 610 million ECU per year over 10 years. If, in addition, vehicle noise emission limits were lowered, the number of homes to soundproof would be limited to 389 000 (1.8% of all homes) located for a third in rural area (table 82). Total investment would thus be limited to 3.5 billion ECU i.e. 350 million ECU per year. A further step in lowering vehicle noise emission would reduce the cost of this programme to 2.6 billion ECU.

Table 82. **Distribution of the dwellings to be insulated**

Area	Number of dwellings
City centres	235 000 (60.5 %)
Suburbs	28 000 (7.2 %)
Rural area	125 500 (32.3 %)

Table 83 summarises the impact and costs of applying the various strategies enabling the target objective to be attained in this scenario.

Table 83. **Cost/effectiveness of noise abatement measures - Scenario 2**

Strategy	Number of people protected	Total investment (million ECU)				Annual cost / people protected **
		Insulation	Low noise surface	Noise barrier	Total	
N1+L1+L3+L5	3 600 000	11092	-	-	11092	103
N2+L1+L3+L5	3 600 000	7406	-	-	7406	91
N3+L1+L3+L5	3 600 000	4231	-	-	4231	77
N1+L2+L4+L5	3 600 000	5437 (7225)*	416 (91)	275 (275)	6128 (7591)	64 (72)
N2+L2+L4+L5	3 600 000	3049 (4119)	416 (91)	84 (84)	3549 (4294)	63 (64)

N3+L2+L4+L5	3 600 000	2130 (2572)	416 (91)	21 (21)	2567 (2684)	69 (64)

* ( ) : *the "low noise surface programme" only concerns city centres.*
** *reducing vehicle noise emission cost included.*

Once more, the most cost-effective strategy is a combination of different local measures associated with a reduction of noise levels at source (EC Directive 92/97). Once more, a further step in reducing vehicle noise emission levels doesn't seem to provide better results.

2.5.3. *Scenario 3*

Applying a corrective policy based exclusively on building insulation concerns 2 725 000 homes, i.e. approximately 12.7% of total homes - 6.670 million people (after figure 7). Most homes requiring soundproofing are located in city centres and suburbs (table 84).

Table 84. **Distribution of the dwellings to be insulated**

Area	Number of dwellings
City centres	1 627 000 (59.7 %)
Suburbs	879 000 (32.3 %)
Rural area	219 000 (8.0 %)

Soundproofing would involve :

- 1 208 000 homes which would require insulation in the 35 to 40 dB(A) range i.e. 10 to 15 dB(A) more than the standard attenuation value ;
- 1 517 000 homes which would require insulation in the 32 to 35 dB(A) range i.e. 7 to 10 dB(A) more than the standard attenuation value.

The total cost of this programme would be approximately 23 billion ECU i.e. 1.5 billion ECU per year if the programme was executed over 15 years.

If, simultaneously, vehicle noise emission limits were lowered (EEC Directive 92/97), this corrective programme would only concern 1 987 000 homes (9.3% of all homes). Approximately 62% of homes requiring corrective treatment would require additional soundproofing of 32 to 35 dB(A). Total investment would be 16 billion ECU i.e. 1 billion ECU over 15 years. A further step in lowering vehicle noise emission limits would reduce the cost of this insulation programme to 10.3 billion ECU (690 million ECU per year).

A strategy combining building insulation, the use of low-noise surfaces and noise barriers would limit the number of homes requiring soundproofing to 1 530 000 (7.2% of the total number of homes). Total investment would be 13.2 billion ECU i.e. 880 million ECU per year). If vehicle noise emission limits were lowered, the number of homes to insulate would be limited to 1 107 000 (5.2% of all homes) located for the most part in urban areas (table 85). Total investment would thus be limited to 9.4 billion ECU i.e. 630 million ECU per year. A further step in lowering vehicle noise emission limits would reduce the cost of this programme to 6.1 billion ECU.

Table 85. **Distribution of the dwellings to be insulated**

Area	Number of dwellings
City centres	765 000 (69.1 %)
Suburbs	123 000 (11.1 %)
Rural area	219 000 (19.8 %)

Table 86 summarises the effects and costs of applying the various strategies enabling the target objective to be attained in this scenario.

