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ANNOYANCE FROM ROAD TRAFFIC NOISE: A REVIEW

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Abstract

In this paper the negative effects resulting from exposure to road traffic noise on people's well being is reviewed in the light of the latest published findings. Annoyance is particularly focused on, which is considered to be one of the first and most widespread reactions to environmental noise. The nonauditory effects of noise on humans are viewed as being generally stress-related, following observations that noise exposures engender physiological reactions typical to those of stress. First, a short presentation is made of what noise in general is. Subsequently, in order to assess some subjective judgements of noise, some of the important noise descriptors, which are often used to quantify various aspects of road traffic noise are introduced. In general terms, it is found from the present review that the continuous exposure of people to road traffic noise leads to suffering from various kinds of discomfort, thus reducing appreciably the number of their well-being elements.

Drawing such a conclusion is hindered by difficulties when nonacoustical factors, for instance socio-economic situation, age and gender, are also taken into account along with the usual acoustical factors of road traffic noise. One of people's first and direct reactions to noise is in terms of annoyance. The results of several decades of research on this topic have permitted lately the establishment of a more or less quantitative relationship between the objective quantities characterizing road traffic noise and the human subjective reaction to it as expressed by annoyance. These findings are important at both the society and the individual level, in as much as they may help in regulating in a more efficient way the planning of road traffic activity in order to secure at least the minimum of comfort to the affected population. © 2001 Academic Press

Introduction

In modern times, noise is recognized as a serious health problem. Annoyance caused by noise has been known since antiquity but it is only during recent times that the importance of environmental factors is taken into consideration in transport planning decisions. This is necessary when facing the growing pollution problems caused by different agents, among which noise is responsible for a non-negligible share. In fact, of the environmental pollution factors that are affected by the use of transportation means, noise is perhaps the most commonly cited. This problem is exacerbated as the number of vehicles circulating in the urban network of roads is steadily increasing while at the same time the number of quiet hours during the night has a tendency to diminish, although at a slower rate. Hence, expressed in terms of social cost, the adverse effects of noise on people in general, and of traffic noise in particular, result in a reduction of their elements of well being.

The technical problems associated with the design of quiet vehicles are still not solved, and unfortunately so is the confinement of the noise emitted by these vehicles within the limits of what is bearable. Another important element to be taken into consideration is the subjective human sensitivity to noise, which requires considerable noise reduction before benefits can be felt. For instance, halving the acoustic power of a sound source results in only a 3 dB reduction of the noise level, and this is scarcely noticeable to the average listener.

In general, every noise problem involves a system of three basic elements: a sound source, a transmission path, and a receiver. When possible, the best way to remedy exposure to undesirable noise, both economically and aesthetically, is to control the noise emission at the source itself. But for most noise sources, the most corrective measure is making changes in the path. Moreover, different noise sources may have different acoustical characteristics. While some generate a pure tone, others may radiate a random noise with a more or less known frequency spectrum. So in this respect the definition of the noise problem is important. For traffic noise, an automobile has in general several noise generating sources, but because of commercial limitations and the very competitive car industry, this has serious difficulties in the matter of noise reduction cost (see, for instance, Mills & Aspinall, 1968; Aspinall, 1970; Rathé *et al.*, 1973). But despite this, in recent years much has been achieved in the car industry in the construction of quieter engines and better exhaust silencers. However, the dominant noise source of the car is due to the contact of the rolling tire on the road.

For traffic noise, not only is the noise source important, but it has been known for many years that driving method also affects the degree of annoyance. Indeed, data from urban traffic experiments have shown, for instance, that sudden accelerations have negative effects on traffic noise control. Efficient road planning could set speed limits and smooth traffic flow (Waters, 1970; Lewis, 1973; Jones & Hothersall, 1979). Earlier experiments have also shown that even a car passenger may be annoyed by the noise inside the automobile conveyance. Hence, through knowing the origins of the noise, and remedying the situations by relatively simple corrective measures, it is possible to reduce the annoyance caused by noise for every case (Johnson, 1979). For a resident away from the car, tire noise is another source of nuisance and its reduction depends more on the absorption properties of road materials than on the road-tire contact mechanisms (Watts, 1996; Nelson & Abott, 1987).

An automobile has a typical normalized noise spectrum, as shown in Figure 1. This feature of the spectrum, with a heavier frequency content at around 1 KHz, is also a property shared by the spectra of light-weight trucks. On the other hand, heavy trucks show different noise emitting behaviour resulting from their larger number of noise sources. Besides the flow noise and the noise due to the tires, a heavy truck has several other noise generators (see e.g. Priede, 1971; Olson, 1972; SOU, 1974; Alexandre *et al.*, 1975). These include the often highly placed exhaust, the engine (at a height of about 1 m), and the side panels. The combination of all these sources results in a noise spectrum which lies higher and is more intense and broader than that of an automobile (see Figure 1).

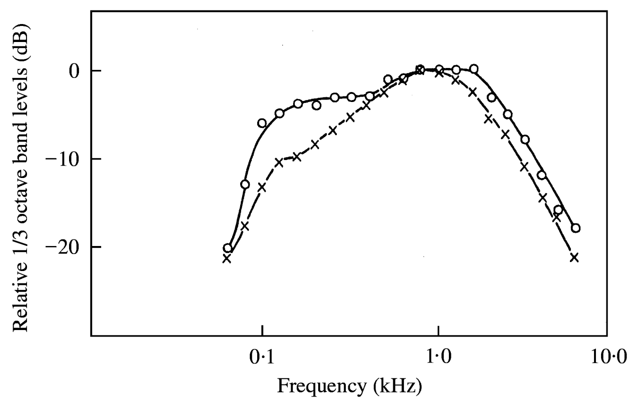

FIGURE 1. Noise spectra for typical cars and heavy trucks at highway speeds (after Hayek, 1990). –○–Heavy trucks; *car (both A-weighted).

It is worthwhile noting that from the spectra shown in Figure 1 it is difficult to conclude that a typical heavy truck may produce a noise level 90 dB more than that of an automobile (Hayek, 1990). In the 1970s and 1990s, the effectiveness of vehicle noise emission regulations permitted the progressive and appreciable reduction of the maximum noise level of cars. However, the reduction in actual road noise levels has not followed this trend and, consequently, smaller achievements are expected for the next few years. Therefore, future noise control programmes must include strategies such as landuse planning and traffic restraints (Berge, 1994).

Important factors and concepts concerning noise

Before entering into the subject of the effects of road traffic noise, and also for later reference, it may be useful to review some important factors related to sound and its quantification, and to present some notions which describe noise in general and traffic noise in particular.

The nature of sound

Sound is the result of the propagation of a disturbance from a vibrating source in a medium, usually air. Sound obeys the law of radiation, i.e. its intensity decreases in proportion to the distance from the source. Sound does not usually propagate from a single source but is more likely to originate from a distributed source, for instance a machine. It is sometimes possible to assimilate the larger source as a collection of simple sources, but, at comparatively large distances, sound can be assumed as originating from a single source.

Sound propagates in air with the typical properties of longitudinal waves, that is, the particles of the medium move in the same direction as that of wave propagation. This motion is characterized by a wave speed, c, and a wavelength, λ. The speed of sound may be calculated according to:

$$c = \sqrt{\frac{\gamma P}{\rho}} \text{ m/s} \tag{1}$$

where P is the ambient static pressure, γ is the ratio of specific heat at constant pressure at constant volume of gas (equal to 1·4 for air) and ρ is density. The accepted value of c in air at normal conditions is $c = 340$ m/s.

If a source is radiating sound at a single frequency f (in Hz), then the wavelength λ, which is the distance between two points with similar particle states, is given by:

$$\lambda = \frac{c}{f} \text{ m} \tag{2}$$

Sound pressure level

The physical quantity that is of interest in noise quantification is the *sound pressure*, which is the incremental pressure due to the passage of the wave in air that oscillates above and below the ambient pressure. The sound pressure is, even in the limits of ear pain, very small compared to the static air pressure. A quantity fluctuating with time like the sound pressure is made up of a series of rapidly varying positive and negative values. These are usually measured by an instrument which is intended to present a statistical value, the so-called *rms* (root mean square) sound pressure (p_{rms}) without taking consideration of its instantaneous time variation. This is given by:

$$P_{rms} = \sqrt{\frac{1}{T}\int_{6}^{T} p^2(l)dt} \text{ N/m}^2 \tag{3}$$

where T is a period of time long enough to permit the built-up of the statistical process. It is this *rms* value of the pressure that is usually of concern and the *rms* index is thus omitted from the pressure symbol. The sound pressure is not given by its absolute value but rather with reference to some quantity, which by convention is chosen as the pressure at 1 kHz of the average limit of audibility of a normal healthy subject. Hence, the *sound pressure level* L_p is defined as:

$$L_p = 20 \log \frac{p}{p_{ref}} \text{ dB} \tag{4}$$

where $p_{ref} = 2 \cdot 10^{-5}$ Pa and the logarithm is taken to cover the large scale of the human sound pressure sensitivity. Figure 2 gives a presentation of some of the most usual noise sources with their typical frequency content and their position on a sound level scale.

