CHAPTER FIFTEEN

Noise Pollution and Its Control

15.1 INTRODUCTION

Sources of noise are numerous but may be broadly classified into two classes such as industrial and nonindustrial. The industrial may include noises from various industries operating in cities like transportation, vehicular movement such as cars, motors, trucks, trains, tempo, motorcycles, aircraft, rockets, defense equipment, and explosions. Among the nonindustrial sources, important ones are loudspeakers, automobiles, aircraft, trains, construction work, radios, microphones, etc. The maximum permissible sound level at a worker's ears and the time of exposure are not related directly to the noise produced by any one machine but depend on the total noise in the area, where the workers are located with respect to the machine and other factors. For this reason, noise emission standards or their intent must be confined with product-oriented noise emission regulations.

15.2 SOURCES OF NOISE

The following are some of the sources of noise pollution with which we are quite familiar:

- Appliances in the home such as mixers, grinders, vacuum cleaners, washing machines, etc., together cause a cumulative sound of about 87 dB. This itself is above the sound limits in most areas. On top of that, if loudspeakers, television sets, and music systems are used with high volumes, then we can well imagine how much noise pollution is being created.
- Factories using single- or multiple-unit machines would cause a sound of about 98 dB and above. The sound will definitely go higher as the number of machines increase.
- Airplanes cause the highest sound among all: 150 dB. But road vehicles are also great contributors of noise pollution. These vehicles include the trucks, buses, tractors, SUVs, and even motorcycles and most cars.

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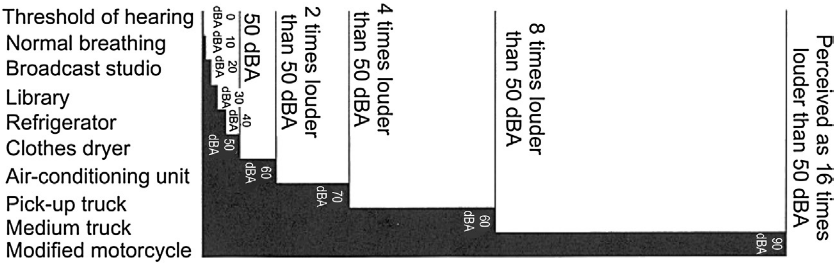

Figure 15.1 Noise levels.

- Then there are lots of environmental sources of noise pollution that cannot be ignored. Continuous noises are the most distressing. Noise coming from sources such as dripping taps and ticking of clocks can contribute to environmental noise pollution.

It has been reported that high intensities, high frequencies, and intermittent nature of noise are the factors of annoyance for workers. Such situations not only bring about physical and psychological damages but also impair workers' efficiency, giving rise to their low production and causing dissatisfaction. Community response to industrial noise and hence the setting of acceptable limits for community areas is difficult to establish precisely because of the variety and complexity of the different factors involved.

The A-weighted decibel scale begins at zero. This represents the faintest sound that can be heard by humans with very good hearing. The loudness of sounds (that is, how loud they seem to humans) varies from person to person, so there is no precise definition of loudness. However, based on many tests of large numbers of people, a sound level of 70 is twice as loud to the listener as a level of 60 (Fig. 15.1).

15.3 EFFECTS OF NOISE POLLUTION

15.3.1 The Physiology of Hearing

The physiology of our hearing mechanism can conveniently be divided into three topics:

1. The outer ear (auricle or pinna) and ear canal
2. The middle ear
3. The inner ear

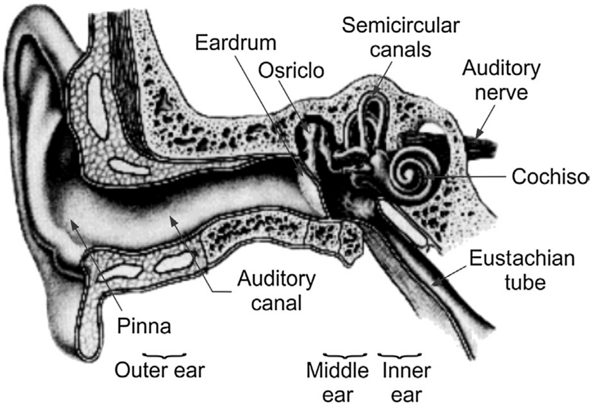

Figure 15.2 The ear canal.

15.3.1.1 The Auricle and Ear Canal

Each hole in the side of the skull leads into an ear canal. The ear canal is an irregular cylinder with an average diameter of less than 0.8 mm and is about 2.5 cm long. The ear canal (Fig. 15.2) is open at the outer end, which is surrounded by the pinna (or auricle). The pinna plays an important spatial-focusing role in hearing. The canal then narrows slightly and widens toward its inner end, which is sealed off by the eardrum. Thus the canal is a shaped tube enclosing a resonating column of air with the combination of open and closed ends. This makes it rather like an organ pipe.

The ear canal supports (resonates or enhances) sound vibrations best at the frequencies that the human ears hear most sharply. This resonance amplifies the variations of air pressure that make up sound waves, placing a peak pressure directly at the eardrum. For frequencies between approximately 2 and 5.5 kHz, the sound pressure level at the eardrum is approximately 10 times the pressure of the sound at the auricle.

15.3.1.2 The Eardrum: Interface Between Outer and Middle Ear

Airborne sound waves reach only as far as the eardrum. Here they are converted into mechanical vibrations in the solid materials of the middle ear. Sounds (air pressure waves) first set up sympathetic vibrations in the taunt membrane of the eardrum, just as they do in the diaphragm of some types of microphones. The eardrum passes these vibrations on to the middle ear structure.

Although we recognize noise pollution as a major environmental problem, it is difficult to quantify the effects it has on human health. Exposure to excessive noise has been shown to cause hearing problems, stress, poor concentration, productivity losses in the workplace, communication difficulties, fatigue from lack of sleep, and a loss of psychological well-being.

15.4 EFFECTS ON HEALTH

Noise pollution can take a severe toll on human health in the long run. These effects will not become apparent immediately, but there could be repercussions later on.

The following is a list of the kinds of effects noise pollution will have on human health after continuous exposure for months, and even years:

- The most immediate effect is a deterioration of mental health. As an example, people who are living too close to airports will probably be quite jumpy. Continuous noise can create panic episodes in a person and can even increase frustration levels. Also, noise pollution is a big deterrent in focusing the mind to a particular task. Over time, the mind may just lose its capacity to concentrate on things.
- Another immediate effect of noise pollution is a deterioration of the ability to hear things clearly. Even on a short-term basis, noise pollution can cause temporary deafness. But if the noise pollution continues for a long period of time, there is a danger that the person might go permanently deaf.
- Noise pollution also takes a toll on the heart. It is observed that the rate at which heart pumps blood increases when there is a constant stimulus of noise pollution. This could lead to side-effects like elevated heartbeat frequencies, palpitations, breathlessness, and the like, which may even culminate into seizures.
- Noise pollution can cause dilation in the pupils of the eye, which could interfere in ocular health in the later stages of life.
- Noise pollution is known to increase digestive spasms. This could be the precursor of chronic gastrointestinal problems.
- Noise can awaken people from sleep, and it can keep them awake, frequently awakening, or awakening for long periods, which can be very disruptive. Even if not awakened by noise, a person's sleep pattern can be significantly disturbed, and a reduced feeling of well-being can result the next day. Frequent and prolonged sleep disturbances can result in physical, mental, or emotional illness.

