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Noise Pollution

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1. INTRODUCTION

Noise is playing an ever-increasing role in our lives and seems a regrettable but ultimately avoidable corollary of current technology. The trend toward the use of more automated equipment, sports and pleasure craft, high-wattage stereo, larger construction machinery, and the increasing numbers of ground vehicles and aircraft has created a gradual acceptance of noise as a natural byproduct of progress. Indeed, prior to 1972 the only major federal activity in noise control legislation was a 1968 amendment to the Federal Aviation Act, whereby the FAA was directed to regulate civil aircraft noise during landings and takeoffs, including sonic booms.

Nevertheless, various noise-monitoring studies and sociological surveys in recent years have indicated the need for noise abatement. Noise pollution is thus another environmental pollutant to be formally recognized as a genuine threat to human health and the quality of life. The fundamental insight we have gained is that noise may be considered a contaminant of the atmosphere just as definitely as a particulate or a gaseous contaminant. There is evidence that, at a minimum, noise can impair efficiency, adversely affect health, and increase accident rates. At sufficiently high levels, noise can damage hearing immediately, and even at lower levels, there may be a progressive impairment of hearing.

This chapter is descriptive. It deals with the sources, characteristics, and effects of noise, describes methods for the measurement and analysis of noise, and lists some of the guidelines that are used to control the problem.

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2. CHARACTERISTICS OF NOISE

For all practical purposes, noise may be defined as unwanted sound; therefore, noise characteristics are essentially sound characteristics. Sound waves propagate through an elastic medium at a speed intrinsic to that material. In a gaseous medium such as air, sound waves produce significant changes in the density of the air, which, in turn, produce pressure changes. The parameter lending itself to quantification is *sound pressure*, the incremental variation in pressure above and below atmospheric pressure. In engineering terms, the acoustic pressure can be viewed as the gage pressure.

The standard US atmosphere has as an ambient pressure 101,300 N/m^2 (pascals, Pa). The human ear can detect sound pressures ranging from as low as 2×10^{-5} N/m^2, the threshold of hearing, to over 200 N/m^2, the threshold of pain. This wide range has prompted the use of a logarithmic scale to express sound pressures. The decibel (dB) is a dimensionless unit used to express the *sound pressure level* (SPL or L_p); the term "level" is used to emphasize the fact that a logarithm of a ratio is being expressed. More specifically, the sound pressure level is defined as

$$\begin{aligned} \mathrm{SPL} &= 10\ \log\left(p^2/p_{\mathrm{ref}}^2\right) \\ &= 20\ \log\left(p/p_{\mathrm{ref}}\right)\ \text{decibels (dB)} \end{aligned} \tag{1}$$

where p is the measured root-mean-square sound pressure (N/m^2) and p_{ref} is the reference sound pressure, 2×10^{-5} N/m^2. It is useful to note that the reference pressure is the threshold of hearing such that 0 dB corresponds to the limit of hearing. Noise measurements are, quite simply, sound measurements, and the term "noise level" is often the word used synonymously with sound pressure level.

Comfort requires that the sound level, from all sources, should be of the order of 65 dB or less (i.e., sound with a root-mean-square pressure of 3.56×10^{-2} N/m^2). Some typical noise levels are as follows (1):

100–110	Jet fly-by at 300 m (1000 ft)
90–100	Power mower
80–90	Heavy truck 64 km/h (40 mph) at 15 m (50 ft), food blender (at receiver), motorcycle at 15 m (50 ft)
60–70	Vacuum cleaner (at receiver), air conditioner at 6 m (20 ft)
40–50	Quiet residential–daytime
20–30	Wilderness

Noise levels in general have increased over the years and some authorities hold that average noise levels in cities have increased at about 1 dB per year for the last 30 yr.

The sound pressure level represents the magnitude of a noise source and is one of the characteristics that can assess whether a given noise is considered to be annoying. There are other characteristics, both intrinsic to the noise and its context, that dictate whether people will consider it to be annoying (2):

1. Frequency content or bandwidth
2. Duration
3. Presence of pure tones or transients
4. Intermittency
5. Time of day
6. Location (or activity)

The above factors introduce much subjectivity into noise pollution characterization, and various rating schemes have been devised by psychoacousticians and researchers that are meant to correlate with the annoyance-related characteristics of a noise signal. More will be said about this in Section 6.