Noise rating indices

Over the years, several noise scales have been introduced in an attempt to give a more or less qualitative assessment of noise exposure. In fact, as the problem of noise disturbance is a subjective matter, a primary task is to translate and process the measured quantities according to the perceptive sensitivity of human hearing (for equal sound pressures, sounds with higher frequencies tend to appear much louder than sounds with lower frequencies). This is usually accomplished by the *A-filtering* of the pressure, a procedure which gives a lighter weight to the lower frequencies over the higher ones as measured by a linear, constant frequency-sensitive microphone. When sound pressures have been measured according to the A-filtering mode, their level is then given in dB(A). Figure 3 presents the curves of equal loudness contours for pure tones and the different international standard weighting curves. Regarding traffic noise, the definition of sound pressure level (SPL) has been somehow refined to take into account the time-dependent character of the traffic flow (whether it is occurring by day or by night) and also the duration of the noise itself. The A-weighted SPL, however, is the basis of most of these measures, and represented by p_A instead of just pressure p. The *Equivalent Continuous Sound Level* (ECSL), L_{eq}, is one of the simplest of these measures and is the A-weighted SPL over a specified time of measurement T:

$$L_{eq} = 10 \log \left[\left(\frac{1}{T} \int_{0}^{T} p_A^2(t)dt \right) \Big/ p_{ref}^2 \right]. \quad \text{dB(A)} \tag{5}$$

where T is the averaging time, usually taken as 1, 8, 12 or 24 h.

The *Day-Night Average Sound Level (DNL)*, L_{dn} is equivalent to L_{eq} for a 24-h day with an extra 10 dB weighting for noise occurring between 2200h and 0700h to account for extra nocturne noise

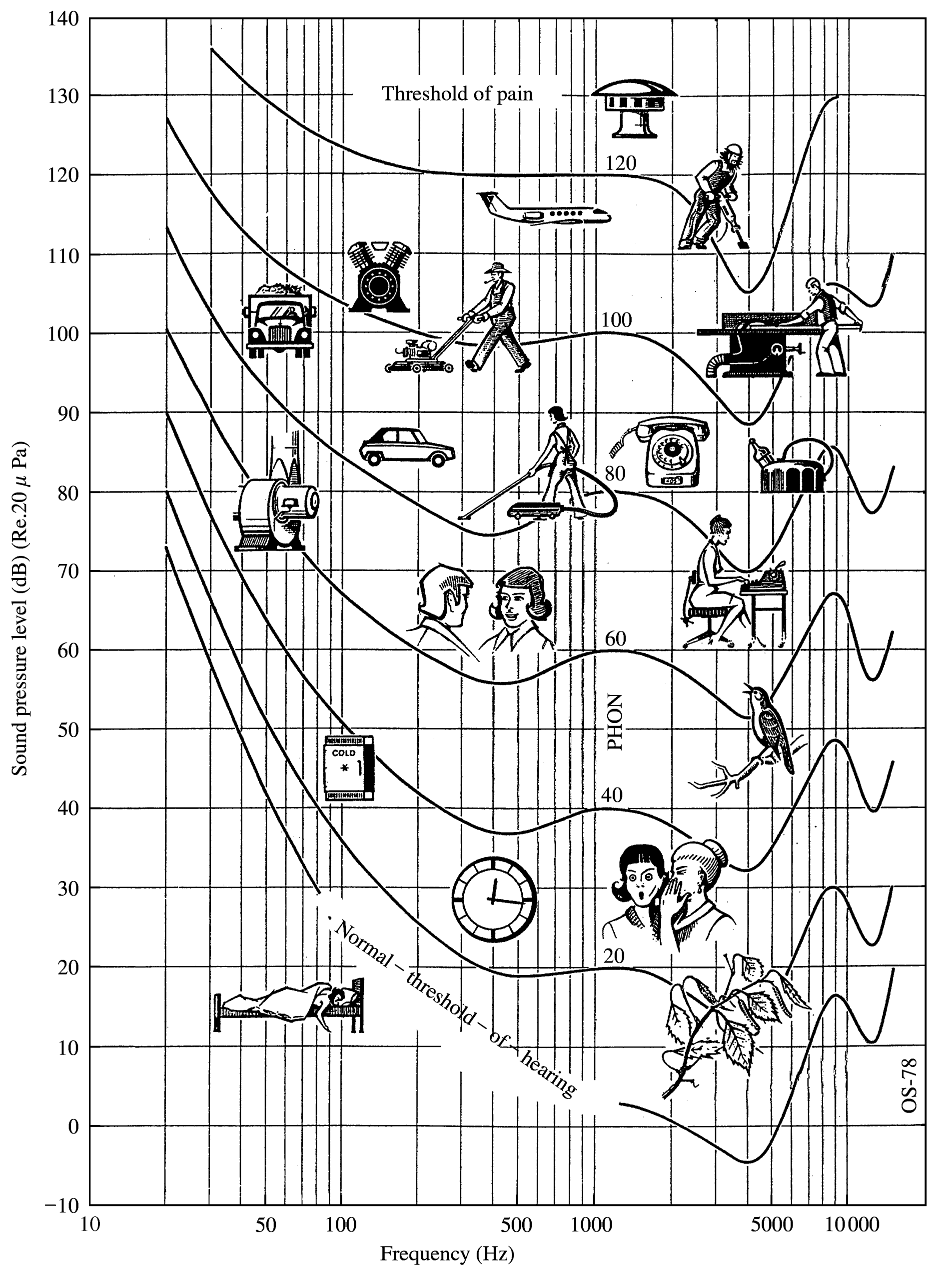

FIGURE. 2. Typical sound levels and frequencies of common noise sources (after Hassal & Zaveri, 1979).

annoyance. Formally, DNL is given by

$$DNL = 10\log\frac{15^{*}10^{L_d/10} + 9^{*}10^{(L_n+10)/10}}{24} \qquad (6)$$

where L_d and L_n are, respectively, the 15-h daytime and 9-h night-time A-weighted equivalent sound levels.

The *Statistical Level (SL)*, L_N, is suitable for a stationary random noise which, in the case of traffic noise, is satisfied only in the case of a free flow of vehicles. An example is illustrated in Figure 4. A time-varying noise level measured in dB(A) can be described in terms of its cumulative distribution. From Figure 4(b) one can determine the level which is exceeded for a particular percentage of the total time. Usual values are L_{10}, L_{50}, and L_{90} which are, respectively, the levels exceeded for 10, 50 and 90 percent of the time. These features are shown in Figure 4(a).

With some restrictions on the vehicle flow rate and the measurement time, a relatively simple empirical relationship has been established between

L_{10} and L_{eq}, namely (Nelson, 1987):

$$L_{10} \cong L_{eq} + 3 \text{ dB(A)}. \quad (7)$$

There are a few other noise ratings that originated in different countries and serve different purposes, but although they have been used for road traffic noise, they have mainly been adapted to aircraft noise rating.

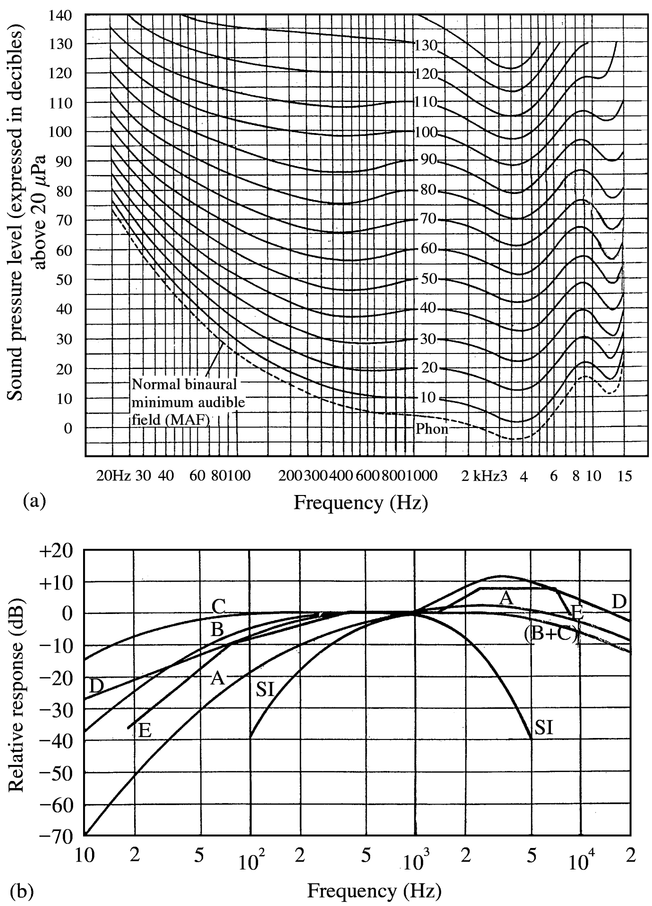

FIGURE. 3. (a) Equal loudness curves; (b) the different international standard weighting filters (from Hassall & Zaveri, 1979).