- External sounds are able to interfere with conversations and use of the telephone as well as the enjoyment of radios, television programs, and like pastimes. It can thus effect the efficiency of offices, schools, and other place where communication has been of vital importance. The maximum acceptable level of noise under such conditions has been 55 dB. 70 dB is considered very noisy, and serious interference with verbal communication is inevitable.

Table 15.1 lists the effects of high intensity noise on human beings.

Noise hazards are classified into several stages based on the quantum of impact they cause. Table 15.2 lists some of the health issues and the quantum of impact they cause.

Table 15.1 Effects of High Intensity Noise on Human Beings

Noise (dB)	Effects Observed
0	Threshold of audibility
150	Significance change in pulse rate
110	Stimulation of reception in skin
120	Pain threshold
130–135	Nausea, vomiting, dizziness, interference with touch and muscle sense
140	Pain in ear, extreme limit of human noise tolerance
150	Prolonged exposure causing burning of skin
160	Minor permanent damage if prolonged
190	Major permanent damage in a short time

Table 15.2 Health Issues Related to Noise Pollution

A. Noise Hazards	
Stage: I **Threat to survival** 1. Communication interference 2. Permanent hearing loss	Stage: II **Causing injury** 1. Neural-humoral stress response 2. Temporary hearing loss
B. Noise Nuisances	
Stage: III **Curbing efficient performance** 1. Mental stress 2. Task interference 3. Sleep interference	Stage: IV **Diluting comfort and enjoyment** 1. Invasion of privacy 2. Disruption of social interaction 3. Hearing loss

Basic noise levels for an industrial zone should not exceed 55 dB at night and 65 dB during the daytime. Noise contributes to development of cardiovascular problems like heart diseases and high blood pressure. Workers exposed to high noise levels are having more circulatory problems, cardiac disturbances, neuro-sensory, motor impairment, and even more social conflicts at home and at work.

15.4.1 Physiological Responses

Physiological responses accompanying a response and other noise exposures include:

1. a vascular response characteristic by peripheral vaso-constriction, changes in heart rate and blood pressure,
2. various glandular changes such as increased output of adrenaline evidenced as chemical changes in blood during circulation,
3. slow, deep breathing,
4. a change in the electrical resistance of skin with changes in activity of the sweat glands,
5. brief changes in skeletal muscle tension.

According to environmentalist Thomsa G. Ayles Worth, "constant noise may cause our blood-vessels to contract, our skin to become pale, our muscles to contract and adrenaline to be shot into our blood stream." This adrenaline is responsible for both excretory and inhibitory responses in living beings. This is the reason that factory workers develop abnormal heartbeat rates and suffer from insomnia, nervousness, and impaired motor coordination. The US Government has kept 90 dB as a health hazard for an 8-h-day working environment. It has been proved that high noise is bad particularly for those suffering from hypertension and diabetics. Noise also produces startling effects on babies, and they may even develop a fear psychosis as a result of sharp and sudden noise.

15.4.2 Effects on Communication

External sounds are able to interfere with conversations and use of the telephone as well as the enjoyment of radios, television programs, and like pastimes. It can thus effect the efficiency of offices, schools, and other place where communication has been of vital importance. The maximum acceptable level of noise under such conditions has been 55 dB. 70 dB is considered very noisy and serious interference with verbal communication is inevitable.

15.4.3 Epidemiological Studies

Several researchers have conducted field studies testing industrial workers and/or collating their health records in an attempt or to overcome the limitations of duration and realism in laboratory studies. The difference between very noisy industries and less noisy industries is the two groups indicate a higher incidence of problems among the high noise group than by the low noise group. The high noise group came from the light industries such as textile industries. There are other numerous differences that could have effects on health, such as heat, physical work load, anxiety, and the type of people.

Noise exposure can cause two kinds of health effects: **non-auditory effects** and **auditory effects**. Non-auditory effects include stress, related physiological and behavioral effects, and safety concerns. Auditory effects include hearing impairment resulting from excessive noise exposure. Noise-induced permanent hearing loss is the main concern related to occupational noise exposure.

15.4.4 Auditory Health Effects

The main auditory effects include these:

Acoustic trauma: sudden hearing damage caused by short burst of extremely loud noise such as a gunshot,

Tinnitus: ringing or buzzing in the ear,

Temporary hearing loss: also known as temporary threshold shift, which occurs immediately after exposure to a high level of noise; there is gradual recovery when the affected person spends time in a quiet place, and complete recovery may take several hours,

Permanent hearing loss: Permanent hearing loss, also known as permanent threshold shift (PTS), progresses constantly as noise exposure continues month after month and year after year. The hearing impairment is noticeable only when it is substantial enough to interfere with routine activities. At this stage, a permanent and irreversible hearing damage has occurred. Noise-induced hearing damage cannot be cured by medical treatment and worsens as noise exposure continues.

When noise exposure stops, the person does not regain the lost hearing sensitivity. As the employee ages, hearing may worsen as "age-related hearing loss" adds to the existing noise-induced hearing loss.

15.4.5 Characteristics of Noise-Induced Permanent Hearing Loss

The main characteristics of noise-induced hearing loss are these:

- Noise-induced hearing loss is a cumulative process: both level of noise and exposure time over a worker's work history are important factors.
- At a given level, low-frequency noise (below 100 Hz) is less damaging compared to noise in the mid-frequencies (1000–3000 Hz).
- Noise-induced hearing loss occurs randomly in exposed persons.
- Some individuals are more susceptible to noise-induced hearing loss than others.
- In the initial stages, noise-induced hearing loss is most pronounced at 4000 Hz, but it spreads over other frequencies as noise level and/or exposure time increases.

Hearing sensitivity declines as people become older. This medical condition is called presbycusis. Age-related hearing loss adds to noise-induced hearing loss. Hearing ability may continue to worsen even after a person stops working in a noisy environment. Noise affects the hearing organs (cochlea) in the inner ear. That is why noise-induced hearing loss is a sensory-neural type of hearing loss. Certain medications and diseases may also cause damage to the inner ear resulting in hearing loss. Generally, it is not possible to distinguish sensory-neural hearing loss caused by exposure to noise from sensory-neural hearing loss due to other causes. Medical judgment, in such cases, is based on the noise exposure history. Workers in noisy environments who are also exposed to vibration (e.g., from a jack hammer) may experience greater hearing loss than those exposed to the same level of noise but not to vibration. Some chemicals are ototoxic; that is, they are toxic to the organs of hearing and balance or the nerves that go to these organs. This means that noise-exposed workers who are also exposed to ototoxic chemicals (e.g., toluene and carbon disulfide) may suffer from more hearing impairment than those who have the same amount of noise exposure without any exposure to ototoxic chemicals.

