1.7.2. Road traffic noise

Noise immission limits depend on two factors :

- the type of road : maximum speed limit 50 km/h or a higher speed limit ;
- the degree (5 categories) to which the roads and housing have been developed : unplanned, planned (i.e. included in an urban zoning plan), under construction, already built, to be rebuilt.

Comparison with noise exposure limits is based on predicted noise levels for daytime (Leq 7.00 a.m. - 7.00 p.m.) and night-time (Leq 11.00 p.m. - 7.00 a.m. + 10 dB(A)). The higher of the two is applied.

In all these situations, maximum and minimum noise limits are determined. Over upper noise limits either it is forbidden to build a new dwelling or its use must be modified or the road in question cannot be open to the public until appropriate measures are taken. Below the minimum level, no measures are taken. In addition to these two limits there is also a maximum indoor noise level which is in fact the objective to be attained. Table 14 summarises the different cases encountered.

Table 14. Road traffic noise immission limits (LAeq - free-field values)

Building	Road	Mini noise	Maxi noise		Maxi indoor
	Unplanned	55	65	60	35
	Planned	55	65	60	35
Unplanned	Under construction	55	65	60	35
	Already built	55	70	60	35
	To be rebuilt	55	65	60	35
	Unplanned	55	65	60	35
	Planned	55	65	65	35
Planned	Under construction	55	70	70	35
	Already built	55	70	70	35
	To be rebuilt	55	65	65	35
	Unplanned	55	70	65	35
	Planned	55	70	70	40
Under construction	Under construction	60	70	70	40
	Already built	60	70	70	40
	To be rebuilt	(1)	(2)	(2)	35
	Unplanned	55	70	65	35
	Planned	55	70	70	40
Already built	Under construction	60	75	70	40
	Already built	65	75	75	45
	To be rebuilt	(1)	(2)	(2)	35

(1) : ambient noise ; (2) : ambient noise + 5 dB(A)

The first maximum noise limit is for townships and the second for non-urban zones ; noise limits are increased by 5 dB(A) to take account of the expected reduction of noise levels in the medium term as vehicle noise emission standards become more severe. To put it another way, the 55 dB(A) limit is equivalent to the 50 dB(A) objective.

The application of these regulations was difficult particularly in large cities where traffic levels are very high authorised noise levels are difficult to respect. Some small cities also had difficulty in understanding the text which it is true can appear to be somewhat complicated for municipalities with no local services specialised in noise-related questions.

1.7.3. Railway noise

Limits for exposure to rail noise are applied both for new and existing railway lines. Comparisons with noise limits are made using predicted noise levels for daytime (Leq 7.00 a.m. - 7 .00 p.m.), evening (Leq 7.00 p.m. - 11.00 p.m. + 5 dB(A)) and night-time (Leq 11.00 p.m. - 7.00 a.m. + 10 dB(A)) periods and the highest of the three is applied.

In the case of new railway lines, the noise limit (free-field values) which must not be exceeded in residential areas is 60 dB(A) (N.B. this limit will be reduced to 57 dB(A) by the year 2000). If this level is exceeded, it is the responsibility of the railway operator to install noise barriers or earthworks or to modify the profile of the line (with a cutting). If the implementation of these measures encounters technical or financial difficulties, the provincial government can dispense the railway operator from such actions providing that the noise level does not exceed 73 dB(A) (70 dB(A) by the year 2000) and that the homes concerned are insulated (indoor level of 37 dB(A) which must not be exceeded).

These limits also apply when new buildings are erected beside an existing railway line. In this latter case it is the property developer (private or public) who is responsible for respecting the limit and for paying the expenses incurred for protection (particularly for insulating the buildings).

If an existing line is extended, the rule is to maintain the noise at the existing level which usually implies the installation of noise barriers. As for new lines, if it is impossible to implement such measures for technical or financial reasons, a waiver may be granted provided that the noise does not exceed 73 dB(A) and that the insulation of the buildings limits indoor noise to 40 dB(A).

In the case of existing railway lines and buildings, it is the responsibility of the State to correct the noisiest situations, i.e. whenever the noise level exceeds 65 dB(A) (the health limit). In this case, the State grants financial assistance to local authorities who have to take corrective actions such as the construction of noise barrier or insulation of the buildings (the indoor noise level which must not be exceeded is 40 dB(A)).

1.7.4. Aircraft noise

Noise zones based on noise levels measured in Ke (Kosten-units) have been set up around airports. This index includes both the maximum noise level for the passage of each aircraft and the number of aircraft movements (with a weighting of 1 for daytime period and 10 for night-times). Table 15 shows the limits which must not be exceeded by existing airports.

For existing dwellings exposed to levels of over 40 Ke, an insulation programme must be implemented.

Table 15. Aircraft noise immission limits

Situation	Initial noise level	Preferred limit	Maximum limit
New dwellings	-	35 Ke	45 Ke
Existing dwellings or under construction	≤ 40 Ke > 40	40 Ke 55 Ke	55 Ke 65 Ke

1.7.5. Industrial noise

When industrial plants are built, the basic noise level must not exceed 50 dB(A) L_{DEN}. As for railway noise, L_{DEN} is the largest of the predicted values calculated for daytime, evening and night-time periods. In the case of new housing, the limit is set at 55 dB(A) and 60 dB(A) for existing dwellings. In all cases, indoor noise must not exceed 35 dB(A).

If new housing is built close to existing industrial plants, the maximum authorised levels depend on pre-existing noise levels (50 to 55 dB(A) or > 55 dB(A)), from 60 to 65 dB(A) on the facades of the dwelling or 35 or 40 dB(A) indoors.

1.8. PORTUGAL

Portugal has national legislation that regulates licensing and fiscalization aspects for noisy activities. The General Noise Regulation (Decree-Law n°251/87) from 87.06.21, with some modifications by the Decree-Law n° 292/89 from 89.09.02).

National legislation became into in force since 1988 and concerns to new activities. There are quality acoustic required for noisy activities in general and particular conditions to be accomplished in buildings and in transport.

1.8.1. Buildings

Construction permits for new buildings must report to the classification of premises and dwellings. Schools and hospitals are not authorised in noisy and very noisy zones. Classification is as follows :

- Quiet zones : $L_{50} \leq 65$ dB(A), day period (7.00-22.00)
  $L_{50} \leq 55$ dB(A), night period (22.00-7.00)

- Noisy zones : $L_{50} \leq 75$ dB(A), day period
  $L_{50} \leq 65$ dB(A), night period

- Very noisy zone : $L_{50} > 75$ dB(A), day period
  $L_{50} > 65$ dB(A), night period

In respect to industry, commerce and service buildings, noisy equipments to be installed must possess an acoustic certificate. In the case of dwellings, schools or hospitals near industries, commerces or services buildings, it is mandatory to observe the following criteria :

$$L_{eq} \text{ (particular noise)} - L_{95} \text{ (background noise)} \leq 10 \text{ dB(A)}$$

This annoyance criteria also applies to outdoors spectacles and noisy activities in general.

Acoustic insulation for facades and between rooms are established for dwellings, schools and hospitals. Rules reports to Airborne Sound Insulation (Ia) and Impact Sound Insulation (Ip). For instance, Ia ≥ 55 dB and Ip ≤ 55 dB in multiple utilisation.

1.8.2. Transportation

Besides from the maximum admissible sound levels for new vehicles regulated in accordance with EC Directives, particularly vehicle conditions were established.

For two and three wheels vehicles emission standards of sound level report to a special determination technique when the vehicle is in maximum instantaneous acceleration. Standards are as follows :

- $CC \leq 80\ cm^3 : L \leq 102$ dB(A) ;
- $80 < CC \leq 175\ cm^3 : L \leq 105$ dB(A) ;
- $CC > 175\ cm^3 : L \leq 110$ dB(A).

Control of noise from air traffic follows the general procedures of the IACO Convention.

Portuguese noise legislation is now being reviewed for actualisation. The main technical modifications are the adoption of the Leq index in the classification of premises and also the substitution of the actual annoyance criteria by the following rule :

Leq (particular noise) - Leq (background noise) ≤ 5 dB(A), day period
≤ 3 dB(A), night period

In addition to the national legislation, there are Police regulations and Local rules from the municipalities concerning noise control. Many of these regulations forbid disturbance during night period.

1.9. SPAIN

Spain has not yet national noise regulations. However, some regions such as Navarre (July 1989), Astúria (October 1985), the Balearics (April 1987) and more recently Extrema Dura (January 1991) adopted regulations for road traffic noise, industrial noise and the noise of specific night-time activities such as discos.

Since the beginning of the 1970s, and more particularly since 1983, many towns have introduced local ordinances concerning external and internal noise levels from industry and commerce but not from road traffic. These ordinances envisage that towns could adopt a zoning system (residential zones, industrial and commercial zones and sensitive zones such as hospitals and schools). But many municipalities have not admitted the concept of a noise control. Regulations contained in these ordinances vary from one city to another. The principle difficulty encountered in the application of local ordinances is control as the police are responsible for verifying the respect of noise limits.

In 1988, the Ministry for Public Works and Urban Planning (MOPU) proposed a project for a national noise law but this was abandoned for technical, economic and political reasons. This proposal fixed maximum daytime and night-time noise limits. For road traffic noise, a distinction was drawn between new roads and existing roads and between the different types of activity areas (table 16).

Each region has the freedom to specify daytime and night-time periods. However, daytime is usually defined as 8.00 a.m. - 10.00 p.m. (or 11.00 p.m.) and night-time as 10.00 p.m. (or 11.00 p.m.) to 8 a.m. The proposal referred to the national road network, i.e. mostly outside urban areas. The most commonly used index in Europe - the L_{Aeq} - was selected. The Ministry of Transport wanted to extend its scope by an index which better accounted for peak noise levels and which simplified measurements and forecasting.

Spanish project law does require a study of the impact on the environment when new roads are projected. Noise is considered very succinctly but there are not yet any official recommendations to assist technicians. However, for national road network, the General Secretariat for the Environment (which reports to the MOPU), is attempting to apply relatively low thresholds during the impact studies for new roads. In particular, it recommends that the upper noise limit should not exceed 55 dB(A) during daytime and 45 dB(A) during the night in residential areas. These levels obviously imply the use of noise barriers or modifications to routes and profiles. These recommendations are recent and it is to early to assess the effectiveness of these measures given the relatively small amount of experience acquired by the Environment Service.

Table 16. **Road traffic noise immission limits set up in the 1988 noise law project**

	Daytime LAeq	Night-time LAeq
I - New road		
- Hospital, school	55	45
- Residential area	65	55
- Commercial and industrial area	75	65
II - Existing road (new building)		
- Residential area	75	65
- Hospital, school	65	55

To summarise, regulations in Spain were as follows up until 1993 :

- no precise national legislation concerning exposure to noise despite the size of the population concerned by unacceptable noise levels ;
- no generalised recommendations for noise immission limits ;
- no official specific methodology for the calculation of road traffic noise levels ;
- no technical regulation concerning the engineering design and construction of corrective measures ;
- no legislation permitting the inclusion of noise levels in town planning.

Confronted with this "mosaic" of local texts and a host of inadequacies, the Ministry for Public Works, Transportation and the Environment (MOPTMA) launched a new study in 1993 to propose national noise legislation [23 and 24]. The principle characteristics of this proposal are the following :

- four sources of noise are defined : industrial activities, means of transport, machines/equipment and recreational and cultural activities.
- four receptive environments are defined :

  - type I = hospital, schools, theatres, parks
  - type II = residential areas, hotels, recreational areas
  - type III = offices, shops, restaurants
  - type IV = industries.

- two types of situations are identified : existing situations - new situations.

- immission limits are expressed in L_{Aeq} in front of the facades (at 1.2 m from the ground and 1.5 m from the facade) for daytime (7.00 a.m. - 10.00 p.m.) and night-time (10.00 p.m. - 7.00 a.m.) periods.

New noise limits in all eight possible cases must not exceed the levels shown in table 17.

Table 17. Noise immission limits set in the 1993 noise law project (LAeq - facade)

Receiver	Existing source Existing receiver		New source Existing receiver		Existing source New receiver		New source New receiver	
	Day	Night	Day	Night	Day	Night	Day	Night
I	60	50	55	45	50	40	50	40
II	65	55	60	50	60	45	55	40
III	70	60	65	60	70	60	65	55
IV	75	75	75	70	75	70	70	65

These limits apply to the whole country and are considered to be minimum requirements. Greater restrictions could be applied in independent regions and by local authorities (using municipal by-laws) insofar as they do not contradict international legislation.

When sources and receptors already exist, the authority responsible should intervene when the thresholds are exceeded. After identification of the source responsible, a delay will be set within which the existing noise level should be reduced to the level of the regulatory limit either by reducing noise at the source or during propagation. If, for technical and economic reasons, it proves impossible to intervene using these means (special situations), buildings will be insulated. In this latter case the objective is to limit indoor noise to the following levels with closed windows :

- 35 dB(A) by day (25 dB(A) by night) in the case of type I receiver
- 45 dB(A) by day (35 dB(A) by night) in the case of type II receiver
- 50 dB(A) by day (40 dB(A) by night) in the case of type III receiver

In the case of a new noise source introduced into an existing environment, the limits to be respected are those shown in table 17, or the existing background noise plus 3 dB(A).

If a new building is erected close to a source of noise and an impact study reveals that noise limits can not be respected for economic or technical reasons, the building should then receive appropriate insulation (special situation).

Finally, the case of totally new situations both in terms of sources and receivers will be integrated into urban land use planning.

In general, local authorities are responsible for ensuring that laws are applied through measurement of noise levels, studies and approvals of building permits, urban zoning, sanctions applied if laws are not obeyed and by the provision of grants (particularly in specific situations) etc. Local authorities would request technical and financial resources from regional and national administrations to enable the foregoing.

1.10. UNITED KINGDOM

1.10.1. General regulatory framework

The recently published Planning Policy Guidance Note [25] sets out recommended noise exposure limits for new residential development near the main existing noise sources which local authorities may apply as appropriate to local circumstances. There are formal regulations for the provision of noise insulation for dwellings affected by increased noise levels from airports and new roads, with similar proposals for new railways.

The land use planning system addresses the problem of noise by, as far as possible, separating noise-sensitive developments from noisy activities or requiring noise mitigation measures to be provided. Noise from existing development, including industrial premises, is controlled through a statutory nuisance regime and is based on the investigation by local authorities of complaints from local residents.

This guidance builds upon the principles established in Circular 10/73 [26], and takes account of the recommendations of the Noise Review Working Party which reported in October 1990 [27].

The planning system is a mix which seeks to :

- prevent excessive noise occurring in the first place, by the application of planning policies and, in certain circumstances, recommended noise limits ;
- compensate those affected by noise from, mainly, new transport sources above certain thresholds ;
- deal with complaints about noise from existing developments as and when they occur.

