



Noise and its Abatement

Module 5c

Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities

OVERVIEW OF THE SOURCEBOOK

Sustainable Transport:

A Sourcebook for Policy-Makers in Developing Cities

What is the Sourcebook?

This *Sourcebook* on Sustainable Urban Transport addresses the key areas of a sustainable transport policy framework for a developing city. The *Sourcebook* consists of more than 31 modules mentioned on the following pages. It is also complemented by a series of training documents and other material available from <http://www.sutp.org> (and <http://www.sutp.cn> for Chinese users).

Who is it for?

The *Sourcebook* is intended for policy-makers in developing cities, and their advisors. This target audience is reflected in the content, which provides policy tools appropriate for application in a range of developing cities. The academic sector (e.g. universities) has also benefited from this material.

How is it supposed to be used?

The *Sourcebook* can be used in a number of ways. If printed, it should be kept in one location, and the different modules provided to officials involved in urban transport. The *Sourcebook* can be easily adapted to fit a formal short course training event, or can serve as a guide for developing a curriculum or other training program in the area of urban transport. GIZ has and is still further elaborating training packages for selected modules, all available since October 2004 from <http://www.sutp.org> or <http://www.sutp.cn>.

What are some of the key features?

The key features of the *Sourcebook* include:

- A practical orientation, focusing on best practices in planning and regulation and, where possible, successful experiences in developing cities.
- Contributors are leading experts in their fields.
- An attractive and easy-to-read, colour layout.
- Non-technical language (to the extent possible), with technical terms explained.
- Updates via the Internet.

How do I get a copy?

Electronic versions (pdf) of the modules are available at <http://www.sutp.org> or <http://www.sutp.cn>. Due to the updating of all modules print versions of the English language edition are no longer available. A print version of the first 20 modules in Chinese language is sold throughout China by Communication Press and a compilation of selected modules is being sold by McMillan, India, in South Asia. Any questions regarding the use of the modules can be directed to sutp@sutp.org or transport@giz.de.

Comments or feedback?

We would welcome any of your comments or suggestions, on any aspect of the *Sourcebook*, by e-mail to sutp@sutp.org and transport@giz.de, or by surface mail to:

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Further modules and resources

Further modules are under preparation in the areas of *Energy Efficiency for Urban Transport* and *Public Transport Integration*.

Additional resources are being developed, and Urban Transport Photo CD-ROMs and DVD are available (some photos have been uploaded in <http://www.sutp.org> – photo section). You will also find relevant links, bibliographical references and more than 400 documents and presentations under <http://www.sutp.org>, (<http://www.sutp.cn> for Chinese users).

Modules and contributors

- (i) *Sourcebook Overview and Cross-cutting Issues of Urban Transport* (GTZ)

Institutional and policy orientation

- 1a. *The Role of Transport in Urban Development Policy* (Enrique Peñalosa)
1b. *Urban Transport Institutions* (Richard Meakin)
1c. *Private Sector Participation in Urban Transport Infrastructure Provision* (Christopher Zегras, MIT)
1d. *Economic Instruments* (Manfred Breithaupt, GTZ)
1e. *Raising Public Awareness about Sustainable Urban Transport* (Karl Fjellstrom, Carlos F. Pardo, GTZ)
1f. *Financing Sustainable Urban Transport* (Ko Sakamoto, TRL)
1g. *Urban Freight in Developing Cities* (Bernhard O. Herzog)

Land use planning and demand management

- 2a. *Land Use Planning and Urban Transport* (Rudolf Petersen, Wuppertal Institute)
2b. *Mobility Management* (Todd Litman, VTPI)
2c. *Parking Management: A Contribution Towards Liveable Cities* (Tom Rye)

Transit, walking and cycling

- 3a. *Mass Transit Options* (Lloyd Wright, ITDP; Karl Fjellstrom, GTZ)
3b. *Bus Rapid Transit* (Lloyd Wright, ITDP)
3c. *Bus Regulation & Planning* (Richard Meakin)
3d. *Preserving and Expanding the Role of Non-motorised Transport* (Walter Hook, ITDP)
3e. *Car-Free Development* (Lloyd Wright, ITDP)

Vehicles and fuels

- 4a. *Cleaner Fuels and Vehicle Technologies* (Michael Walsh; Reinhard Kolke, Umweltbundesamt – UBA)
4b. *Inspection & Maintenance and Roadworthiness* (Reinhard Kolke, UBA)
4c. *Two- and Three-Wheelers* (Jitendra Shah, World Bank; N.V. Iyer, Bajaj Auto)
4d. *Natural Gas Vehicles* (MVV InnoTec)
4e. *Intelligent Transport Systems* (Phil Sayeg, TRA; Phil Charles, University of Queensland)
4f. *EcoDriving* (VTL; Manfred Breithaupt, Oliver Eberz, GTZ)

Environmental and health impacts

- 5a. *Air Quality Management* (Dietrich Schwela, World Health Organization)
5b. *Urban Road Safety* (Jacqueline Lacroix, DVR; David Silcock, GRSP)
5c. *Noise and its Abatement* (Michael Jaecker-Cueppers, Civic Exchange Hong Kong; GTZ; UBA)
5d. *The CDM in the Transport Sector* (Jürg M. Grütter)
5e. *Transport and Climate Change* (Holger Dalkmann; Charlotte Brannigan, C4S)
5f. *Adapting Urban Transport to Climate Change* (Urda Eichhorst, Wuppertal Institute)
5g. *Urban Transport and Health* (Carlos Dora, Jamie Hosking, Pierpaolo Mudu, Elaine Ruth Fletcher)

Resources

6. *Resources for Policy-makers* (GTZ)

Social and cross-cutting issues on urban transport

- 7a. *Gender and Urban Transport: Smart and Affordable* (Mika Kunieda; Aimée Gauthier)

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Module 5c

Urban Transport and Health

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1. Introduction

Noise has always been an important environmental problem. In ancient Rome, rules existed as to the noise emitted from the ironed wheels of wagons which battered the stones on the pavement, causing disruption of sleep and annoyance to the citizenry. In Medieval Europe, horse carriages and horse-back riding were not allowed during night time in certain cities to ensure peaceful sleep for inhabitants. However, the noise problems of the past are incomparable with those of modern society. An immense number of cars, motorcycles, trucks and other motorised vehicles criss-crosses developing cities, day and night. In comparison to other pollutants, the control of environmental noise has been hampered by insufficient knowledge of its effects on humans and of dose-response relationships as well as a lack of defined criteria. While it has been suggested that noise pollution is primarily a "luxury" problem for developed countries, exposure to noise is often higher in developing countries, due to higher densities, and poor planning and construction. The effects of the noise are just as widespread and the long term consequences for health are the same. In this perspective, practical action to limit and control the exposure to environmental noise are essential (WHO, 2002).

Noise pollution in large developing cities is an insidious issue. In such noisy cities, many people seem to have become accustomed to the higher noise levels that underpin their daily activities. Yet in a city such as Hong Kong, for example, noise is the most common cause of complaints. Of the 23 678 environmental complaints received by the Hong Kong Environmental Protection Department (EPD) in 2010, 29% were noise related (http://www.epd.gov.hk/epd/english/laws_regulations/enforcement/pollution_complaints_statistics.html). The Hong Kong Institute of Acoustics carried out a noise survey to assess the degree of noise pollution suffered by the public (see <http://www.hkioa.org>). From the roughly 100 responses, the most serious source of noise pollution was seen to be construction noise, followed by traffic noise. These

Box 1: Noise in developing cities: Is it a problem?

There is a widespread view that noise from transport is currently not a critical issue for developing cities, especially compared to other environmental issues such as air pollution. This view is exemplified in the World Bank *Urban Transport Strategy Review* (<http://www.world-bank.org/transport>, 2001), which states that:

Noise from transport appears to be considered much less seriously in developing countries than in high income countries. While there have been studies of the physical damage resulting from exposure to occupational noise these have been mostly in manufacturing establishments. The levels experienced in the streets of developing countries, while not pleasant, approach but do not exceed the lower limits above which noise is considered an occupational hazard.

Evidence from dense Asian cities such as Hong Kong or Bangkok, however, suggests that noise, even if currently not a high priority issue in developing cities, will in coming years increasingly represent an important public health issue in rapidly motorising, dense developing cities.

sources most commonly affected private study, although personal emotional states and classes were also disrupted, through loss of concentration, annoyance and frustration, and anxiety and stress.

Though it receives a large number of complaints from citizens, few consider noise to be a serious health hazard. However, noise has not only been linked to many serious health risks, such as hypertension and heart disease, but also to a deteriorating quality of life, by interfering with speech, performance, and ultimately, productivity. In many large developing cities, those who have not been physiologically damaged by noise may nevertheless have been mentally affected by it. Recently citizens in developing countries start to organize initiatives against noise. One example is "Quiet Bangkok" which fights against noise pollution in Bangkok (see <http://www.quietbangkok.org/index.en.html>)

2. Aspects of noise

Noise is unwanted and impairing sound. Sound has a range of different physical characteristics, but only becomes noise when it has an undesirable and detrimental physiological or psychological effect on people (see Section 4). Environmental noise refers to noise that can affect our surroundings, and includes construction noise, machinery noise, transportation noise, as well as domestic noise.

Sound is created when vibrations in the air move particles in a wave-like pattern that are perceived by the ear. The pressure waves are then converted into ionic and electric events by sensory cells in the cochlea, creating nerve impulses that are interpreted by the brain as sound.

2.1 Describing sound

Sound may be described in terms of amplitude, frequency, and time pattern. Amplitude, perceived as loudness, is the fundamental measure of sound pressure used in most measurements of environmental noise. The sound pressure levels are measured in decibels (dB), and the range is

distributed on a logarithmic scale. Thus sharply painful sounds, which are 10 million times greater in sound pressure than the least audible sound, are in decibels simplified logarithmically to a manageable range for comparison.