3. STANDARDS

The Noise Control Act of 1972 became Public Law PL 92574 in October of that year. Under the Act, the Environmental Pollution Agency (EPA) had to develop criteria identifying the effects of noise on public health and welfare in all possible noise environments and to specify the noise reduction necessary for protection with an adequate margin of safety. The EPA's basic "Identification of Levels" document (3) was published in March 1974 and it concluded that virtually all of the population is protected against lifetime hearing loss when annual exposure to noise, averaged on a 24-h daily level, is less than or equal to 70 A-weighted decibels (dBA) (See Section 6 for discussion on A-weighted decibels.) This noise-level goal forms the initial base of the long-range federal program designed to prevent the occurrence of noise levels associated with the adverse effect on public health and welfare. Even so, noise levels in excess of 55 dBA can cause annoyance. The federal government's regulatory development and related activity is aimed at the annoyance-type noises that pervade the community. These noises in the approximate order of importance, especially to urban communities, are (1) surface transportation noise, (2) aircraft noise, (3) construction equipment and industrial noise, and (4) residential noise.

Although states and municipalities retain primary responsibility for noise control, they often rely on EPA recommended limits of noise levels and exposures. Presently, industry is governed by noise regulations adopted by OSHA (Occupational Safety and Health Administration), which sets noise exposure limits at an employee's location for environments of steady noise, mixed noise, and impact noise. For steady noise (i.e., noise at a constant dBA level over a period of time), a maximum exposure of 90 dBA (about the sound level emitted from a loud engine) for an 8-h day is prescribed, with a halving of exposure time for each additional 5-dBA increment.

Table 1 presents permitted exposure times for various noise levels. For mixed or varying-level noise, the exposure may not exceed a daily noise dose (D_t) of unity, as expressed in Eq. (2):

Table 1
Permissible Steady Level Noise Exposure

Sound level (dBA)	Time permitted (h-min)	Sound level (dBA)	Time permitted (h-min)
85	16–0	102	1–31
89	9–11	104	1–9
90	8–0	106	0–52
92	6–4	108	0–40
94	4–36	110	0–30
96	3–29	112	0–23
98	2–50	114	0–17
100	2–0	115	0–15

Source: ref. 4.

$$D_t = D_1/T_1 + D_2/T_2 + D_3/T_3 + \ldots + D_n/T_n < 1 \tag{2}$$

where D_n is the actual duration of exposure at noise level n and T_n is the noise exposure limit for noise level n from Table 1.

Impact noises are generated by machines such as drop hammers and punch presses and exposure to such noises must not exceed a 140-dB peak sound pressure level. The peak sound pressure level also determines the maximum number of impacts per day that an employee may be exposed to, as indicated in Table 2.

Table 2
Permissible Impact Noise Exposure

Peak SPL (dBA)	Impacts/day
140	100
130	1,000
120	10,000
110	100,000

Source: ref. 4.

If an employee is exposed to both steady noise and impulsive noise throughout the day, the combined effect can be handled quite simply. For predictave purposes one needs to treat the ratio of the number of impacts N_n at a given peak sound pressure level to the maximum number of impacts allowed at that level and add this fraction to the steady-level calculation. The combined fractions from all sources should not exceed unity. Furthermore, a hearing conservation program must be implemented that will include, at least, an annual audiometric test for employees exposed to noise levels greater than 85 dBA for 8 h or whose noise dosage D_t meets or exceeds 0.5. Such a plan protects the workers by monitoring potential deterioration of their hearing and protects employers from unwarranted claims of damaged hearing prior to employment. For measurement purposes, the use of a sound level meter with A weighting filter and slow time response (Section 6) functionally incorporates both steady and impulsive noise.

Example

A group of factory workers are subjected to the following sound levels daily.