Particularly, it introduces the concept of noise exposure categories for residential development, encourages their use and recommends appropriate levels for exposure to different existing sources of noise. Table 18 shows the four noise exposure categories (NEC) and the advices to be follow.

Table 18. Noise exposure categories for dwellings

NEC	Advices
A	Noise need not to be considered as a determining factor in granting planning permission, although the noise level at the high end of the category should not be regarded as a desirable level.
B	Noise should be taken into account when determining planning applications and, where appropriate, conditions imposed to ensure an adequate level of protection against noise.
C	Planning permission should not normally be granted. Where it is considered that permission should be given, for example because there are no alternative quieter sites available, conditions should be imposed to ensure a commensurate level of protection against noise.
D	Planning permission should normally be refused.

1.10.2. NEC and noise levels

Table 19 refers to noise levels (L_{Aeq}) corresponding to the noise exposure categories near existing noise sources (road and rail traffic, air traffic, mixed sources).

Table 19. Recommended noise exposure categories for new dwellings near existing noise sources (LAeq - free-field values)

Noise source	Noise exposure category			
	A	B	C	D
road traffic				
07.00 - 23.00	< 55	55 - 63	63 - 72	> 72
23.00 - 07.00	< 45	45 - 57	57 - 66	> 66
rail traffic				
07.00 - 23.00	< 55	55 - 66	66 - 74	> 74
23.00 - 07.00	< 45	45 - 59	59 - 66	> 66
air traffic				
07.00 - 23.00	< 57	57 - 66	66 - 72	> 72
23.00 - 07.00	< 48	48 - 57	57 - 66	> 66
mixed sources				
07.00 - 23.00	< 55	55 - 63	63 - 72	> 72
23.00 - 07.00	< 45	45 - 57	57 - 66	> 66

The level at the boundary of NRC A and NEC B is based on guidance provided by the WHO that general daytime outdoor noise levels of less than 55 dB(A) are desirable to prevent any significant community annoyance. The night-time noise level is based also on the WHO guideline which states that an indoor level of 35 dB(A) is recommended to preserve restorative process of sleep.

The daytime noise levels for all three transport modes at the boundary of NEC B and NEC C are based on the levels that trigger official grant schemes :

- For road traffic noise, the trigger level is 68 dB(A) $L_{10,18h}$ at a facade which finally is converted to 63 dB $L_{Aeq,16h}$ free-field ;
- For railway noise, the proposed trigger level is 68 dB $L_{Aeq,18h}$ at a facade ; this has been converted to 66 dB $L_{Aeq,16h}$ free-field ;
- For air traffic noise, 66 dB(A) $L_{eq,16h}$ previously 50 NNI, was the daytime criterion for noise insulation schemes at Heathrow, Gatwick and Stansted.

The night-time level at the boundary of NEC B and NEC C for road traffic noise is based on the WHO figure of 35 dB(A). Single glazed windows provide insulation of about 25 dB(A) ; therefore, in order to achieve 35 dB(A) inside a bedroom, the facade level should not exceed 60 dB(A) or 57 dB(A) free-field. For rail traffic, the proposed level to trigger the official grant scheme has been adopted : 63 dB $L_{Aeq,6h}$ which has been converted to 59 dB $L_{Aeq,8h}$ free-field. For air traffic, the level proposed to trigger the recent grant scheme at Stansted airport has been adopted : 57 dB(A) L_{eq} contour value.

The daytime noise level at the boundary of NEC C and NEC D for road traffic is based on a survey which has shown that insulation is inadequate for noise levels of 78 dB(A) $L_{10,18h}$ and above at a facade, i.e. equivalent to 72 dB (A) $L_{eq,16h}$ free field which is the maximum external level that the standard noise insulation package will reduce to an acceptable internal level. For railway noise, the level has been set 2 dB higher than the free-field level for road traffic noise. For air traffic noise the value put forward in Circular 10/73 has been used : this is 60 NNI or 72 dB $L_{Aeq,16h}$ including a 2 dB allowance for ground reflection.

The night-time levels are based on the WHO figure of 35 dB(A) and an insulation value of 35 dB(A). Therefore, the free-field level is 66 dB $L_{Aeq,8h}$ for road, rail and aircraft noise.

2. OTHER COUNTRIES

2.1. AUSTRALIA [28]

Most states apply recommendations concerning the exposure of populations to noise. However, there are differences between states, particularly in the limit values adopted.

2.1.1. Road traffic noise

Most states use L_{10} (6.00 a.m. - midnight) as the road noise index. The limit not to be exceeded is often 68 dB(A) as in Great-Britain. But the current trend is to lower this limit to 63 dB(A) for new roads (table 20) and in some states to use L_{Aeq} (New South Wales). If these limits are exceeded, protective measures are implemented (noise barriers - insulation of the buildings etc.).

Table 20. Road traffic noise immission limits

States	Index - period	Limit	Notes
New South Wales	L10 (6am - 12pm)	68 dB(A)	New policy goal is 63 dB(A)
Queensland	L10 (6am - 12pm)	68 dB(A)	Draft policy proposes 63 dB(A) for new roads
South Australia	L10 (6am - 12pm)	68 dB(A)	A lower limit is favoured
Western Australia	L10 (6am - 12pm)	68 dB(A)	A reduction to 60 dB(A) is favoured
Victoria	L10 (6am - 12pm)	68 dB(A)	Draft policy goal is 63 dB(A)
Tasmania	L10 (6am - 12pm)	63 dB(A)	

More specific objectives were presented in 1992 by the services responsible for roads in New South Wales [29] and in Queensland [30] (tables 21 and 22).

Table 21. **Traffic noise level objectives for new road in NSW**

Area	Index - period	Base objective	Lower noise area	Higher noise area
Residential	Leq (24h) Leq (10pm- 6am)	60 dB(A) 55 dB(A)	Ambient * + 12 dB(A) Ambient + 12 dB(A)	Ambient + 3 dB(A) Ambient + 3 dB(A)
Classroom	Leq 1h (indoor level 8.30 am - 3.30 pm)	45 dB(A)	45 dB(A)	Ambient + 3 dB(A)

* prior to road construction

When the initial noise level is low - i.e. lower than the basic objective by at least 12 dB(A) - the limit not to exceed will be the initial noise level + 12 dB(A). If the initial noise level is higher than the basic objective less 3 dB(A), then the limit not to exceed will be equal to the initial noise level + 3 dB(A). The originality of this proposal is that it uses the initial noise environment to calculate the limit not to be exceed.

Table 22. **Interim guidelines to road traffic noise levels in Queensland**

Situation	Index - period	Noise criteria	Measures
New road	L10 (6am - 12pm)	$\geq$ 63 dB(A) and $\Delta \geq$ 3 dB(A)*	obligatory
		< 63 dB(A) and $\Delta \geq$ 10 dB(A)*	obligatory
Modification of road	L10 (6am - 12pm)	$\geq$ 68 dB(A) and $\Delta \geq$ 3 dB(A)	obligatory

* difference between ambient level prior to construction and noise level predicted

The initial situation also applies to variations in noise levels following the creation or extension of roadways. In the case of schools, protective measures are taken when level L_{10} (1 hour) is at least equal to 55 dB(A) and if the variation in noise levels is at least equal to 3 dB(A). In parks and recreational areas, the level above which noise ameliorative measures will be considered is 63 dB(A) in L_{10} (12 hours) and if the variation of noise levels is at least 3 dB(A).

2.1.2. Railway noise

The State of Queensland recently proposed new short-term and long-term levels that must not exceeded when building new railway lines. In 15 to 20 years time, only the long-term levels will apply.

- short-term levels : LAeq (24 hours) $\leq$ 70 dB(A)
  LAmax $\leq$ 95 dB(A)
- long-term levels : LAeq (24 hours) $\leq$ 60 dB(A)
  LAmax $\leq$ 85 dB(A)

2.1.3. *Aircraft noise*

The index used in Australia is the NEF (Noise Exposure Forecast) which approximately corresponds to LAeq (24 hours) - 35. For the construction of new buildings, noise level recommendations exist but are not mandatory (table 23).

Table 23. **Land use compatibility advice**

Land use	**NEF**			
	< 20	20 - 25	25 - 30	> 30
residential	yes	yes	no	no
hotel - public building	yes	yes	*	no
school - church	yes	no	no	no
hospital, theatre	yes	*	no	no
commercial and industrial	yes	yes	yes	*
outdoor recreation	yes	yes	yes	yes

* noise control features in the construction of residences.

2.2. CANADA

The Ministry for the Environment in Ontario applies the following limits to traffic noise :

- outdoor noise : 55 - 60 dB(A) for daytime period 7.00 a.m. - 11 p.m.
- indoor noise : 45 dB(A) in the daytime in living rooms (lounge) ;
  40 dB(A) at night (11.00 p.m. - 7.00 a.m.) in bedrooms.

As most windows are double-glazed due to the rigorous climate, the external noise level is apparently somewhat restrictive. However, the impact of the 8.00 p.m. - 11.00 p.m. period on the 7.00 a.m. - 11 p.m. period has not been established.

Since the 1970s, the Ministry of Transport would only accept complaints about noise in Quebec if L_{10} exceeded 70 dB(A) at the noisiest peak hour.

Since 1990, the Ministry has been using Leq 24 hours ; the noise immission limit has been fixed at 65 dB(A).

2.3. JAPAN

2.3.1. *Environmental noise*

Decisions concerning noise aspects in environmental protection were initiated in 1967 and defined in 1971 [31]. Because the rules were already quite sophisticated and considered periods and zone sensitivity, few modifications have been introduced since that date.

Morning, daytime, evening and night-time periods are : Morning : 5.00 a.m. to 7.00 a.m., Daytime : 7.00 a.m. to 6 p.m., Evening : 6.00 p.m. to 9.00 p.m., Night-time : 9.00 p.m. to 7.00 a.m.. Levels are given in L_{50} dB(A), measured 1m from the facade of dwellings (table 24).

Table 24. **Ambient noise limits in Japan**
(L_{50} - dB(A))

Area	Time of day		
	Day	Morning / Evening	Night
Hospital, convalescent facilities	45	40	35
Primarily residential	50	45	40
Mixed : residential, commercial, industrial	60	55	50
Industrial	65 - 70	60 - 70	55 - 65

2.3.2. *Road traffic noise*

Different values have been adopted for road traffic noise (table 25). They primarily depend on the number of road lanes [32].

Table 25. **Road traffic noise immission limits**
(L50 - dBA)

Area	Number of lane	Maximum noise limit		
		Day	Morning Evening	Night
I - Residential (particularly quiet)	single lane	55	50	45
II - Residential	single lane	60	55	50
I + II	two lanes	70	65	55
I + II	+ two lanes	75	70	60
III et IV - Mixed or industrial	single lane	70	65	60
III et IV	two lanes	75	70	65
III et IV	+ two lanes	80	75	65

If noise levels follow a standard distribution L_{50} is 3 dB lower than Leq. The noise level for a given site is obtained by averaging the values for each period - a complicated method for a statistical index.

2.3.3. *Railway noise*

Noise environment quality standards were prepared in 1975 for the Shinkansen, the Japanese "bullet" train. At the facades of homes, peak noise levels should not exceed :

- 70 dB(A) in residential areas,
- 75 dB(A) in commercial and industrial areas.

These levels are calculated by averaging the mid-point of the highest peak levels during the 6.00 a.m. to midnight period.

When new railway lines are created, protective measures (noise barriers, earthworks and insulation for dwellings) must be taken if these exposure thresholds are exceeded.

In the case of existing lines, the time allowed to clear up black spots is :

- 3 years if average peak levels exceed 80 dB(A)
- 7 to 10 years if average peak levels are between 75 and 80 dB(A)
- 10 years if average peak levels are between 70 and 75 dB(A).

2.3.4. *Aircraft noise*

Standards were prepared in 1973 to protect people living near airports. The index use is the WECPNL. This is calculated from peak noise levels (when they exceed background noise by 10 dB(A)) and the number of aircraft movements in a 24-hour period (with a weighting of 10 for night-time, 3 for the evenings and 1 for daytime movements).

In the case of new airports, exposure limits which must not be exceeded are :

- 70 WECPNL in residential areas,
- 75 WECPNL in other zones.

In the case of existing airports, a lead time of 5 years has been allowed to tackle the noisiest situations (over 80 WECPNL) and reduce them to below 85 WECPNL or 65 WECPNL inside homes. Also within 10 years since the establishment of standards, it is expected to reduce the level to below 75 WECPNL outside or 60 WECPNL inside home. In principle, building is not permitted where noise levels exceed 80 WECPNL.

2.4. NORWAY [33]

2.4.1. *Road traffic noise*

Noise immission limits are applied for land use planning, planning of new buildings, roads and expansion of roads (table 26). Noise limits are given in pairs. Noise shall primarily not exceed the lowest stated levels, but on condition of adequate protection within reasonable costs, noises are allowed to reach the highest pair level.

Table 26. **Road traffic noise immission limits (levels at the facade)**

Location/Situation	LAeq, 24h outdoor	LAeq, 24h indoor	Lmax, night outdoor	Lmax, night indoor
Dwellings	55-60	30-35	70-80	45-55
Health institutions	50-55	25-35	65-75	40-50
Schools	50-55	30-35	-	-
Occupational premises with low noise levels		40-45		

2.4.2. Railway noise

The noise immission limit has been set at 60 dB(A) Leq 24h for new railway lines. Protective measures must be undertaken above this limit. From 1980, some of the existing exposed dwellings with Leq, 24h + 3 dB above 73 dB(A) has been protected by barriers or insulation.

Proposals have been recently (1992) made by the State Pollution Control Authority for planning and intervention purpose (table 27).

Table 27. **Railway noise immission limits (proposals) (levels at a facade)**

Location/Situation	LAeq, 24h outdoor	LAeq, 24h indoor	Lmax, 22-08 outdoor	Lmax, 22-08 indoor
Dwellings (livingrooms)	55	30	80	50
Health institutions (bedrooms)	50	30	75	50
Schools	50	30	75	50
Hotels	55	30	80	50
Holiday homes	55	30	80	50
Recreational areas	55			
Offices		40		

Intervention : along planned and rebuilt lines, existing noise sensitive premises should be offered (to be paid out) if Leq > 65 dB(A) or Lmax > 90 dB(A). If the owner do not accept to be paid out, the premises shall be insulated to a resulting indoor noise of Leq < 35 dB(A), Lmax < 55 dB(A).

2.4.3. Aircraft noise

Guidelines for land use planning in aircraft noise zones are applied since 1994 (table 28).