Frequency, perceived as pitch, is determined by the rate at which sound makes the air vibrate. Time pattern refers to a sound's pattern of time and level, which can be continuous, intermittent, fluctuating, or impulsive. Continuous sound is a constant level of sound for a relatively long period, such as the sound of a waterfall, whereas intermittent sound is sound produced for short periods, such as the ringing of a telephone. Fluctuating sound varies in level over time, such as the loudness of traffic sounds in a busy intersection, and impulsive sound is sound produced in an extremely short span of time, such as a pistol shot (US EPA, 1979).

Noise measurement units

It is common international practice to determine noise in terms of levels which are expressed as a logarithmic function L of the sound pressure and adapted to the sensitivity of the human ear.

Environmental sound is typically measured by four descriptors which are used to determine the impact of environmental noise on public health and welfare. These are: the A-weighted Sound Level L_{Ap} , A-weighted Sound Exposure Level SEL, Equivalent Sound Level L_{eq} , and weighted Sound Levels for the whole day (day-night L_{dn} , day-evening-night L_{den}). The A-weighted sound level (dB(A)) is the most common measure of expressing noise (compare box 'sound level measurements').

A conversation in a quiet living room would register at 60 dB(A), average road traffic 25 m away from a busy primary road would register at 70 dB(A), and a diesel freight train at 25 m would register at around 80 dB.

Box 4 gives the noise levels recommended for specific environments (dwellings, schools and pre-schools, and hospitals), though it should be noted that few places in many large developing cities achieve the recommended level.

To get an impression of dB(A) values, Table 1 provides a list of sound levels from typical situations, and Figure 1 provides a graphic scale of transport-oriented sound levels.

Table 1: Typical sound levels encountered in daily life and industry

Activity	Sound level (dB(A))
Desert	10
Rustling leaves	20
Room in a quiet dwelling at midnight	32
Soft whispers at 5 feet	34
Men's clothing department of large store	53
Window air conditioner	55
Conversational speech	60
Household department of large store	62
Busy restaurant	65
Vacuum cleaner in private residence (at 10 feet)	69
Ringing alarm clock (at 2 feet)	80
Loudly reproduced orchestral music in large room	82
Prolonged exposure – beginning of hearing damage	85
Lorry or motorbike close by	90
Rock concert, loud disco	100
Pneumatic drill	110
Jet aircraft take-off	130
Gunshots, explosions	140

Tam 2000

Due to the logarithmic scale, a 3 dB(A) increase in sound levels represents a doubling in noise. However, since the measurement of noise and the perception of noise do not always coincide, a doubling of sound intensity projected by the scientific scale with a 3 dB(A) increase may only be perceived by humans after a 10 dB(A) increase (Tam, 2000). The loudness of sounds (namely, how loud they seem to humans) varies from person to person, so no precise definition of loudness is possible. However, the FHWA (1992) notes that based on many tests, a sound level of 70 is twice as loud to the listener as a level of 60. This principle is illustrated in Figure 2.

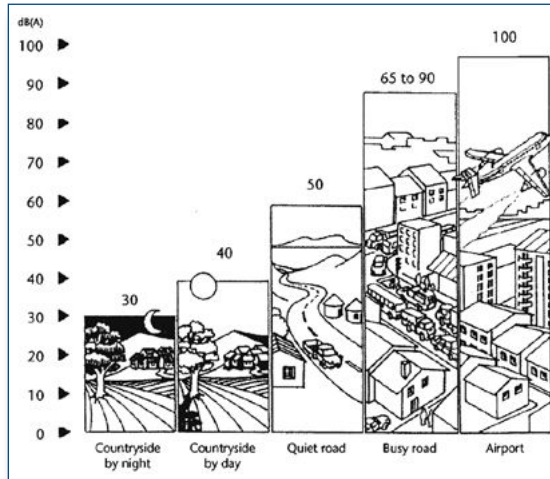


Fig. 1
Scale of sound levels.
World Bank, 1997

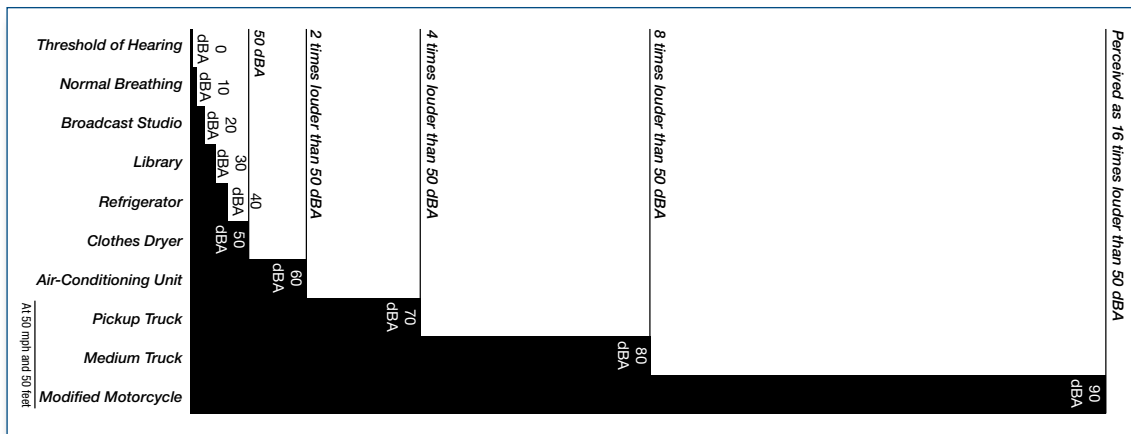


Fig. 2
The principle of doubling noise.
FHWA, 1992

Figure 3 shows the noise transmitted or propagated from a mobile emitting source to a receptor. The emissions of a source and consequently the reception levels are usually not constant. For moving sources such as road traffic noise, the noise level is constantly changing with the number, type, and speed of the vehicles which produce the noise.

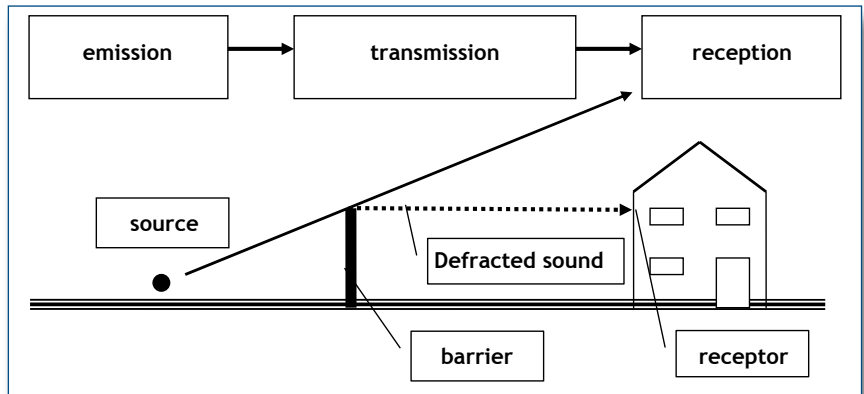


Fig. 3
Emission, transmission and reception of noise.

The equivalent acoustic level (L_{eq}) is the sound level of a stable noise which contains the same energy as a variable noise over the same period. It represents the mean of the acoustic energy perceived during the period of observation. The equivalent acoustic level of noise during the period 8:00–20:00 is written as L_{eq} (8:00–20:00) or $L_{eq}(12\text{ h})$.

$L_{10}(12\text{ h})$ is an alternate measure, indicating the noise level exceeded 10% of the time over a twelve-hour period. For the 18-hour period 6:00 to 24:00, $L_{10}(18\text{ h})$ is typically 3 dB(A) higher than L_{eq} for the same period.

Nocturnal noise levels are generally lower than during the day. For example, the nocturnal L_{eq} (12:00–6:00) is typically 10 dB below the L_{eq} (8:00–20:00), except in the case of especially high nocturnal traffic with a high percentage of heavy goods vehicles or freight wagons.

The equivalent acoustic level L_{eq} in front of (outside) a building facade facing the traffic determines the building's exposure to noise. This is the most commonly used indicator of the

discomfort caused to the building occupants (World Bank, 1997). For sleeping disturbances the maximum indoor level $L_{A,max}$ is another important indicator. $L_{A,max}$ is also relevant for single event levels that may cause hearing impairments.

Forecasting noise levels

It is common practice to calculate noise reception levels, for various reasons:

- A prognosis of future noise situations is only possible on the basis of calculations;
- Measurements are influenced by random factors such as meteorological conditions and source characteristics, making it costly to get representative results.

Forecasting methods include equations, computer modelling and physical models, though equations which estimate noise based on traffic flow, composition and speed are simplest. The applied calculation schemes are based on emission and propagation assumptions which are normally gained by measurements.

Examples of computer noise models in use are the FHWA *Highway Traffic Noise Prediction Model* (FHWA-RD-77-108), and the *Traffic Noise Model 2.5* (TNM), which is operational since 2004 (see http://www.fhwa.dot.gov/environment/fhwa_tnm.htm for more

Box 2: Sound level measurements

The A-weighted sound level measures sound on a scale that closely mirrors the way it is heard by people, by giving more weight to the frequencies that people hear more easily, within 1–6 kHz.

A-weighted Sound Exposure Level (L_{Σ}) measures the total energy of sound by summing the intensity during the exposure duration, accounting for the variation in sound levels from moving sources such as airplanes, trains, or trucks, in order to measure environmental noise. A-weighted Equivalent Sound Level (L_{Aeq}) is used to measure average environmental noise levels to which people are exposed. It expresses a single value of sound level for any projected duration, including all of the time-varying sound energy in the measurement period, and is used when the duration and levels of sound, and not their occurrence (day/night), are relevant. When the occurrence of sound is relevant, such as in residential areas, the Day-Night Sound Level (L_{dn}) is used. This A-weighted equivalent sound level covers a 24-hour period with an extra 10 dB weighting added on the equivalent sound levels occurring during night-time hours (22:00–7:00).

information). In the European Union the development of common assessments methods (“CNOSSOS”) which shall replace the various national prediction schemes is planned for 2012 (see http://circa.europa.eu/Public/irc/env/noisedir/library?l=/material_mapping/cnossos-eu&vm=detailed&sb=Title).