15.4.6 Measurement of Hearing Loss

Hearing loss is measured as a threshold shift in dB units using an audiometer. The 0 dB threshold shift reading of the audiometer represents the average hearing threshold level of an average young adult with disease-free ears. The PTS, as measured by audiometry, is the decibel-level of sounds of different frequencies that are just barely audible to that individual. A positive threshold shift represents hearing loss, and a negative threshold shift means better than average hearing when compared with the standard. Several methods of calculating the percentage of hearing disability are in use. The American Medical Association (AMA)/American Academy of Otolaryngology (AAO) formula is widely accepted in North America. The current method recommended by AMA/AAO is as follows:

1. The average hearing threshold level at 500, 1000, 2000, and 3000 Hz should be calculated for each ear.
2. ultiplying, one should calculate the percentage of impairment for each ear (the monaural loss) as 1.5 times the amount by which the aforementioned average exceeds 25 dB (low fence). Hearing impairment is 100% for the 92-dB average hearing threshold level.
3. The hearing disability (binaural assessment) is calculated by multiplying the smaller percentage (better ear) by 5, adding it to the larger percentage (poorer ear), and dividing the total by 6.

15.4.7 Relationship Between Noise Exposure and Hearing Loss

From the scientific data accumulated to date, it is possible to determine the risk of hearing loss among a group of noise-exposed persons. To do this we need the following data:

- a measure of daily noise exposure level,
- duration of noise exposure (months, years),
- age of person,
- Hearing loss is defined as average threshold shift at 500, 1000, 2000, and 3000 Hz (Fig. 15.3).

15.5 INDUSTRIAL NOISE

No environmental factor has caused so much confusion regarding its effect on workers efficiency and workers health as industrial noise. Noise in industry originates from processes causing impact, vibration or reciprocation movements, friction, and turbulence in air or gas streams. Noise emission standards have only an indirect control over the noise radiated by a machine. They state maximum permissible sound levels in

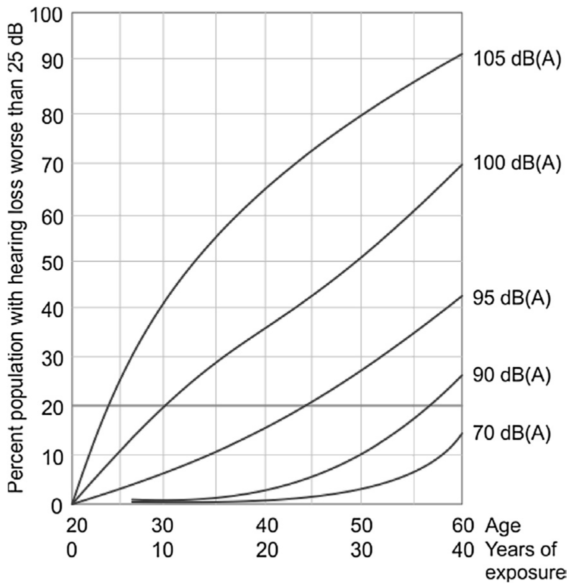

Figure 15.3 Relation between exposure and hearing loss.

work places; acceptable daytime and nighttime levels in residential, commercial, and industrial areas; and maximum permissible noise crossing industrial and construction site boundaries. The maximum permissible sound level at a worker's ears and the time of exposure are not related directly to the noise produced by any one machine but depend on the total noise in the area, where the workers are located with respect to the machine, and other factors. For this reason, noise emission standards or their intent must be confined with product-oriented noise emission regulations. It has been reported that high intensities, high frequencies, and the intermittent nature of noise are the factors of annoyance for the workers. Such a situation not only brings about physical and psychological damages but also impairs workers' efficiency, giving rise to their low production and causing dissatisfaction. Community response to industrial noise and hence the setting of acceptable limits for community areas is difficult to establish precisely because of the variety and complexity of the different factors involved.

The measured noise in such cases may be produced by a single machine or by a combination of many kinds of machinery. Fig. 15.4(A) shows the interrelationship between the elements of noise. Fig. 15.4(B) shows the various paths for the management of noise.

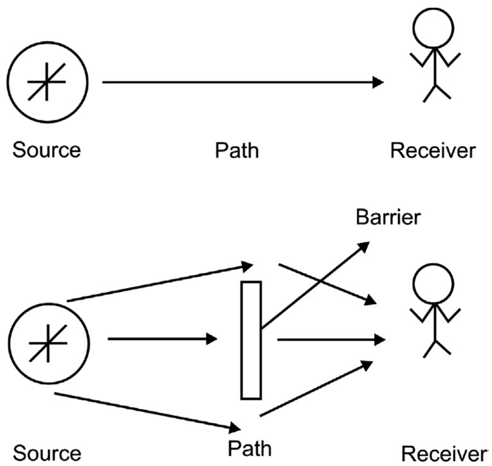

Figure 15.4A Interrelation between elements of noise.

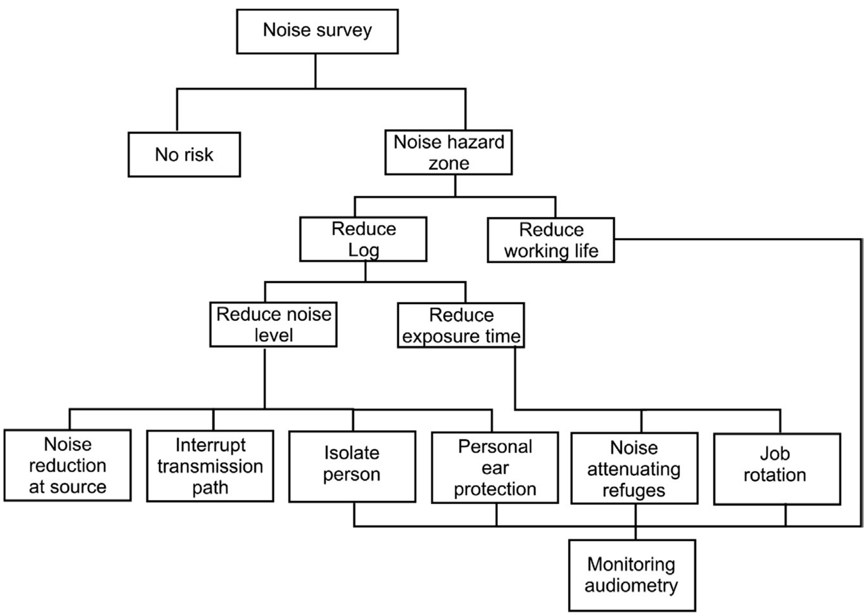

Figure 15.4B Management of noise.