Acoustical characteristics of road traffic noise

In the built-up environment of the city, road traffic is the main source of noise. Under the plausible assumption that small vehicles are numerically the greatest contributor to urban traffic, the noise generated by a small vehicle is thought to have four different origins: the engine, the exhaust, the tires, and the air tubulence. Other sources of noise, such as fan and structure vibrations, are likely to be less important in this study, but are reviewed in Alexandre *et al.*, 1975; Nelson, 1987. Noise due to tire–road contact becomes significant only for relatively high driving speeds, so this is negligible at the limited car speeds in a town. For the same reasons, air turbulence also makes only a small contribution, so that only leaves the noise from the engine and the exhaust of the vehicles.

There are two ways traffic noise can reach subjects living in an apartment with windows facing the street. One is that the waves generated by the vehicle are transmitted directly through the air to the windows of the residence, or that they cause vibration in the building. The other way is that the rolling tires of the vehicle induce vibrations in the road beneath which when transmitted to the building through structural contact generate sound waves inside the building (Figure 5).

In practice, people have different sensitivities for building vibrations, ranging from sensing the vibrations of the structure to aural perceptions of the sound of rattling ornaments, or sensitivity to low frequency noise at certain levels.

Traffic noise generates from a mixture of different vehicles, light and heavy, running in the streets of a city or in the different lanes of a highway. The usual

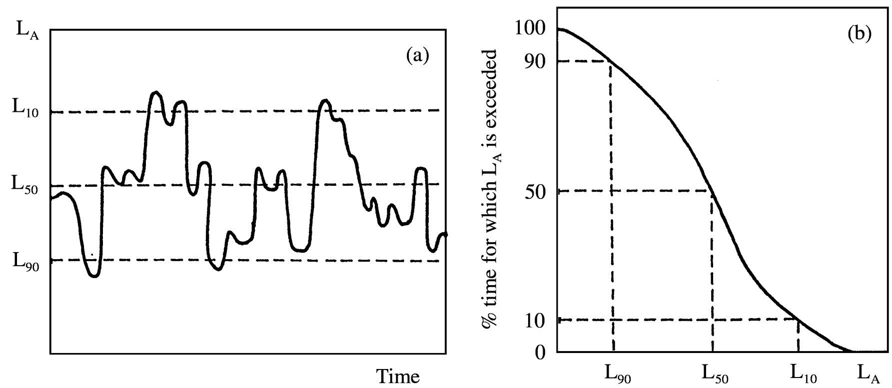

FIGURE 4. (a) Typical traffic noise level variation with time; (b) its cumulative distribution.

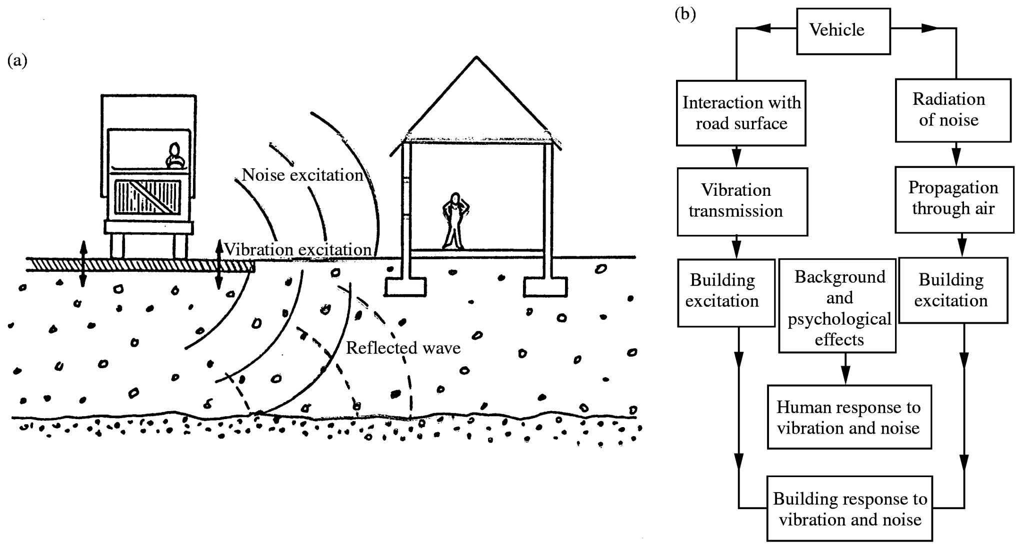

FIGURE 5. The different ways traffic noise can reach the inside of a building. (a) Pictorial presentation; (b) schematic presentation (Adapted from Nelson, 1987).

way of evaluating the sound level received at any one point is by calculating the sound level at each frequency band (1/3 or 1/1 octave) and then summing these individual levels in an *incoherent* way. The result of the incoherent summation of two sounds is a sound with a mean square pressure which is equal to the sum of the mean square pressures of each constituent sound. In this way the incoherent summation of two sounds with equal levels gives a sound which is 3 dB higher in level than that of the individual sounds. For the coherent summation, where the pressures undergo an addition operation, the result of the summation would be 6 dB. There are simple mathematical models that permit the approximation (with satisfactory accuracy) of a row of sound sources to either a simple source or to an extended source based on the knowledge of just the distance between the sources and their distance to the observer (Rathé, 1969).

Road traffic noise may be assumed to have two components: the noise generated by the mainstream of cars and the noise generated by each individual car. It is important to make a distinction between these two types of noise because in the overall noise level, the peaks (which may be defined by L_{10} or L_1) are due to the passing of individual vehicles. These individual noise sources behave as simple, point sources, i.e. their corresponding peak sound level decreases at the rate of 6 dB per doubling of the distance from the source (the sound pressure is inversely proportional to the distance). On the other hand, the whole stream of cars has similarities with a line source of sound. Its corresponding noise level, which may be considered as background noise, can be described by L_{90} or L_{99}, and decreases by only 3 dB for each doubling of the distance (the sound pressure is inversely proportional to the square root of the distance). This is illustrated in Figure 6 where the variation with distance of L_N for different values of N is shown.

From extensive measurements on different car models, it has been confirmed by Rathé *et al.* (1973) that in principle the noise level from the engine and the exhaust increases in proportionality to the logarithm of the speed of the vehicle, and that two-fold increase in speed leads to an increase of about 10 dB (A) in the maximum noise level (Rathé *et al.*, 1973). From this last study, one also finds that noise increases as a function of load and that it increases with acceleration at low speeds, particularly when starting away. For the directivity characteristics, and due to the ground reflection, the sound radiation is predominantly along 20° to 40° above the horizontal.

The measurement of traffic noise from streams of vehicles is more complicated than the measurement from single vehicles as it involves many operations, such as statistical analysis and time-consuming integration procedures. The distribution of noise levels in the case of heavy and steady traffic approaches nearly that of a Gaussian distribution. From the knowledge of two parameters, for instance the median level, L_{50}, and the standard deviation, σ, one can normally make an estimate of different noise parameters (Alexandre *et al.*, 1975). As regards the inclusion of heavy vehicles in the traffic stream, several curves have been proposed from different studies for the correction of the noise level due to light traffic as a function of the extra percentage number in trucks.

In Figure 7, two traffic noise time histories are shown to demonstrate the difference between the noises from typical city centre traffic and traffic from a typical highway. One can clearly see that the effects of congestion causing sudden acceleration result in the emergence of occasional high peaks in urban traffic noise. On the other hand, the motorway noise has a steadier level because of the constant cruising speed and the relatively short time between successive vehicles in the stream.

The analysis of the noise level distribution also reveals a difference between the two noises, namely that the distribution of the highway noise is more symmetrical and narrower than that of the city centre (Hassal & Zaveri, 1979).