2.2 Characterising noise levels

Traffic noise variations can be plotted on a graph as shown in Figure 4. However, it is usually inconvenient and cumbersome to represent traffic noise in this manner. A more practical method is to convert the noise data to a single representative number. Statistical descriptors are almost always used as a single number to describe varying traffic noise levels. As mentioned above, the three most common descriptors used for traffic noise are L_{10} , L_{eq} and $L_{A,max}$. L_{10} is the sound level that is exceeded 10% of the time.

In Figure 4 the shaded areas represent the amount of time that the L_{10} value is exceeded. Adding each interval during which this occurred shows that during the 60-minute measuring period the L_{10} was exceeded 6 minutes ($\frac{1}{2} + 2 + 2 + 1\frac{1}{2} = 6$) or 10% of the time. The calculation of L_{eq} is more complex. L_{eq} is the constant, average sound level, which over a period of time contains the same amount of sound energy as the varying levels of the traffic noise. L_{eq} for typical traffic conditions is usually about 3 dBA less than the L_{10} for the same conditions. $L_{A,max}$ is the A-weighted maximum sound level, *i.e.* the maximum pass-by level of a vehicle, which is among others relevant for sleep disturbances.

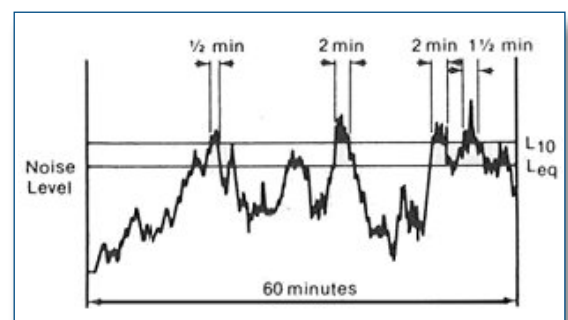


Fig. 4
Statistical descriptors of traffic noise.

FHWA, 1992

3. Sources of road noise

Noise associated with road development and traffic has four main sources:

- Propulsion noise of vehicles;
- Interaction between vehicles (especially tires) and road surface;
- Driver behaviour; and
- Construction and maintenance activity.

Each is discussed briefly in this section.

Vehicle noise

Vehicle noise comes from the engine, transmission, exhaust, and suspension, and is greatest during acceleration, on upward slopes, during engine braking, on rough roads, and in stop-and-go traffic conditions. Poor vehicle maintenance is a contributing factor to this noise source. It generally increases with the engine speed and depends therefore on the vehicle speed and gear selection.

Road/tire noise

Noise from the contact between tires and pavement contributes significantly to overall traffic noise. There are two important mechanisms of noise generation:

- The roughness of the road surface causes vibrations of the tires leading to sound radiation;
- The compression and relaxation of the air in the tire profiles in the contact area lead to aerodynamic noise; so called “air-pumping”.

Road/tire noise of modern cars driving with constant speed above 30 km/h is dominant in inner urban situations. The noise level depends on the type and condition of tires and pavement. Road/tire noise is generally greatest at high speed and during quick braking.

Driver behaviour

Drivers contribute to road noise by driving with high engine speed, by using their vehicles’ horns, by playing loud music, by shouting at each other, and by causing their tires to squeal as a result of sudden braking or acceleration.

Construction and maintenance

Road construction and maintenance generally require the use of heavy machinery, and although these activities may be intermittent and localised, they nevertheless contribute tremendous amounts of sustained noise during equipment operation (World Bank, 1997).



Fig. 5
Heavy trucks are an important source of traffic noise.

Klaus Neumann, Germany, 2010

4. The nature and scale of impacts

Noise exposures in developing countries due to road traffic are found to be up to 85 dB(A) (daytime outdoor $L_{A,eq}$). Other major sources such as *e.g.* festivals register at up to 95 dB(A) with maximum levels $L_{A,max}$ up to 150 dB(A) (Schwela 2007). Exposure to excessive sound pressure levels ($L_{A,eq} > 85$ dB, $L_{A,max} > 120$ dB(A) resulting in immediate and persistent hearing loss of children), not only from occupational noise but also from urban, environmental noise, is the major avoidable cause of permanent hearing impairment. Such sound pressure levels can also be reached by leisure activities at festivals, concerts, discotheques, motor sports and shooting ranges; by music played back in headphones; and by impulse noises from toys and fireworks (WHO, 2002). In developing countries quite often special sources such as the wide-spread use of vehicle horns are the major cause of annoyance.

4.1 Health effects of noise

4.1.1 Introduction

Noise impacts health. Although it has been traditionally difficult to establish a direct and significant correlation between noise and illness, much scientific literature exists linking noise to numerous health effects. Noise is generally considered to be very loud at equivalent levels of 70 dB(A). Repeated exposure at levels of, or above, 85 dB(A) can cause hearing loss, though some more susceptible individuals will incur hearing loss below this level.

Noise has long been documented to contribute to stress levels, leading to subsequent effects on the cardiovascular and immune systems. Noisy environments can adversely affect language acquisition and reading development in children. A mother's response to noise also affects fetal development, and has been linked to pre-term delivery, low birth weights, growth retardation and birth defects. Noise is also linked to a deteriorating quality of life, by interfering with speech, by accelerating and intensifying the development of negative social behaviours such as neurosis and irritability, as well as interfering with attention and consequently performance and productivity.

4.1.2 Effects of noise on human hearing

Hearing disability is the difficulty in understanding acoustic signals and speech. Studies disagree over the relationship between the relative hearing-damaging capacity of the sound pressure level and its duration. However, general consensus is that noises from 55–60 dB(A) create annoyance, and 60–65 dB(A) considerably increases annoyance. Noise exposure levels below 75 dB $L_{A,eq}$ pose negligible risk, although some would have it raised to 80 dB $L_{A,eq}$. The threshold value, where noises below this value cannot damage hearing, may be even lower due to exposures interacting with certain drugs that affect hearing, chemicals, vibration and shift-work. Damage may also result from impulsive noise as well as low-frequency noise, although it is not yet clear whether these will be factored into damage risk calculations.

4.1.2.1 Hearing impairment

Hearing impairment is where the hearing threshold level lies outside the normal range, whereas hearing loss refers to hearing impairment that is causing difficulties, or a hearing threshold level that has deteriorated. Normal hearing sensitivity (in a young, healthy teenager) can detect sounds in the audiofrequency range (about 20–20 000 Hz). However, individual hearing sensitivity varies. Presbycusis (age-related hearing loss) and sociocusis (non-occupational hearing loss) must be corrected into data when examining hearing loss caused by noise exposure.

4.1.2.2 Noise-induced hearing loss

Noise-induced hearing loss refers to the quantity of hearing loss attributable to noise alone, after values for presbycusis and sociocusis have been subtracted. Noise-induced threshold shifts may be temporary or permanent, and are affected by the individual's own susceptibility to hearing impairment risk as well as the intensity and duration of noise exposure. The exposure to high levels of noise initially may lead to a temporary threshold shift, where there is a shifting of the person's hearing level. Normally pre-exposure hearing levels will recover after the exposure ends.

Repeated exposures over several years can result in a permanent threshold shift, which is an

irreversible, sensorineural hearing loss. Since individual susceptibility is subject to considerable variation, it is difficult to identify a safe limit of noise exposure applicable for all people. Both men and women, however, are equally at risk of hearing damage, when exposed.

4.1.2.3 Occupational hearing loss

Occupational Hearing Loss has been found in working populations consistently exposed to intense noise daily. Noise has been recognized as one of the most prevalent workplace hazards. Such hearing loss is more common at higher frequencies. Studies typically show a risk of hearing damage at sound pressure levels of around 85 dB(A) or more, although it is well known that some more susceptible workers will incur hearing losses at levels below 85 dB(A). In Hong Kong, there are an estimated 75 000 industrial workers exposed to noise levels of 90 dB(A) and above.

4.2 Societal Economic Costs of Noise Pollution

4.2.1 Introduction

No economic models have yet been developed in developing cities that may be used for calculating the total costs for the society at large caused by noise pollution. This is important in light of decisions concerning government noise policies that are often based on economic models, such as cost-benefit analyses. In the short term, increased noise pollution usually results in lowered market values of real estate, population segregation, and general deterioration of residential areas.

For example, noise from aircraft has been linked to a depreciation of real estate values, between 0.5 and 0.9% per decibel increase (Jon P. Nelson “Meta-Analysis of Airport Noise and Hedonic Property Values: Problems and Prospects”, 2003, <http://www.wyle.com/PDFs/archive/NHPV.pdf>)

Cost-benefit analyses would need to consider the societal costs for noise-induced illnesses, disabilities, as well as losses in productivity. There are other less easily quantified effects of noise on the quality of life, such as the annoyance and discomfort caused by noise exposure. More quantifiable among the costs are certainly

public and private expenditures for noise abatement measures such as noise barriers, buffering vegetation, and sound insulating windows.

The final costs of damage caused by noise pollution include productivity losses, health care costs, effects on property values, and loss of psychological wellbeing. The Asian Development Bank estimated the cost of pollution to Asian economies to be equivalent to between 1–6% of their GNP, depending on the country and the impacts included in the estimates (ADB, 2001). European studies examining the external costs of noise to society, especially transport noise, estimate that cost of damage to societies range from 0.2–2.0% of GDP.

An additional impact of noise is vibration. The vibration induced by traffic can have a detrimental effect on structures standing near roads and railways. This is of particular concern in the case of cultural heritage sites, which may have been standing for many centuries, but which were not designed to withstand such vibration. Makeshift or lightly constructed buildings, common in many developing countries, may be the first to succumb to vibration damage.