15.6 NOISE SOURCE FROM TRANSPORTATION SECTOR

1. **Aircraft noise**: The noise spectra of a wide-body fan jet reveal that sound pressure levels are higher on takeoff than during the approach to land. This is typical of all aircraft. The annoyance criteria for aircraft operations are based on extensive field measurements.
2. **Highway vehicle noise**: The level of highway traffic noise depends on three things: (1) the volume of the traffic, (2) the speed of the traffic, and (3) the number of trucks often in the flow. Generally, the loudness of traffic noise is increased by heavier traffic volumes, higher speeds, and greater numbers of trucks. Vehicle noise is a combination of the noises produced by the engine, exhaust, and tires: the loudness of traffic noise can also be increased by defective mufflers or other faulty equipment on vehicles. Any condition (such as a steep incline) that causes heavy laboring of motor vehicle engines will also increase traffic noise levels. In addition, there are other more complicated factors that affect the loudness of traffic noise. For example, as a person moves away from a highway, traffic noise levels are reduced by distance, terrain, vegetation, and natural and manmade obstacles. Traffic noise is not usually a serious problem for people who live more than 500 ft from heavily traveled freeways or more than 100–200 ft from lightly traveled roads.

For most automobiles, exhaust noise constitutes the predominant source for normal operation below about 55 km/h. Although tire noise is much less of a problem in automobiles than trucks, it is the dominant noise source at speeds above 80 km/h. While not as noisy as trucks, the total contribution of automobiles to the noise environment is significant because of the large number of vehicles in operation. Diesel trucks are 8–10 dB noisier than gasoline-powered ones. At speeds above 80 km/h, tire noise is the source on trucks. The "crossbar" tread is the noisiest. Motorcycle noise is highly dependent on the speed of the vehicle. The primary source of noise is the exhaust. The noise spectra of two-cycle and four-cycle engines are of somewhat different character. The two-cycle engines exhibit more frequency spectra energy content:

1. based on estimates of the total number of units in operation per day
2. equivalent level for evaluation of relative hearing damage risk
3. during engine trimming operation.

Table 15.3 Summary of Noise Characteristics of Internal Combustion Engines

Source	A-Weighted Noise Energy (kWh/day)[a]	Typical A-Weighted Noise Level at 15.2 m [dB(A)]	8-h Exposure Level [dB(A)][b] Average	Maximum	Typical Exposure Time (h)
Lawn mowers	63	74	74	82	1.5
Garden tractors	63	78	N/A	N/A	N/A
Chain saws	40	82	85	95	1
Snow blowers	40	84	61	75	1
Lawn edgers	16	78	67	75	½
Model aircraft	12	78	70[c]	79[c]	¼
Leaf blowers	3.2	76	67	75	¼
Generators	0.8	71	—	—	—
Tillers	0.4	70	72	80	1

[a]Based on estimates of the total number of units in operation per day.
[b]Equivalent level for evaluation of relative hearing damage risk.
[c]During engine trimming operation.

15.6.1 Sources of Traffic Noise

At low speeds, vehicle engines, transmissions, exhausts, and brakes cause most traffic noise. The stop–start braking and acceleration during peak-hour congestion also increases noise levels. On freeways where speeds are high and relatively constant, most noise is caused by a combination of tire contact with the road and aerodynamic drag over the vehicle.

Trucks and motorcycles combine to make up 7% of vehicles on our roads, but they are largely responsible for the peak noises that stand out from the steady background rumble. It is these sharp and intermittent noises that are more likely to cause sleep disturbances and to contribute to other physical and psychological problems. The noise levels of internal combustion engines of various sources are given in Table 15.3.

15.7 THE NOISE POLLUTION (REGULATION AND CONTROL) RULES, 2000, IN INDIA

In exercise of the powers conferred by clause (ii) of subsection (2) of section 3, subsection (1) and clause (b) of subsection (2) of section 6 and section 25 of the Environment (Protection) Act, 1986 (29 of 1986) read with rule 5 of the Environment (Protection) Rules, 1986, the central government hereby makes the rules for the regulation and control of noise producing and generating sources, namely:

1. Short-Title and Commencement:

(1) These rules may be called the Noise Pollution (Regulation and Control) Rules, 2000.
(2) They shall come into force on the date of their publication in the Official Gazette.

2. Definitions: In these rules, unless the context otherwise requires,

(a) "Act" means the environment (protection) Act, 1986 (29 of 1986);
(b) "Area/zone" means all areas which fall in either of the four categories given in the schedule annexed to these rules;
(c) "Authority" means and includes any authority or officer authorized by the central government, or as the case may be, the state government in accordance with the laws in force and includes a district magistrate, police commissioner, or any other officer not below the rank of the deputy superintendent of police designated for the maintenance of the ambient air quality standards in respect to noise under any law for the time being in force;
(d) "Court" means a governmental body consisting of one or more judges who sit to adjudicate disputes and administer justice and includes any court of law prescribed over by a judge, judges, or a magistrate and acting as a tribunal in civil, taxation, and criminal cases;
(e) "Educational institution" means a school, seminary, college, university, professional academies, training institutes, or other educational establishment, not necessarily a chartered institution and includes not only buildings, but also all grounds necessary for the accomplishment of the full scope of educational institution, including those things essential to mental, moral, and physical development;
(f) "Hospital" means an institution for the reception and care of sick, wounded, infirm, or aged persons, and it includes government or private hospitals, nursing homes, and clinics.
(g) "Person" shall include any company or association or body of individuals, whether incorporated or not.
(h) "State government" in relation to a union territory means the administrator thereof appointed under article 239 of the constitution.

3. Ambient air quality standards in respect to noise for different areas/zones:

(1) The ambient air quality standards in respect to noise for different areas/zones shall be such as specified in the schedule annexed to these rules.
(2) The state government shall categorize the areas into industrial, commercial, residential, or silence areas/zones for the purpose of implementation of noise standards for different areas.
(3) The state government shall take measures for abatement of noise including noise emanating from vehicular movements and ensure that the existing noise levels do not exceed the ambient air quality standards specified under the rules.
(4) All development authorities, local bodies, and other concerned authorities while planning developmental activity or carrying out functions relating to town and country planning shall take into consideration all aspects of noise pollution as a parameter of quality of life to avoid noise menace and to achieve the objective of maintaining the ambient air quality standards in respect of noise.
(5) An area comprising not less than 100 meters around hospitals, educational institutions, and courts may be declared as a silence area/zone for the purpose of these rules.

4. Responsibility as to enforcement of noise pollution control measures:

(1) The noise levels in any area/zone shall not exceed the ambient air quality standards in respect to noise as specified in the schedule.
(2) The authority shall be responsible for the enforcement of noise pollution control measures and the due compliance of the ambient air quality standards in respect to noise.

5. Restriction on the use of loudspeakers/public address system:

(1) A loudspeaker or a public address system shall not be used except after obtaining written permission from the authority.
(2) A loudspeaker or a public address system shall not be used at night (between 10:00 p.m. and 6:00 a.m.) except in closed premises for communication within, e.g., auditoria, conference rooms, community halls, and banquet halls.
(3) Notwithstanding anything contained in sub-rule (2), the state government may subject to such terms and conditions as are necessary to reduce noise pollution a permit for the use of loud speakers or public address systems during night hours (between 10:00 p.m. and 12:00 midnight) on or during any cultural or religious festive occasion of a limited duration not exceeding 15 days in all during a calendar year (*added vide S.O. No. 1088(E) dated 11th October, 2002*).