The frequency composition of the noise is also important in the matter of sound insulation. Unfortunately, traffic noise has a large composition in low frequencies, especially at about 60 Hz and in this range of low frequencies sound insulation is most difficult to achieve in both structural and airborne sound insulation. Figure 8 represents typical spectra of traffic noise registered outside or inside a building, and it is clear that large differences between the indoor and outdoor noise levels occur only at relatively high frequencies.

It might be interesting to point out that one direct effect of low frequency noise on people is the excitation of body resonances. It has in fact been found that, depending on individual characteristics, humans have a chest resonance lying in the range 30–90 Hz. More precisely, a study on a group of male and female subjects resulted in an estimation of the average chest resonance at 64 Hz and 74 Hz for females and males, respectively. Another study using subjects breathing helium/oxygen instead of air showed no shift of the resonance frequency indicating that the chest resonance is a structural effect rather than an effect due to air filled cavities. The

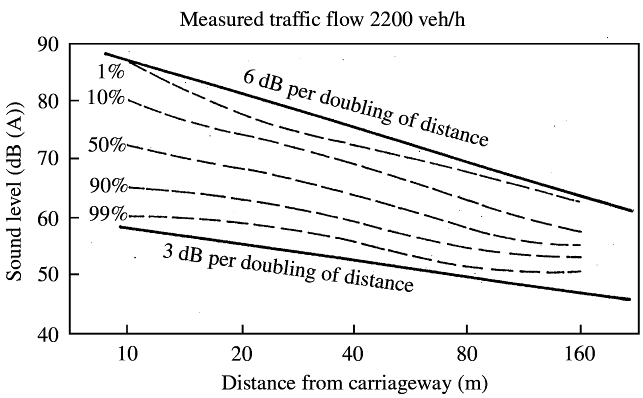

FIGURE 6. Variation of traffic noise levels L_N with different values of N as a function of distance (From Hassall & Zaveri, 1979).

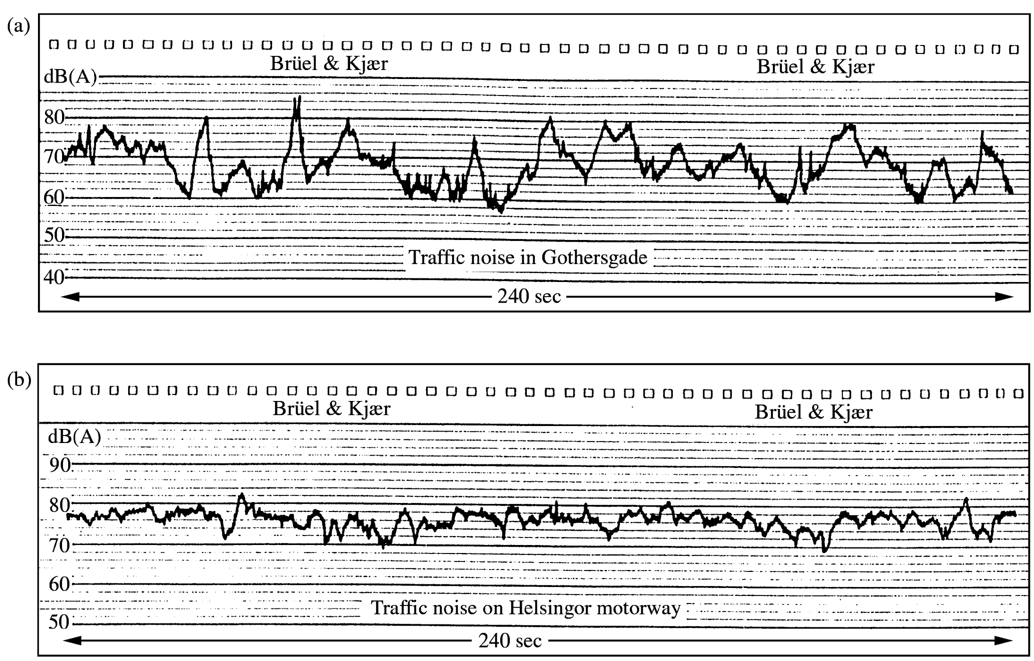

FIGURE 7. Typical traffic noise time histories. (a) City centre; (b) highway (from Hassall & Zaveri, 1979).

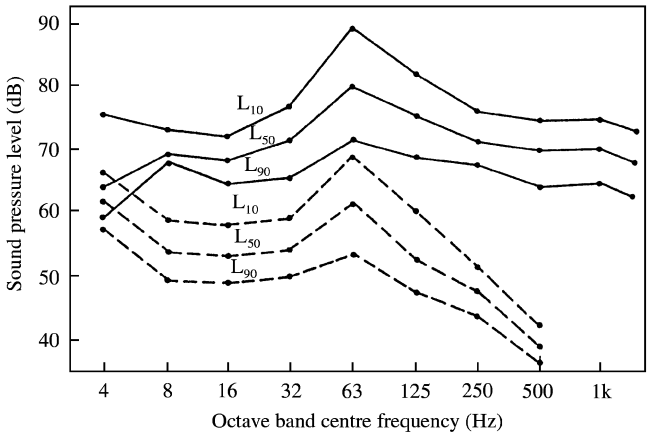

FIGURE 8. Statistical analysis of a traffic noise outside and inside a double-glazed house (from Nelson, 1987). — outside; ---- inside.

effect of chest resonance excitation is best shown in pedestrians walking alongside heavy vehicles, especially during start-up, but for people staying indoors, although chest vibrations are perceptible, noise level is the more general complaint (Nelson, 1987).

Road traffic noise as a source of human discomfort

Generally, the term 'noise' is used to describe an undesirable sound. As people may not perceive all undesirable situations to be dangerous, a definition containing the word *undesirable* becomes ambiguous. In acoustics, one usually distinguishes between two kinds of sound: noise and signal. The latter is of more interest in measurements, and has particular characteristics both in time and frequency which are usually lacking in the former. But in the case of traffic noise this ambiguity persists because of the fact that, although random, traffic noise has distinguished spectral and temporal uniformities. This problem of definition pertains also at the biophysical level. A radio turned to a high volume may convey perfectly meaningful information to the nonvoluntary listener who nevertheless perceives it as an annoying event. Thus, with this signal–noise consideration it seems difficult to set a line of demarcation between what is considered as a useful and desirable signal and what is considered as a useless and disturbing noise event (Relster, 1975). It is, however, a well established fact that, across measurement techniques and cultures, noise-reaction relationships show a remarkable similarity (Job, 1988).

In the complex realm of stimuli where people are the receptors, the differences between individuals in assessing noise effects are made more difficult by many acoustical and nonacoustical factors. Among the important acoustical factors one can cite pressure level, duration of exposure, frequency spectrum, impulsive character, and level fluctuations, whereas the nonacoustical factors may include time of day, time of year, and past experience. One can also add the physiological and psychological states of the person. This domain becomes even more confused when one takes into consideration people's social attitudes and their belonging to different cultural groups (Alexandre *et al.*, 1975; Relster, 1975). So, with respect to taking into account the many different components of the reaction to noise, it is important to realize that the relationship between measured noise level and its effects on people is not easy to determine in a systematic way so as to be able to build an 'annoyance measurer'.

The amount of literature written on the subject of the various effects of traffic noise on people, whether in the form of articles, books or reports, is so large that to survey it all in this single article would be an almost impossible task. Broadly speaking, the effects of noise on people can be divided into three main categories: psychological, social and physiological effects. This can be illustrated by a simple imaginative experiment where the SPL of a noise is increased, and its effect ranges from attitudinal to behavioural to physiological effects. Thus, at levels above 130 dB, noise can cause temporary deafness, intense pain, or in the extreme case damage of the inner hearing system. In broad terms, noise is thought to evoke physiological responses which are characteristic for stress (DeJoy, 1984; Saadu *et al.*, 1996) and this has led several researchers to consider the hypothesis that long-term noise exposure contributes to the genesis of serious disease. However, the controversy of the results of epidemiological studies permits us to keep this hypothesis only under the assumption of a particular noise sensitivity presented by the affected population (Griefahn & Di Nisi, 1992). The auditory effects of noise on people have been quite well-known for some decades (see for instance Kryter, 1985), however, as a relatively accessible personal necessity, cars are invading the urban landscape more and more, contributing to a higher level of noise pollution than any other man-powered engine. Therefore, most of today's research on noise control is focused on noise from transportation with special emphasis on that of urban traffic. One should note that until the late 1970s, active research