In general *road traffic noise*, especially in innerurban situations is considered to be the dominant noise source and will therefore be treated in the following sections. The treatment of other sources can be based on analogous assumptions and techniques.

4.2.2 Effect of noise on human activity

4.2.2.1 Speech interference

Speech is an essential form of communication in society, and its interference by environmental noise lowers the quality of life, by not only disturbing normal social and work-related activities but also by causing annoyance and stress. Speech interference may also mask vital warning signs, such as cries for help. Speech discrimination particularly affects hearing-impaired persons, and becomes harder for all persons when outdoors compared to indoors. Speech intelligibility, when interfered with noise, leads to decreased working capacity, problems in human relations, and stress.

Fuel and engine type also affects noise

As well as the size of vehicle, fuel type and combustion technology also has a significant impact on noise. See for example Module 4d: *Natural Gas Vehicles* (both CNG and LPG are significantly quieter than gasoline or diesel vehicles) and Module 4c: *Two- and Three-Wheelers* (4-stroke engines significantly quieter than 2-stroke). The new electric cars have no relevant engine noise so that acceleration is significant quieter. Driving with constant inner-urban streets instead is dominated by road/tire-noise also for electric cars.

4.2.2.2 Sleep disturbance

Good physiological and mental health requires sleep with a sufficient amount of the different sleep stages (REM sleep – rapid eye movement – important for mental and emotional recreation, sleep stage N3, the deep sleep stage, important for physiological recreation). Sleep contributes to the development and maintenance of sensorimotor competence. Sleep is affected by noise, and measurable effects begin at 30 dB L_{Aeq} and $L_{A,max}$ above 45 dB(A) (indoor levels). Exposure to noise induces sleep disturbances by making it difficult to fall asleep, altering sleep pattern and stages or depth, and increasing the number of awakenings during the night. Noise-induced sleep disturbances also cause physiological vegetative reactions such as increased blood pressure, increased heart rate, vasoconstriction, cardiac arrhythmia and stress hormone emissions. After effects of exposure to nighttime noise may include reduced perceived sleep quality, decreases performance, increased fatigue, decreased mood or wellbeing.

Research still needs to be done exploring the noise-induced sleep disturbances on health, work performance, accident risk and social life, including exposed (sensitive) groups and long-term effects of exposure to, and also on the relationship between psychosocial symptoms and the reduced perceived sleep quality of the person. WHO recommends in its Night Noise Guidelines (WHO 2009) not to exceed an outdoor equivalent level L_{eq} of 40 dB(A).

4.2.2.3 Psychophysiological effects: stress, cardiovascular, and immunological effects

Noise affects both mental and physical wellbeing. The resulting stress increases production

of adrenaline in the body, leading to increases in heart rate and blood pressure. In addition to elevating adrenaline, noise exposure has been found to elevate levels of cortisol in the body, which has been related to suppressed immune system functioning, making the individual more susceptible to disease. Bodily fatigue has been linked to noise, either directly or indirectly through interference with sleep. Exposure to noise may also result in a variety of biological responses, by causing nausea, headache, irritability, instability, argumentativeness, anxiety, reduced sexual drive, nervousness, insomnia and loss of appetite.

More research is still needed to estimate the long-term cardiovascular and psycho-physiological risks due to noise.

4.2.2.4 Language acquisition in children

Noise has not only been documented to affect adults, but correlations have been found with children as well as with fetuses of pregnant women. Noisy environments causing speech interference in classrooms may have serious ramifications on a child's education, especially if this occurs during the language acquisition development stage. Children who cannot distinguish different sounds may not learn to tell them apart, and may also distort their speech as they may drop parts of words, especially their endings. Reading development has also been linked to noise levels.

4.2.2.5 Fetal effects

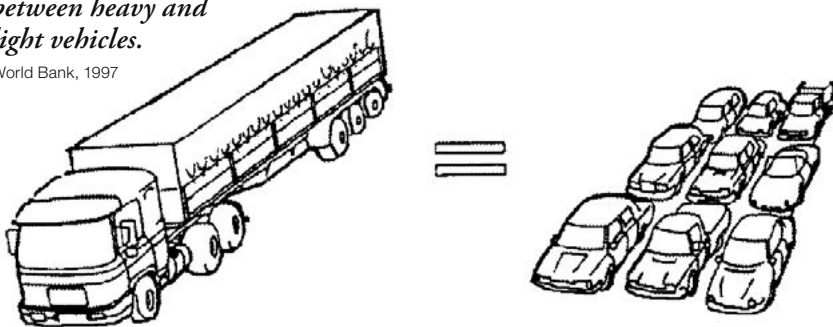
The fetus is responsive to its mother's environment, and can be directly stimulated by noise. The fetus is also affected by the mother's response to noise. These combinations of effects have been linked to pre-term delivery, low birth weights, growth retardation and birth defects.

4.2.2.6 Performance and productivity

Performance, and subsequently productivity, is affected by noise. Noise interferes with complex task performance, such as tasks that require continuous and sustained attention to detail, attention to multiple cues, and a large working memory capacity. Thus inefficiency results when noise interferes with attention, leading to reduced productivity.

Fig. 6
Acoustic equivalence between heavy and light vehicles.

World Bank, 1997



4.2.2.7 Social behaviour

Noise, such as in the occupational setting, has been associated with development of neurosis and irritability. Although noise does not physiologically correlate with the development of mental illness, it is believed to accelerate and intensify this development. Noise may reduce helpfulness and increase aggressiveness. Noisy environments cause annoyance and irritability, and have been found to reduce helping behaviours, heighten social conflicts, and increase tensions.

4.3 Factors contributing to noise impacts*

* Based on World Bank, 1997

Motor vehicles are inherently noisy, and noise impacts are inevitable in any road development and traffic situation, regardless of scale or character. The factors contributing to noise impacts are, however, highly variable; consequently, the nature of the noise impacts associated with individual road projects differ greatly. Contributing factors fall into six groups, which are described in the following sections.

4.3.1 Vehicular factors

Different vehicle types produce different levels of noise. In general, heavy vehicles such as transport trucks make more noise than do light cars; they tend to have more wheels in contact with the road (see Figure 6), and often use engine brakes while decelerating. Poorly maintained vehicles, such as those with incomplete exhaust systems or badly worn brakes, are noisier than well-maintained ones. Also, certain types of tires, such as off-road or snow tires, are especially noisy.

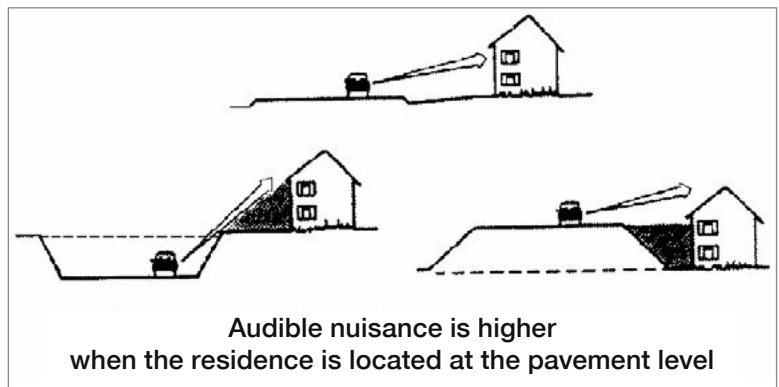
4.3.2 Road surfaces

The physical characteristics of the road surface and its surroundings play a large role in determining noise output. Well-maintained, smooth-surfaced roads with small maximum grain size are less noisy than those with rough, cracked, damaged, and patched surfaces. Expansion joints in bridge decks are especially noisy. Roadside surfaces such as vegetated soil tend to absorb and moderate noise, while reflective surfaces like concrete or asphalt do not have any beneficial function (Figure 7).



4.3.3 Road geometry

The vertical alignment of the road can affect the ease with which noise can be transmitted to roadside receptors. For instance, siting a road in a cut below ground level or on a raised platform may serve to keep receptors out of the impact zone. This concept is illustrated in Figure 8. Also, the presence of barriers along the roadside, whether specially installed for noise control or naturally occurring, can lower the impact of road noise. Vehicles tend to produce the most noise while ascending and descending steep slopes and while rounding sharp corners; this means that roads which incorporate these features will tend to be noisier at those points.



4.3.4 Environmental factors

Weather conditions such as temperature, humidity, wind speed, and prevailing wind direction can play a role in determining how individual sites are affected by road noise. Temperature and humidity determine air density, which in turn affects the propagation of sound

Fig. 7

As well as substantially reducing construction cost, the use of vegetation and open soil in this busway in the Ipswich (UK) results in much less noise.

Lloyd Wright, 2001

Fig. 8

Relative positions of roadway and receptor.

World Bank, 1997

waves. Downwind sites are generally exposed to greater noise levels than are sites upwind of roads.

Ambient noise levels, associated with industrial and other human activity, affect the perception of the magnitude of the road noise impact. In areas with low ambient noise levels, the noise from a new road development will generally be more noticeable than a similar noise level would be in an environment with higher ambient noise levels. New roads in quiet areas or noisy trucks at night are often perceived as worse than higher levels of noise in a busy area during the day. On the other hand, measured noise levels and potential health impacts are highest where traffic noise combines with noise from other sources, possibly producing an unacceptable overall noise level.

Topography can also influence noise impact. For instance, noise from roads occurring in mountain valleys or canyons tends to be more

noticeable than that from a similar road on a flat plain, because noise is reflected off valley walls. By the same token, hills and knolls can act as natural barriers to noise if they occur between the road and receptors. Above-grade roads, which are often necessary in flood-prone areas, tend to broadcast noise over greater distances.

4.3.5 Spatial relationships

Perhaps the greatest determinant of noise impacts is the spatial relationship of the road to the potential noise receptors. The closer the road to receptors, the greater the impact (see Figure 9). The higher the population density in roadside areas, the greater the number of people likely to be receptors, and, consequently, the greater the impact. Inner-urban roads with closed building facades on both sides will on the one hand have increased noise levels due to reflections; on the other hand in this case the buildings serve as shielding devices with low exposures at the facades pointing away from the roads.