Location	Noise	Time
Tool crib	85 dBA	8–11 AM
Press room	92 dBA	11–12 noon
HVAC room	85 dBA	1–4 PM
Turbine room	94 dBA	4–5 PM

In addition, they are exposed to 12 impulsive events from various sources that have a sound level of 130 dB (peak). The workers are off-site for lunch from 12 noon until 1 PM. Determine if it is permissible (i.e., safe, from an acoustic/ hearing standpoint) for the workers to work in this environment.

From Eq. (2), the noise dosage from all events is $D = 3/16 + 1/6.06 + 3/16 + 1/4.6 + 12/1000 = 0.772$. Therefore, the workers can work in this environment, but they should have their hearing checked periodically because their exposure is greater than 0.5.

4. SOURCES

In trying to identify the various sources of noise, one immediately thinks of the din that characterizes modern cities. In fact, a major emphasis has been placed on community sound studies in urban areas (5–10). This owes to the demonstrable fact that urban areas are generally noisier than rural areas, and because larger numbers of people live in urban areas, where they are presumably affected by the noise, the benefits may be expected to be proportionally larger. Urban noise levels are a complex mixture of noise from transportation, factories, industries, machines, and people. Basically, noise sources can be grouped into three types: transportation, industrial, and residential.

Transportation sources of noise are comprised principally of automotive and aircraft noises; motorcycles, scooters, and snowmobiles should also be considered. A main contributor to transportation noise is automotive traffic. At speeds in excess of 60 miles/h (mph), tire noises are most discernible, whereas at lower speeds, engine noises tend to dominate. The road gradient can also have an effect on vehicular noise emission; for example, a 5% road gradient adds about 3 dBA to truck noise, whereas the effect on cars is usually insignificant. Noise levels increase as the number of vehicles and average speed increases. Aircraft noises have been the source of nuisance complaints from the public for a long time. Here again, various factors, such as the amount of aircraft activity, flight paths, takeoff, and approach and landing procedures, determine the amount of noise contributed to the total level. For example, the reduction in community noise from a plane at an altitude of 3000 ft as opposed to 1500 ft (prior to entering its glide slope) can be as much as 9 dBA.

Some industrial operations and equipment are significant noise sources. Principal examples are machinery or machine tools, pneumatic equipment, high-speed rotating or stamping operations, and duct, fan, and blower systems. Typical noise levels for operating personnel may be quite high. Noise levels of 105–115 dBA are encountered in grinding polycarbonates and other tough plastics; industrial wood saws emit noise levels of 100–105 dBA depending on the type of wood being cut; noise levels of 100–110 dBA are common with lathe operations; and structure-borne noises from gear housings can vary between 92 and 105 dBA. In some cases, the personnel exposure time is small, perhaps 10 min for a quick equipment check. In other cases, a full 8-h day may be spent in the vicinity of the noise. Community exposure to such noises would, of course, depend on the proximity to the noise sources, and ambient noise levels in residential areas could be affected by more than 10 dBA.

Residential sources, both indoor and outdoor, may not seem so significant at first. However, when one considers air conditioners, lawn mowers, power saws, dishwashers, kitchen and laundry appliances, television, stereos, pets, and children, the overall severity of these sources cannot be ignored. Furthermore, the simple increase in the numbers of tools, cars, gadgets, and appliances used by modern industrial societies can create a substantial noise burden.

5. EFFECTS

Sound is of great value to mankind. It warns of danger and appropriately arouses and activates all of us. It allows us the advantages of music and speech. It can calm or excite us; it can elicit our joy or sorrow. However, irrelevant or excessive sound becomes noise and is undesirable. People react to noise through its effect on the nervous system, and at this point, a certain amount of subjectivity and value judgment enters our considerations; for example, not all people react to noise in the same way. A lawn mower and motorcycle may emit an equivalent sound level, but a certain portion of the population may find one to be inoffensive and the other to be annoying. At the high and low ends of the noise-level scale, the effects on humans are obvious; for example, at 30 dBA, noise is not an annoyance, whereas at 120 dBA, it is definitely annoying to the point of producing physical discomfort in all hearers. It is at the in-between values of noise level that humans show varying susceptibility to it.