Table 28. **Aircraft noise immission limits**

Purpose	NEF outdoor	NEF indoor
Suited for most development, except health institutions, churches, schools and holiday houses	55-60	
Suited for supplementing existing dwellings only, on condition of specific insulation	60-65	
Rebuilding only, on condition of specific insulation	65-70	
Unsuited for most developments	> 70	
Dwellings		35
Health institutions		30
Schools		35

2.4.4. Industrial noise

Guidelines for limitations of noise from industry are applied since 1985 for planning, expansion or revision of existing plants purposes (table 29).

Table 29. **Industrial noise immission limits (free-field LAeq, outdoors)**

Area	Daytime LAeq (06-18h)	Evening LAeq (18-22h)	Night-time LAeq (22-06h)
Residential areas and areas with educational premises	50	45	40
Areas for holiday homes, recreation, hospitals	40	35	35

* Momentary sounds should not exceed the limits by more than + 10 dB(A).

2.5. SWEDEN

2.5.1. Legislative framework

Policies to control community noise is normally based on the Environment Protection Act. According to this Act, all activities that might create risks for the environment has to be located so that the purpose of the activity is attainable with the least possible encroachment and detriment, without unreasonable expense.

To further prevent nuisance, all technical feasible actions should be taken. Finally, if the activity is causing substantial detriment even if precautionary measures are taken, the activity may be carried out only on special grounds.

To give more substance to the common paragraphs in the Environment Protection Act, the Swedish Environmental Protection Agency has been given the mandate to publish guidelines concerning noise from different activities covered by the Act. Those guidelines are not mandatory or legal binding. In practice, they however have got a strong influence on the policy used by authorities and courts.

Based in a report concerning a "National Plan of Actions against Noise"[34], the Swedish Government has given different authorities the task to present recommended limit values and to propose actions plan for the noise abatement work in Sweden. The result of those tasks can influence current guidelines described below.

2.5.2. Road traffic noise

A proposed guideline in accordance with the Environment Protection Act has been published by the Swedish Environmental Protection Agency. This applies for planning purposes (table 30). When criteria levels are exceeded, alterations of plans and protective measures within reasonable costs are considered.

Table 30. **Road traffic noise immission limits (free-field values)**

Location/Situation	LAeq, 24h	LAmax (7pm - 7am)
Outdoors*		
At permanent dwellings, care-institutions, educational premises	55	
Recreational parts of built-up areas, including private areas and spaces	55	
At occupational premises	65	
Indoors		
Permanent dwellings and holiday homes, care institutions	30	45
Educational premises	30	
Occupational premises	40	
Areas with low outdoor initial noise level		
Areas for open-air recreation included in the Municipal Master Plan	40	
Purely residential areas with low initial levels	45-50	

For existing situations, several local communities have established plans for noise reduction (barriers, insulation). Intervention level : $L_{eq,24h}$, free-field = 65-70 dB(A) or $L_{eq,\,24h}$, indoor = 40 dB(A).

2.5.3. *Railway noise*

To day no guidelines have been published concerning railway noise. The environmental authorities normally are using the same requirements as for road traffic. The railroad Administration however is using a more lenient standard. This area is one of those covered by tasks referred to under 2.5.1. and the Swedish Environmental Protection Agency shall present proposed guidelines before 1 March 1995.

2.5.4. *Aircraft noise*

Commercial airports have to get a specific permission according to the Environmental Protection Act before they can used. The decisions are based on the circumstances in each individual case. The L_{DEN} (day, evening, night) level as well as the "peak level" is used. For L_{DEN}, the weightings of + 5 dB(A) for evenings (19-22h) and + 10 dB(A) for nights (22-07h) are used. Also this area is covered by tasks given by the government, in this case to the EPA, the Civil Aviation Administration and to the Military Aviation Administration.

2.5.5. *Industrial noise*

Noise guidelines issued by the Environmental Protection Agency for industrial sites for both new and intervention at existing establishments have been used since 1975. These recommendations concern three periods of the overall day (daytime, evening, night-time) and are expressed as an LAeq level that must not be exceeded. Also "peak levels are regulated (table 31).

Table 31. **Industrial noise immission limits (LAeq, peak level, free-field value)**

Area	Day (7am - 6pm)		Evening (6pm - 10pm)		Night (10pm - 7am)		Peak level Night	
	New	Existing	New	Existing	New	Existing	New	Existing
Industrial	60	65	55	60	50	55	-	-
Residential Hospital School	50	55	45	50	40	45	55	55
Outdoor recreational	40	45	35	40	35	40	50	50

Impulsive noises and noise containing perceivable pure tones shall be compared to 5 dB(A) stricter limits.

2.5.6. *Building and construction activity*

At present guidelines are in use to prevent of excessive noise nuisance and promote low noise machinery and methods (table 32).

Table 32. **Building and construction activity noise immission limits (all levels in the front of an open window)**

Area	Daytime LAeq (07-18h)	Evening LAeq (18-22h)	Night-time LAeq* (22-07h)
Industry	75	70	70
Office and similar occup..	70	65	
Noise sensitive premises	60	50	45

* Momentary sounds at night may not exceed the limits by more than + 10 dB(A)

2.6. SWITZERLAND

2.6.1. *Legislative framework*

Policies to control nuisances and particularly noise are based on the environmental protection law dated October 1983 which became effective on the 1st of January 1985. Switzerland thus has a legal framework for fighting every type of pollution.

The Federal Council adopted an ordinance more specific to noise on the 15th of December 1986 [35] which became mandatory in April 1987 [36]. This defines noise immission limits to respect in the case of projected buildings and obliges the Cantons to define noise areas within 5 years after publication of the ordinance and to clear up existing black spots (exposed to noise levels exceeding the limits defined) within a maximum of 15 years (2001) in the case of creation of roadways and railway lines.

The Cantons are responsible for executing these laws (apart from railways which report to the Federal Department of Transportation). The Cantons are empowered to delegate all such responsibilities to the communities.

2.6.2. *Noise immission limits*

Noise abatement is based on respecting immission limits which are the maximum noise levels which can be tolerated (using the most sensitive rooms such as bedrooms with the windows open as benchmark references). Three limit values correspond to three different objectives :

- the immission limit value : this is the reference level ; it must be respected particularly when new buildings are to be built along existing roads and for corrective programme. It is determined from the results of scientific work. It is considered that below this threshold, public well-being and health are not seriously affected. When this limit is exceeded, the buildings concerned must be insulated.

- the planning value : this is applied for planning (new areas) and for the development of new infrastructures. This criterion enables preventive measures to be taken. It is below 5 dB(A) at the immission value. In the case of new roads, noise barriers or earthworks must be erected to protect existing dwellings.

- alarm value : his criterion is used to define noise abatement priorities in extremely noisy streets by determining the urgency of the action. Appropriate measures must be taken immediately if this value is exceeded.

Noise limits also depend on the use of the space, i.e. on the degree of sensitivity to noise of the zone concerned. The 1986 ordinance distinguishes four sensitivity categories :

- I : sensitive zone requiring specific protection - hospitals, schools, convalescent homes, recreational areas ;
- II : residential zones in which no disturbing installations are located ;
- III : residential zones with shops in which moderately disturbing installations are permitted ;
- IV : industrial zones.

Part of the zones in the sensitivity categories I & II can be transferred to a higher category if they are already exposed to noise. Cantons and communities are responsible for allocating sensitivity categories to the different zones in their urban planning. Current noise limit values are shown in table 33.

The noise index retained for most noise sources is daytime L_{Aeq} (6.00 a.m. - 10.00 p.m.) and night-time L_{Aeq} (10.00 p.m. - 6.00 a.m.). The assessment level is $Lr = L_{Aeq} + K$ (corrective term) which is compared to the noise immission values. For road and rail traffic, K depends of the volume of the traffic :

1/ Road traffic :

- $K = -5$	for $N < 31,6$
- $K = 10 \log (N/100)$	for $31,6 \leq N \leq 100$
- $K = 0$	for $N > 100$

N is the average hourly day or night-time traffic volume.

2/ Rail traffic :

- $K = -15$ for $N < 7,9$
- $K = 10 \log (N/250)$ for $7,9 \leq N \leq 79$
- $K = -5$ for $N > 79$

N is the number of trains during day or night period.

In area categories I to III, buildings with rooms used for commercial purposes benefit from a 5 dB(A) tolerance for planning levels and immission levels. In hotels, this tolerance also applies if the ventilation system is adequate with the windows closed. Tolerance is also applied to every type of office, laboratory and shop.

Table 33. **Noise immission limit values in Switzerland (facade - window open)**

Area	Planning value		Immission limit value		Alarm value	
	Day	Night	Day	Night	Day	Night
I	50	40	55	45	65	60
II	55	45	60	50	70	65
III	60	50	65	55	70	65
IV	65	55	70	60	75	70

2.6.3. *Railway noise*

For railway noise, predicted Lr (L_{Aeq} + K) levels are compared with the above exposure limit values taking account of the corrective term. This, for example, is - 5 dB(A) when the rail traffic is greater than 79 trains.

2.6.4. *Aircraft noise*

Regional traffic

For regional aircraft traffic noise, immission limits are the same as those shown in table 33. In the case of regional airports with exclusively helicopter traffic, immission limits are expressed in average Lmax as well as the immission limits given in Lr (L_{Aeq} + K). For example, in the case of residential areas (category II) Lmax immission limit must not exceed 80 dB(A) (85 dB(A) in category III).

Domestic and International traffic

Noise for domestic and international traffic from Geneva and Zurich airports are not included in the 1986 ordinance. For these airports the NNI index is used but studies are currently in hand to examine the possibility of replacing this index by the L_{Aeq}.

2.6.5. *Industrial noise*

The daytime period is considered to be 7.00 a.m. to 7.00 p.m. and the night-time period 7.00 p.m. to 7.00 a.m. Predicted L_{Aeq} levels are compared to exposure noise limits (table 33) and corrected (K) for the type of manufacturing installation and for the audibility of the tonal and impulsive components of the noise at source.

2.7. UNITED STATES OF AMERICA

The Department of Transport (DOT) and the Environmental Protection Agency (EPA) have developed extremely consistent regulations for the USA.

The use of Ldn by the EPA is not always convincing as it weights night-time by 10 dB(A). Ld is the daytime 7.00 a.m. - 10.00 p.m. Leq., Ln is the night-time Leq from 10.00 p.m. - 7.00 a.m. ; this is increased by 10 dB. It should be noted that Ld is typically 65 dB(A) which corresponds to the daytime acceptability level, this gives :

- Ldn = 65 dB(A) if Ln = 55 dB(A)
- Ldn = approximately 63 dB(A) if Ln = 45 dB(A)

This means that Ldn is not very sensitive to the quality of night-time background noise.

The DOT super-highway service works with Leq and L_{10} indices [37]. It defines two types of threshold : the noise interference threshold and the intervention threshold. It also defines three types of zone and outdoor and indoor thresholds for buildings.

The values of Leq and L_{10} represent peak hour values (table 34).

Table 34. **Noise immission limits in the USA**

Type of zone and activity	Index	Interference threshold	Intervention threshold
Park	L10 Leq	48 45	60 57
Leisure area, sport area : dwelling, hotel, school, hospital	L10 Leq	58 55	70 67
Dwelling, hotel, school, hospital	L10 Leq	43* 40*	55* 52*

* indoor

3. SUMMARY

Most European nations possess and apply national regulations or recommendations designed to protect local inhabitants from environmental noise through the use of noise limits.

These regulations appeared initially in Northern European countries during the 70s and 80s (Holland, Germany) and then more recently in Southern European nations (Italy, Spain, Greece). These regulations are increasingly integrated into national noise abatement laws (Holland, Switzerland, Germany, Italy, France ; in project for Spain).

Noise immission limits most often result from a compromise between the effects of noise on the population (disturbance and more particularly the effects of noise on sleep) and the costs of implementing noise protection measures. This compromise, most often decided by governmental authorities, tends to evolve over time insofar as populations are more demanding now than they were in the past (populations have become more sensitive to noise, there is increased social pressure and people are worried about the loss of their "capital of silence"). The costs of protection are now better integrated into projects for new infrastructures.

3.1. Road traffic noise

In many case, regulations basically apply to new roads and major modifications to existing roads in national road networks. Communal roads, which are basically urban roads, are very infrequently concerned by regulations : decisions concerning noise are often taken by local authorities, in this case they have the right to decide to apply regulations concerning the national network or not.

Recently, some countries adopted policies designed to correct critical situations affecting the existing roadway network. But the problems of funding encountered when undertaking this type of action somewhat limits the scope. Increasing fuel taxes to fund these corrective actions - as in Holland and in Switzerland - seems to be a particularly interesting solution for the future.

Most European nations use the L_{Aeq} (equivalent noise level) ; Great Britain is an exception as it uses, for insulation scheme, the L_{10} index (however the Planning Policy Guidance recommends now the use of L_{Aeq}). In fact, in the case of relatively continuous traffic, these two indices correlate extremely well. The mean difference between them is 3 dB(A) (L_{10} - Leq = 3 dB(A)) and so the choice of one or other index is basically made by the way in which the authorities consider their respective benefits and drawbacks :.

- the L_{Aeq} index is easy to calculate from simple data typifying traffic and urban planning (flow rate, speed, percentage of heavy goods vehicles, the distance of dwellings from roads, etc). It does, nevertheless, have the drawback that it is not easy to understand by the local inhabitants and elected representatives when new road projects are presented as they consider that this index is an average and does not handle peak noise levels correctly.
- the characteristics of the L_{10} index are exactly opposite : it is more difficult to use L_{10} to predict noise levels but populations understand it more easily as they perceive that it is more appropriate for peak levels.

However, although U.S. DOT continue to use the L_{10} index, there is a trend to abandon L_{10} and replace it with Leq in a certain number of countries (Great-Britain, Greece, Australia, for example).

Noise immission limits are generally applied to daytime and night-time periods. Some countries use three periods, adding the evening which is an extremely sensitive period for local residents but only slightly different from daytime in terms of exposure to noise. Nordic countries use a single 24-hour period. Definitions of daytime and night-time vary from one country to another. The most commonly used definition for the daytime is 6.00 a.m. to 10.00 p.m. and 10.00 p.m. to 6.00 a.m. for night-time. Provided that the difference between daytime Leq and night-time Leq is relatively significant (approximately over 5 dB(A)) the use of an index for a single period such as the daytime can be admitted given the strong relationship between noise levels during both periods. However, the growth in night-time road traffic observed over the last few years implies the need to differentiate between the reference periods. In fact, night-time noise is no longer systematically related to daytime noise levels. Extremely small differences, two or three dB(A), are often measured on major roads in city centres and close to urban expressways with heavy goods traffic.