4.3.6 Traffic stream

The noise production of a particular traffic stream is determined by a number of factors: the type of vehicles in the stream and their level of maintenance; the number of vehicles passing per unit time (see Figure 10); the constancy of flow (vehicles tend to be noisier in stop-and-go traffic); and the speed of traffic flow (noisiest at high speeds) (see Figure 11). The relationship between traffic stream cycles and ambient noise is also important. Ambient noise levels are

generally lowest at night, and if traffic noise peaks at night, the impact will be great. Conversely, if traffic noise peaks at the same time that ambient noise levels do, the effects will be less noticeable.

Fig. 9
Doubling the distance between the road and the receptor results in a decrease of 3 db(A) in the noise level.

World Bank, 1997

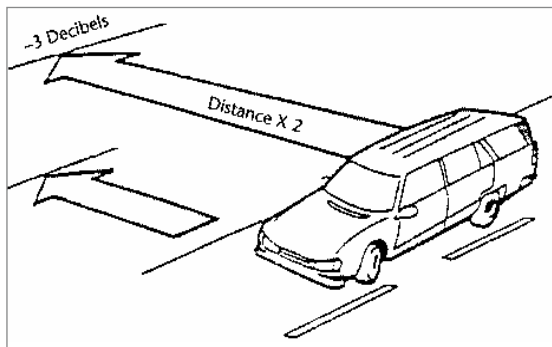


Fig. 10
When traffic on a road is doubled, the noise level increases 3 dB(A), all other factors being equal.

World Bank, 1997

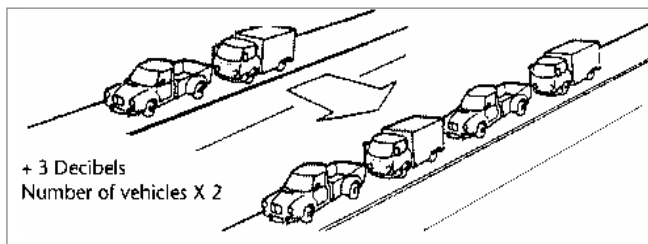
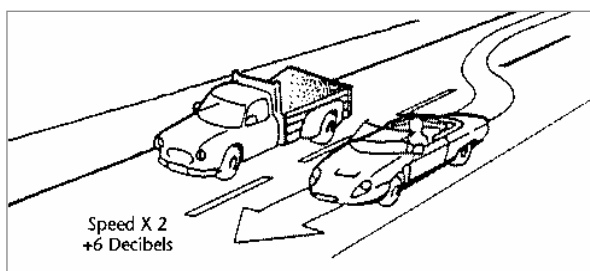


Fig. 11
Doubling the speed results in an increase of 6 dB(A).

World Bank, 1997



Box 3: Noise in Latin American cities

In general, community noise in Latin America remains above accepted limits. As more and more cities in Latin America surpass the 10 million inhabitants mark, the noise pollution situation will continue to deteriorate. Most noise pollution in Latin American cities comes from traffic, industry, domestic situations and from the community. Traffic is the main source of outdoor noise in most big cities. The increase in automobile engine power and lack of adequate silencing results in L_{Aeq} street levels >70 dB, above acceptable limits. Vehicle noise has strong low-frequency peaks at ~ 13 Hz, and at driving speeds of 100 km/h noise levels can exceed 100 dB. The low-frequency (LF) noise is aerodynamic in origin produced, for example, by driving with the car windows open. Little can be done to mitigate these low-frequency noises, except to drive with all the windows closed. Noise exposure due to leisure activities is growing at a fast rate, and construction sites, pavement repairs and advertisements also contribute to street noise. Noise levels of 85–100 dB are common.

The Centro de Investigaciones Acústicas y Lumínótécnicas in Córdoba, Argentina has investigated

noise pollution in both the field and the laboratory. The most noticeable effect of excessive urban noise is hearing impairment, but other psychophysiological effects also result. The effects of noise on hearing can be especially detrimental to children in schools located downtown.

At the municipal level Argentinean Ordinances consider two types of noises: unnecessary and excessive. Unnecessary noises are forbidden. Excessive noises are classified according to neighbouring activities and are limited by maximum levels allowed for daytime (7:00 to 22:00) and night-time (22:00 to 7:00).

Similar actions have been prescribed at the provincial level in many cities of Argentina and Latin America. Control efforts aimed at reducing noise levels from individual vehicles are showing reasonably good improvements. However, many efforts of municipal authorities to mitigate noise pollution have failed because of economic, political and other pressures. For example, although noise control for automobiles has shown some improvement, efforts have been counteracted by the growth in the number and power of automobiles.

Adapted from WHO, 2002



Fig. 12
Due to the low ambient noise level, traffic noise has an especially large impact during the night (Bangkok).

Dominik Schmid, 2011

5. Remedial measures

It has been shown in many studies that the L_{eq} has a very good correlation to the long-term effects of noise such as health effects. It is also a good indicator for annoyance effects. For sleep disturbances the L_{max} is an additional important indicator. Noise abatement should therefore concentrate on the reduction of the L_{eq} and for sleep disturbances additionally on the reduction of the maximum levels.

Once noise is recognised as a serious issue in sustainable transport planning the question arises as to what can be done about it. Road traffic noise in developing cities can be attacked through a eight-part strategy:

- raising public noise awareness,
- avoiding motorised traffic,
- setting reception standards,
- motor vehicle control (vehicular measures),
- land use control,
- traffic management,
- surface design and maintenance,
- road geometry and design.

5.1 Raising public noise awareness

“The most important problems in the control of noise pollution [in Southeast Asia] include lack of public awareness, stakeholder participation, inadequacy of noise emission standards, and lack of enforcement of existing laws and regulations”



Box 4: Recommended noise levels for specific environments

Dwellings

The critical effects of noise on homes are sleep disturbance, annoyance, and speech interference. The World Health Organisation (see WHO, 2002 and WHO/Europe 2009) recommends guideline values for inside bedrooms are 30 dB L_{Aeq} for steady-state continuous noise, with a maximum level of 45 dB $L_{A,max}$. Sound pressure level from steady, continuous noise on balconies, terraces, and in outdoor living areas should not exceed 55 dB L_{Aeq} , and daytime noise should not be louder than 50 dB L_{Aeq} , while night-time outdoor levels should not exceed 40 dB L_{Aeq} , so that people can sleep with their bedroom windows open.

Schools and preschools

Noise critically effects speech interference, disturbance of language acquisition (including comprehension and reading acquisition), message communication, and annoyance. Noise levels should not exceed 35 dB L_{Aeq} during teaching sessions, if students are to be able to hear and understand spoken messages in class rooms, and this value should be even lower for hearingimpaired children. Outdoor playgrounds should not have noise levels exceeding 55 dB L_{Aeq} . Sleeping hours in preschools should abide by the guideline values for bedrooms in dwellings.

Hospitals

Noise in hospitals causes sleep disturbance, annoyance, and communication interference, including warning signals. Patients also have less ability to cope with stress, thus rooms in which patients are being treated, observed, or resting should not exceed 35 dB L_{Aeq} . Noise levels in intensive care units and operating theatres should also be carefully monitored.

Fig. 13

Raising awareness is a first step to address traffic noise problems.

Photo by Santhosh Kodukula, India, 2011

(Schwela 2007). As long as noise is considered to be a mere problem of annoyance an ambitious noise control policy is unlikely. Public awareness – that noise may have severe health effects and that the benefits of noise control exceed the mitigation costs – is the fundamental first step for the improvement of noise policy in the developing countries.

5.2 Avoiding motorised traffic

Mobility without motorised traffic has still an important role in developing countries. In Europe the adverse effects of motorised traffic have caused a revival of mobility without cars, *i.e.* with bicycles and by walking. Non-motorised mobility can be supported by low traffic land use that is the “short distance city” which will be promoted by urban land use planning with the instruments “mixture of use”, “decentralisation” and “condensation” It is recommended to safeguard urban quarters with high historic urban quality, to build dwellings preferably in down town areas and to preserve the greenbelts around the cities.

Land use structures can only slowly be changed, therefore the conservation or extension of structures with mixed land use should be promoted with additional instruments such as a housing policy which eases moves nearer to the workplace, the decentralisation of urban services, the conservation of service facilities near to the dwellings such as the village store through corresponding trade and commerce policy, etc.

The short distance city ideally allows making the necessary journeys by foot or bicycle. After all, 50 % of the journeys in Europe made by car are shorter than 5 km (see <http://www.umwelt-daten.de/publikationen/fpdf-l/3705.pdf>, p. 10). There is thus a high potential for mobility without emissions.

5.3 Noise reception level standards

As the indicators to determine noise are defined, noise level regulations or standards can be stipulated. The World Bank (1997) provides the following useful advice on such standards.

National standards may specify one noise level not to be exceeded for all types of zones (such as $L_{eq}(12\text{ h})$ under 70 dB(A)) or, more realistically,

different noise levels for different zones, such as industrial, urban, residential, or rural areas. Lower limits are sometimes specified for nocturnal noise.

Details of road noise standards are usually available from national transportation agencies. If no national standards exist, objectives can still be established for various types of road projects. Indicative standards used in Western Europe might be not to exceed a L_{eq} (8:00–18:00) of 65 dB(A) for residences in urban areas, and 60 dB(A) for rural areas. It is important, when considering international standards, to take into account the differences in noise criteria, measurement methods, and applicability to various types of projects.

It should be noted that noise standards are only applicable for a defined measurement method which specifies the location of measurement devices and the duration of measurement. Indeed, one obstacle to consistent compliance with standards is the fact that noise measurement is dependent on so many variables, such as weather and the type, position, and number of sensors. Unless the values of the variables are clearly defined and strictly adhered to, compliance with standards may not be especially meaningful.