Effects of noise include physiological and annoyance types. In the former category, there is evidence indicating that exposure to noise of sufficient intensity and duration can permanently damage the inner ear, with resulting permanent hearing loss. Loss of sleep from noise can increase tension and irritability; even during sleep, noise can lessen or diminish the relaxation that the body derives from sleep. In the annoyance category, noise can interfere with speech communication and the perception of other auditory signals; the performance of complicated tasks can be affected by noise. Noise can adversely affect mood, disturb relaxation, and reduce the opportunity for privacy (2). In all of the above ways, noise can detract from the enjoyment of out environment and can affect the quality of human life.

6. MEASUREMENT

An effective noise abatement program is difficult to establish without an adequate survey and assessment of the noise problem. However, attempting to quantify ambient noise levels can be a tedious and frustrating undertaking. Unlike air and water pollution measurements, noise measurements must include subjective as well as objective factors; that is, a straightforward physical measurement of noise magnitude must be augmented with subjective loudness and annoyance-related factors. This complication has given rise to a multitude of units, rating scales, and measurement schemes (10). Nevertheless, there are some basic elements that must be considered with regard to the magnitude of noise and its frequency and temporal distribution. These elements will be considered in the following paragraphs along with some of the more prominent noise measurement parameters.

Noise levels are commonly measured by a hand-held instrument called a sound-level meter that gives either a single-number evaluation of the time-varying pressure in decibels or a spectral breakdown of the signal. The most vital part of a sound meter is the microphone, and an important measure of microphone performance for noise surveys is its directional response to sound. When noise comes from many different directions (owing to multiple sources and reflections from walls, ground, etc.), the measuring microphone must respond identically to the various noises regardless of the angle of incidence.

The sound pressure level is a purely objective quantification of noise based on the measured physical property, sound pressure. The effect of noise on humans, however, depends not only on its magnitude but also on its frequency content because the ear is not equally sensitive to noise (and its loudness) at all frequencies in the audible range of 20–20,000 Hz. Attempts to characterize the frequency response of the human ear by subjective methods have given rise to psychoacoustic data, which, in turn, have been used to develop frequency correction factors. Thus, a frequency-weighting system was derived according to which some frequencies were emphasized more than others. This system yields a single-number rating of the noise, representing noise levels in a manner similar to the subjective impression of the human ear. This particular weighting system is designated scale "A" and readings using this system are expressed as A-level decibels or dBA. Sound-level meters are available that allow the sound to pass through an electronic A-weighting network, thus yielding a single number that approximates the response of a human ear to the sound. The A-scale places less emphasis on low-frequency sound (below 500 Hz), and provides more weight to annoying middle- and high-frequency sounds (500–4000 Hz). In practice, regulations are set limiting the maximum permissible level of A-weighted sound that may be emitted from a source. An alternate weighting scale, C-weighting, was developed to incorporate the human response to loud and typically lower-frequency sound sources such as explosions. Because the use of dBC is typically in niche applications, the use of the more utilized dBA will be considered here.

An A-weighted sound-level measurement is the least complex noise evaluation system. It is adequate, perhaps, to quantify human response to a noise, but it does not give any information on how various frequency components contribute to a particular noise dBA level. This type of frequency information is most useful when designing a noise control system. Because absorption materials and other noise control products exhibit different noise attenuation characteristics at different frequencies, choosing the proper materials and devices must be based on a frequency analysis of the noise source. For such an analysis, an instrument called the octave band analyzer is most commonly used. As its name implies, this instrument separates the noise frequency spectrum into contiguous frequency bands one octave in width and it measures the sound pressure level in each of the bands. Some modern sound-level meters incorporate octave band measurements.

An octave is the interval between two sounds having a basic frequency ratio of 2; that is, the upper cutoff frequency is twice the lower cutoff frequency and the center frequencies are progressively doubled for each octave. In noise studies, the center frequencies are 31.5, 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. The center frequency of each octave band is the geometric mean, or the square root, of the lower and upper cutoff frequencies; that is, $f_0 = \sqrt{f_1 f_2}$, where f_0 is the center frequency in Hertz, f_1 is the lower cutoff frequency in Hertz, and f_2 is the upper cutoff frequency in Hertz. Table 3 illustrates the center, lower, and upper frequencies for each of the octave bands in the range of human hearing.