6. Consequences of any violation in silence zone/area:

Whoever, in any place covered under the silence zone/area, commits any of the following offenses shall be liable for penalty under the provision of the Act:

(i) whoever plays any music or uses any sound amplifiers,

(ii) whoever beats a drum or tom–tom or blows a horn either musical or pressure, or trumpet or beats, or sounds any instrument,

(iii) whoever exhibits any mimetic, musical, or other performances of a nature to attract crowds.

7. Complaints to be made to the authority:

(1) A person may, if the noise level exceeds the ambient noise standards by 10 dB(A) or more given in the corresponding columns against any area/zone, make a complaint to the authority.

(2) The authority shall act on the complaint and take action against the violator in accordance with the provisions of these rules and any other law in force.

8. Power to prohibit, etc., continuance of music sound or noise:

(1) If the authority is satisfied from the report of an officer in charge of a police station or other information received by him/her that it is necessary to do so to prevent annoyance, disturbance, discomfort, or injury or risk of annoyance, disturbance, discomfort, or injury to the public or to any person who dwells or occupies property on the vicinity, he/she may by a written order issue such directions as he/she may consider necessary to any person for preventing, prohibiting, controlling, or regulating the following:

 (a) the incidence or continuance in or upon any premises of

  (i) any vocal or instrumental music,

  (ii) sounds caused by playing, beating, clashing, blowing or use in any manner whatsoever of any instrument including loudspeakers, public address systems, appliance, or apparatus or contrivance that is capable of producing or re-producing sound

 (b) the carrying on in or upon any premises of any trade, avocation, or operation or process resulting in or attended with noise.

(2) The authority empowered under sub-rule (1) may, either on its own motion or on the application of any person aggrieved by an order made under sub rule (1), either rescind, modify, or alter any such order: Provided that before any such application is disposed of, the said authority shall afford to the applicant an opportunity of appearing before it either in person or by a person representing him/her and showing cause against the order and shall, if it rejects any such application either wholly or in part, record its reasons for such rejection.

15.8 GENERAL NOISE CONTROL

15.8.1 Source Path Receiver Concept

It you have a noise problem and want to solve it, you have to find out something about what the noise is doing, where it comes from, how it travels, and what can be done about it. A straightforward approach is to examine the problem in terms of its three basic elements:

1. Sound arises from a source.
2. Travels over a path.
3. Affects a receiver or listener.

The source may be one or any number of mechanical devices that radiate noise or vibratory energy. Such a situation occurs when several appliances or machines are in operation at a given time in a home or office.

The most obvious transmission path by which noise travels is simply a direct line-of-sight air path between the source and the listener. Noise can travel from one point to another via any one path or a combination of several paths. The receiver may be, for example, a single person or a group of people.

Solution of a given problem might require alternation or modification of any or all these three basic elements.

1. Modifying the source to reduce its noise output,
2. Altering or controlling the transmission path and the environment to reduce noise level reaching the listener,
3. Providing the receiver with personal equipment.

15.8.2 Control of Noise Source by Design

15.8.2.1 Reduce Impact Factors

Many machines and items of equipment are designed with parts that strike forcefully against other parts, producing noise. Often, this striking action or impact is essential to the machine function. Several steps can be taken to reduce noise from impact forces. The particular remedy to be applied will be determined by the nature of the machine in question.

Some of the obvious design modifications are as follows:

1. Reduce the weight, size, or height of fall of the impacting mass.
2. Cushion the impact by inserting a layer of shock-absorbing material between the impacting surfaces.
3. Whenever practical, one of the impact heads or surfaces should be made of nonmetallic material to reduce resonance.
4. Substitute the application of a small impact force over a long time period for a large force over a short period to achieve the same result.

5. Smooth out acceleration of moving parts by applying accelerating forces gradually. Avoid high, jerky acceleration or jerky motion.
6. Minimize overshoot, backlash, and loose play in cams, followers, gears, and other parts.

15.8.2.2 Reduce Speeds and Pressures

Reducing the speed of rotating moving parts in machines and mechanical systems results in smoother operation and lower noise output. Likewise, reducing pressure and flow velocities in air, gas, and liquid circulation systems lessens turbulence, resulting in decreased noise radiation. The following suggestions can be implemented:

1. Fans, impellers, rotors, turbines, and blowers should be operated at the lowest blade tip speeds that will still meet job needs.
2. All other factors being equal, centrifugal, squirrel-cage type fans are less noisy than vane, axial, or propeller type fans.
3. In air ventilation systems, a 50% reduction in the speed of the air flow may lower the noise output by 10–20 dB, or roughly one-quarter to one-half of the original loudness.

15.8.2.3 Reduce Frictional Resistance

Reducing friction between rotating, sliding, or moving parts in mechanical systems frequently results in smother operation and lower noise output. The other points to be checked include these:

1. *Alignment*: Proper alignment of all rotating, moving, or contacting parts results in less noise output.
2. *Polish*: Highly polished and smooth surfaces between sliding, meshing, or contacting parts are required for quiet operation, particularly where bearings, gears, cams, rails, and guides are concerned.
3. *Balance*: Static and dynamic balancing of rotating parts reduces frictional resistance and vibration, resulting in lower noise output.
4. *Eccentricity*: Off-centering of rotating parts such as pulleys, gears, rotors, and shaft/bearing alignment causes vibration and noise.

15.8.2.4 Reduce Radiation Area

Generally speaking, the larger the vibrating part or surface is, the greater the noise output will be. The rule of thumb for quiet machine design is to minimize the effective radiating surface areas of the parts without impeeding their operation or structural strength. This can be done by making parts smaller, removing excess material, or cutting openings, slots, or perforations in the parts.

15.8.2.5 Reduce Noise Leakage

In many cases, machine cabinets can be made into rather effective sound-proof enclosures through simple design changes and the application of some sound-absorbing treatment.

15.8.2.6 Isolate and Damper Vibrating Elements

Generally, vibration problems can be considered in two parts. First, we must prevent energy transmission between the source and surfaces that radiate the energy. Second, we must dissipate or attenuate the energy somewhere in the structure. The first part of the problem is solved by *isolation*. The second part is solved by *damping*.

15.8.2.7 Provide Mufflers/Silencers

There is no real distinction between mufflers and silencers. They are often used interchangeably. They are, in effect, acoustical filters and are used when fluid flow noise is to be reduced. The devices can be classified into two fundamental groups: *adsorptive mufflers* and *reactive mufflers*.

15.8.3 Noise Control in the Transmission Path

The next method is to set up devices in the transmission path to block or reduce the flow of sound energy before it reaches your ears. This can be done in several ways:

1. absorb the sound along the path,
2. deflect the sound in some other direction by placing a reflecting barrier in its path,
3. contain the sound by placing the source inside a sound-insulating box or enclosure.