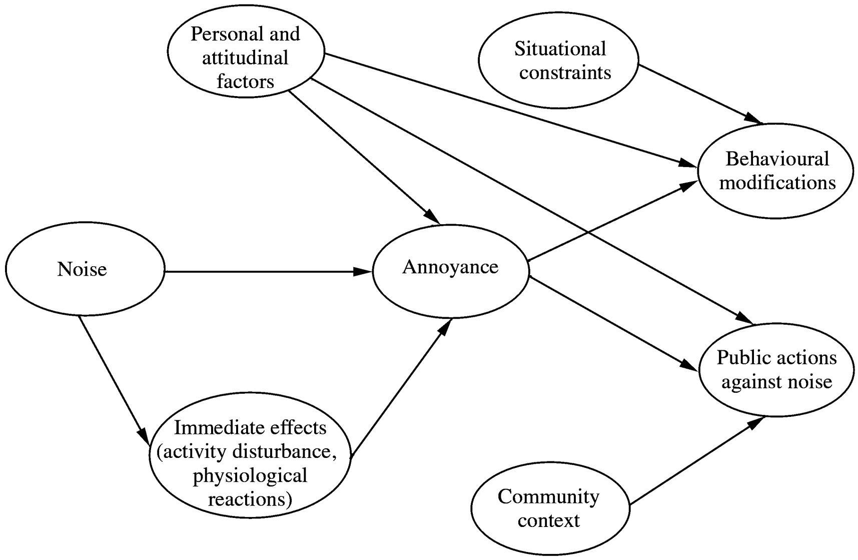

FIGURE 9. A simplified model relating noise and its effects in community (from Nelson, 1987).

on the hazardous effects of traffic noise on people mostly focused on auditory-related topics, with attention to the nonauditory health dimensions of the problem.

Figure 9 presents a simplified model for the main relationships between noise, its effects and the social context of people. From the diagram in this figure, noise causes some direct effects or more delayed reactions in the form of annoyance.

The set of personal characteristics may cause some annoyance but not necessarily physiological reactions. In turn, annoyance may lead to some obvious changes in one's actions, e.g. shutting the window to isolate the source of noise (or, for people with less tolerance to noise, moving away to quieter areas), or it may engender less evident effects in the form of emotional reactions.

It is a well-known fact in all societies worldwide that noise is a serious environmental pollutant. Governments, especially in the industrialized world, aware of this danger to a level of litigation (Bryan & Tempest, 1973; SOU, 1974; Fidell, 1996; Saadu *et al.*, 1996), have organizations and commissions which operate for the regulation of exposure to noise. In the case of traffic, not only inhabitants of residential areas are subject to noise nuisance, but vehicle drivers are also exposed, both to the surrounding traffic noise and to the noise from their own vehicle. However, it is not an easy matter to predict a community's reaction to a specific street or highway noise traffic level based on simple quantitative measures. From the late 1960s and for more than a decade thereafter, many publications have presented the results of studies on traffic noise annoyance in the major cities of Europe and the U.S.A. (it is worth noting that Sweden was among the leading countries in this important large-scale project; Fogs & Jonsson, 1968). The major aim of collecting data for the different physical characteristics of urban noise was to assess the importance of the problem, and to possibly process suitable descriptors for the subjective judgement of noise exposure through simple objective measures. As mentioned earlier, this is not an easy mission in the case of noise annoyance when so many nonacoustical variables, such as age, sex, social status, education, etc., have been found to play roles that cannot be neglected. Several attempts have thus been made to correlate subjective annoyance and noise exposure (Langdon & Scholes, 1968; Matschat *et al.*, 1977; Osada, 1991). Schultz, after reviewing different surveys, was able to determine a single curve for the relationship reaction/noise exposure (Schultz, 1978) (see Figure 11 later). This has in turn led to interesting observations, for instance, that annoyance could be predicted by simple indices like L_{eq} or L_{10} (Yaniv *et al.*, 1982), or that annoyance is more related to attitudes than to noise levels (Fields, 1993).

Annoyance resulting from exposure to road traffic noise

From Figure 9, it can be seen that a person busy with some activity may react to noise either immediately (distraction from activity, or violent reaction due to the attack of the auditory system by an intense noise), or in a more discrete manner in the form of annoyance. Several publications have reported the efforts of researchers to develop similar models for predicting annoyance by people as a function of exposure at different noise sources. Hence, Hall *et al.* (1985) were able to produce a model that showed a strong relationship between activity interference and the probability of annoyance. Izumi and Yano (1991) used a 'path model' to explain the variations in the annoyance responses, and to confirm the strong effect of sleep disturbance to road traffic noise. It is usual that after the physiological reaction has ceased (a reaction that may be considered as a natural means of protection from noise), it is followed by annoyance. Annoyance is, in general, defined as a feeling of displeasure that is believed to negatively affect an individual or a group of individuals (Borsky, 1972; Rice, 1975). It is believed that with this definition annoyance can be distinguished from other subjective reactions to noise. The motivation behind this assertion is that judging the degree of noisiness caused by a sound level change contains two components. The first component is cognitive and is concerned with expectations for the sound to meet some characteristics for an ideal environment, and the other component is purely emotional, and is related to the change in mood of the affected person as caused by exposure to the noise event.

When attempting to carry out a survey of a sample population, such as a measurement of annoyance caused by traffic noise, the questionnaire to be answered by the test volunteers is important. There are several models of such questionnaires. Fields (1984) categorizes them under several types, but among the simplest and most widespread schemes in use is the presentation of a self-reported scale of annoyance. This scale may be set to a range, for instance, in the order: 'Very much', 'Moderately', 'A little', and 'Not at all', and the person is asked to mark where his/her judgement is likely to be. An example of a five-level annoyance scale curve as a function of noise level is shown in Figure 10. A more subtle variation of this scheme is to refine the scale 'Not at all disturb' to 'Unbearable' by several steps (usually between 7 and 10).

Sometimes it is necessary to proceed with a different procedure. If the matter of investigation is a noise already causing complaint, the investigator can rely on asking his subjects a single question, which could be formulated as: 'Are you very annoyed by this noise?'. Consequently, the results in this case are presented on a percentage scale. This method was used by Schultz in his review study (Schultz, 1978), and the results of which are presented in the curve of Figure 11.

Since the publication of Schultz' review analysis, more data have become available, and Fidell *et al.* (1993) processed 453 data curves compared to the 161 available earlier to Schultz. A later study conducted by the U.S. Air Force resulted in an equation for the curve of the percentage of the population that is highly annoyed (%*HA*) as a function of day-night average sound level (*DNL*). This equation is

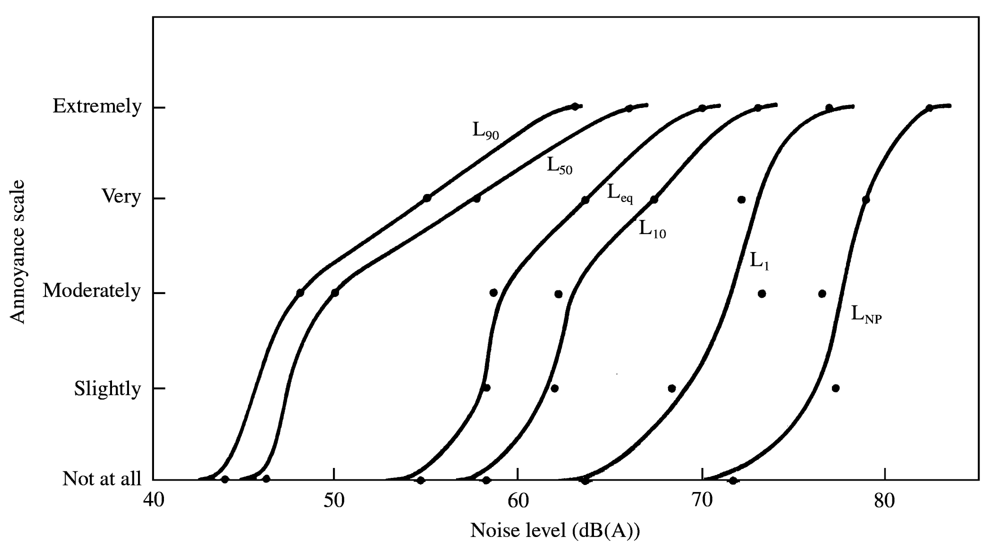

FIGURE 10. Annoyance as a function of noise level (from Crocker, 1997).