The sound pressure level versus frequency information provided by the octave band analyzer usually enables one to identify the dominant noise bands and thereby select the proper control materials. There are, however, certain noise control cases (e. g., sound reduction of machinery noise) in which narrower-band analyzers become necessary. In such instances, so-called narrow-band (or spectrum) analyzers are used. Half-octave analyzers have an upper cutoff frequency of $\sqrt{2}$ times the lower cutoff frequency; third-

Table 3
Octave Band Lower–Center–Upper Frequencies

Lower cutoff	Center frequency	Upper cutoff
22	31.5	44
44	63	88
88	125	176
176	250	352
352	500	706
706	1,000	1,414
1,414	2,000	2,828
2,828	4,000	5,656
5,656	8,000	11,312

Source: ref. 4.

octave analyzers have an upper cutoff frequency equal to the cube root of 2, or 1.26, times the lower cutoff frequency; tenth-octave analyzers have an upper cutoff frequency equal to the tenth root of 2, or 1.07, times the lower cutoff frequency.

The definition of center frequency still applies to narrow-band analysis. Consequently a table of center frequencies and frequency ranges (as in Table 3) may be constructed for any of the above fractional octave analyzers. For example, the lowest band of the one-third octave analyzer covers the range from 22 to 28 (22×1.26) Hz and the center frequency is 25 Hz. The next band covers the range from 28 Hz to 35 (28×1.26) Hz and the center frequency is 31.5 Hz, and so on into higher-frequency bands.

In addition to magnitude and frequency, noise can also have a temporal or time-varying character. This additional dimension of time establishes the need for supplementary equipment to record temporal variations in sound pressure levels. A temporal parameter of great value in determining noise control in indoor spaces is the reverberation time. The reverberation time (RT) of a space is defined as the time required for the sound pressure level to decay 60 dB. The usual equipment required to measure the RT for noise control purposes consists of an impulsive sound source, a sound-level meter, and a recording device. The RT is calculated from the sound decay curve based on the measurement of slope.

Temporal distribution is particularly useful for determining and expressing noise exposure in urban areas, where the noise levels fluctuate considerably in the course of a 24-h day. One way of evaluating temporal characteristics of noise is by expressing noise levels (L) represented by L_x, where x is the maximum percent of the time that a specified dBA level may be exceeded. Thus, L_1 may be read as a noise level that is exceeded only 1% of the time—a very high noise level indeed; on the other hand, L_{95} may be regarded as background noise that is exceeded 95% of the time. L_{50} corresponds to a temporal median noise level.

L_x for a particular community may be determined either by a sufficiently advanced sound-level meter or direct acquisition and manipulation with a digital computer. The results are shown as a curve whose ordinate is the percent of time a sound level h is exceeded and the abscissa is the sound level (in dBA).

Another way of expressing the temporal behavior of community noise is by the equivalent sound level (L_{eq}) as shown in Eq. (3). This is a single-number noise descriptor whose mathematical definition for a time interval t_1 to t_2 is

$$L_{eq} = 10 \log\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} \frac{p^2(t)}{p_{ref}^2(t)}\,\mathrm{d}t\right] \tag{3}$$

where $p(t)$ is the time-varying A-weighted sound pressure (in N/m^2) and p_{ref} is the reference root-mean-square sound pressure of 2×10^{-5} N/m^2.

L_{dn} is yet another descriptor of community noise and is called the day–night average sound level, as shown in Eq. (4). Here, data are analyzed as in the case of L_{eq} except that a 10-dBA penalty is applied to nighttime levels, with nighttime being defined as the period between 10 PM and 7 AM. The minimum sampling period for the evaluation of L_{dn} is 24 h, and the formula used is

$$L_{dn} = 10 \log\left\{\frac{1}{24}\left[15\left(10^{L_d/10}\right) + 9\left(10^{(L_n+10)/10}\right)\right]\right\} \tag{4}$$

where L_d is L_{eq} during daytime hours (7 AM to 10 PM) and L_n is L_{eq} for nighttime hours (10 PM to 7 AM). The L_{dn} obtained from the above equation may be corrected for seasonal, background noise levels and the presence of pure tones or impulses (10).