Apart from the daytime period, noise immission limits depend on the sensitivity of the zones where they apply : sensitive areas (hospitals, schools ...), residential areas, mixed residential and commercial areas, industrial areas as well as the development phase of the infrastructures and buildings (existing, projected or planned). Differences of 10 to 15 dB(A) are frequently encountered between the noise limits of the areas considered as the most sensitive (hospitals and schools) and the least sensitive areas (industrial zones). The situations are therefore extremely diverse and often difficult to compare. Nevertheless, it can be considered that the 58 to 62 dB(A) limit measured in Leq by day at the facades of buildings and 48 to 55 at night seems, in many countries, to be the basic rule used to consider noise in zones bordering on new roads in residential areas. Differences of 5 to 10 dB(A) are also commonly observed between noise limits for new situations (preventive actions) and existing situations (corrective actions). In addition to noise immission limits some countries such as Switzerland have introduced both a planning value which represents the long-term objective and an alarm value used to define priorities in the implementation of corrective actions. These values are respectively higher or lower than immission limits by 5 dB(A).

3.2. Railway noise

As for road traffic noise, noise limits are applied in many industrialised nations. Their main objective is to protect people living near new lines. In this case, L_{Aeq} is the most common index. However, some countries also use L_{Amax}, particularly for night-times to limit the effects of noise on sleep.

The periods to which these limits generally apply are daytime (6.00 or 7.00 a.m. to 10.00 p.m.), night-time (10.00 p.m. to 6.00 or 7.00 a.m.) and sometimes the evenings (7.00 to 11.00 p.m.). Nordic countries use a single 24 hour period.

Noise limits often depend on the sensitivity of zones affected by noise. When new lines are created in residential areas, noise limits (at the facade) are in the 62 to 69 dB(A) range for daytime, 53 to 62 dB(A) at night and 60 to 63 dB(A) if a 24 hour period is used. Permissible L_{Amax} is generally in the 75 to 85 dB(A) range for night-times (i.e. 50 dB(A) indoors).

3.3. Aircraft noise

The purpose of fixing noise limits for aircraft noise is to ensure that rules are followed when building new dwellings close to existing airports. Generally, these rules specify if construction is permitted or not or if it is necessary to strengthen insulation depending on the zone of the building exposed to noise.

Unlike road noise and rail noise, the noise indices used in regulations relating to aircraft noise are extremely numerous. In fact, two approaches seem to coexist : one uses the LAeq (in Great Britain, Germany and Sweden, for example), the other uses indices which consider both the number of aircraft movements and the peak noise level of each passage (NNI, IP, Ke, NEF, WECPNL, etc) with different weightings for the different periods during the day. In most cases, two periods are used : daytime (6.00 a.m. - 10.00 p.m.) and night-time (10.00 p.m. - 6.00 a.m.).

Given the diversity of the indices used, it is extremely difficult to compare noise immission limits, particularly when noise levels are either expressed in dB(A) or in EPNDB.

3.4. Industrial noise

All industrialised nations apply noise limits when noisy industrial establishments are built. The index used in the LAeq. It applies to both the daytime period (usually 6.00 a.m. - 10.00 p.m.) and the night-time period (10.00 p.m. - 6.00 a.m.) and sometimes the evening period (6.00 p.m. - 10.00 p.m.). Here again, values depend on zone sensitivity ; in the residential zones these are generally 50 to 55 dB(A) by day and 40 to 45 dB(A) by night.

3.5. Conclusion

Analysis of national regulations (or guidelines) highlights favourable elements but also underlines the political, technical, economic and social obstacles to harmonising noise regulations.

In general, most European nations fight noise by defining and then applying regulations which impose noise immission limits which should not be exceeded. This trend will obviously grow in the future. Not all European countries have yet reached the same level of development in applying this environmental noise management policy. The differences observed in applying regulations and particularly noise limits demonstrate the priorities allocated to this objective.

On a technical level, the virtually universal adoption of the L_{Aeq} index both for road and rail noise, is an important element in convergence. Moreover, it should be easy to harmonise measurement procedures because an international standard already exists (ISO 1996/1, 2, 3) for the characterisation and measurement of environmental noises which many European countries have adopted in their national standards. However some noise levels are presented as free-field values whilst others may include an allowance for facade or ground reflection effects.

Exposure periods to which limits apply now tend to distinguish one, two or three periods. There is not yet total convergence on this point in all European countries ; it should not be too difficult harmonise this aspect of the problem if recommendations are limited to qualitative time measurement (daytime, evening and night-time for example).

It is interesting to characterise zones within urban land use by the nature of the majority of the activities in those zones to determine the exposure to noise which should not be exceeded. This approach should become more generalised because taking noise into account as a planning criterion will become an important element in urban planning.

In some European nations the political and administrative organisation grants powers to regions and/or local authorities with a high level of autonomy - often generating a mosaic of regulations. Spain is a very revealing case. Minimum harmonisation of the main clauses of these regulations based on community texts would probably enhance efficacy in adopting measures to fight noise and enable local and regional authorities to adapt these texts to specific situations that they encounter in the field. This quite obviously requires close co-ordination with the different decision levels.

Similarly, differences in climate and lifestyles between Northern European and Southern European countries - such as the high level of night-time activity during the summer, having to leave windows open at night to sleep, the use of outdoor spaces (balconies, gardens, etc) are all factors to consider in the definition of a community policy. These three examples alone underline the lack of interest and even the possibility of making an accurate definition in quantitative terms of noise exposure periods (daytime, evening, night-time) and even of fixing a single limit value for all European nations. A solution would be to recommend a reference limit value for each daytime period and each exposure area while allowing every nation to apply lower values reflecting national sensitivities and economic and financial constraints.

The problem of limiting noise inside homes is also a major topic about which we should think in the future. It is easy to understand a regulation defined both in terms of levels that should not be exceeded outdoors and/or indoors as is the case in Holland. This enables architects to select the means to be used to reach the objectives from a much wider range of options. In Southern European countries it seems of little interest to insulate dwellings because of climatic conditions in summer and consequent lifestyles. Regulations which establish noise levels not to exceed inside buildings would be singularly inappropriate in this type of situation.

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PART 3 : NOISE EXPOSURE AND ANNOYANCE

1. THE SITUATION IN THE 1990s

Most of the recent data was collated by the OECD in 1993 [1] and then completed by several research works and publications [2 and 3]. We currently possess estimations for a certain number of European nations, primarily for road traffic noise. The exposure of populations to noise is usually estimated with a simulation model (in France and Germany, for example) or by national measurement surveys using typical cities (as in France, Spain and Great-Britain). Accuracy and significance of the results varies from one country to another in both cases. It is often difficult to compare results and combine findings as the period concerned (day, night, evening) and the noise indices used are not always the same. Despite these difficulties it is possible to present a global picture for exposure to transportation noise. The number of people disturbed or annoyed by traffic noise is assessed from social survey usually run at the same time as the measurement surveys designed to establish noise exposure levels.

1.1. Germany

For what was previously West Germany [4] relatively complete data are available concerning the exposure of the population to daytime and night-time noise sources (tables 35 and 36). Results are calculated with a mathematical model.

Table 35. **Exposure (%) of the western German population to daytime noise (LAeq 6.00 am-10.00 pm)**

Noise source	Class/dB(A)				
	< 45	45 - 55	55 - 65	65 - 75	> 75
Road	31	35	26	8	-
Railway	59	28	12	1	-
Industry	59	31	9	1	-
Construction sites	64	20	14	2	-

Table 36. **Exposure (%) of the western German population to night-time noise (LAeq 10.00 pm - 6.00 am)**

Noise source	Class/dB(A)				
	< 45	45 - 55	55 - 65	65 - 75	> 75
Road	60	29	9	2	-
Railway	65	24	10	1	-
Industry	95	4	1	-	-
Construction sites	-	-	-	-	-

Less complete assessments have been implemented more recently (table 37).

Table 37. Exposure (%) of the German population to noise (day-time LAeq)

Noise source	Class/dB(A)			
	< 55	55 - 65	65 - 75	> 75
Road	49,9	34,7	14,3	1,1
Railway	81,4	15,4	3,1	0,1
Aircraft	-	-	0,8	0,2
Industry	92,2	6,7	1,1	-

Data for annoyances or disturbances were collated in 1986. They confirm that road traffic noise is a major concern (25% of the population estimate that they are very affected) in comparison with the other main sources of noise : railways (3,9 %), aircraft (16,5 %) and industrial noise (3,2 %).

1.2. Belgium

Very little data are available. Estimates only concern road traffic noise (table 38).

Table 38. Exposure (%) of the Belgian population to road traffic noise (day-time LAeq)

Noise source	Class/dB(A)			
	< 55	55 - 65	65 - 75	> 75
Road	31,2	56,8	12,0	-

1.3. Denmark

Data available only concern noise from different means of transportation (table 39).

Table 39. Exposure (%) of the Danish population to transportation noise (24h Leq)

Noise sources	Class/dB(A)			
	< 55	55 - 65	65 - 75	> 75
Road	79,9	14,2	5,9	-
Railway	-	-	0,6	-
Aircraft	98,3	1,6	0,1	-

Road traffic noise exposure data are based on the situation in 1991.

1.4. Spain

Sound levels were measured by a campaign run in 12 Spanish towns of more than 20 000 inhabitants (600 points) in 1993 [5]. These measurements enabled the exposure of the urban Spanish population to daytime (7.00 am - 10.00 pm) and night-time (10.00 pm - 7.00 am) noise from all sources to be estimated (table 40).

Table 40. **Exposure (%) of the urban Spanish population to noise (all noise sources)**

Time of day	Class/dB(A)			
	< 55	55 - 65	65 - 75	> 75
Day (7.00 am - 10.00 pm Leq)	4,6	38,7	52,6	4,1
Night (10.00 pm- 7.00 am Leq)	28,0	55,3	16,7	-

The mean difference between daytime and night-time levels is approximately 8 dB(A). No significant difference between different urban zones (residential zones, hospitals, schools, commercial areas and industrial areas) has ever been demonstrated. The only significant factor in noise levels is the size of the towns : 2 to 2,5 dB(A) more in large cities (with a population of over 500 000) than in medium sized towns (with a population between 100 000 and 250 000) ; 2 dB(A) less in small towns (with populations of under 50 000) than in medium size towns. The situation in 1993 does not seem significantly different from that observed in 1983 [6].

Unlike Northern European nations, Spain is very exposed to noise. Most noise comes from traffic (83%) : apart from private cars, the loudest noise source is considered to be mopeds and motorcycles as well as heavy goods vehicles, particularly at night. Neighbourhood noises score 12%. This situation is probably due to climatic conditions : the population spends many hours out-of-doors which means that noise lasts late into the night and, as most homes do not have air conditioning systems, people leave their windows open in summer.

1.5. France

At the end of the 1980s, approximately 40 % of the French population declared that it was annoyed by noises in their homes : 13% were very annoyed and 20% slightly annoyed [7]. The main zones concerned were major cities (57 % of people living in Greater Paris said they were annoyed as did 46% in cities with a population of over 100 000), and tenants in blocks of flats (58 % of whom stated they were annoyed). The main causes of annoyance were road traffic (25 %) - and more particularly cars (9 %) -, mopeds and motorcycles (7,5%), heavy goods vehicles (4,5%) - and neighbours (9 %). This means that one person in five is annoyed by road traffic noise. Train noise only affects 1,8% of the French and aircraft noise only 1,7%. Traffic noise affects people living in large towns whereas the noise from mopeds, motorcycles and heavy goods vehicles appears to affect more specifically people living in the countryside, in housing estates, in villages and in isolated dwellings.

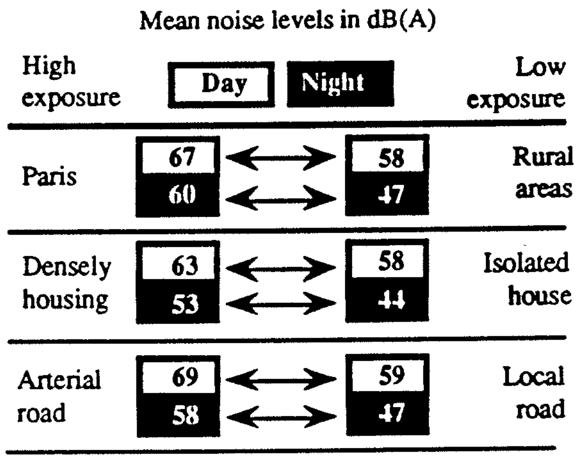
Two estimates are available for land transportation noise : one from a national survey run in 1986 [8] in which 375 noise measurements over 24 hours were implemented using a sample representing the French population as a whole and another calculated by the "Noise 2010" simulation model [9] which addresses exposure of populations to traffic and rail noise. Both methods reach similar conclusions (table 41). Data for aircraft noise are rather more fragmented.

Table 41. **Exposure (%) of the French population to transportation noise (8.00 am - 8.00 pm LAeq)**

	< 55	55 - 65	65 - 75	> 75
1/ Road traffic noise				
- 1986 INRETS survey	43,0	46,0	10,6	0,4
- Noise 2010 model	45,9	40,1	13,5	0,5
2/ Railway traffic noise	98,6	1,0	0,4	
3/ Aircraft noise			0,4	

This overall picture of the French situation hides important geographical differences in where homes are situated (town size, district type and roadways) (figure 3). Mean differences between the zones most exposed and least exposed to traffic noise during the day are a measured 10 dB(A). This difference increases significantly at night to reach 12 dB(A) and more.

Figure 3. **Examples of geographical differences in the exposure of the French population to noise (Leq)**



This overall picture also masks significant social differences : low income groups are proportionately exposed 4 times more by environmental noise than higher income groups.

1.6. United-Kingdom

A recent noise incidence survey (1990) have been carried out on a sample of 1000 people in England and Wales [10].

Results presented concern all noise sources (table 42) but traffic noise is preponderant [11] (table 43).

Table 42. **Exposure (%) of the English and Welsh population to noise (all noise sources)**

Time of day	Class/dB(A)			
	< 55	55 - 65	65 - 75	> 75
Day (7.00 am - 11.00 pm LAeq)	44,4	45,6	9,9	0,1
Night (11.00 p.m. - 7.00 am LAeq)	87,6	11,3	1,1	-

Table 43. **Main noise sources outside dwellings**

Noise source	% of dwellings
Road	66
Railway	1
Aircraft	3
Public works	1
Industry	1
Neighbourhood	17
Others	11

56% of the population are exposed to daytime noise levels exceeding 55 dB(A), which is the threshold recommended by WHO. At night 63% of the population are exposed to noise levels which exceed the WHO recommendation of 45 dB(A). A comparison with an identical noise measurement campaign run in 1972 by the TRRL [12] does not show any significantly favourable progress (a reduction in average noise levels of only 1,4 dB(A)). It should be noted that while traffic volume has increased over this period, the noise generated by vehicles and aircraft has been reduced and that 100 by-passes were built between 1979 and 1990. However, a detailed examination of exposure data reveals an increase in "grey zones" (where noise levels are in the 55 to 65 dB(A) range) and in exposure to night-time noise. The survey run in 1991 with 2373 residents in England and Wales gives the following results for expressed annoyance (table 44).