Table 86. **Cost/effectiveness of noise abatement measures - Scenario 3**

Strategy	Number of people protected	Total investment (million ECU)				Annual cost / people protected**
		Insulation	Low noise surface	Noise barrier	Total	
N1+L1+L3+L5	6 667 000	22762	-	-	22762	114
N2+L1+L3+L5	6 667 000	15851	-	-	15851	101
N3+L1+L3+L5	6 667 000	10306	-	-	10306	89
N1+L2+L4+L5	6 667 000	12023 (17870)*	416 (91)	772 (772)	13211 (18733)	70 (95)
N2+L2+L4+L5	6 667 000	8564 (11436)	416 (91)	421 (421)	9401 (11948)	73 (83)
N3+L2+L4+L5	6 667 000	5544 (6882)	416 (91)	162 (162)	6122 (7135)	72 (74)

* ( ) : the "low noise surface programme" only concerns city centres.
* * reducing vehicle noise emission cost included.

The best result (lowest annual cost/ people protected) is obtained by all the three strategies that combine local measures and a reduction of noise at the source. However a further step in reducing vehicle noise emission levels (N3) limit the number of dwellings to be insulated and provide a better outdoor noise environment.

2.5.4. Comparison of the scenarios

Table 87 summarises the results for all 3 scenarios considered which correspond to steps in environmental noise quality. The annual cost/people protected corresponds to the most cost-effective strategy.

Table 87. **Cost/effectiveness of the scenarios**

Scenario	Number of people protected	Annual cost/ people protected *	Total annual cost (million ECU)
1	670 000	49	32,80
2	3 600 000	63	226,80
3	6 667 000	72	480,00

* the cost takes into account of the length of life of each type of measure

Analysis of the 18 simulations suggests that :

1/ As the environmental noise quality target is raised, the number of people to protect and the average cost of protection significantly increases. Therefore, the annual total cost of black spot corrective programmes thus varies by a factor of 15.

2/ A corrective programme based exclusively on building insulation is not the best overall action strategy. Apart from the fact that exterior noise levels are unchanged, it leads, for a given objective, to higher costs than any other strategy. The most cost/effective strategy to meet the noise environment quality target consists in combining different types of measures. The choice of these measures depends on the objective fixed : the more ambitious the target (target 3), the more essential it is to use broad-scale measures. Conversely, critical situations correction (target 1) leads to the implementation of actions that are more precisely targeted to specific areas, particularly in those with high population densities exposed to high noise levels (i.e. city centres).

3/ More stringent vehicle noise emission limits (Directive 92/97 EEC) would permit a significant reduction (30 to 60%) of the cost of soundproofing homes located in urban areas depending on the target. A further reduction of the noise emission levels of vehicles doesn't seem to be the most cost-effective strategy when the target is only to eliminate the critical noise exposure situations (target 1). However, if the target is to promote high quality noise environments (target 3), lowering vehicle noise emission levels combined with local measures could be an effective strategy : the number of dwellings to be insulated and the total insulation cost are reduced, the outdoor noise levels are lowered.

2.6. Cost-benefit analysis of the scenarios

Although remaining cautious in the interpretation of the results, net annual benefit (i.e. the difference between costs and benefits) subsequent to the adoption of each scenario can be assessed.

2.6.1 Assessment of the benefits

To calculate benefits we use recent results (see § 1.2.2.) of hedonic pricing. Two hypotheses concerning the impact of noise on the house market have been considered :

- H1 : depreciation of 1% of the value of the homes per decibel over 55 dB(A) ;
- H2 : depreciation of 0.8 % per decibel in the range of 55 - 65 dB(A), 1 % per decibel in the range of 65 - 70 dB(A) and 1.2 % per decibel for Leq > 70 dB(A).

The average value of homes in France was thus estimated to be 68 000 ECU (1992) : 94 000 ECU for a house in urban area, 66 000 ECU for a flat in urban area, 59 000 ECU for a house in rural area.

The total benefit (reduction of the damages) - i.e. the annual house price depreciation - can be expressed by the following equation :

$$B = \Sigma (N_i * (L_i - L_s) * d * V_i/n)$$

where : N_i = number of homes exposed to noise level L_i
L_s = target of the scenario (noise exposure level to be attained)
d = rate of depreciation
V_i = average value of homes
n = 30 years

2.6.2. Results and comments

Figure 8 and table 88 show the average annual costs and benefits for each scenario. The net benefit is the difference between the total annual benefits and the total annual cost of implementing the most cost-effective strategy.