Noise reception standards are well established in developing countries. In Brazil, for example, noise exposure thresholds are defined by the Rule NBR 10151 of the Brazil Standard Association ABNT (Carolina Moura-de Sousa, Maria Regina Alves Cardoso 2002). For areas where residences predominate a threshold of 55/50 dB(A) for daytime/night-time is valid. The daytime threshold is even lower than the German noise reception limit of 59 dB(A) for new or substantially altered roads (49 dB(A) at night). The noise limit in residential neighbourhoods in India is even more ambitious and set at 45 decibels at night and 55 decibels in the day (http://www.geonoise.com/articles_shhh_indians_told_to_keep_the_noise_down.html). This underlines the importance of better enforcement of existing legislation.

In China noise reception limits are based on the “Law on Prevention and Control of Noise Pollution” of 1996 with limits depending on the type of land use. Night levels for the L_{eq} are between

35 and 55 dB(A), daytime levels between 45 and 70 dB(A) (see Chen Ming “Urban environmental noise pollution and control criteria”, ftp://ftp.demec.ufpr.br/disciplinas/TM124/ORG.MUNDIAL_SA_DEexposeresnoise.pdf)

5.4 Motor vehicle control

This part of the strategy goes to the source of traffic noise: the vehicles. For example, vehicles can be designed with enclosures for the engine, fans that turn off when not needed, and better mufflers. Quieter vehicles would bring a substantial reduction in traffic noise along those roads and streets where no other corrective measures are possible. The European Union and many states in the USA have issued regulations placing a limit on the noise which new vehicles can emit. Generally the current regulations aim at limiting the propulsion noise, but the European Union and the UN-ECE plan a new measurement method with a combination of constant speed and wide-open-throttle acceleration. This method should be more representative of real driving conditions. In addition, many local and state governments have passed legislation requiring existing vehicles to be properly maintained and operated. Unfortunately, due to limitations in technology, these regulations for new vehicles and state and local regulations for maintenance of vehicles can only partially reduce the noise created by traffic. The best that

can be expected is a 5 to 10 dB(A) decrease depending on the current emission levels.

In developing countries where usually no noise regulations on vehicles exist, it is recommended to introduce such regulations at least for new cars to be allowed to enter traffic.

In some countries (e.g. European Union) in addition to the limits for propulsion noise, emission limits for tires have been introduced. The reduction potential for low noise tires is considered to be up to 5 dB(A).

The wide-spread use of vehicle horns in developing countries is a source of major annoyance.

Fig. 14
Use of car horns is banned in this area of Nanjing Road, Shanghai.

Karl Fjellstrom, Jan. 2002

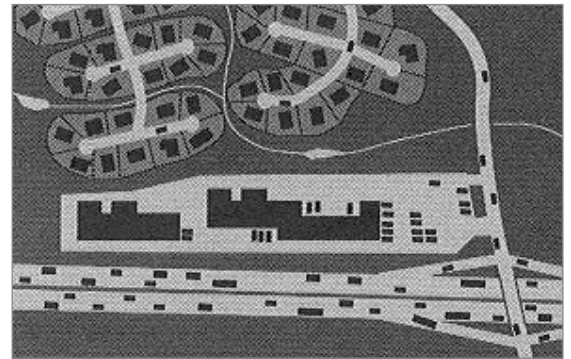


Fig. 15
Less noise-sensitive commercial buildings can be placed next to a street, with residences farther away.

FHWA, 1992

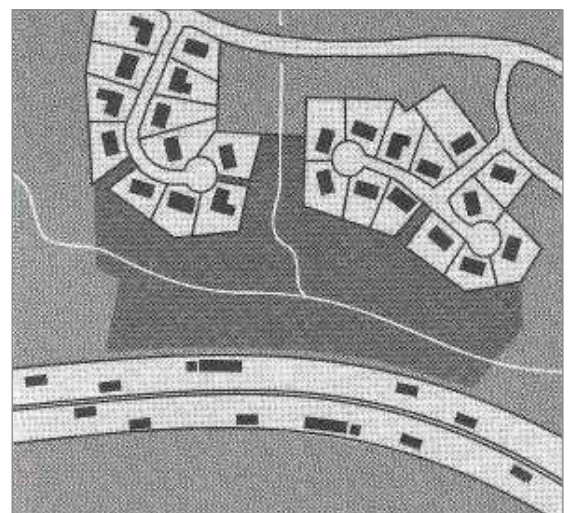


Fig. 16
Open space can be left as a buffer zone between residences and a street.

FHWA, 1992

This could be tackled either by limiting the allowed emissions, forbidding the use of horns (see Figure 14) or by drivers education.

5.5 Land use control

The fifth part of the strategy calls for the control of future development (see Figures 15 and 16). Sometimes, complaints about highway traffic come from occupants of new homes built adjacent to an existing highway. Many of these highways were originally constructed through undeveloped lands. Prudent land use control can help to prevent many future traffic noise problems along highways bordered by vacant land which may one day be developed. Such controls need not prohibit development, but rather can require reasonable distances between buildings and roads as well as “soundproofing” or other abatement measures to lessen noise disturbances. Many local governments are working on land use control (FHWA 1992).



Fig. 17
Lorry ban in the German city of Heidelberg from 11:00 to 7:00 with the exemptions of low noise lorries.

Photo by M. Jaecker, Heidelberg, Germany, 1994



Fig. 18
Night-time speed limit on a main road in Berlin for noise protection “Lärmschutz”.

Photo by M. Jaecker, Berlin, Germany

5.6 Traffic management

Managing traffic can reduce noise problems. For example, trucks can be prohibited from certain streets and roads, or they can be permitted to use certain streets and roads only during daylight hours (see Figure 17). Traffic lights can be changed to smooth out the flow of traffic and to eliminate the need for frequent stops and starts. Speed limits can be reduced: in Europe the establishment of zones with a maximum speed of 30 km/h is very popular, with a level reduction between 2 and 3 dB(A). Some German cities have introduced speed limits for the night on main roads (Figure 18).

One element of traffic management is the application of economic instruments (parking fees, road charges, etc.). In London a Congestion Charge was introduced in 2003 (today GBP 8) in order to reduce motorised traffic in the inner zones of the city (Figure 19). The Congestion Charge caused a reduction of the car traffic of nearly 40%.

5.7 Surface design and maintenance

The application of low noise road surfaces has a high reduction potential especially on motorways (reductions up to 8 dB(A) by open-graded asphalts for new surfaces, – 5 dB(A)) after 6 years according to the German calculation scheme for road traffic noise (compare also



Fig. 19
Traffic sign in London for congestion charging.

Photo by M. Jaecker, London, UK, 2008

FEHRL Report 2006/02 “Guidance manual for the implementation of low-noise road surfaces”, p. 67; http://www.trl.co.uk/silvia/Silvia/pdf/silvia_guidance_manual.pdf). In Europe a lot of innovative solutions for low noise surfaces are currently developed. Two layer open-graded asphalts for example seem to be efficient in inner-urban situations. Closed surfaces with a small maximum grain size (5 mm) are another alternative. Poroelastic road surfaces with rubber particles – which may be taken from scrap tyres – yield a very high reduction (between 8 and 11 dB(A)) but are very sensitive against construction mistakes (see http://www.trl.co.uk/silvia/Silvia/pdf/Associated_Reports/SILVIA-VTI-005-02-WP4-141005.pdf). Generally, smooth, well-maintained surfaces such as freshly laid asphalt without grooves and cracks will keep noise to a minimum (World Bank, 1997) (see also margin note *Pavement options*).

5.8 Road geometry and design

The eighth part of the traffic noise reduction strategy is the road geometry and design.

Road design should avoid steep grades and sharp corners to reduce noise resulting from acceleration, braking, gear changes, and use of engine brakes by heavy trucks at critical locations.

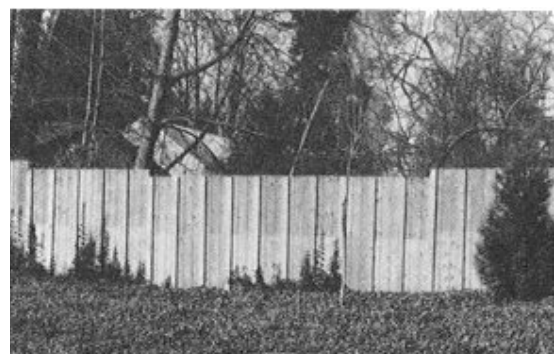
Noise barriers are among the most common mitigative measures used. They are most effective if they break the line of sight between the noise source and the receptors being protected, and if they are thick enough to absorb or reflect the noise received. Various materials and barrier facade patterns have been tested to provide maximum reflection, absorption, or dispersion of noise without being aesthetically ugly.

Noise barriers

The types of noise barriers most commonly employed consist of earth mounds or walls of wood, metal, or concrete which form a solid obstacle between the road and roadside communities (Figures 20a, b, c). Noise mounds require considerable areas of roadside land; for narrow alignments, bridges, and roads on embankments, wall-type barriers may be the only viable option. Two or more barrier types are often combined to maximise effectiveness. Plantations of trees and shrubs, for instance, contribute



Earth Berm Noise Barrier



Wooden Noise Barrier



Concrete Noise Barrier with Woodgrain Texture

Figures 20a, b, c

Types of noise barriers.

FHWA, 1992

little to actual noise reduction, but they do confer a psychological benefit in reducing the perceived nuisance of traffic noise, and they are often used to soften the visual appearance of mounds and walls (World Bank, 1997).

However, barriers do have limitations. For a noise barrier to work, it must be high enough and long enough to block the view of a road. Noise barriers do very little good for homes on a hillside overlooking a road or for buildings which rise above the barrier. Openings in noise walls for driveway connections or intersecting

streets destroy the effectiveness of barriers. In some areas, homes are scattered too far apart to permit noise barriers to be built at a reasonable cost (FHWA, 1992).