15.8.3.1 Separation

The use of the absorptive capacity of the atmosphere can be made use of as well as divergence, as a simple, economical method of reducing the noise level. Air absorbs high-frequency sounds more effectively than it absorbs low-frequency sounds.

If we can double the distance from the point source, we will succeed in lowering the sound pressure level by 6 dB.

15.8.3.2 Absorbing Materials

Noise, like light, will bounce from one hard surface to another. In noise control work, this is called *reverberation*. Sound absorbing materials are rated either by their *Sabin absorption coefficients (α_{SAB})* at 125, 500, 1000, 2000, and 4000 Hz or by a single number rating called the *noise reduction coefficient*. Sound absorbing materials such as acoustic tile, carpets, and drapes placed on ceilings, floors, or wall surfaces can reduce the noise level in most rooms by about 5–10 dB for high-frequency sounds, but only by 3 or 3 dB for low-frequency sounds.

15.8.3.3 Acoustic Lining

Noise transmitted through ducts, pipes chases, or electrical channels can be reduced effectively by lining the inside surfaces of such passageways with sound-absorbing materials. A comparable degree of noise reduction for the lower frequency sounds is considerably more difficult to achieve because it usually requires at least a doubling of the thickness and/or length of acoustic treatment.

15.8.3.4 Barriers and Panels

Placing barriers, screens, or deflectors in the noise path can be an effective way of reducing noise transmission, provided that the barriers are large enough in size, and depending upon whether the noise is high frequency or low frequency. High-frequency noise is reduced more effectively than low-frequency noise. The effectiveness of a barrier depends on its location, its height, and its length. Fig. 15.5 shows the frequencies and the center frequencies of the octave band. The barrier may be either close to the source or receiver, subject to the condition of $R \ll D$, or in other words, to increase the traverse length for the sound wave. It should also be noted that the presence of the barrier itself can reflect sound back toward the source. At very large distances, the barrier becomes less effective because of the possibility of refractive atmospheric effects.

15.8.3.5 Transmission Loss

When the position of the noise source is very close to the barrier, the diffracted noise is less important than the transmitted noise. If the barrier is in fact a wall panel that is sealed at the edges, the transmitted noise is the only one of concern. The ratio of the sound energy incident on one surface of a panel to the energy radiated from the opposite surface is called the *sound transmission loss* (TL). The actual energy loss is partially reflected and partially absorbed.

15.8.3.6 Enclosures

Sometimes, it is much more practical and economical to enclose a noisy machine in a separate room or box than to quiet it by altering its design,

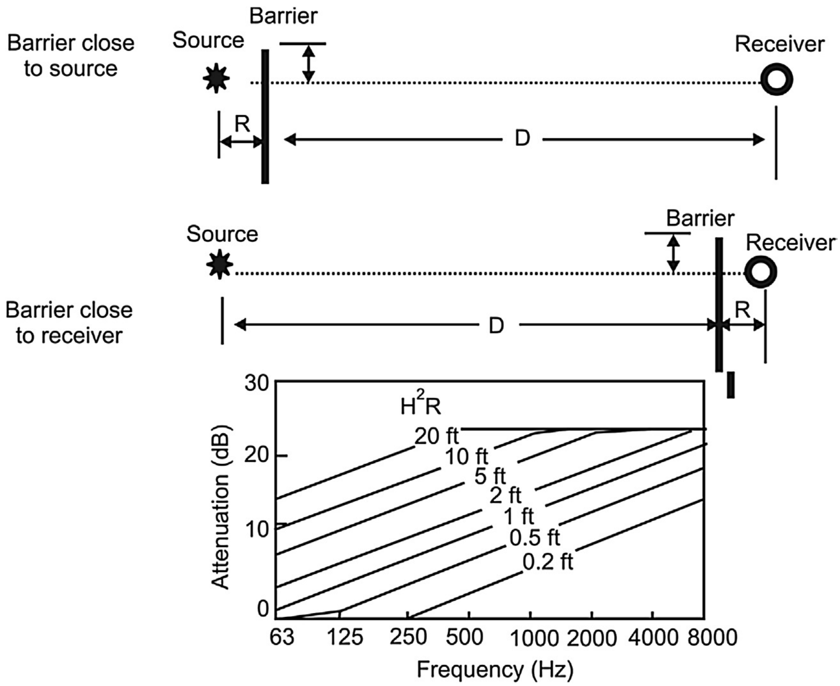

Figure 15.5 Attenuation of noise levels using barriers.

operation, or parts. The walls of the enclosure should be massive and air-tight to contain the sound. Absorbent lining on the interior surfaces of the enclosure will reduce the reverberant build-up of noise within it. Structural contact between the noise source and the enclosure must be avoided, or else the source vibration will be transmitted to the enclosure walls and, thus, short-circuit the isolation.

15.8.3.7 Control of Noise Source by Redress

The best way to solve noise problems is to design them out of the source. Hence, we are frequently faced with an existing source that, either because of age or poor design, is a noise problem. The result is that we must redress, or correct the problem, as it currently exists.

Balance Rotating Parts

One of the main source of machinery noise is structural vibration caused by the rotation of poorly balanced parts, such as fans, fly wheels, pulleys, cams, and shafts. Measures used to correct this condition involve the addition of counterweights to the rotating unit or the removal of some weight from the unit.

Reduce Frictional Resistance

A well-designed machine that has been poorly maintained can become a serious source of noise. General cleaning and lubrication of all rotating, sliding, or meshing parts at contact points should go a long way toward fixing the problem.

Apply Damping Materials

Since a vibrating body or surface radiates noise, the application of any material that reduces or restrains the vibrational motion of that body will decrease its noise output. The basic types of redress vibration damping materials are available:

1. liquid mastics, which are applied with a spray gun and harden into relatively solid materials, the most common being automobile "undercoating,"
2. pads of rubber, felt, plastic foam, leaded vinyls, adhesive tapes, or fibrous blankets, which are glued to the vibrating surface,
3. sheet metal viscoelastic laminates or composites, which are bonded to the vibrating surface.

Seal Noise Leaks

Small holes in an otherwise noise tight structure can reduce the effectiveness of the noise control measures. If the designed TL of an acoustical enclosure is 40 dB, an opening that comprises only 0.1% of the surface area will reduce the effectiveness of the enclosure by 10 dB.

Perform Routine Maintenance

Regular maintenance is required. For example, studies of automobile tire noise in relation to pavement roughness show that maintenance of the pavement surface is essential to keep noise at minimum levels. Normal road wear can yield noise increases on the order of 6 dB.

Protect the Receiver

When all else fails: When exposure to intense noise fields is required and none of the measures are practical, then the following two techniques are commonly employed to limit noise.

Alter work schedule: Limit the amount of continuous exposure to high noise levels. In terms of hearing protection, it is preferable to schedule an intensely noisy operation for a short interval of time each day over a period of several days rather than a continuous 8-h run for a day or two. Inherently noisy operations such as street repair, municipal trash collection, factory operation, and aircraft traffic should be curtailed at night and early morning hours to avoid disturbing the sleep of the community.