Figure 8. **Cost and benefits of the scenarios**

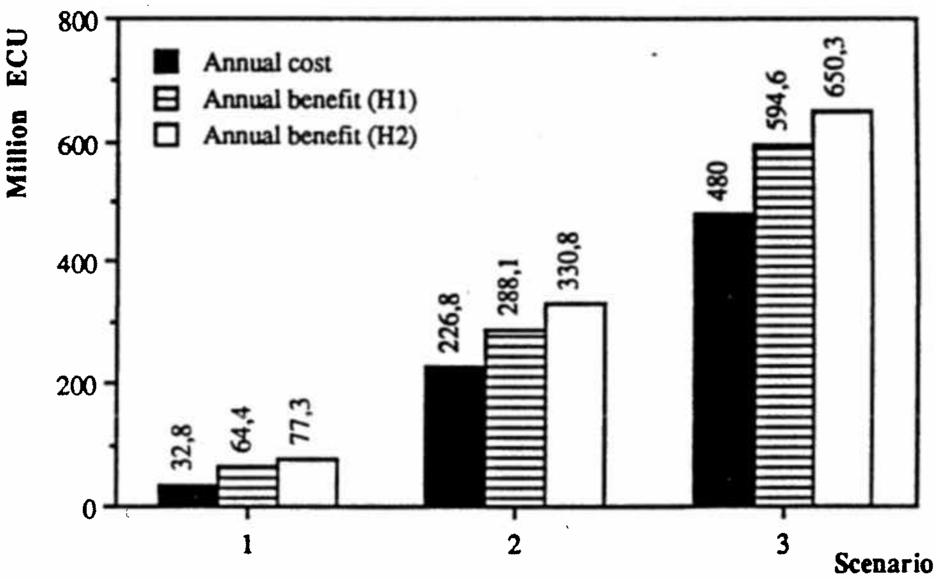


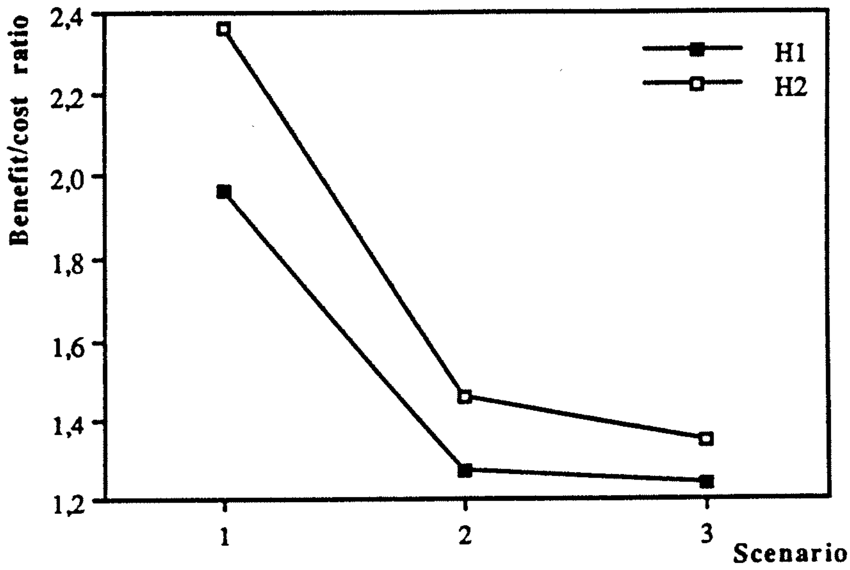
Table 88. **Net benefit of the scenarios**

Scenario/Objective	Number of people to be protected	Total annual cost (million ECU)	Total annual benefit (million ECU) H1	H2	Net annual benefit (million ECU) H1	H2
1 - Limit critical noise exposure situations	670 000	32.8	64.4	77.3	31.6	44.5
2 - Provide satisfactory protection to people exposed	3 600 000	226.8	288.1	330.8	61.3	104.0
3 - Promote good quality noise environments	6 667 000	480.0	594.6	650.3	114.6	170.3

Whatever the target, i.e. the noise quality criteria, the net annual benefit is positive. This net benefit would be very likely more important insofar as the noise abatement costs could be lowered in the future (scale effects) and the benefits measured by the hedonic price method underestimate the real damages.