Table 44. **People (%) affected by noise (% annoyed)** [13]

Road traffic:	28 %	(15%)
Railway traffic :	4 %	(1%)
Air traffic :	16 %	(5%)
Industry :	2 %	
Construction :	3 %	
Neighbours :	22 %	(12%)

In the U.K. the 16 hour Leq daytime aircraft noise index has been correlated with annoyance (as was the previous UK index, NNI), 57 dB(A) correlating with the onset of annoyance [14].

1.7. Greece

Some recent works have been carried out in Greece [15] to improve the knowledge of the exposure of the Greek population to road and aircraft noise.

Concerning road traffic noise, noise maps have been established for 10 main cities : Athens (and the suburban areas), Volos, Thessaloniki, Kavala, Rhodes, Piraeus, Patra, Ionnina, Larissa and Heraklion. Noise measurements were executed in every city centre and along main roads.

Table 45 indicates the results of the acoustic measurements concerning Athens area.

Table 45. **Distribution of the acoustic measurements in the Athens area (%) (Daytime Leq)**

Noise exposure	Athens	Holargos	Papagos
Leq ≥ 78 dB(A)	11,5	7,3	1,6
70 dB(A) ≤ Leq < 78 dB(A)	59,5	29,4	19,4
64 dB(A) ≤ Leq < 70 dB(A)	21,2	23,5	21,2
Leq ≤ 64 dB(A)	7,8	39,8	57,8

Traffic noise maps for other cities were compiled during the period 1988-92. Table 46 shows the main results.

Table 46. **Distribution of the acoustic measurements in selected Greek cities (%) (Daytime Leq)**

Noise exposure	Thessalonik	Volos	Kavala	Rhodes	Piraeus	Patra	Ioannina	Larissa	Heraklion
≥ 78 dB(A)	11,5	7,3	1,6	18,5	29,8	23,0	5,3	13,9	12,0
70 dB(A) - 78 dB(A)	59,5	29,4	19,4	68,5	42,9	48,3	44,7	60,9	66,0
64 dB(A) - 70 dB(A)	21,2	23,5	21,2	13,0	17,0	19,6	40,7	14,6	18,0
≤ 64 dB(A)	7,8	39,8	57,8	-	10,2	9,1	9,3	10,6	4,0

It is worth noting the extremely increased value of the L_1 index (82-84 dB(A) mean value) of numerous cities as well as in the Athens central area which implies the strong concentration of motorcycles and mopeds.

In the greater Athens area (peninsula of Attica) are concentrated 45% of the total Greek population which also corresponds to about 75% of the total urban population of the country. The centre of Athens and the municipality of Piraeus (port of Athens) presents today a total population of some 925.000 habitants (about 20% of the total Attica population).

The acoustic measurements presents a total of 870 different points in the urban road network of the relevant areas. The total of the affected population sample by the traffic noise corresponds to approx. 154.000 people who represents 15% of the total population of those areas and 3% of the population of Attica (estimations based on a 1991 survey).

Data are now available (1993) concerning the affected population in 6 major Greek international airports in tourist areas : Thessalonik, Rhodes, Kerkyra (Corfu), Kos, Limnos and Mykonos. Noise Exposure Forecast (NEF - EPNdB) curves along with real time acoustic measurements were executed in the greater area of every airport, mainly in residential areas. Today, the major part (76 %) of the affected population living next to these airports is exposed to aircraft noise levels of more than 30 NEF (table 47).

Table 47. **Estimated affected population to aircraft noise in 6 major Greek airports (1993 situation)**

Noise exposure (NEF)	Estimated affected population	%
≤ 25	5 278	3.7
25 - 30	29 330	20.3
30 - 40	98 262	68.1
≥ 40	11 376	7.9
Total	144 246	100

1.8. Italy

Noise levels were measured in 49 Italian towns between 1981 and 1988 [16]. Although these measurements do not represent the national situation, results nevertheless give an idea of exposure to noise in Italian towns (table 48).

Table 48. **Results of the noise measurements campaign in Italian towns**

Daytime levels (6.00 am - 10.00 pm)	≥ 55	≥ 60	≥65	≥70	≥75	Mean LAeq
Pop. < 50 000	98,7	93,5	80,5	76,1	35,9	71,5
50 000 - 500 000	99,3	78,6	66,3	54,2	27,6	70,0
Pop. > 500 000	99,6	98,7	92,2	76,1	44,4	73,5
Night-time levels (10.00 pm - 6.00 am)	**≥ 55**	**≥ 60**	**≥65**	**≥70**	**≥75**	**Mean LAeq**
Pop. < 50 000	82,9	74,4	72,1	14,0	9,3	65,0
50 000 - 500 000	85,9	75,2	47,5	9,8	1,7	65,0
Pop. > 500 000	84,5	76,8	57,6	27,0	3,4	65,5

As in Spain, the mean difference between day and night-time levels is approximately 6 to 8 dB(A) which is quite low compared with differences observed in other European countries.

1.9. Netherlands

Data are from the OECD survey [17]. Table 49 shows the impact of aircraft noise, explained by the presence of several international (Schiphol Amsterdam) and national (Rotterdam, Beek, South Limburg) airports and the small surface area of the country (which means that exposure levels are high). However, road traffic noise only concerns a relatively low percentage of the population due to the effectiveness of the noise abatement policy implemented in the Netherlands over the last 15 years.

Table 49. **Exposure (%) of the Dutch population to daytime noise (7.00 am - 7.00 pm LAeq)**

Noise source	Class/dB(A)			
	< 55	55 - 65	65 - 75	> 75
Road	46,2	49,3	4,4	0,1
Railway	94,0	5,4	0,5	0,1
Air	64,0	33,0	3,0	-
Industry	98,7	1,3	-	-

1987 expressed annoyance data confirm noise exposure data, i.e. a high impact of aircraft noise (15 % of the population) vs. road traffic noise (20 %), railway noise (1.5 %) and industrial noise (4.5 %).

1.10. EC countries

It is possible to estimate exposure of Europeans to road, rail and aircraft noise from data collected in the various EC member states. This estimation is relatively reliable for road traffic noise insofar as we have obtained data from 7 countries which represent 71% of the total population of the 12 member states. As data is more limited for other noise sources, the estimates proposed should be treated with caution.

1.10.1 Road traffic noise

Table 50 shows the wide disparity between countries. Southern European countries are much more exposed to road traffic noise than Northern European countries.

Table 50. **Exposure (%) of selected EC member states population to road traffic noise (LAeq)**

Member state	Index - Time of day	< 55	55 - 65	65 - 75	> 75
Germany (Western)	6.00 am - 10.00 pm Leq	49,9	34,7	14,3	1,1
Belgium	Daytime Leq	31,2	56,8	12,0	-
Denmark	24 h Leq	79,9	14,2	5,9	-
Spain *	7.00 am - 10.00 pm Leq	4,6	38,7	52,6	4,1
France	8.00 am - 8.00 pm Leq	45,9	40,1	13,5	0,5
Great-Britain*	7.00 am - 11.00 pm Leq	44,4	45,6	9,9	0,1
Netherlands	7.00 am - 7.00 pm Leq	46,2	49,3	4,4	0,1
Total	Daytime Leq	40,1	40,5	18,3	1,1

* *all noise sources (mainly road traffic noise)*

From the data available for 7 countries, regression can be used to estimate the distribution of daytime road traffic noise levels in Europe (table 51).

Table 51. **Exposure of the EC population to road traffic noise**

Daytime noise exposure	**% of the population**	**Number of people exposed**
< 55 dB(A)	39,6	136 972 000
55 - 60 dB(A)	21,7	75 124 000
60 - 65 dB(A)	19,1	65 893 000
65 - 70 dB(A)	12,8	44 252 000
70 - 75 dB(A)	5,5	18 911 000
> 75 dB(A)	1,3	4 563 000
Total	100,0	345 715 000

Approximately 67 million people (19 %) are located in black zones and over 140 million people (40 %) live in grey zones.

1.10.2 Railway noise

Much less data is available about railway noise. In fact, data has only been obtained from three EC states, i.e. 38% of the total population (table 52).

Table 52. **Exposure (%) of selected EC member states population to railway noise (LAeq)**

Member state	**Index - Time of day**	**< 55**	**55 - 65**	**65 - 75**	**> 75**
Germany (West.)	6.00 am - 10.00 pm Leq	81,4	15,4	3,1	0,1
France	8.00 am - 8.00 pm Leq	98,6	1,0	0,4	-
Netherlands	7.00 am - 7.00 pm Leq	94,0	5,4	0,5	0,1
Total	Daytime Leq	90,2	8,1	1,6	0,07

Extrapolating these results to all EEC member states (table 53) leads to an estimation that approximately 6 million people (1.7 %) are exposed to daytime noise levels exceeding 65 dB(A).

Table 53. **Exposure of the EC population to railway noise**

Daytime noise exposure	**% of the population**	**Number of people exposed**
< 55 dB(A)	90,2	312 008 000
55 - 60 dB(A)	5,2	17 943 000
60 - 65 dB(A)	2,9	9 991 000
65 - 70 dB(A)	1,3	4 425 000
70 - 75 dB(A)	0,3	1 175 000
> 75 dB(A)	0,05	173 000
Total	100	345 715 000

1.10.3 Aircraft noise

Available data only concerns four European countries, - 40% of the total population of Europe (table 54).

Table 54. **Exposure (%) of selected EC member states population to aircraft noise (LAeq)**

Member states	Index - Time of day	65 - 75 dB(A)	> 75 dB(A)
Germany (West.)	Daytime Leq	0,8	0,2
Denmark	Daytime Leq	0,1	-
France	Daytime Leq	0,4	-
Netherlands	Daytime Leq	3,0	-
Total	Daytime Leq	0,85	0,07

Extrapolating data to all European countries leads to the following results (table 55).

Table 55. **Exposure of the EC population to aircraft noise**

Daytime noise exposure	% of the population	Number of people exposed
65 - 70 dB(A)	0,60	2 074 000
70 - 75 dB(A)	0,35	1 210 000
> 75 dB(A)	0,05	173 000
Total	1,00	3 457 000

1.10.4 Transportation noise : exposure and annoyance

Given the lack of data about noise from industrial and construction noise sources, it is only possible to present a global picture for noise arising from means of transport (table 56).

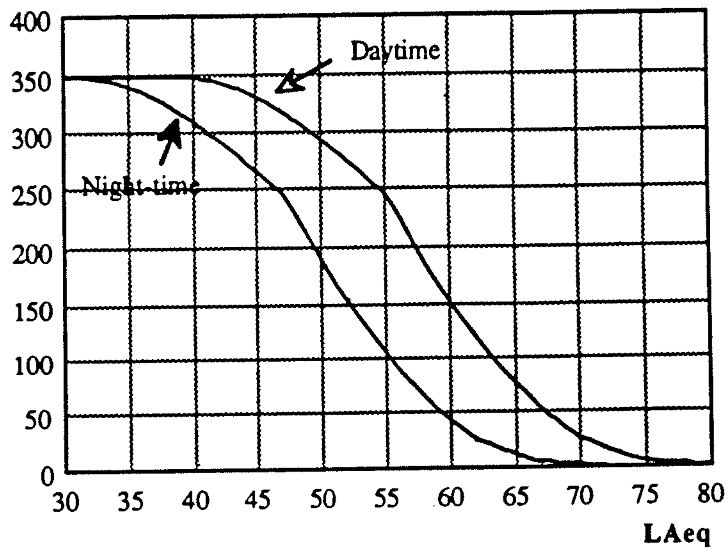
Table 56. **Exposure of the EC population to transportation noise**

Daytime noise exposure	% of the population	Number of people exposed
< 55 dB(A)	28,9	99 808 000
55 - 60 dB(A)	26,9	93 067 000
60 - 65 dB(A)	21,9	75 884 000
65 - 70 dB(A)	14,7	50 751 000
70 - 75 dB(A)	6,2	21 296 000
> 75 dB(A)	1,4	4 909 000
Total	100,0	345 715 000

During daytime, approximately 77 million people in the EEC (22 %) are exposed to transportation noise levels exceeding 65 dB(A) - which many countries consider to be unacceptable (the black zones of the OECD). Almost 170 million Europeans (49 %) live in grey zones, i.e. zones which do not ensure acoustic comfort to residents (figure 4).

Night-time noise exposure has been estimated by subtracting 8 dB(A) to the daytime noise exposure curve (average difference between daytime and night-time noise exposure). More than 100 million Europeans (30 %) are exposed at night to noise levels exceeding 55 dB(A). In these unacceptable situations, sleep is highly disturbed.

Figure 4. **Exposure of the EC population to transportation noise (cumulative distribution - million of people)**



Insufficient data is available for expressed annoyance. National surveys do not always use the same wordings of questions to enable assessment of the way in which noise is perceived (disturbed, annoyed or affected). Table 57 collates comparable data.

Table 57. **People "annoyed" by noise (%)**

Member state	Indicator	Road	Railway	Aircraft	Industry
Germany (1986)	severely affected	25,0	3,9	16,5	3,2
France (1989)	annoyed	21,0	1,8	1,7	
Great - Britain (1991)	annoyed affected	15,0 28,0	1,0 4,0	5,0 16,0	 2,0
Netherlands (1987)	very affected	20,0	1,5	15,0	4,5

Road traffic noise seems to annoy between 20 and 25 % of the population and railway noise between 2 and 4 % (6 to 13 times less). It would not be meaningful to extrapolate this data to all EEC states.

2. FUTURE TRENDS

Examination of the last 15 years does not show any significant improvement in exposure to road traffic noise. In fact, the introduction of noise emission standards for vehicles has only had a relatively limited impact up until now [18]. Consequently, if the total number of people exposed to noise in some countries (Germany, the Netherlands and France) is decreasing, particularly due to the implementation of "black spot" correction policies (Leq > 70 dB(A)), the number of people living in "grey zones" (Leq = 55 to 65 dB(A)) continues to increase.

However, there was a significant improvement in aircraft noise during the 1970s and 1980s. This is basically due to the introduction of stricter noise certification standards (IACO Annex 16, Chapters 2 and 3), but other measures to minimise noise (air traffic control procedures, restrictions on night movements and the use of controlled take-off and landing flight paths to avoid noise sensitive areas) will also have tended to reduce noise exposure. For example, the number of people affected by aircraft noise at Heathrow has declined significantly between 1972 and 1989 when there has been a substantial growth (35 per cent) in air traffic movements (table 58).