Ear protection: Molded and pliable earplugs, cup type protectors, and helmets are commercially available as hearing protectors. Such devices may provide noise reductions ranging from 15 to 35 dB. Earplugs are effective only if they are properly fitted by medical personnel. These devices should be used as a last resort after all other methods have failed to lower the noise level to acceptable limits.

15.9 CONTROL OF NOISE FROM INDUSTRY

Acoustic design criteria: One of the first decisions that should be made before starting a noise reduction program on a machine has been to establish an acoustic design goal this should be slightly lower, because the cost of noise reduction rapidly as design goals are lowered.

They must be set somewhat below what is actually needed, however, to allow for errors in measurement, unexpected acoustic leaks, differences in quality of acoustic materials, and if a group of machines is involved, to allow for difference between machines. Even though the objective may be to meet a certain noise omission standard or to comply with the same community noise ordinance, the design criteria must be either the sound power level of the machine or the sound pressure level at a fixed distance from the machine.

The main feature of effective noise control has been the provision of adequate sound insulation between the noise source and the desired environment. Sound-insulating materials must be impervious and of high density as the insulation value increases by about 5 dB for each doubling of the weight according to a relationship known as mass law. The maximum attenuation is expected from a barrier that has been about 15 dB, although in most industrial applications, reductions would be much lower than this. The attenuation requirement for a majority of industrial noise problems will usually be in the range of 15–25 dB. This order of attenuation on machines can only be attained by complete enclosure if only insulation principles have been used. Attention to detail in the design, construction, and erection of an enclosure is extremely important as any gaps or leaks severely limit the insulation potential.

1. **Screen the receiver**: In most of the industries, noise is an essential part of their machines used, and if a worker is continuously exposed to sound hazards for a long period, he may suffer from annoyance, loss of efficiency, and damage to hearing. It has become necessary that employees be given ear defenders or earplugs to protect them from such losses.

2. **Internal design changes**: Centrifugal compressor noise can be controlled to a limited extent by internal design changes, but large, high-speed high-horsepower machines require additional external sound control when they must meet low noise criteria. Noise reduction can be accomplished by selecting the proper combination of blades and by controlling clearance between rotating and stationary vanes.
3. **External design techniques**: The EPA has designated profitable air compressors as a major noise source. Their noise can be reduced by external design techniques. It would be a waste of time and money to attempt reduction by internal design changes in compressor because the driving internal combustion engine is the major noise source. The situation will probably remain this way until quieter engines can be obtained. Small compressors can be reduced to acceptable sound levels without much trouble, but the large units require complete enclosures including sound absorption and sound isolation.
4. **Silencers**: Generally speaking, two types of silencers are known
   - **a.** reactive
   - **b.** absorptive

     The reactive type has been analogous to an electrical jetter. It is frequently selective, and it does not absorb energy but either transmits or reflects it back to the source depending on the frequency of sound. Most reactive silencers for industrial applications have been high-pass filters that alternate low-frequency noise only; the main reason for this has been that the dimensions of the reactive elements must be small compared with the wavelength of sound to be alternated, and high-frequency attenuation is more readily achieved by absorptive means.
5. **Vibration isolation**: A vibration machine could be isolated from the surrounding structure by supporting it on resistant mountings. This then may be associated as a simple mass spring.
6. **Miscellaneous methods**: Impact and vibration noises are considerably reduced by the mass, careful design of shape, and arrangement of parts and machines so that resonance is avoided. Nevertheless certain machines will remain inherently noise, and demand to be surrounded with absorbent or insulating screens. Noise caused by gas streams can be alternated or even eliminated by the use of suitable ducts and by correct design and positioning of inlets and outlets.

The Bureau of Indian Standards (BIS) has published several code books for sampling and analysis of noise pollution and guidelines for control of noise pollution from domestic and industrial sources. The reader is advised to refer to the BIS code books (Table 15.4) for a better understanding of methods of noise sampling. For sampling of noise levels from industrial sources, noise levels in the different octave bands are measured by a sound level meter in conjunction with octave band filters at the worker's ear level or at about a distance of 1 m from the source of noise.

15.10 CONTROL OF NOISE FROM TRANSPORTATION

Control of airport noise: Noise complaints from people living beneath flight paths have reached record levels across the world. Most of the time a "three-legged stool" approach to the problem has been adopted. The first is to ensure that aircraft emit the lowest possible noise levels, compatible with airline safety. Aircraft such as the Boeing 727 and 757 are as much as 20 dB quieter than the Boeing. The second is to impose controls on airport operations, such as restricting the number of arrivals and departures, imposing night curfews, and minimizing flight paths over populated areas. The third is to control urban development near existing airports and the site of future airports. Homes, schools, hospitals, and commercial and public buildings all need protection from excessive aircraft noise.

Traffic noise has become a serious problem now because of inadequate urban planning in the past. Homes, schools, hospitals, churches, libraries, and other community buildings were routinely built on main roads without buffer zones or adequate soundproofing. The problem has been compounded by increases in traffic volumes far beyond the expectations of our early urban planners.

Table 15.4 Selected BIS Code Books on Noise Pollution

BIS Code	Description
IS—4954-1968	Noise abatement in town planning recommendations
IS—3098-1990	Noise emitted by moving road vehicles, measurement
IS—10399-1982	Noise emitted by stationary road vehicles, methods of measurement of
IS—6098-1971	Airborne noise emitted by rotating electrical machinery, method of measurement of
IS—4758-1968	Noise emitted by machines, methods of measurements of
IS—3483-1965	Noise reduction in industrial buildings, code of practice for
IS—1950-1962	Sound insulation of nonindustrial buildings, code of practice
IS—9167-1979	Ear protectors

15.10.1 Structure-Borne and Airborne Noise

Noise can pass from one room to another either through the building structure itself (structure-borne noise) or through the surrounding air (airborne noise). Airborne noise is the more common and occurs, for example, when loud music in a living area interferes with people sleeping in bedrooms. Airborne noise can pass from one room to another along a variety of paths such as open doors and windows, openings in walls separating the rooms, stairwells, or heating and air conditioning ducts. Structure-borne noise occurs when the building structure itself is made to vibrate, for example, a washing machine in contact with a wooden floor, a saucepan falling to the kitchen floor, and the impact of footsteps on hard floors.

There is excessive noise from trucks that use engine braking as a backup to conventional wheel braking. While engine braking is an indispensable safety device, fitting trucks with improved and relatively inexpensive mufflers can significantly reduce the noise levels.

The installation of noise barriers along major roads and freeways is another way to combat traffic noise. The barriers deflect noise from adjoining urban areas and can be made from relatively light and inexpensive materials such as timber, fibro-cement sheet, or Perspex. An effective barrier needs to be long enough and high enough to deflect noise from the area that is to be protected. Usually, this means that the barrier blocks the line of sight to the noise source. Any gaps in the barrier (e.g., driveways) decrease its effectiveness.