Figure 9 which shows the benefit/cost ratio of the three scenarios suggests that scenario 1 is the most cost/benefit scenario : it leads to eliminate over a 10 year period the critical noise exposure situations by implementing a strategy combining local measures (low noise surface, noise barrier, building insulation) and a reduction of vehicle noise emission levels (Directive 92/97 EEC). But given the uncertainties inherent in this type of calculations, it is difficult to choose one scenario before the others solely on the basis of the cost-benefit ratios.

Figure 9. **Benefit-cost ratio of the scenarios**



However, such results are, for night-time, very close to the EC targets up to 2000 [32] envisaged in the 5th Environmental Action Programme [EAP] approved by the Commission and adopted by the Council in February 1993 : " no person should be exposed to noise levels which endanger health and quality of life". But different land use patterns, standards of living and design of housing reflecting climatic differences are likely to lead to differences in the ratio of costs and benefits of particular measures as between Member States.

3. TOWARDS A FUTURE EC NOISE POLICY

Beyond the quantitative results provided by the cost-benefit analysis, some more qualitative considerations can be added. They concern both the need to define objectives and targets and the need for an integrated and co-ordinated noise abatement policy.

3.1. Objectives, targets and priorities

In most countries the objectives of noise abatement policies are neither explicit nor quantified at either national or local level. Therefore, to be successful, a EC noise abatement policy requires first objectives to be defined. The objectives of community noise might be set as " ensuring that the health of the inhabitants of the community is not adversely affected by exposure to environmental noise and in the longer term ensuring that the work, home life and recreation of the inhabitants of the community are not adversely affected by noise exposure".

Cost-benefit analysis showed that, in residential areas, for existing situations (corrective plan), this could translate into targets of 65 dB(A) L_{Aeq} for daytime (or 40 dB(A) indoors) and 55 dB(A) for night-time, for people exposed to land transport noise levels exceeding 73 dB(A) (daytime). Achieving these targets would concern about 8 to 10 million people in the European Communities.

For new situations (preventive plan), more ambitious targets could be achieved : for example, maximum 63 L_{Aeq} for daytime, 53 dB(A) for night-time at the facade referring to road traffic noise. Net benefit would be more important that for existing situations insofar as the implementing costs (noise barrier, insulation of dwellings) would be lower.

These noise quality criteria should represent a minimum standard for all citizens in the EC.

Road traffic noise requires the highest priority in abatement policies, followed by aircraft and railway noise and at last industrial noise and other environmental noise sources like recreational noise and construction noise.

3.2. Noise abatement strategy : some recommendations

As suggested by the cost-effectiveness analysis, fighting noise must not rely solely on the reduction of vehicle noise emission levels but also include other important actions such as sound insulation of houses, highway noise barrier, low noise road surface, traffic restraint and land use planning.

Vehicle noise emission regulations have been effective for more than 20 years. Limits have been lowered in the EC by 8 dB(A) for passenger cars and 11 dB(A) for heavy trucks (including Directive 92/97 EEC). However, the reduction in actual road traffic noise levels was much less, about 1 - 2 dB(A). As suggested by U. Sandberg [33], the reasons for the poor effectiveness of the vehicle noise regulations are assumed to be " a combination of rather relaxed limits the first years, slow exchange of old to new vehicles, counteracting trend towards bigger and more powerful vehicles and a lower floor to achievable overall noise reductions caused by tire /road noise".

For the future (2010), vehicle noise regulation alone (Directive 92/97 EEC + a further reduction of 2 dB(A) + introduction of a regulation to limit noise from tires) could not lead to a reduction in average traffic noise levels of more than 4 dB(A) [30]. More, vehicle noise control through regulations has the following disadvantages :

- the test procedure of ISO R 362 doesn't reflect the realistic and commonly encountered driving conditions of traffic ;
- it needs an important time delay because it can take 15-20 years to replace older noisiest vehicles ;
- if no regular inspection procedure is established at a national level to ensure the proper maintenance and function of the acoustical design features installed by the vehicle manufacturers, then the noise levels of the vehicles may increase over time.