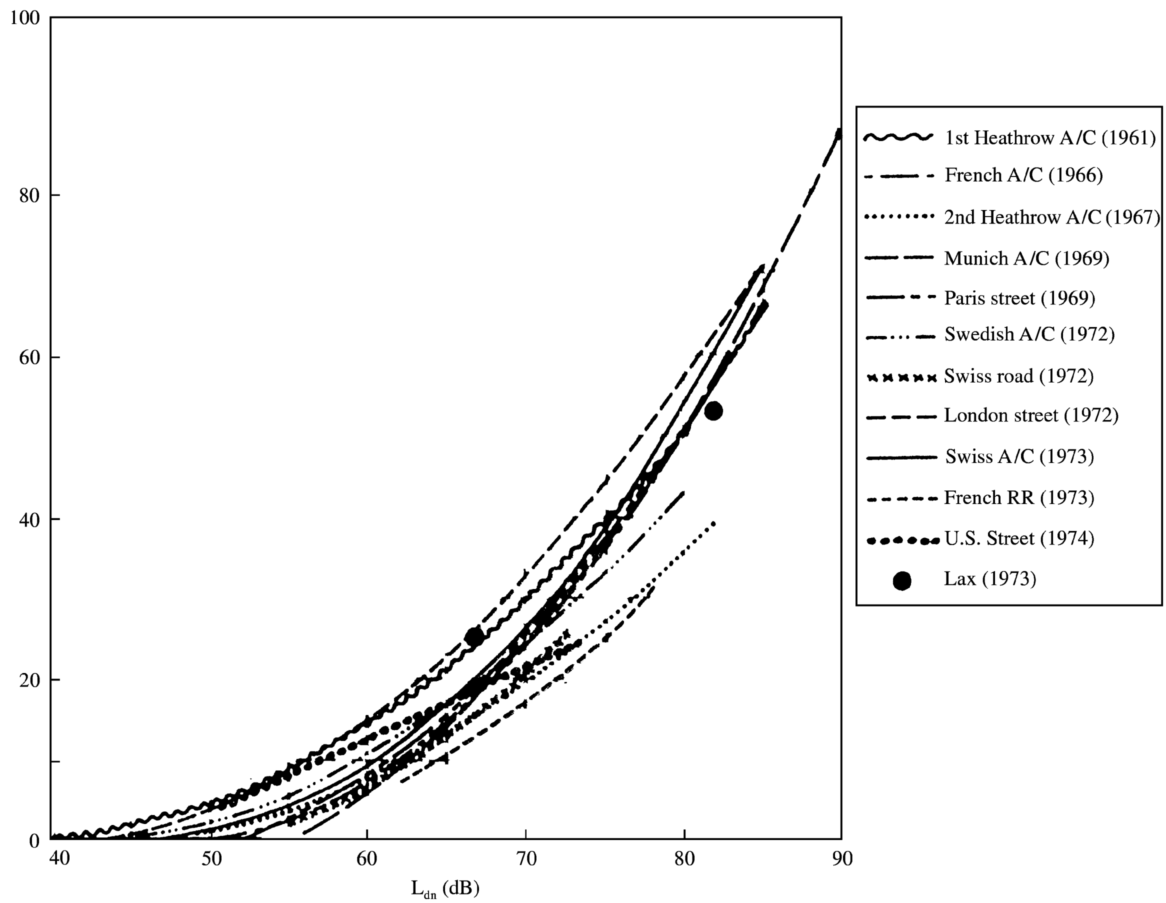

FIGURE 11. Revised analysis of surveys using highly-annoyed response as the response falling on the 27 per cent of the annoyance scales (from Schultz, 1978).

formulated as:

$$\%HA = \frac{100}{1 + \exp(11{\cdot}13 - 0{\cdot}14DNL)} \qquad (8)$$

and its curve is plotted in Figure 12 alongside other curves resulting from earlier studies.

The different factors that have an influence on the subjective reaction to noise have been the subject of studies reported over several decades by many researchers from different parts of the world. In his review of studies over three decades, Job (1988) concludes that the studies, although carried out in different nations and with different measurement techniques, led to similar results. The studies can be subdivided into two main categories: in the field, where the subjects are answering questionnaires in their homes, and in the laboratory, where subjects are subjected to artificial experimental conditions. In his analysis of several different surveys on the effect of the number of noise events on people's reactions, Fields (1984) identified a major difference between rating the results

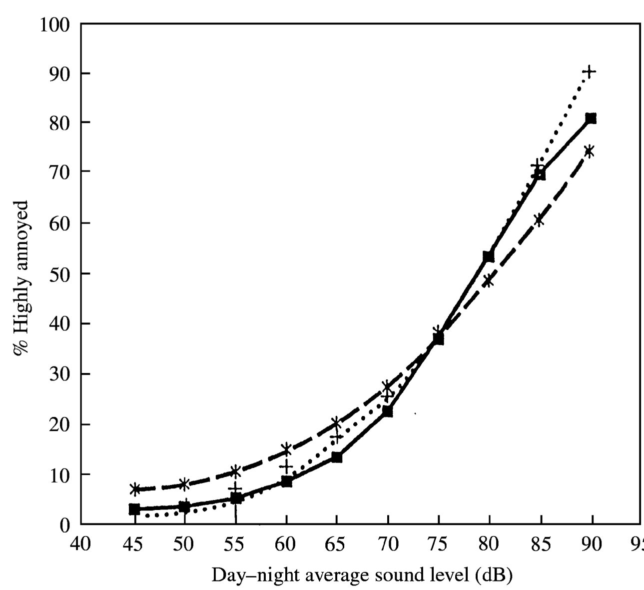

FIGURE 12. Curves representing the percentage of people that were highly annoyed by noise as a function of day-night exposure level.–■–: Finegold *et al.* (1994, Eqn (8));.· · ·+.· · ·: Schultz (1978); - - - * - - - Fiedell *et al.* (1991) (From Finegold *et al.*, 1994).

under field and laboratory conditions. In the field, residents attempt to concentrate on ongoing activities, whereas in the laboratory subjects tend to notice each noise event. In the field, people use adaptive mechanisms helping them to ignore many noise events for long periods of time because the noise becomes routine. In interpreting the results of these different kinds of studies, Job stresses the fact that authors, with a few exceptions, have often considered other issues of the problem (for instance, cultural or socio-economic status) only as secondary topics and have instead given considerable attention to classical factors, such as noise indices, or scales of community reaction. Hence, in the light of the latest findings, and in order to achieve a better understanding of the human reactive mechanism to noise exposure, factors other than the noise level index must be taken into consideration. Variables such as previous experience and attitudes towards the noise source account for more variation in reaction than does, for example, noise exposure.

Stansfeld *et al.* (1993) support the observation that noise sensitive individuals are likely to be more annoyed by traffic noise than people who are less noise-sensitive, and which supports the outcomes of several other studies (Griffiths & Langdon, 1968; Langdon, 1976*c*; Öhrström *et al.*, 1988; Matsumara & Rylander, 1991). There are difficulties associated with the measurement of noise sensitivity, but it is worth mentioning the scale developed by Weinstein (1980), which has been used in road traffic noise assessments. The respondants are asked to state their agreement or disagreement using a scale for different items related to sensitivity to noise in daily life (Weinstein, 1980). In an investigation made with the purpose of examining the effect of changed traffic noise conditions on subjective response to noise, Raw and Griffiths (1988) found that self-related sensitivity to noise is apparently the most important individual characteristic for predicting dissatisfaction with road traffic noise. From this same study, the authors confirm that sensitivity to traffic noise is independent of noise level, and that based on several measures of response to noise, no advantage can be gained by combining several scales (dissatisfaction, loudness, and interference in the investigation) to produce an annoyance index (Raw & Griffiths, 1988). To give stronger evidence to the importance of sensitivity, data from a random sample population taken from a survey in a medium-sized city show that the proportion of sensitive people to noise may be estimated at about 25 per cent, which is a quite significant figure (Matsumara & Rylander, 1991; the city used was Gothenburg, Sweden's second largest city).