Vegetation

Vegetation, if high enough, wide enough, and dense enough (cannot be seen through), can decrease street traffic noise. A 200-foot width of dense vegetation can reduce noise by 10 decibels, which cuts the loudness of traffic noise in half. It is often impractical to plant enough vegetation along a road to achieve such reductions, although if dense vegetation already exists, it

could be retained. If it does not exist, roadside vegetation can be planted to create psychological relief, if not an actual lessening of traffic noise levels (FHWA, 1992).

Box 5: Pavement options: reducing roadside noise levels by changing the pavement composition and porosity



Figure 21

Conventional asphalt is replaced by noise reducing drainage asphalt pavement during rehabilitation work on a road bridge leading through a residential area.

Klaus Neumann, Germany, 2010

Conventional asphalt pavement usually consists of a mixture of bitumen and a range of graded aggregate materials, yielding *densely graded asphalt pavement*. In contrast, *drainage asphalt pavement* uses an open graded asphalt mixture, which eliminates the aggregates of intermediate grading to

obtain a higher porosity mixture. Noise levels from vehicles travelling on the drainage asphalt pavement (DA) are lower than on the densely graded asphalt pavement (DGA). For more information see World Bank 1997, page 161 and Reichart, 2009.

Fig. 22
Noise barriers designed as wooden or concrete walls (center of the photo) occupy less space than a heap-up earth wall (right side of the photo).
 Klaus Neumann, 2011



Insulation

Building facade insulation, such as double window glazing, is an option usually adopted as a last resort in order to dampen noise in buildings.

The relative costs and effectiveness of some of the measures outlined above are compared in

Table 2. A successful mitigation plan will often incorporate several of the measures. A busy road passing by a high-rise building, for example, may require specialised surfacing, a barrier or screen to reduce traffic noise at lower levels, and facade insulation for the upper floors of the building (World Bank, 1997).

Table 2: Indicative comparison of various noise mitigation measures

Measure	Effectiveness	Comparative costs
Earth barrier	Same as that of other types of barriers (e.g. wood or concrete); needs more space	Very cheap when spare fill material is available on site
Concrete, wood, metal or other barrier fences	Good, requires less space	10 to 100 times the cost of an earth barrier, but may save land cost
Underground road (cut and cover)	An extreme option for very heavy traffic; requires ventilation if over 300 m long	80 to 16 000 times the cost of an earth barrier
Double glazing of windows for facade insulation	Good, but only when windows are closed; doesn't protect outside areas	5 to 60 times the cost of an earth barrier

Fig. 23
A reasonable implanted noise barrier protects a near-by recreation-forest-area from the heavy noise emitted by the never-ending stream of cars and trucks on a highway in Germany.
 Klaus Neumann, 2009



Source: World Bank 1997

6. Lessons learned from Noise Action Planning in Europe

In 2002 the European Union adopted the Directive on the assessment and management of environmental noise (Directive 2002/49/EC, <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:189:0012:0025:EN:PDF>). (Environmental Noise Directive END).

The Directive foresees

- The calculation of noise exposures with harmonised prediction models; the results to be presented in so called strategic noise maps;
- The design of noise action plans for “preventing and reducing environmental noise where necessary and particularly where exposure levels can induce harmful effects on human health and to preserving environmental noise quality where it is good”;
- “Ensuring that information on environmental noise and its effects is made available to the public”.

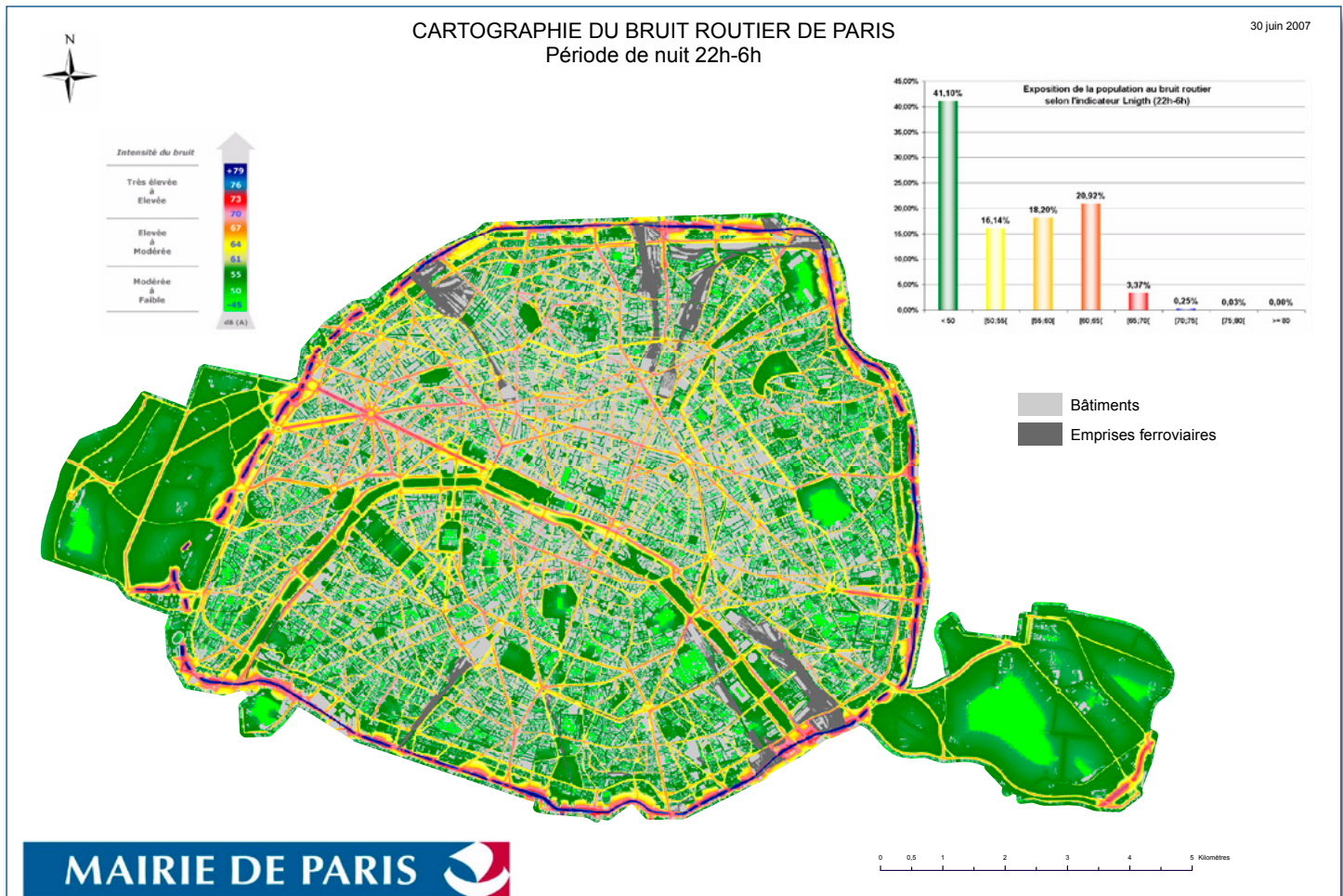
The assessment and management of noise has/ will be done in various steps:

- Step 1: By June 30, 2007 *strategic maps* must have been established for:
 - Agglomerations with more than 250 000 inhabitants;
 - Major roads with more than 6 000 000 vehicle passages per year;
 - Major railways with more than 60 000 train passages pro Jahr per year;
 - Major airports with more than 50 000 movements per year.
- Step 2: By June 30, 2012 *strategic maps* must be established for:
 - Agglomerations with more than 100 000 inhabitants;
 - Major roads with more than 3 000 000 vehicle passages per year;
 - Major railways with more than 30 000 train passages per year.

Most of the European agglomerations have calculated their strategic noise maps (see the the

Fig. 24
Noise map of Paris for nocturnal road traffic noise.

Source: Mairie de Paris (<http://www.paris.fr/viewmultimediacdocument?multimediacdocument-id=30660>)



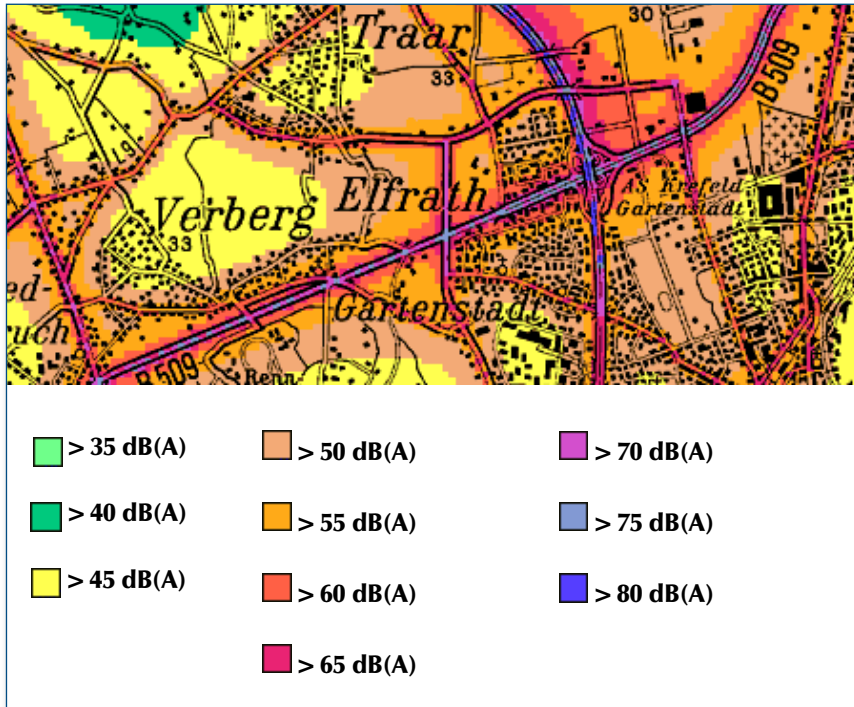


Fig. 25
Noise levels due to daytime traffic on major roads in the German town of Elfrath.
UBA, Oct. 1999

website of the European Environment Agency <http://noise.eionet.europa.eu>). Figure 24 shows the noise map of Paris for nocturnal road traffic noise.