Therefore, already implemented in several European cities [34], the introduction of low-noise vehicles (quieter than those conforming to EC directive) in specific areas (historic city centres) appears to be a particularly effective measure : only a low percentage of vehicles are concerned (generally delivery vehicles), and a high proportion of the population exposed to high noise levels benefits. Promoting at a wider scale the purchase and the use of low-noise vehicles is also possible through voluntary agreements between vehicle manufacturers and operators : for example, in the Netherlands (1981), operators of heavy goods vehicles and buses are offered a two tier subsidy if they purchase and use vehicles fitted with "hush kits" which result in specified lower noise levels.

Inside towns, traffic noise abatement must rely more heavily on measures generally summarised under the heading of "traffic restraint" and decided locally [35] : reducing traffic volumes [36] in city centre (already implemented in Milan, Bologna, Geneva, Bern, Lübeck, York etc.), reducing the lorry component (lorry ban with exemptions for low-noise vehicles), reducing vehicle speed widely used in Germany (Tempo 30), Holland and France (Zone 30), smoothing the speed curve (traffic calming), promoting low-noise public transport and the use of bicycles.

Even though the primary objective of traffic restraint measures is usually road safety, it doesn't cost a lot to implement and noise reduction is often one of the major benefits (improve the air quality and reduce congestion too). However, to integrate noise concerns in the development of transport policies and traffic management policies requires careful planning and effective co-ordination between multiple local (and regional) responsible authorities.

Land-use planning has to be used to avoid future conflicts between noise-sensitive buildings and noise-generating sources such as airports, railways, roads, industrial plants. It is often a cheap and a very effective noise control measure and should always be considered as a first option when designing new residential areas (preventive measure) whereas noise barriers (limited applicability in built-up areas) and insulation of dwellings (do not improve the noise quality of the residential environment) are no more than curative measures, but in many existing situations appear to be the only viable option.

3.3. Conclusions

Implementation of noise quality criteria involves to take measures to reduce or limit noise at source, at transmission and receptor levels. These are to be seen as a package of complementary engineering and legal actions that should form a coherent and co-ordinated noise abatement policy.

However, implementing such a policy implies [37] :

- firstly, to link the objectives to be attained and the resources needed to guarantee complete implementation. This means clearly that future financial efforts of the EC member states should be probably much more important than in the past. For example, extrapolating corrective "black spots" policy costs concerning France to the whole European Community could lead to an annual investment cost of about 1 billion ECU if executed over 5 years.

- secondly, to provide the resources needed for an effective implementation. This is probably one of the main difficulties in applying public abatement noise policies. Current policies in Holland and in Switzerland show that increasing taxation on vehicle fuels would be a relatively simple way of raising the money required.

- finally, to define clearly the distribution of responsibilities among the various decision levels : (1) EC level for noise emission standards (vehicle, train, aircraft, ...), minimum noise quality standards, R & D ; (2) National level for vehicle noise control through inspection/maintenance programme, subsidies for low-noise technology, government support for R&D, law or guidance on land use planning, national noise quality standards within the framework of EC noise quality standards, economic incentives ; (3) Local level for execution of national law or guidelines or recommendations through traffic management, low noise surface, land-use planning, insulation of buildings etc.

References

[1] OECD. Environmental policy benefits : monetary evaluation. OECD, Paris 1989.

[2] C. Lamure et J. Lambert. Impact des transports terrestres sur l'environnement : méthodes d'évaluation et coûts sociaux. Synthèse INRETS n° 23, septembre 1993.

[3] F. J. Langdon. Monetary evaluation of nuisance from road-traffic noise : an exploratory study. Environment and Planning A, volume 10, 1978.

[4] A.A. Walters. Noise and prices. Clarendon Press, Oxford, 1975.

[5] D. Starkie D & D. Johnson. The economic value of peace and quiet - Saxon House, Westmead, Farnborough -Hants - 1975.

[6] M. Weinberger. Gesamtwirtschaftliche Kosten des Lärms in der Bundesrepublik Deutschland. Z. Lärmbekämpfung 39 (1992).

[7] Echo Bruit. Coût social du bruit en Allemagne. Fiche Europe 4, février 1992.

[8] D.C. Colony. Expressway traffic noise and residential properties. US DOT. Washington D.C., 1967.

[9] R. Towne. An investigation of the effect of freeway traffic noise on apartment rents. R Towne and Associates. Seattle 1968.

[10] J. Diffey. An investigation into the effect of high traffic noise on house prices in a homogeneous submarket. Centre for Environmental Studies, London 1971.