The control variable in assessing traffic noise reaction is primarily sound pressure, with its level, frequency and time characteristics. Annoyance is dependent on the noise level (Lambert *et al.*, 1984; Osada, 1991) and the length of the time period of exposure (Fields, 1993). A correlation has been found between noise and annoyance, and this correlation becomes even stronger for high levels of road traffic noise reaching inside dwellings. More specifically, people can get annoyed by noise for *DNL* below 55 dB (Fields, 1993) and that levels above 65 dB(A) may induce behavioural responses such as moving to a quieter room or blocking sound transmission paths (Langdon, 1976*a*; Lambert *et al.*, 1984). Jonah *et al.* (1981) found that the correlation between noise level and individual response is improved a little by incorporating individual differences measures in the analysis. However, it has also been concluded from independent studies that the best correlation between traffic noise at moderate levels and community reactions was found for the A-weighted sound levels, and for L_{eq} and L_{10} evaluations. Therefore, and due to their relative simplicity, the A-weighted level, L_{eq}, and L_{10} have sometimes been recommended as useful predictors of community response to traffic noise annoyance (Rylander *et al.*, 1976; Yaniv *et al.*, 1982; Watts & Nelson, 1993); the observations were also proven for the case of free flowing traffic (Yeowart *et al.*, 1977). Gjestland (1987) proposes a combination of L_{eq} and L_{max}, whereas Eldred (1975) proposes L_{eq} as a principal component of what he introduced as the normalized L_{dn}. The generalization of the L_{eq}–annoyance relationship is made more evident by the high correlation between L_{eq} and annoyance that was found in experiments under artificial laboratory settings, where simulated road traffic noise was presented to test subjects (Rasmussen, 1979; Labiale, 1983). More specifically the L_{eq} index may be used as an adequate measure of nuisance for traffic noise distributions whose L_{10}–L_{50} values range from 0·4 to 24·6 dB(A) (Pearsons, 1978). It has also been conjectured that the use of L_{eq} is limited by a possible disadvantage which is its inability to account for background noise situations. This has been known for some time from studies where judgements of nuisance caused by aircraft noise has been found to be influenced by varying road traffic noise backgrounds (Rice, 1975). The universal use of the L_{eq} measure as a unifying index for noise annoyance appears not to be strongly substantiated for all types of traffic noise, at least when considering the results of laboratory experiment (Rice, 1977). A further aspect of the problem is that a study on residential areas heavily exposed to road traffic noise found that measures such as L_{eq} and L_{DN} were unsatisfactory indices in explaining the variation in annoyance responses (Izumi & Yano, 1991). Moreover, in studying seasonal effects on annoyance, noise is considered as a problem in any season (Saadu *et al.*, 1996) and no evidence has been found for the effect of different seasons of the year and of open or shut windows (Griffiths *et al.*, 1980).

Depression, a psychological effect of noise which is more lasting than annoyance, was on the contrary found to less severely affect people with windows facing away from traffic than those with windows facing towards traffic (Öhrström, 1991).

A simplified approach to the propagation of traffic noise is to consider the 90 per cent sound level (L_{90}) as being due to the whole stream, whereas the other 10 per cent as resulting from individual vehicles. As seen in the introduction, a heavy vehicle can emit a sound that may be several tens of dBs higher than that of a light car. So on average, it can be estimated that around 10 per cent of the traffic mass is composed of heavy transport vehicles. A typical distribution over time in a city is illustrated in Figure 13. This kind of statistical-based estimation is important for elaborating a reliable scheme for the extra noise annoyance caused by heavy-weight traffic in cities. In fact, for the typical congested traffic flow in a city, noise nuisance predictions using simple indices like L_{10} and L_{90} become useless in this case, and one relies instead on the percentage number of heavy vehicles, or more specifically, on the logarithm of this number (Langdon, 1976*b*). Griffiths and Langdon (1968) present a model for urban traffic nuisance, and add a third component, the distance to the traffic line, to the two existing factors, the composition proportions of the different vehicles and their individual intensity levels (Griffiths and Langdon, 1968).

The main difference of noise from heavy trucks compared to that from light cars is its higher content in low frequency components. This is true for both free-flowing or congested traffic. A study that aimed to predict the noise level caused by a mixed traffic flow led to an equation incorporating the percentage number of heavy vehicles (Hollingsworth & Gilbert, 1982). In this respect, during acceleration the noise level increases linearly with the logarithm of the speed of the vehicle. In simple models, typical values for the level increase per ten-fold increase in speed are 28 dB(A) for light vehicles and 14 dB(A) for heavy vehicles (Lewis, 1973). Some more elaborate models which include the vehicle's acceleration have also been suggested (Jones & Hothersall, 1979). The shape of the noise spectrum, as well as its level, have been found to change to some degree with speed. Therefore, considering the emergence of the heavy vehicles' noise from that of the mainstream traffic noise, it may be concluded that intermittent noise causes less accuracy and more response failures in vigilance tasks. This suggests that the intermittent character of noise produces detrimental behavioural outcomes through increased mental load (Carter & Beh, 1987). Related to this issue, Fields (1998) recently re-examined the publications of many field and laboratory surveys on several different environmental noises. This author found that the residents' annoyance reactions to an audible

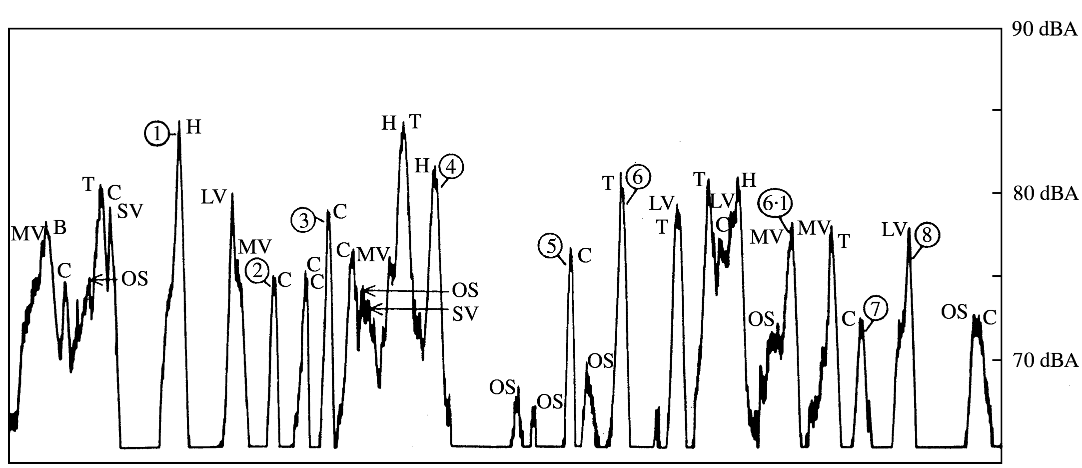

FIGURE 13. An example of a traffic noise trace in a city. C=car, SV=small van, MV=medium van, LV=large van, T=truck, H=heavy, B=bus, OS=other side of road (from Lewis, 1973).

(target) environmental noise is scarcely reduced by the presence of another (ambient) noise in residential areas. Laboratory studies show from this analysis that the perceived loudness of tones and the annoyance with individually presented noise events are reduced in the presence of background noise (Fields, 1998).

Considering the exposure of people to low frequency noise, a review has revealed that it has similar effects to that of high frequency noise, and that the possible danger of infrasound has been overestimated. The effect of low frequency noise in the range 20–100 Hz has, in fact, much greater significance than infrasound noise (Broner, 1978). In a popular paper, Bryan and Tempest (1972) assert that infrasound from the engines of vehicles could be the cause of many unexplained accidents on highways. These results, however, do not apply to vehicle drivers who are exposed to noise levels below 100 dB in the frequency range up to 30 Hz. At higher levels, drivers would suffer from feelings of intoxication and visual nystagmus (unvoluntary eye movement) (Evans & Tempest, 1972). Nonetheless, only further, more careful research can confirm the speculated detrimental effects of infrasound, which may have simply been exaggerated. In fact, significant health effects of infrasound could be expected to take place only under long exposure and at extremely high levels, which occur only under laboratory conditions, and are extremely rarely, if ever, found in our real daily environment (Broner, 1978; Nelson, 1987).

Other related effects and after-effects of sleep disturbances

In city quarters densely loaded with traffic or near highways, inhabitants are passively subjected to noise disturbances, and nocturnal road traffic noise interferes destructively with sleep quality.

Often, after a test night, subjects are required to fulfil a performance test and fill in a questionnaire. These tests are usually short and are aimed at determining the vigilance of the subjects. Most common is the reaction test (RT) which consists of asking the subject to respond as quickly as possible to a stimulus (Carter, 1996). In their update of the literature on the general after-effects of sleep disturbances on health, Griefahn and Muzet (1978) conclude that sleep deficits accumulate with persisting disturbances and that, at a certain point, they lead to a decrease in performance. These decreases may in turn gradually cause functional diseases (Griefahn & Muzet, 1978). Poenaru *et al.* (1978) and Öhrström (1989) report that people complaining about noise are significantly slower in executing tasks. For subjects exposed to less intense noise (below 90 dB), no impairment in the performance of tasks has been found. At the extreme where subjects have been completely deprived from sleep, the speed and accuracy in the performance of tasks is much poorer than for sufficiently rested subjects (Alexandre *et al.*, 1975). Although the results from different studies on the topic of task performance seem controversial, due to known or unknown reasons (an interesting discussion on this issue may be found in Nelson, 1987), Öhrström and colleagues report on the poorer performance of their subjects on the day following a noisy night in the laboratory (Öhrström & Björkman, 1988; Öhrström *et al.*, 1988). Similarly, other research groups ascertain that the reaction time to a psychomotor performance is palpably shorter after a quiet night as compared to a noisy one (Vallet *et al.*, 1983; Wilkinson & Campbell, 1984). Furthermore, recuperation during sleep definitely improves performance, and intermittent noise exceeding certain levels negatively affects recovery from tiredness (Öhrström & Rylander, 1982; Öhrström, 1995).