Action plans must be designed about one year after the date for the noise maps. The specific mitigation measures identified in the preceding section can be carried out in the context of these noise action plans. There are many guidelines for the design of noise action plans (*i.e.* see “Practitioner Handbook for Local Noise Action Plans” within the European research project Silence, http://www.silence-ip.org/site/fileadmin/SP_J/E-learning/Planners/SILENCE_Handbook_Local_noise_action_plans.pdf).

A good example of a Noise Action Plan is the plan of the city of Berlin.

Table 3: Threshold values for harmful effects of noise

Equivalent Noise Level day/night (24 h) [db(A)]	Threshold values		
	Road/Rail	Aircraft	Industrial/Commercial Plants/Sports
Hospital areas	57/47	62	45/35
Sensitive housing	59/49	62	50/35
General housing	59/49	62	55/40
Mixed areas	64/54	62	60/45

Source: UBA 2001

In Germany noise action plans started already in 1990 (“Noise Abatement Planning” (NAP)). In the field of NAP the German Environmental Agency (Umweltbundesamt – UBA) obtained much practical experience in cooperation with the European Union, working on model towns.

Results indicate that noise monitoring should be applied over the whole city area. In order to draw up efficient NAPs and to avoid simply shifting problems from one edge of the city to the other, it is indispensable to do the assessment of noise impact for the whole area of the city or agglomeration.

In order to limit expenses, simplified methods for noise monitoring (screening) were developed. Experience with these simplified methods in more than 30 cities showed that depending on the local situation, the depth of investigation and the database available, the cost of noise monitoring will range between EUR 0.25 and 1.00 per inhabitant in Europe. Expenses can be adapted in developing countries depending on the area to be monitored. The time required varies between six and twelve months.

Specific outputs of noise monitoring are:

- **Noise maps** showing the distribution of noise emissions from one or several sources in the urban area (see Figure 25 for an example).
- **Noise conflict maps** indicating those parts of the urban area where noise levels from one or several sources exceed critical threshold values (German thresholds are shown in Table 3).
- **Lists of noise indices** for street areas, compiling the extent of noise conflicts considered together with the number of people affected (UBA, 2001).

Action planning

After the noise monitoring, **action planning** should be conducted, taking another six to twelve months, depending on the situation.

Action plans normally include:

- Noise reduction or noise impact targets for various sites or the whole city;
- The description of the actions intended in short, medium or long terms, covering a time period of 5, 10 or even more years;

- The prognosis of the effects of each action and the combination of actions on noise impact;
- A description of the probable expenses for each measure, and the intended method of financing, including subsidies from different sources;
- The legal framework for each measure;
- The specification of the local or regional authority responsible for each measure and of other institutions which may have to cooperate;
- A ranking of priority measures, if necessary (UBA, 2001).

Typical actions

Typical actions to be taken by city decision makers will include:

- Reducing speeds in urban trunk roads; traffic calming in minor streets;
- Improvement of the pedestrian and biking infrastructure and of public transport (including technical upgrades of the urban rail infrastructure and the promotion of low noise trams and buses);
- Parking management, parking restrictions; management of freight traffic and the distribution of goods in the inner city;
- Lorry bans in sensitive roads, probably with the exception of low noise vehicles;
- General traffic bans in very sensitive streets (with the exception of defined groups of users, *e.g.* public services, taxis, public transport, the inhabitants of the street);
- Diverse instruments of town planning (*e.g.* noise zoning in commercial or industrial areas adjoined to housing areas, noise insulation of buildings in the vicinity of main roads and railways, positioning of less sensitive functions in the vicinity of noise sources);
- Subsidies to proprietors of real estate for the installation of noise insulating windows;
- Improvement or replacement of road pavement; low noise road surfaces;
- Noise barriers;
- Proposals for actions of external public authorities (*e.g.* traffic management on federal roads leading through the city; planning of bypasses through less sensitive areas for federal or regional roads; appeal for mitigation measures in the vicinity of federal railways or of airports).

Box 6: Education and public awareness

Noise abatement policies can only be established if basic knowledge and background material is available, and the people and authorities are aware that noise is an environmental hazard that needs to be controlled. The lack of noise awareness in developing countries is the major obstacle for an ambitious noise control. It is, therefore, necessary to include noise in school curricula and to establish scientific institutes to study acoustics and noise control. People working in such institutes should have the option of studying in other countries and exchanging information at international conferences. Dissemination of noise control information to the public is an issue for education and public awareness. Ideally, national and local advisory groups should be formed to promote the dissemination of information, to establish uniform methods of noise measurement and impact assessment, and to participate in the development and implementation of educational and public awareness programs.

Acoustics training in South Africa

Local authorities responsible for applying regulations published by the Department of Environmental Affairs and Tourism must employ a noise control officer who has at least three years tertiary education in engineering, physical sciences or health sciences, and who is registered with a professional council. Alternatively, a consultant with similar training may be employed. Most of the universities in South Africa provide the relevant training, with at least part of the training in acoustics. Universities and technical colleges also provide a number of special acoustics courses. Over the last couple of years awareness of environmental conservation has expanded dramatically within the academic community, and most universities and colleges now have degree courses in environmental management. At the very least, these courses include a six-month module in acoustics, and usually also include training in basic mathematics, the physics of sound, sound measuring methodologies, and noise pollution.

WHO, 2002, http://www.who.int/environmental_information/Noise/Commnoise5.htm

Additional strategies adopted by various German cities

Other possible strategies include these examples from various German cities:

- Far-sighted urban planning in order to reduce the need for traffic. The city of Leipzig for example is developing strategies to improve the distribution of shopping centres in the inner city and in the most important housing areas in order to promote shopping by walking, biking and public transport. See related modules, especially Module 2a: *Land Use Planning and Urban Transport*, regarding transit, pedestrian and cycling oriented urban development.
- Policies to promote housing without owning a car. The city of Halle on Saale, in the framework of a model project, tries to transform an existing housing area into a “zone where you need no car of your own”, by promoting car sharing, biking facilities and special shopping or transportation services for the benefit of the inhabitants. Public transport is improved and measures for traffic calming or traffic bans at particular times in the neighbourhood are applied.
- The town of Pritzwalk built a new pedestrian bridge linking directly the town center to an important housing area on the other side

of a brook. This bridge avoids a lot of car traffic. As the bridge had been constructed in the framework of an exercise of the Army, the town had only to pay for the building materials.

- The city of Oberhausen and several towns in Brandenburg found a low cost solution to the noise impact of federal railways. In order to establish noise barriers, they permitted building contractors to deposit soil out of building sites along existing railway lines under the condition that the soil would be sufficiently clean and that the resulting barrier finally would be planted and maintained by the contractors. To the contractors this spares the dumping fees, which are quite considerable in Germany (UBA, 2001).

Fig. 26 a, b
Where necessary, user-friendly access gates for pedestrians and cyclists must be included in noise barriers (Germany).

Klaus Neumann, 2011



7. Conclusion

The WHO (2002) and Dieter Schwela *et al.*, (2008) provide proposals for a strategic approach and a good summary of measures applicable to developing cities. Noise management should:

- a. Commence monitoring human exposures to noise.
- b. Have health control require mitigation of noise emissions. The mitigation procedures should take into consideration specific environments such as schools, playgrounds, homes and hospitals; environments with multiple noise sources, or which may amplify the effects of noise; sensitive time periods, such as evenings, nights and holidays; and groups at high risk, such as children and the hearing impaired.
- c. Consider noise consequences when making decisions on transport-system and land-use planning.
- d. Introduce surveillance systems for noise-related adverse health effects.
- e. Assess the effectiveness of noise policies in reducing noise exposure and related adverse health effects, and in improving supportive "soundscapes".

After initial description of basic concepts of noise and some of its impacts, remedial measures relevant to developing countries have been outlined, focussing on a eight-pronged strategy of:

- raising public noise awareness,
- avoiding motorised traffic,
- noise level standards,
- motor vehicle control (vehicular measures),
- land use control,
- traffic management,
- surface design and maintenance,
- road geometry and design.

To assist developing cities considering building an attractive, low noise environment, some innovative strategies and actions attacking noise in German towns were given.



Fig. 27 a, b, c

Traffic calming and restrictions in residential areas (top right) and the introduction of car-free zones in inner cities (center and right) are among the strategies that can lead to a significant reduction of traffic noise.

Photos: Top right: Robin Hickman, Freiburg/Germany, 2003;
Center right: Manfred Breithaupt, Tallinn/Estland, 2010;
Bottom right: Paul Fremer, Frankfurt/Germany, 2010

8. References and resources

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Video and print references from the FHWA

- **FHWA (US)**, *Acoustics and Your Environment – the Basics of Sound and Highway Traffic Noise Video*, 1999, http://www.fhwa.dot.gov/environment/noise/ac_vid_m.htm. The video is approximately 48 minutes long and is intended for an audience that desires a thorough, detailed explanation of the subject matter, e.g. traffic noise analysts or residents immediately adjacent to a proposed noise barrier.
- **FHWA (US)**, *Entering the Quiet Zone: Noise-compatible Land Use Planning*, 2002. Available online at <http://www.fhwa.dot.gov/environment/noise/quietzon/> or as a pdf (2.8 MB) at <http://www.fhwa.dot.gov/environment/noise/quietzon/quietzon.pdf>. This brochure 1) summarizes the general nature of highway traffic noise, 2) provides examples of Noise Compatible Land Use strategies either constructed or planned, and 3) encourages a proactive posture by local decision makers, developers and citizens to share in and actively influence land use next to highways.
Other noise-related FHWA resources: http://www.fhwa.dot.gov/environment/ab_noise.htm.



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