15.10.2 Control of Highway Traffic Noise

The level of highway traffic noise depends on three things:

1. the volume of the traffic
2. the speed of the traffic
3. the number of trucks in the flow of the traffic

Generally, the loudness of traffic noise is increased by heavier traffic volumes, higher speeds, and greater numbers of trucks. Vehicle noise is a combination of the noises produced by the engine, exhaust, and tires. The loudness of traffic noise can also be increased by defective mufflers or other faulty equipment on vehicles. Any condition (such as a steep incline) that causes heavy laboring of motor vehicle engines will also increase traffic noise levels. In addition, there are other more complicated factors that affect the loudness of traffic noise. For example, as a person moves away from a highway, traffic noise levels are reduced by distance, terrain, vegetation, and natural and manmade obstacles. Traffic noise is not usually a serious problem for people who live more than 500 ft from heavily traveled freeways or more than 100–200 ft from lightly traveled roads.

1. Two-thousand vehicles per hour sound twice as loud as 200 vehicles per hour.
2. Traffic at 65 miles per hour sounds twice as loud as traffic at 30 miles per hour.
3. One truck at 55 miles per hour sounds as loud as 10 cars at 55 miles per hour.

15.10.3 Determining Noise Impact

Highway traffic noise is never constant. The noise level is always changing with the number, type, and speed of the vehicles that produce the noise. Traffic noise variations can be plotted on a graph, as shown in Fig. 15.6. 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. The two most common statistical descriptors used for traffic noise are L_{10} and L_{eq} L_{10} is the sound level that is exceeded 10% of the time.

In Fig. 15.6, 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-min measuring period the L_{10} was exceeded 6 min ($1/2+2+2+11/2=6$) 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 dB less than the L_{10} for the same conditions.

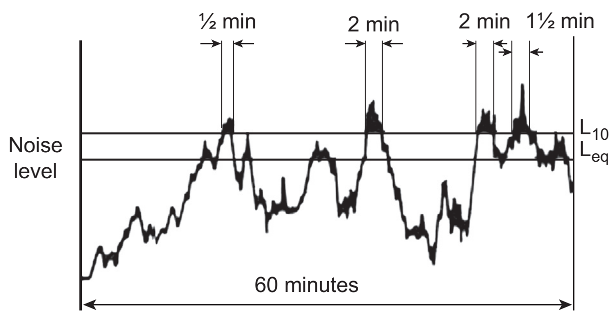

Figure 15.6 L_{10} and L_{eq} values of noise levels.

If a project causes a significant increase in the future noise level over the existing noise level, it is also considered to have an impact. Highway noise is being attacked with a three-part strategy: motor vehicle control, land use control, and highway planning and design. The responsibilities for implementing these strategies are to be shared by all levels of government: national, state, and local. The following two sections briefly describe how traffic noise impacts can be reduced or prevented through efforts to obtain quieter vehicles and efforts to control future development near highways.

The following methods can be employed:

1. **Highway planning and design**: In the planning stages of most highway improvements, highway agencies do a noise study. The purpose of this study is to determine if the project will create any noise problems. First, the existing noise levels of a highway are measured or computed by models and suitable alternatives sought.
2. **Noise reduction on existing roads**: Some noise reduction measures that are possible on existing roads or on roads that are being rebuilt include creating buffer zones, constructing barriers, planting vegetation, installing noise insulation in buildings, and managing traffic. Buffer zones are undeveloped open spaces that border a highway. Buffer zones are created when a highway agency purchases land or development rights, in addition to the normal right of way, so that future dwellings cannot be constructed close to the highway. This precludes the possibility of constructing dwellings that would otherwise experience an excessive noise level from nearby highway traffic. An additional benefit of buffer zones is that they often improve the roadside appearance. However, because of the tremendous amount of land that must be purchased and because in many cases dwellings already border existing roads, creating buffer zones is often not possible.
3. **Open space can be left as a buffer zone between residences and a highway**: Noise barriers are solid obstructions built between the highway and the homes along the highway. Effective noise barriers can reduce noise levels by 10–15 dB, cutting the loudness of traffic noise in half. Barriers can be formed from earth mounds along the road (usually called earth berms) or from high, vertical walls. Earth berms have a natural appearance and are usually attractive. However, an earth berm can require quite a lot of land if it is very high. Walls take less space. They are usually limited to 25 ft in height for structural and aesthetic reasons. Noise walls can be built of wood, stucco, concrete, masonry, metal, and

other materials. Many attempts are being made to construct noise barriers that are visually pleasing and that blend in with their surroundings.

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 that 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.

- earth berm noise barrier
- wooden noise barrier
- concrete noise barrier with woodgrain texture

Vegetation, if high enough, wide enough, and dense enough (cannot be seen through), can decrease highway traffic noise. A 200-foot width of dense vegetation can reduce noise by 10 dB, which cuts the loudness of traffic noise in half. It is often impractical to plant enough vegetation along a road to achieve such reductions; however, if dense vegetation already exists, it could be saved. If it does not exist, roadside vegetation can be planted to create psychological relief, if not an actual lessening of traffic noise levels.

15.10.4 Vegetation and Noise Reduction

Insulating buildings can greatly reduce highway traffic noise, especially when windows are sealed and cracks and other openings are filled. Sometimes, noise-absorbing material can be placed in the walls of new buildings during construction. However, insulation can be costly because air conditioning is usually necessary once the windows are sealed.

Managing traffic can sometimes 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. 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; however, about a 20 mile-per-hour reduction in speed is necessary for a noticeable decrease in noise levels.

Pavement is sometimes mentioned as a factor in traffic noise. While it is true that noise levels do vary with changes in pavements and tires, it is not clear that these variations are significant when compared to the noise from exhausts and engines, especially when there are a large number of trucks on the highway. More research is needed to determine to what extent different types of pavements and tires contribute to traffic noise. Until this research is completed, the use of different types of pavement cannot be depended upon to reduce traffic noise.

15.10.5 Noise Reduction on New Roads

All of the measures described earlier can be employed on both existing roads and new roads. There are, however, some additional measures that can usually be used only on new roads.

First, a new road can be located away from noise-sensitive areas, such as schools or hospitals, and placed near non-sensitive areas, such as businesses or industrial plants. New roads can also be located in undeveloped areas.

Second, a new road can be constructed below ground level. Much of the noise from vehicles traveling on this type of road is deflected into the air by embankments on the side of the road. Thus, these embankments function in much the same way as noise barriers.

15.11 COMPARISON OF AIR AND NOISE POLLUTION

There are a number of difference between air pollution and noise pollution.

1. The source of air pollution persists for some time, while the source of noise pollution can be immediately controlled or removed.
2. Air pollution is more serious than noise pollution because air pollution adversely affects human health and can even be very fatal. The effects caused by noise pollution are not as fatal.
3. Noise pollution is not as serious as air pollution is because air pollution may be extremely serious, leading to death.
4. Noise pollution is local, while air pollution is international.
5. Noise pollution does not contain harmful substances, while air pollution is due to various toxic substances such as CO_2, CO, SO_x, NO_x, particulate matter, organic matter, fly ash, etc.
6. Noise pollution cannot be fatal, even if not treated properly, but air pollution may cause havoc, and so control measures are extremely necessary.

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