There are several additional noise descriptors in addition to the above that tend to characterize the "noisiness" or annoyance of sound and are based on a fair amount of subjectivity. These metrics include the perceived noise level (PNL), the effective perceived noise level (EPNL), and speech articulation index (AI) (10).

Most of the measurements and parameters described above have been designed to characterize ambient noise levels and community exposure to noise. Such measurements aid in formulating legislation and standards and in devising community-related noise control programs. In contrast to community noises, there are industrial noises within factories, workshops, and so forth that must be monitored in order to determine compliance with OSHA noise regulations. Such acoustical measurements are meant to evaluate employee exposure to work-related noises and require different measuring techniques.

For steady-level noise surveys, measurements are performed with an A-weighted sound-level meter utilizing the slow response setting, and a comparison is then made with Table 1 to check for compliance or violation. When noise is not at a constant level or when an employee's tasks take him or her from one area to another of differing sound levels, the daily noise dose can be computed from Eq. (2). Thus, a sound-level meter and stopwatch could be used to provide the D_n and T_n of Eq. (2). However, such procedures may grow time-consuming and distracting to the worker. An easier way is to use a noise dosimeter. The dosimeter is a light, compact instrument that can be carried in a pocket and allows continual, unobtrusive monitoring of noise-exposure levels. The instrument constantly measures and records noise-exposure, and at the end of the work shift it will indicate the percentage of allowable exposure received by the individual. Thus, it continually and automatically computes the dosage/time formula of Eq. (2). For extremely loud impulsive sources the use of a sound-level meter with a special accessory called the peak-hold circuit can be useful.

In order that measurement accuracy is ensured, acoustical instruments such as sound-level meters and dosimeters must be calibrated regularly. Calibration is required by OSHA before and after each day of use. If measurements are continuous over a period of hours, periodic checks on calibration are recommended. These calibration checks are necessary to obtain valid data. Calibrators called pistonphones are available that allow a rapid field calibration of acoustical instruments. Also, when purchasing instruments, it is worthwhile to ensure that the instruments are amenable to field calibration. Having to return an instrument to the factory for calibration can be time-consuming and expensive.

Hearing conservation programs to monitor sound responses of employees are also part of the noise measurement program. Hearing tests are performed on employees with the aid of an audiometer. Basically, the employees listen through headphones to test tones generated at various frequencies and the employees respond to what they hear. Such tests, carried out annually, detect changes in the employees' hearing ability.

In order that noise measurements are valid for legal purposes, they and the devices that make these measurements must meet certain standards that were developed by the American National Standards Institute (ANSI). Indeed, if action against an alleged violation is contemplated, meter and recorder construction, calibration, and use must conform strictly to ANSI standards; if not, the quality and validity of the tests and data will come into question.

In the above paragraphs, we have tried to present some of the more salient features of noise measurement and instrumentation. The technical literature abounds with descriptions of various noise studies and measurement techniques, and the interested reader would do well to consult these references (5–16).

7. CONTROL

There are essentially three approaches to noise reduction and control. The first of these is to control noise at the source. If the source is sufficiently quiet, the rest of the problem is essentially solved. Source control can be achieved by careful consideration of noise control during the design of new products. Thus, adequate mufflers to control intake and exhaust noises and absorptive enclosures and design modifications to engines can result in quieter industrial operations and automobiles. Improved rib design can result in reduced tire noise. Similar considerations apply to jet aircraft. Noisy sources can be housed in enclosures whose performance depends on the type of enclosure material used. Source noise control can also be undertaken as a retrofit measure, but this may be more expensive and could result in performance compromises. Examples of retrofit noise reduction efforts are seen in the aircraft industry. Also, in many machines, there can be found metal-to-metal contacts; these may be replaced with softer material or a cushioning element can be introduced between the metal parts. A new course of action that has arisen recently is active noise/vibration control that attempts to reduce radiated sound levels by means of either injecting sound near the source to force destructive interference or modifying the radiation efficiency of the source.