[11] J.P. Nelson. The effects of mobile-source air and noise pollution on residential property values. DOT-TST-75-76. Springfield, april 1975.

[12] H.B. Gamble and al. The influence of highway environmental effects on residential property values. Research publication n° 78. University Park, april 1974.

[13] R. Anderson, D. Wise. The effects of highway noise and accessibility on residential property values. DOT FH-11-8841, NTIS, Springfield, march 1977.

[14] R J. Vaughan, L. Huckins. The economics of expressway noise pollution abatement. Rand Corporation. Santa Monica (Ca), august 1975.

[15] T. Hammar. Trafikimmisjoners innverkan pa villapriser. Statens Vägverk, Vägförvaltningen i Stockholm län. Solna, des. 1974.

[16] M. J. Bailey. Report on pilot study : highway noise and property values. University of Maryland, 1977.

[17] F. Hall and al. Effects of highway noise on residential property values. TRR 686. NAS Washington DC. 1978.

[18] G.R. Allen. Highway noise, noise mitigation and residential housing values. Virginia highway and transportation research council. 1980.

[19] R.B. Palmquist. Impact of highway improvements on property values in Washington state. TRR 887, 1981.

[20] W.W. Pommerehne. Der monetäre Wert einer Flug - und Strassenlärmreduktion : eine empirische Analyse auf der Grundlage individueller Präferenzen. In : Umweltbundesamt (éd.), Kosten der Umweltverschmutzung. Berlin 1986.

[21] N. Soguel. Evaluation du coût social du bruit généré par le trafic routier en ville de Neuchâtel. IRER, working paper n° 9105, Neuchâtel, août 1991.

[22] M.C. Streeting. A survey of the hedonic price technique. Ressource Assessment Commission. Canberra, 1990.

[23] C. Deslorieux. Le contentieux du bruit des transports routiers. Analyse de la jurisprudence administrative. Rapport INRETS NNB 8801, février 1988.

[24] CIDB. Les nuisances sonores - Recueil de jurisprudence commentée. Paris, 1992.

[25] M. Maurin. Community noise impact indicators : a framework with examples. Journal of Sound and Vibration, vol 79 n°4, 1981.

[26] Planco Consulting Gesellschaft mbH. Evaluations macroéconomiques des investissements dans l'infrastructure de transport. Expertise pour le Ministre Fédéral des Transports. Publications n° 69. Bonn, 1986.

[27] V. Himanen, K. Mäkelä, K. Alppivuori, P. Aaltonen & J. Louhelainen. The monetary valuation of road traffic's environmental hazards. Technical Research Centre of Finland (VTT), Research notes 943, february 1989.

[28] G. Nielsen & S. Solberg. Costs and effects of traffic noise abatement measures : basis for a national programme. Applied Acoustics 25 (1988) 149-168.

[29] J. Lambert. Evaluation économique des politiques à long terme de lutte contre le bruit routier. Rapport INRETS-LEN 9006, avril 1990.

[30] T. Berge. Vehicle noise emission limits : influence on traffic noise levels past and future. Noise Control Engineering Journal, 42 (2) 1994 march-april.

[31] B. Favre, J. Lambert & J. Delsey. Perspectives de réduction du bruit des véhicules routiers pour 1985 et 2000 compte tenu des possibilités techniques, de la consommation énergétique et du coût. Rapport EUR 8573, CCE, 1983.

[32] H. Müller. Reflections on the future development of noise policy in the european commission. Proceedings of INTER-NOISE 93, Leuven, Belgium, 1993 August 24-26.

[33] U. Sandberg. Noise emission of road vehicle - Effects of regulations. Status report of an I - INCE Working party. Proceedings of INTER-NOISE 93, Leuven, Belgium, 1993 August 24-26.

[34] M. Jäcker & H. Rogall. Benutzervorteile für lärmarme Lastkraftwagen : das Heidelberger Modell. Zeitschrift für Lärmbekämpfung 40 (1993) 161-168.

[35] H. Steven. Experience with traffic noise restraint measures in Germany. Proceedings of INTER-NOISE 93, Leuven, Belgium, 1993 August 24-26.

[36] B. Hardstedt, H. Silborn, J. Söderström. Réduction de la circulation automobile en centre-ville. Routes (Roads) n° spécial, 1990.

[37] OECD. Fighting noise in the 1990s. OECD, Paris, 1991.