Table 58. **Population (thousands) within noise contours (NNI) around Heathrow (1972 - 1989)**

Period	35 NNI	45 NNI	55 NNI
1972	2,092	373	78
1989	562	153	28

The reduction of exposure to railway noise has been associated with the changeover to electrification from previously diesel powered trains, the gradual introduction of welded rails to replace jointed rail and general reductions in railway vehicle noise including the greater use of disc braked rolling stock which compensate for a slight increase in rail traffic.

What is likely to happen over the next 20 years ?

2.1. Road transport

Long-term forecasts available show a high growth in road traffic. In Great Britain, for example, from 1992 to 2025 this increase will be in the 65 to 106 % range for the whole traffic. Growth is higher for goods vehicles than for cars. In France, it is forecast that between 1990 and 2010 road traffic will grow by 34 to 54 % with a more important increase in freight transport (+ 38 to 130 %) than for car traffic (+ 33 to 38 %).

Given these forecasts, and without implementing strengthened noise abatement policy, traffic noise is expected to spread to urban and rural areas which up until now have been spared. It is also expected that noise to be present for longer due to increases in evening and night-time traffic (in particular of goods vehicle traffic). The consequences of the increase of traffic on noise exposure levels should be partially limited by the introduction of more stringent noise emission standards concerning vehicles (EEC Directive 92/97, 1992) during the 1990s.

An evaluation of the impact of this directive is shown in table 59 which indicates trends in the exposure of the French urban population to traffic noise following the introduction of these standards. These results were calculated by simulations [9].

Table 59. **Forecasts of the future exposure of the French urban population to traffic noise**

	1985		2010 Trend		2010 Directive CEE 92/97	
Day Leq	%	Pop. (million)	%	Pop. (million)	%	Pop. (million)
< 55	46,4	17,1	49,5	18,8	53,7	20,3
55 - 65	37,2	13,7	40,2	15,2	38,3	14,6
> 65	16,4	6,0	10,3	3,9	8,0	3,0
Total	100	36,8	100	37,9	100	37,9

Simulations also show that the impact of road traffic noise could be further mitigated through the implementation of local policies such as the creation of by-passes for through traffic, traffic management (urban speed limits, traffic restraints in city-centre, development of low-noise public transport, etc.) and widespread use of low-noise road surfaces and noise barriers. The implementation of such local level approaches in addition to the reduction of vehicle noise emissions would further reduce exposure to noise in urban areas. Table 60 shows the effects for France.

Table 60. **Long term impact of the implementation of noise abatement policies in France**

	2010 - Local policy		2010 - Local policy + Directive CEE 92/97	
Day Leq	%	Pop. (million)	%	Pop. (million)
< 55	60,9	23,1	66,8	25,3
55 - 65	32,8	12,4	29,1	11,0
> 65	6,3	2,4	4,1	1,6
Total	100	37,9	100	37,9

2.2. Rail transport

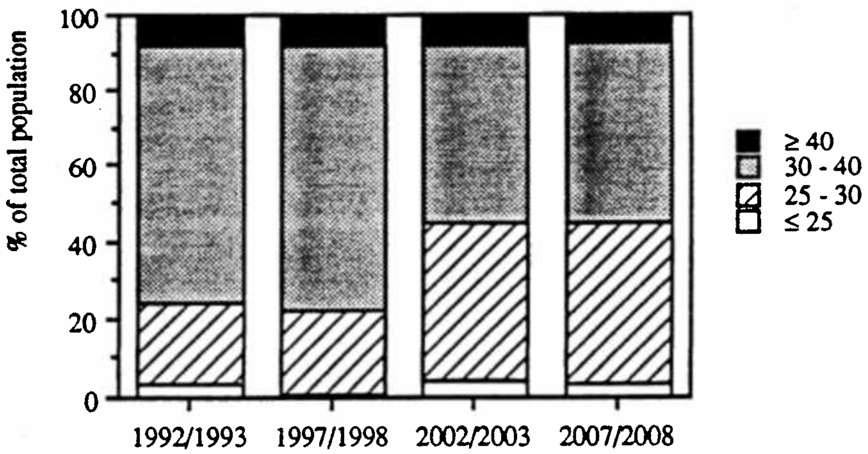
Future exposure of populations to railway noise will probably be directly linked to the development of the European high-speed train network [19 - 20] and also to the use of light rail system in cities and suburbs. This is likely to mean that new zones will become exposed to noise but at relatively acceptable levels insofar as the noise produced by high-speed trains is much better controlled now (probably due to the increasing use of disk brakes) and that noise barriers have been installed in the most exposed sites in a large number of countries. Nevertheless, the foreseeable increase in night-time rail traffic appears today to be the major risk for people living near railway lines. For the moment there are no quantitative data available enabling this question to be addressed.

2.3. Air transport

A substantial growth in air transport is expected in the future. For example in the U.K. a 50 to 80 % increase in the number of passenger movements between 1995 and 2005 is expected. At the same time, between 1995 and 2002, all second generation sub-sonic jets be phased out in Europe, and replaced by aircraft which are typically 8 to 12 dB quieter.

In the long term a reduction in aircraft noise could therefore be expected as indicated in figure 5 which concerns Greek airports.

Figure 5. **Forecasts of affected population by aircraft noise in 6 major Greek airports (NEF)**



However, an increase in general aviation noise, and consequently in noise annoyance, is expected with the growth of corporate and private jets, turboprops and helicopters at regional airports [21].

2.4. Noise problems in the future

Available statistics on the current state and the forecasts of the noise environment, which have serious shortcomings, show that, in the absence of ambitious noise abatement policies, the noise environment risks to remain unsatisfactory or even deteriorate. The deterioration would result primarily from :

- an increase of numerous and powerful sources of noise of which increasing use is made (greater mobility for example) ;
- a wider geographical dispersion of noise sources (urban areas, construction of new highway and railways, spread of leisure activity and tourism etc.) ;
- a spread of noise over time, particularly early in the morning, evenings and nights and weekends.

Therefore, it means first that a better knowledge of our future noise environment is necessary so as to provide policy guidance ; secondly it means that strengthened and co-ordinated noise abatement policies would have very likely to be implemented to improve the quality of the state of the noise environment for which public demands are expected to increase.

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PART 4 : NOISE ABATEMENT MEASURES AND POLICY INSTRUMENTS

The range of sources of noise and possible effects on receivers creates difficulties in developing comprehensive and coherent noise abatement policies. Moreover, there are a number of technical issues which give rise to problems in policy development, implementation and enforcement.

This fourth part gives an overview of the techniques available to reduce the impact of transport noise. It goes on to summarise and discuss the types of policy that may be put in place to encourage these techniques of noise reduction to be put into practice. Future trends in noise abatement policy are discussed.

1. METHODS OF ABATING NOISE IMPACT FROM TRANSPORT

This section deals with three basic approaches to noise abatement :

- noise reduction at the source
- limiting the transmission of noise
- reducing noise at the reception point

1.1. Road traffic noise

a. Reducing vehicle noise at source

Of the three primary transport modes of road, rail and air, road transport produces the most widespread noise intrusion. The noise produced by vehicles running on roads form the components of traffic stream noise. The different components of each vehicle contribute their particular characteristics to the sound ; for example, noises from the engine, exhaust, transmission, cooling fan and tyres all combine to produce the characteristic noise from that vehicle. The noise of vehicles at different distances from the observer and travelling at different speeds, including changes in pitch according to whether the vehicles are approaching or receding, combine to produce the familiar sound of moving traffic. At low road speeds and correspondingly high engine speeds, the mechanical noises predominate while at higher speeds and lower engine speed and power, the tyre-road interaction noise becomes important. Thus in order to reduce noise from a traffic stream at source, it is necessary to make individual vehicles quieter.

The sources and control of vehicle noise have been described in a lot of documents [1 - 2 - 3]. Cars are the quietest vehicles in the traffic stream and heavy goods vehicles are the noisiest both in permitted levels and their actual noise in service. Small motorcycles in urban conditions are often as noisy as medium goods vehicles but this is usually due to the vehicle having a defective exhaust system or being fitted with an inadequate replacement silencer. Noise level reductions to cars have been achieved over the years by refinements to the engine and to the exhaust silencer and the current (1994) 84/424/EEC drive-by noise limit of 77 dB(A) has been attained without encapsulation of the engine. The new EC Directive 92/97/EEC limit for cars of 74 dB(A) (due in 1995/96) may well require manufacturers to employ some form of engine shielding. In view of the difficulty in quietening heavy goods vehicles, over the last eighteen years many countries have set up research and development programmes to quieten this class of vehicle and to help the vehicle manufacturing industry meet the EC levels of 84/424/EEC (84 dB(A) for the heaviest and most powerful vehicles) and those coming into force under 92/97/EEC (80 dB(A)).

The focus of these programmes of noise reduction was on the use of one or more of the following methods : (i) quietening the engine and transmission, (ii) improving the silencers on the exhaust and air intake, (iii) quietening the cooling system by reducing fan noise, (iv) shielding the top and sides of the engine with additional noise absorbing panels, (v) enclosing the engine, cooling fan and gearbox in a noise absorbing tunnel, open at the front and back for the passage of cooling air and (vi) encapsulating the engine and gearbox in a sealed noise-insulating box with a remote cooling system (an approach often used for buses with rear mounted engines. These techniques have been successful in reducing vehicle noise over the years. For example by 1995 the drive-by noise of a heavy goods vehicle will have been reduced from 92 to 80 dB(A) in a twenty five year period; that is, quieter than a passenger car was in 1970, and a reduction equivalent to removing over 90% of the acoustic energy emitted by the vehicle. The equivalent reduction in passenger car noise (drive-by test) by 1995 will have been about 6 dB(A).

The increases in production and operating costs for quieter vehicles varies with the type of vehicle and the degree of quietening but typical costs are ; passenger car quietened to 77 dB(A), 1-4 % increase in production costs and 3 % in operating costs ; goods vehicle under 3.5 t and under 75 kW engine power quietened to 83 dB(A), 4 % increase in production costs and 0.8 % in operating costs ; heaviest goods vehicle quietened to 83 dB(A), 5-10 % increase in production costs and 1.3-1.6 % in operating costs [3 - 4].

With the reduction in mechanical noise sources from vehicles the noise from tyres rolling on the road surface has become the dominant source over a wide range of vehicle speeds. This is well known in the case of cars travelling at speeds above about 60 km/h. With commercial vehicles, the engine and transmission still contribute a significant proportion of low frequency noise, even when cruising at high speeds. The solution to this problem is likely to be reached by two routes, limited redesign of tyres, bearing in mind possible safety implications, and the development and use of quieter road surfaces with good high speed skidding resistance.

These porous road surfaces reduce both the generation and propagation of vehicle noise by a range of mechanisms which can be related to the open structure of the surface layer. Various laboratories [5 - 6] have examined the mechanisms of noise reduction for vehicles running on porous road surfaces. Results have shown that vehicle noise levels can be reduced from levels generated on equivalent non-porous road surfaces by between 3 to 5 dB(A) on average, although by optimising the surface design larger noise reductions are feasible. When used on urban high speed roads porous road surfaces can complement or replace noise barriers to reduce the traffic noise levels at residential properties. At present the cost of porous asphalt surfacing is higher than conventional surfaces, but this may fall as road contractors gain experience with laying the surface. The material is also less durable. However, improvements are being made to durability and, in many countries, these materials are being used as part of normal road construction in noise sensitive areas.

b. Limiting the transmission of traffic noise

The propagation of traffic noise is influenced by a number of factors including the attenuation due to distance, the interaction of the propagating wave with the ground surface, the screening provided by buildings and noise barriers, the effect of vegetation, and, for long distance propagation, the effect of varying weather conditions.

Thus, wherever possible new roads should be located away from residential areas, or when that is not feasible, screened by locating in cutting or tunnel, or provided with wall or earth bank noise barriers. Noise barriers have been used for many years alongside major roads to screen residential areas from high levels of traffic noise. With new roads which have to be located near existing centres of population, noise barriers can be an effective method of reducing noise at the facade of houses.

The acoustic performance of traffic noise barriers has been reviewed by Watts [7]. The amount of sound energy reaching the observer from the traffic is chiefly dependent on the path difference between the direct sound from source to receiver and that grazing the top of the barrier, although sound absorption by the ground surface can affect the actual efficiency of the barrier. To be efficient the barrier should largely prevent the direct transmission of acoustic energy. In practical situations this will occur if the sound energy that leaks through the barrier is more than 10 dB below the energy that is diffracted over the top of the barrier and round its edges.

Barriers do not attenuate sounds of different frequencies to the same degree and are relatively less efficient at reducing the low frequency components of traffic noise. To avoid reflections from the barrier surfaces which can lead to increased noise levels due to reverberation between barriers on both sides of the road, absorbent treatments to the surface have proved effective and many designs of barrier include sound absorbing materials.

It is a common misunderstanding that roadside hedges and thin bands of shrubs act as a barrier to noise. These will rarely provide a sufficiently dense screen to make a noticeable difference. However, measurements in natural woodland close to the roadside have indicated that noise is attenuated more quickly than in open country. For example an excess attenuation of up to 6 dB(A) through a 30 metre depth of dense coniferous plantation, and 5 dB(A) through a 10 metre depth have been observed [8]. A thick layer of leaf mould or pine needles helps to increase the absorbency of the ground. This helps to reduce low frequency sound and the densely interwoven leafy structure of trees and shrubs has some effect on high frequency sounds. Unfortunately, the important mid-frequencies are not screened so effectively. However, there are more substantial forms of vegetative barrier in which a wall of earth is contained by some form of lattice structure which allows low, spreading species of plant to be used. These constructions generally require a good deal of attention, including irrigation because the raised soil mass cannot retain water for long.

c. *Reducing the impact of traffic noise at the receiver*

The principal method of reducing the noise nuisance where people live and work is by noise insulation of buildings, that is, the provision of secondary glazing. Attenuation up to 42 dB(A) can be achieved with double-windows. Typically the cost of noise insulation in the UK is £1500 to £2000 per house.

1.2. Railway noise

a. *Reducing railway noise at source*

Wayside noise from trains is generated by the interaction of the wheels and rails, the locomotive propulsion system and by radiation from vibrating structures such as steel bridges. The noise is affected by the speed and length of individual trains. Aerodynamic noise may also be important for high-speed operation (speed over 350 km/h).