One variation of the source control theme is operation oriented, in that effective noise control may be achieved by introducing alternative methods of performing an operation. One can see that noisy operations at night incur the 10-dB penalty in the LDN metric of Eq. (4), whereas the same operation performed during the day would not. This approach is being followed by major airlines in their normally scheduled flights by following certain noise-abatement takeoff and landing procedures at major airports. Similar practices may be introduced wherever applicable in industry.

When the desired amount of noise reduction cannot always be achieved by good acoustic design at the noise source, the next best solution is the modification or alteration of the noise path between the source and the receiver. Rerouting or relocating noise sources is an example of path modification and is best applied in the planning stage of highways and airports. In many plants, noisy and quieter equipment is dispersed throughout the plant and it may be found feasible to concentrate the noisier equipment in a special limited area where effective noise control procedures may then be introduced.

Another method of path modification is to interpose barriers between the source and receiver. Such a "shielding" is useful in attenuating highway noise levels imposed on nearby areas. Absorbent-lined telephone booths are good examples of barriers being used to reflect or absorb noise into enclosed spaces. More sophisticated versions of this approach are used to combat noise intrusions into buildings.

Usually, the source control step coupled with path modification should result in an adequate noise reduction whereby the individual is subjected to no more than an acceptable noise level. However, this is not always possible, as in the case of factories and workshops, where noise levels may be high in spite of adequate controls. In such cases, the third approach to noise control is that of personal protection or control at the receiver. Either the individual's exposure to noise levels must be limited to dosage levels (as in the OSHA specifications) by limiting time and dosage level, or by further protection being afforded through the wearing of devices such as ear plugs or head phones. In the case of residential or community noise control, replacement windows or doors (with better fitting seals) may be needed on older homes to reduce interior noise in houses.

One method of noise control that does not quite fall into any of the above three categories is the concept of land-use planning. The noise levels for proposed airport, highway, and building sites can often be reasonably predicted. It is therefore the responsibility of designers, planners, and builders to assess the compatibility of proposed land use with the acoustic environment (17). Establishing land-use patterns that separate the most objectionable noise sources from noise-sensitive areas (by means of acoustical zoning, noise contours, and community noise-source inventories) is an appealing solution to a substantial part of the urban and community noise problem. The widespread implementation of land-use planning depends on the availability of highly simplified tests and screening procedures (such as EPNL and L_{dn}) that enable persons with no background in acoustics to determine the potential severity of a noise problem and thereby to assess the acoustic suitability of proposed sites. The obvious advantages of land-use planning is that it prevents noise from becoming a problem in the first place. The equally obvious limitation of land-use planning is that it does nothing to improve the existing noise situation.

It should be borne in mind that in order to achieve effective and economic noise control, a complete study and analysis of the noise problems is essential. An attempt to characterize a noise problem by using a single-decibel-level reading may not always result in an effective solution. Such single-level readings, although appealing and easily understood, are subject to error in overlooking the major importance of decibel levels in each frequency band, particularly when there are pure tone components present (see Section 6). Annoyance is strongly dependent on dB level in each frequency band, and noise control techniques are equally dependent on the decible level in each frequency band. Thus, identifying noise problems with regard to both magnitude and frequency is an important step toward intelligent noise control (10). Noise control is unique in that the solution of a noise problem ordinarily will not create other environmental problems, as is often the case with air, water, and solid waste disposal methodologies. An improperly controlled noise problem will always manifest itself as a noise problem only.

Much of noise-abatement technology is within the existing state of the art and needs only the proper incentives to be applied. OSHA and other governmental regulations have already and will continue to provide that incentive, and practical techniques will be demonstrated and documented to serve as guides for future noise-abatement programs.

Chapter 13 will deal more specifically with the subject of noise control and abatement and will provide design examples for both indoor and outdoor noise abatement.

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