The diesel locomotive represents an array of noise sources. When the diesel engine is on a high power setting it will often be the dominant noise source. Usually this will be mainly exhaust noise, but engine cylinder block and crankcase vibration radiating either directly or via the locomotive structure will also contribute. Attempts to quieten these sources have to cope with severe restrictions on the space available - i.e. imposed by limits on the external dimensions of the locomotive.

Other noise sources associated with the cooling system fans are amenable to modern design techniques. Compressors and exhausters, associated with the train services and braking system, usually only become important sources when engine noise has been reduced. In the context of overall train noise, the diesel locomotive is likely to be the dominant source on slow freight trains because of predominantly low speeds and high power settings. On passenger trains above about 100 km/h, the locomotive noise is of the same order as wheel/rail noise for traditional iron block-braked rolling stock. With modern disc-braked stock, the diesel locomotive on power is the dominant source up to the highest speeds likely to be operated by diesel traction.

Compared with the diesel locomotive, the electric locomotive is very much quieter as it carries no prime mover on board and derives its power from a third rail or overhead catenary. However there are problems of noise from the fans required to cool the electrical control equipment, the traction motors and the compressors.

Reduction of wheel/rail noise has been achieved by controlling the roughness of both the wheel and the rail. The use of disc brakes minimises the formation of corrugations on both the rail and the wheel. Flange squeal is the piercing resonant response of wheels as they negotiate sharp curves and this source of train noise has been successfully treated by the damping of the wheels.

There is no specific information on the costs of quietening railway vehicles probably because the improvements occur during the normal development by the manufacturers. In the UK, British Rail require manufacturers to meet certain noise specifications for new rolling stock based on their experience as operators and their measurements of railway noise but there are no noise limit values imposed on manufacturers similar to type approval limits that road vehicle makers have to meet. However, the requirements of passenger comfort have resulted in rolling stock that has much reduced internal noise levels and as a consequence lower external noise.

b. *Limiting the transmission of railway noise*

Railway noise differs from that produced by road traffic in the way the noise is distributed over time. Road traffic noise usually has a fairly uniform sound level interspersed with frequent peaks generated by individual vehicles, whereas railway noise is usually characterised by relatively short periods of noise followed by longer periods of quiet, when the noise returns to the local ambient levels.

The remedies available for reducing the propagation of train noise include the use of trackside barriers, screens on bridges and rail isolation. The former method has been used in the USA and Japan while in Europe, Germany and the Netherlands have fairly stringent noise design goals for both new and existing or altered railways which involve the use of barriers or other forms of screening.

c. *Reducing the impact of railway noise at the receiver*

As with road traffic a solution to the problem of noise immission to houses from rail noise sources is the provision of noise insulation. In the UK, a committee set up to establish a national noise insulation standard for new railway lines, recommended "that those responsible for new railway lines should take all reasonably practical steps to reduce noise in the corridor along the line. The steps considered should include quietening the locomotives, rolling stock and permanent way at source, track maintenance, lowering the level of the track to shield it by the surrounding terrain and installing noise barriers. Insulation of dwellings against noise should be considered when the noise level near the line cannot be reduced to a defined level by other means" [9]. Levels of railway noise for which noise insulation grants would become available were also recommended. Since the publication of the report work has been done on developing a calculation method for railway noise equivalent to that used for traffic noise. Also draft amendments to the Noise Insulation Regulations have been issued. Those responsible for new railway lines would have a duty to offer insulation or to pay a grant for rooms of dwellings exposed to a noise level of at least 68 dB(A) $L_{Aeq,\ 18hr}$ during the day (0600-midnight) and to 63 dB(A) $L_{Aeq,\ 6hr}$ at night.

1.3. Aircraft noise

a. Reducing aircraft noise at source

Although fewer people are disturbed by aircraft noise than road traffic noise, the degree of disturbance is greater to those who do suffer it. With aircraft the reduction of noise at source includes not just the design of quieter aircraft but also the way they are operated, that is, take-off and landing controls, movement on the ground and height restrictions.

Noise from commercial jet aircraft has been reduced over the years by the introduction of quieter engines of the high by-pass ratio turbo-fan type [10].

In Europe the EC's Directive 80/51/EEC prevented the addition of civil subsonic aircraft to the registers of Member States unless they met at least the standards set out in Chapter 2 of Volume 1 of Annex 16 to the Convention on International Civil Aviation 1944 ("the Chicago Convention") and required the removal of such aircraft from the registers by 31 December 1986. With effect from 1 January 1988, amendment (83/206/EEC) banned the operation within the Community of civil jets which failed to meet Chapter 2 standards even when they were registered in countries outside the Community. From 1 November 1990, Directive 89/629/EEC prevented the addition to the registers of Member States of civil subsonic jets, being either of a maximum total weight authorised of more than 34 tonnes or having a passenger capacity of more than 19 unless they met at least the noise standards of Chapter 3 of Volume 1 to the Annex. Under the terms of Directive 92/14/EEC (as amended) from 1 April 1995, the use within the European Economic Area (EEA) of similar civil jets which meet only the standards of Chapter 2 will be banned if such aircraft are more than 25 years old. Between 1 April 1995 and 31 March 2002, individual Chapter 2 aircraft will be phased out as they reach the age of 25 years. From 1 April 2002, only aircraft of this type which meet at least the standards of Chapter 3 will be allowed to operate in the EEA.

b. Limiting the transmission of aircraft noise

The main methods of restricting the propagation of noise from aircraft when in flight consist of air controls such as curfews, landing and take-off restrictions, special procedures and specification of noise-minimising flight paths.

Night flights at major airports have been restricted for many years and a quota system is usually operated where aircraft types are allocated night movements according to their noise class.

c. Reducing the impact of aircraft noise at the receiver

In the UK, owners of designated airports are directed by the Secretary of State to operate noise insulation grant schemes for dwellings around airfields that have experienced increases in noise. It is the intention that the sections of the Civil Aviation Act 1982 which at present give the Secretary of State these powers, will be repealed and the day to day responsibility for noise control given to the airport operators who will be accountable to the local community [11].

2. NOISE ABATEMENT POLICIES

Many different types of policy are available to cause or encourage the use of the above noise abatement techniques. They are not easy to classify because they vary along several inter-related dimensions :

- Whose decisions or behaviour does the policy seek to influence (Public authorities, manufacturers, users, developers, people exposed to noise) ;
- Type of influencing mechanism and degree of compulsion (regulation, persuasion, incentive) ;
- Type of noise change being sought (emission, immission) ;
- Source of funds (government, polluter).

Nevertheless, policies will be classified as follows :

- Regulations and standards
- Planning and decision-making procedures
- Economic policies
- Education and information
- Voluntary agreements

2.1. Regulations and standards

In a sense the most straightforward type of noise abatement policy is for governments to specify emission and/or immission standards, build them into planning or Type-Approval procedures, and enforce them.

One potential disadvantage of this approach is the tendency to set a lowest common denominator standard - i.e. one achievable by or acceptable to the least able or willing participant. This is particularly so with internationally co-ordinated standards and can hold back progress in noise abatement. However, as reported by OECD [12], Switzerland has shown that it is possible to adopt more stringent emissions standards than other OECD countries without major difficulties. Countries can also use economic incentives or other noise abatement policies if they wish to adopt more effective noise abatement than would be produced by the standards alone.

It is crucial that standards are effectively monitored and enforced. However, few countries have effective in-service testing of noise emissions for road vehicles (Australia for example), or monitor compliance of aircraft with noise-reducing flight procedures.

a. Road traffic

Road traffic noise abatement policies implemented throughout the 80's were based on three main concepts : reducing the source of noise by new restrictions on the noise emissions of motorised vehicles, the protection of people living close to new roads or in new housing developments exposed to high noise levels and the correction of particularly critical noise "black spots".

Type approval for road transport vehicles is a well established policy for ensuring that new vehicles are, at the time of manufacture, complying with noise limits laid down by EC Directives.

Progress in maximum noise emission levels, notably by the application of European directives has been slow for the overall vehicle fleet apart from buses for which a low noise vehicle demand was stipulated in the mid-70's by some local authorities. The current directive is 84/424/EEC and this will be amended by 92/97/EEC in the mid 1990's. The type approval test (ISO R 362) is a low speed full acceleration type test and has always sought to limit the noise produced in a typical urban traffic situation. This has inevitably focused attention on mechanical noise rather than tyre noise. As limit values have fallen (table 61) and the manufacturers have responded by reducing mechanical noise, tyre/road surface noise has become more significant during the type approval test. The point may soon be reached where tyre noise could restrict any further lowering of limits in the future.

Table 61. **EEC noise emission limits for selected vehicle categories**

Vehicle category	1972	1982	1988/1990	1995/1996
Passenger car	82 dB(A)	80 dB(A)	77 dB(A)	74 dB(A)
Urban bus	89 dB(A)	82 dB(A)	80 dB(A)	78 dB(A)
Heavy truck	91 dB(A)	88 dB(A)	84 dB(A)	80 dB(A)

The impact of the regulations on the overall levels of noise emitted by road traffic depends on several factors, on significantly on the percentage of heavy goods vehicles in the traffic flow. Gains expected in urban traffic conditions (i.e. where drive line noise is the major factor) were estimated to be 2 to 3 dB(A). However, as road traffic increased, effective gains were only approximately 1.5 dB(A) [13 - 14].

No particular problems are involved in respecting new noise level regulations in force since 1988/1990. Many new cars registered in the 80's (approximately 40 %) were already in conformity with the 1988 values before the regulations became applicable. This is also the case for buses, the current noise levels of which are generally lower than permitted maxima.

For the future, the European Parliament, having considered the new noise directive, suggested several amendments, the most notable being considerable reductions in the drive-by noise limit values, e.g. 74 to 71 dB(A) for cars ; 80 to 78 dB(A) for heavy goods vehicles. These are generally considered to be ultimately achievable but in the timescale suggested are likely to force the manufacturers to increase the use of acoustic shields which would increase the capital and maintenance costs. A longer time scale would allow the manufacturers to develop more permanent and longer lasting solutions.

This regulatory trend raises the problem of tyre/ road noise which is now becoming one of the major problem and will be even more so in the coming decade [15]. This will require the establishment of an international action plan. The new Directive places a commitment upon the European Commission to present a proposal to the Council of Ministers to deal with the noise generated by the interaction of the tyre and the road surface. In addition to the new noise limits the Directive will introduce a manufacturing (conformity of production, CoP) tolerance of 1 dB(A), introduce a limit value and test procedure for the noise from air brake systems, and will lay down a uniform standard for the test track surface.

Finally, to strengthen the effectiveness of these measures, it will be necessary to integrate noise emission tests into technical tests carried out on vehicles.

As described in § 1.1, road traffic noise can also be reduced by using roadside noise barriers and quieter road surfaces. Both of these measures can be regarded as complementary to reducing vehicle noise. In many countries policies to achieve these aims are embodied in laws or guidelines (noise exposure limits) : to fight road noise both state and private sector property developers and promoters are obliged to reinforce the insulation of the facades of new buildings and/or to set noise barriers along noisy new roads. Where appropriate the use of porous road surfaces is encouraged.

At the same time as protective measures related to new roadways and buildings were implemented, some countries, including Holland, France, Germany and Switzerland, have started to take remedial action (mainly noise barriers and insulation of the facades) on noise black spots (i.e. with Leq exceeding 65 or 70 dB(A)). However, given the financial resources allocated to these programmes, some countries will take anything up to 50 years to absorb the backlog of work involved !

b. Railways

Most railway operators set their own limits for the pass-by noise from locomotives and rolling stock that manufacturers have to meet, and these do not seem to cause excessive technical or financial problems. Provided the railway operators continue to reduce pass-by noise from new trains, then type approval regulations to limit the maximum level from train sets as is done for road vehicles and aircraft ought not to be needed. However, for the future, a CEN working group is at present discussing the development of a type approval system for rail vehicles for use within the EC.

A lot of European countries have set noise standards for new railways, which have to be achieved by the design of the railway or the use of barriers and screens. If the standards cannot be met then additional insulation has to be fitted to the affected properties.

In the USA the noise generated by trains is subject to a range of controls as a result of design guidelines and performance criteria. The Federal Railroad Administration has established noise measurement standards and emission criteria to cover a wide range of main line rail vehicles. In addition, most mainline and transit authorities have procurement specifications which limit both the interior and exterior noise produced by the vehicle. This form of noise control is seen as a means of encouraging patronage of the system.

c. Aircraft

Noise standards for all types of aircraft, except microlights, at the International Civil Aviation Organisation (ICAO) - a UN body - and are published in Volume 1 of Annex 16 to the Convention on International Civil Aviation 1944. The standards relating to civil subsonic jets are contained in Chapters 2 and 3 of Volume 1 where the more stringent standards of Chapter 3 are applied to those aircrafts for which the prototypes received their certificates of airworthiness on or after 1 October 1977. In the countries of the European Economic Area (EEA), the standards agreed at ICAO are used by the national regulatory bodies in framing domestic noise controls. These may be enhanced as the international standards are revised.

2.2. Planning and decision-making procedures

a. Planning

Planning procedures can be seen as a way of putting noise abatement regulations - particularly immission regulations - into practice. Effective *transport planning* can reduce noise impact by moving traffic from residential areas, encouraging less noise polluting forms of transport, and optimising freight distribution. *Land use planning* can reduce the need for transport, separate noise generators from noise receivers, and encourage developments to be designed in a way to minimise noise impacts.

In particular, noise abatement via land use planning can include :

- Restricting the use of land that is already subject to high levels of noise. Permissible land use can be related to both a preferred and a maximum permissible noise level. Special attention to acoustic design may be required for sensitive developments in high noise zones. This could involve clustered housing situated away from roads and protected by noise-insensitive buildings, and/or noise insulation.

- Restricting the siting of new noise generators such as roads, railways and airports in order to protect existing developments.

- Encouraging noise-generating activities to cluster together, so as to preserve areas of relatively low noise elsewhere.

In many countries noise immission standards for new development near existing routes are normally set by local authorities as part of planning policy and serve as a means of ensuring that the building developer takes appropriate measures to minimise the noise impact at a site. When the prescribed noise levels are exceeded, the developer may be required to improve the noise insulation or the design of the buildings or, for conditions where an acceptable noise environment cannot be achieved, the authority may refuse planning permission altogether.

In the UK, new airport developments are subject to planning permission under the Town and Country Planning Act 1990. However, airports which have established use operate without planning controls and increasing use do not require planning permission. Permanent helicopter landing sites require planning permission, although temporary use of land for up to 28 days per year is permitted under the General Development Order 1988. Where private aerodromes are established by individuals and companies, normal planning procedures will apply. Planning permission may include conditions to secure the abatement of noise and local authorities bye-laws may also be used to restrict operations so as to limit or mitigate the effect of noise. The operating authority of the aerodrome may also make such bye-laws. OECD [12] reports that enforcement of urban development restrictions near airports has proved difficult in most countries.

b. Decision making : Environmental appraisal as a noise abatement policy

Government and other bodies have to make many decisions affecting the environment. They include formulating transport policies, environmental policies and standards, and promoting or arbitrating road, air and rail projects. If they are to make good decisions, such bodies need to know the environmental consequences of the various options open to them. Establishing procedures and techniques for identifying and assessing noise impacts can therefore be seen as a noise abatement policy itself. Once such procedures are in place, developers and promoters have an incentive to design their projects in such a way as to satisfy the decision making authority.

Many environmental appraisal methods have been proposed or are in use [16]. They range from simple descriptive techniques to grand index methods that seek to combine impacts to produce a single index of environmental performance or even to allow environmental impacts to be expressed in money units and considered in the project cost-benefit analysis. Intermediate techniques use a formal and detailed analytical phase but do not attempt to produce grand index, instead leaving the decision, with its associated value judgements, to the decision maker. For trunk road appraisal in England and Wales, the Department of Transport currently uses an intermediate type of appraisal framework. Depending on the stage of planning that has been reached, this requires the effects of the scheme on the noise exposure of housing to be predicted, and shows how this can be interpreted in terms of effects on nuisance experienced by residents.

EC directive 85/337/EEC (CEC, 1985) requires an environmental assessment of certain types of project to be made before development consent is given. The projects covered include motorways and express roads, airports, and long-distance railways. Developers must provide an environmental statement describing the project and its environmental effects, and measures designed to mitigate adverse effects. The public are given the opportunity to comment, and the decision-making authority is required to take into account the information gathered and comments received. A five-year review of the implementation of this Directive was published in 1993 (CEC 1993).

2.3. Economic Instruments

Economic measures form an important type of noise abatement policy. They include economic incentives to encourage noise abatement, special taxes and charges to raise funds for noise abatement, and the payment of compensation to people who are affected by noise impacts. Table 62 summarises types of economic measure available to noise abatement policy-makers.

2.3.1 Taxes and Charges

Imposing taxes or charges on a polluter can be an incentive to reduce emissions and/or a way of raising funds for use in environmental protection. In principle, charges can be set to persuade polluters to comply with a pre-set standard. If the charges are equal to the true social cost of the pollution, polluters will, given certain assumptions, adjust their level of pollution to the socially optimal level.

Theoretically it is cheaper to reach a given overall level of pollution by means of charges than it is by regulatory standards alone. Standards are inefficient because all polluters have to comply, irrespective of cost. Charges allow the necessary overall reductions in pollution to be achieved mainly by those polluters who can reduce their emissions most cheaply. Charges are best used in combination with direct controls such as regulatory standards which reflect international obligations [17].

Despite their advantages, noise charges are not widely used (except in the field of aircraft noise). This seems to be partly because of lack of confidence in their effectiveness, and because they tend to be opposed by groups who stand to loose by them. There are also fears about transition costs, and concerns about the difficulty in deciding on the level of charges. The latter concern is largely misplaced if the objective is to reduce noise rather than to achieve a theoretically optimal level of pollution.

Whether charges do act as an effective incentive depends on the level of charge in comparison with other operating costs, and the feasibility of penalising only noisy activities. Charges have so far generally been set too low to act as an incentive to reduce noise. Their main function has been to raise funds for noise control measures such as insulation of buildings.

a. Landing charges for aircraft

Charges can be made for all aircraft (they are used to generate income for the airport) but particularly for noisy types of aircraft, or noisy aircraft movements (e.g. takeoff patterns that expose local residents to high levels of noise). Noise-related charges can in principle act as an incentive to use quiet aircraft or procedures, whereas charging all aircraft or all passengers is a direct incentive to reduce noise only via a reduction in aircraft movements.

Table 62. **Economic instruments in noise abatement**

Instrument	Objective	Comments
Taxes and charges	**Incentive to:**	
Landing charges for all or noisy aircraft Refunds of charges for quiet aircraft or road vehicles	Reduce emissions (if charge depends on emission level)	Compared to standards alone, charges in theory are a low-cost method of achieving a given level of noise pollution. Noise charges are not widely used in field of environmental protection because of: - lack of political confidence, - difficulty in choosing the optimum tax level,
Taxes on noisy vehicles Fuel taxes	Reduce the impact of each noisy vehicle by restricting speed and/or distance travelled (fuel tax)	- possibility that the polluter may be taxed for optimal or sub optimal pollution, - fears about compatibility with legal system, - fears about transition costs.
	Promote use of more fuel-efficient vehicles (may tend to be quieter) (fuel tax)	Existing noise charges tend to be too low to have much incentive effect, and are used instead to raise funds for noise abatement.
		Charges may be used to encourage a market for quieter vehicles, thus complementing other economic noise abatement policies such as R&D subsidies.
Road pricing	Reduce congestion, with concomitant effects on the environment (road pricing)	Strict definition of road pricing is to charge road user for the full marginal costs of trips as they affect other road users, but can include other external costs including noise.
	Change to a less environmentally damaging mode of transport	Road pricing can redistribute traffic onto other roads and increase or reduce environmental impacts.
	Fund raising for noise abatement.	
Tradeable permits so far mainly used for air pollution from static sources. Vehicle noise emission certificates(tradeable)	**Incentive** to reduce noise i.e. polluter can reduce permit costs by reducing emissions and selling permits or not buying them in the first place.	Advocated as a way of overcoming lack of political faith in efficacy of emissions charges. Advantages : - Minimises total cost of pollution abatement - Authorities can vary standards by buying and selling permits - Groups could buy-up permits to reduce pollution (but governments could just issue more). - Avoids difficulties of choosing a noise charge that will achieve desired standards because actual standard is set by the issuer of permits, not by the unpredictable influence of a given charge on the behaviour of polluters.
Financial aid R&D funding	Assist and encourage **development of low noise vehicles** ;	Subsidies can risk increasing the total level of pollution by increasing total number of vehicles or amount of travel.. They are widely used in environmental protection because, unlike charges, they seldom adversely affect any interest group.
Subsidised purchase of quiet vehicles	Encourage purchasing of quiet vehicles thereby **creating a market** for them ;	
	Demonstrate feasibility of reducing emission limits.	
Reductions of taxes affecting quiet hardware or modes of operation	Subsidise a **less environmentally harmful mode of transport**	

Table 62 (continued). **Economic instruments in noise abatement**

Measure	Objectives	Comments
Compensation		
- for house price depreciation	Reducing or removing the **financial impact** of noise on individuals	Methods of determining the correct amounts of compensation for welfare loss problematical.
- for loss of social welfare	Counteracting effects of noise on welfare. Providing incentive to the payer of compensation to reduce noise impacts instead.	Removes incentive for people to move away, install insulation, etc. Not desirable as a noise abatement policy on its own.

Landing charges are or have been used in several countries. Of the six countries reviewed by OECD [12], France, Japan, the Netherlands and Switzerland had charges. Germany has a system of landing charge refunds for quiet aircraft. In UK, a Working Party [18] recommended that consideration should be given to imposing a noise levy on passengers or airlines in order to provide funds for noise control measures and insulation in areas around airports. But the UK government has indicated that it is not minded to accept this as airports already pay for such measures to ameliorate noise. Major UK airports also have an element within their charging structure which favours modern quieter aircraft at the expense of older, noisier type.

b. *Fuel taxes*

Fuel taxes are an incentive to reduce noise in as much as they reduce distance travelled. Fuel taxes may also be used to encourage the use of 'quieter' fuels - e.g. petrol as opposed to diesel. Fuel taxes will also encourage the use of more fuel-efficient vehicles. These will tend to be newer and better maintained, and hence quieter. A fuel tax may also tend to encourage operators to favour smaller vehicles, though the noise effects of this are not straightforward to predict. Fuel taxes will also tend to encourage fuel-efficient driving styles - which will tend to be quieter. In addition, the funds raised by fuel taxes can be used for noise abatement and/or compensation payments.

Fuel taxes have been used as part of noise abatement policy by the Netherlands and by Switzerland. Until 1988 a fuel tax was levied to fund the Netherlands' noise abatement programme. It penalised diesel fuel more than petrol. In 1988 it was replaced by a general tax on fuel. The position of both fuel and vehicle tax in Britain is discussed below.

c. *Taxes on noisy vehicles*

Possibilities for taxing noisy vehicles include :

- A tax on new vehicles, dependent on their noise category (which may depend on noise emission and type of use/average annual mileage).
- An annual tax dependent on noise category. Such a tax may be used in conjunction with in-service checks that a vehicle is still within its designated noise category (this would also open the possibility of operators being able to reduce their annual tax by fitting noise suppression equipment).

- A charge on noisy vehicles when they are used in an environmentally sensitive area. This could be achieved by selling permits to operate inside the designated area, the price of the permit depending on the noise category of the vehicle.

Noise taxes paid by manufacturers have the advantage of encouraging them to produce quieter vehicles. However, if users pay, they have an incentive to reduce noise by maintaining the vehicle, fitting better noise suppression equipment, and using the vehicle less (assuming that the taxes are made dependent on in-service noise and distance travelled). OECD [12] reported that taxes on noisy vehicles had been discussed in member countries, but had not been implemented.

In Britain, vehicle and fuel taxes for individual types of vehicle are not calculated to reflect the external costs such as noise associated with each vehicle type. Though vehicle taxes do depend on `track costs' (i.e. road wear) associated with each category of vehicle. However the rates are set to ensure that the overall tax yield does cover the cost to the Government of environmental protection measures such as provision of noise barriers and insulation where these are required by law. In fact the tax yield exceeds the costs as currently calculated. The excess is a sumptuary tax (i.e. not earmarked for specific uses) but is sometimes said to cover, at least in part, the external costs of environmental impacts such as noise.

The British Government has recently indicated that it would like to include both capital and environmental costs in vehicle taxation. Differential vehicle excise duty based on fuel consumption, noise emission or air pollution are possibilities here. Many difficulties and uncertainties remain as to how the charges might be calculated. For example, vehicles with the highest noise emissions (heavy lorries) tend to be used on inter-urban routes away from housing, though this may be compensated for by their higher annual mileage.

d. Road pricing

Strictly, road pricing is the charging of road users for the full marginal cost of trips as they affect other road users. This will tend to optimise the use of the road network and may lead to both increases and decreases in noise nuisance. However, there is no reason in principle why the costs included in road pricing should not be broadened to include externalities such as noise costs, which should be a further incentive to reduce noise on the routes where prices are introduced.

Road pricing is implemented in Singapore since 1975 and in some Scandinavian cities (Oslo, Trondheim) since 1988 [19]. It have been discussed in the Netherlands where the charge is being related to vehicle size and weight, and thus indirectly to noise nuisance. In Britain, there is considerable government interest in road pricing though research and debate continue on what costs it should cover and the method of collection. A system involving a combination of electronic pricing in urban areas (Cambridge for example) and fuel duty as a way of covering other roads seems a possibility.

2.3.2 Tradeable permits

Tradeable permits to pollute are an attempt to combine the advantages of regulations and charges. They avoid the need to decide what level of charge will be sufficient to achieve a desired standard. Authorities decide on a required pollution standard, and issue permits that allow pollution only up to that standard. Polluters who wish to produce more pollution can only do so if they can purchase sufficient permits from polluters who are willing to reduce their own pollution. Tradeable permits to pollute therefore act as an incentive because polluters who reduce their level of pollution can sell permits. Also polluters with low levels of pollution do not have to buy so many permits in the first place. Other advantages are summarised in Table 62.

Although permits have been used mainly in the control of air pollution from static sources in the USA, a possible application in noise abatement was suggested by W. Rothengatter [20]. Vehicle manufacturers would have to purchase a noise emission certificate for each vehicle they built, the price depending on the vehicle's noise category. Owners who later modified their vehicles to reduce noise would benefit by being able to sell their certificate and buy a cheaper one. It is also possible to envisage a system that allows manufacturers to trade permits to produce vehicles of different noise categories.

2.3.3 Financial aid

One noise abatement policy is to pay polluters to reduce their level of pollution to a socially optimal level - the "Pigouvian subsidy". Setting a subsidy to achieve this optimal level of pollution requires a knowledge of the true social costs of the pollution, and there are complications in that subsidies can actually increase total pollution by increasing the number of polluters (e.g. number of vehicles). Choosing subsidies that will achieve pre-defined (though non-optimal) levels of pollution is also problematical.

Financial aid has an important practical advantage over other economic measures : it seldom has direct adverse effects on any interest group and is therefore easier to introduce. For this reason, financial aid has been widely used in environmental protection, despite its shortcomings. An example of financial aid is government funding for the development of quieter vehicles. This can be seen as encouraging manufacturers to undertake research and development that they would not otherwise do, or as demonstrating the feasibility of producing quiet vehicles as part of a case for imposing new and tighter emission regulations.

Government sponsored research on quieter vehicles has been carried out in many European countries and in the USA [4]. For example the QHV90 Project in the UK helped manufacturers meet the 84/424/EEC noise limits which came into force in 1989. The cost of the research was shared equally between government and industry and produced techniques and expertise which is proving of value in developing vehicles to meet future legislation requiring reductions in vehicle noise levels.

Assuming that quieter vehicles tend to be more expensive, further steps need to be taken to encourage a market for them. These can be the introduction of tighter emission regulations, but economic measures such as charges on noisier vehicles could also be used. A further possibility is another type of financial aid - namely subsidies for the purchase of quieter vehicles. For example, voluntary agreements between vehicle manufacturers and operators can lead to tax concessions for the use of vehicles quieter than those conforming to EC directives. In 1981 in the Netherlands [21] operators of heavy goods vehicles are offered a two tier subsidy if they purchase and use vehicles fitted with 'hush kits' which result in specified lower noise levels. Subsidy levels were 7.5% and 5% for noise reductions of 6 dB(A) and 3 dB(A) respectively. The costs of the quietening measures are borne by the operators. In 1988 because of reduced availability of funds, only heavy vehicles (over 12 tonnes) with drive-by noise levels of 79 dB(A) or less were eligible, receiving a maximum subsidy of 4.5%. Similar schemes are operated in Germany. Although of limited scope, this type of initiative is likely to become more widespread in the future [22].

A further form of financial aid is the subsidising of a less environmentally damaging form of transport. In economic terms this is inefficient because subsidies cannot be tailored to just cause each individual to switch modes. Other problems include low cross-elasticities between modes and latent demand for road use. These are discussed by K. Button [23]. Nevertheless, many European countries do have a policy of subsidising public transport for environmental reasons.

2.3.4 Compensation

Instead of being paid as financial aid to polluters to encourage them to reduce pollution, money