Mood—which is a state of feelings—has also been found to diminish significantly after noise exposure during the night. This factor is usually defined as a set of four parameters: activity, relaxation, extroversion, and pleasantness. Activity and extroversion have been measured as decreasing after a succession of noisy nights, and then increasing after a return to quiet nights (Öhrström *et al.*, 1988; Öhrström, 1995). This supports the findings made earlier by Poenaru *et al.* (1978) showing that individuals complaining about noise suffer from more personal disorders, such as nervousness, anxiety and phobia. During experiments, especially under laboratory conditions, unexpected results have been attributed to the problem of adaptation of the subjects to new conditions. However, it normally takes only a few days (usually two days are sufficient; Öhrström & Rylander, 1982) for habituation to laboratory conditions and it is fairly conclusive that habituation is the factor that least correlates with noise exposure. Whether the subjects have been living in noisy areas for many years or that they have been exposed to artificial noise for less than a week, habituation ceases after only a few days at most (Thiessen & Lapointe, 1978; Griefahn & Gros, 1986; Eberhardt & Akselsson, 1987; Eberhardt 1998; Öhrström *et al.*, 1988). This finding does not concern traffic noise in particular, but applies to any type of noise (Weinstein, 1982; Griefahn, 1991).

Regarding problems with individual differences, noise has in general different effects on people of different age, sex, sensitivity to noise, or socio-economic situation (Hall *et al.*, 1981; Hall, 1984; Åhrlin, 1988; Izumi & Yano, 1991; Osada, 1991). Results from research on this topic give the general consensus that the factors previously cited do not affect noise annoyance to a great extend, as does noise itself with its level and time exposure characteristics (Osada, 1991; Fields, 1993). In his review of the importance of gender in sleep disturbance by different noise signals, Lukas (1975) generalizes that women have lower arousal thresholds than men. This result is also valid in the case of nocturnal road traffic noise (Langdon & Buller, 1977; Griefahn & Gros, 1986), although some studies could not give a clear-cut answer on this issue (Griefahn & Muzet, 1978) or could find no distinction between the reactions of men and women (Wilkinson, 1984; Öhrström, 1989). In the early 1980s, Hall (1984) reviewed the available data published on community responses to noise from different transportation means and ranked these noise sources according to their various adverse effects on humans. The review included aircraft, rail, and road traffic noises. There was no clear indication of which acoustical or community factors could explain the differences in responses, and therefore the differences were simply categorized according to the type of source (Hall, 1984). Åhrlin (1988), in a paper published some years later, confirms that in general there is a difference between the sound sources with references to specific effects, and that the differences are accentuated with increasing dB(A) levels. Differences are found in the community responses, and although the problem of source differences is complex with contradictions between the results of similar studies (Berry, 1983), an important outcome of Hall's study is that these differences are attributed to the noise source itself (Hall, 1984). A more recent study using simulated noises from different traffic sources by Kurra *et al.* (1999) shows that when people are concentrating on daily work at home, the noise source type is not a highly deterministic factor in the noise–annoyance relationship (Kurra *et al.*, 1999). In comparing the different means of transportation, noise from road traffic is more annoying than that from the railroad (Hall, 1984), and with equal L_{eq} values, road traffic noise is reported to be more difficult to live with than aircraft noise (Rice, 1977; a study that was conducted in laboratory). Hence, at any given noise level, railway noise seems to be the least annoying traffic noise with annoyance increasing the least with noise level. This may be partially explained by the acoustical characteristics of train noise and by the positive attitudes of people towards train noise (Fields & Walker, 1982). Comparing air and railroad traffic, noise from freight traffic has been found to be more annoying than noise from passenger traffic (DeJong & Miedema, 1996; Taylor *et al.*, 1981).

As to matters regarding age, there is a greater probability that the elderly experience awakening reactions. This is straightforward conclusion from many investigations (Lukas, 1975; Griefahn & Muzet, 1978; Wilkinson, 1984; Griefahn & Gros, 1986; Eberhardt, 1988). Thiessen (1978), on the other hand, after subdividing his subjects into groups with different age ranges, found that people over 55 years of age had nearly the same response as young adults (under 25 years), whereas middle-aged people had a sensitivity to noise around 15 dB lower than that of the former groups (Thiessen, 1978). Finally, it is worth noting that people with a higher sensitivity to noise tend to experience more critical effects of road traffic noise by night than people who are less sensitive (Langdon & Buller, 1977; Öhrström *et al.*, 1988; Stansfeld *et al.*, 1993; Öhrström, 1995).

In today's cities and towns, the presence of noise is becoming so evident that people are usually unaware of it. Since streets and roads are becoming more and more loaded with car traffic, traffic noise is nowadays considered as a real problem of society with direct or indirect repercussions on people's behaviour and way of life (Alexandre *et al.*, 1975). One of the most common critical judgements of people of their noisy environment regards speech communication and other activities involving listening, such as speech intelligibility (Eldred, 1975). A laboratory study conducted with the aim of measuring the levels at which various traffic noises start to interfere negatively with speech, led to several interesting observations. A comparison of the performance of different noise indices gave most weight to the L_{10} measure in dB(A). This index resulted in the least scatter of the subjective responses and the levels measured outside the home gave somewhat better results than those measured inside, suggesting the significant effect of high frequencies. On the other hand, measures based on peak level values performed better for levels measured inside than those measured outside the home, and those taking account of low frequency components (e.g. filter B or D in Figure 3(b)) agreed better than those with the A-weighting. In terms of the L_{10} index, subjects on average set the intrusion level to 6 dB(A) below the common daily-occurring speech level (54 dB(A)) as a 'just acceptable' level of noise–speech interference (Rice *et al.*, 1974). A similar study conducted by Pearsons (1978) led to the conclusion that L_{eq} is an acceptable predictor of interference of speech of road traffic noise whose L_{10}–L_{50} values range from 0·4 to 7·8 dB(A). Again with these same considerations, Hall *et al.* (1985) proposed a model containing three basic components: single noise level, activity interference, and annoyance for modelling noise annoyance. The links between these components can be expressed mathematically as a set of probability equations, the estimation of which is provided by appropriate analysis. From the analysis of several survey data, this procedure permitted to find that the maximum indoor level is the strongest predictor of activity interference and a level of 58 dB(A) may be considered as the level at which 50 per cent of the people report speech interference. This analysis also shows no significant difference between type of source, the A-weighted level being a reasonable basis of measurement, and that for equal 24-h L_{eq}, annoyance is predicted differently in road traffic and aircraft situations (Hall *et al.*, 1985).

Efforts have also been made in heavily traffic-loaded areas near airports, railroads and facing dense highways to assess the long-term effects of transportation noise on nearby residing people. In his updated review, Thompson (1996) revised the conclusions of the possible nonauditory outcomes of road traffic noise on health, but could find no clear relationship between noise and, among others, abnormal course of pregnancy, mental disorder, or immune system defects (Thompson, 1996). Regarding psycho-social behaviour, and monitoring medication habits, people in close contact with traffic noise during long hours of the day tend to suffer more unrest (Relster, 1975) and suffer from depression associated with tiredness, bad mood, headache and nervous stomach (Öhrström & Björkman, 1988; Öhrström, 1991). In attempting to approach the problem of psychologically scaling the effects of noise on community, Langdon presents, in connection with anecdotes, several nonacoustical factors which rate positively or negatively the judgement of transportation noise sources. After covering this subject from different sides he concludes: '... it is evident that despite the growing sophistication of social research and the proliferation of both psychological scales and noise units, the effects of noise on attitudes—self-evident to all of us, a source of frustration to citizens, and concern to governments—is not easy to measure' (Alexandre *et al.*, 1975). Job's (1988) extensive and cautious review of many studies concludes that at the individual level there is a weaker correlation between noise exposure and subjective reaction as compared to the correlation for data studied in groups.

Conclusions

This paper reviewed the various effects of road traffic noise on people's well-being with special emphasis on annoyance. According to the World Health Organization, 'health is a state of complete physical, mental and social well-being. Governments have a responsibility for the health of their people which can be fulfilled only by the provision of adequate health and social measures'. Noise is, in this respect, more than just a nuisance, and it constitutes a danger that is real to people's health by producing both physical and psychological stress. Although people seem to adjust to noise by ignoring it, the ear is, in fact, always operative by transmitting signals to our nervous system which stimulates reactions from our bodies. The fact that irritability is a very apparent reaction to noise has caused legislators to often consider public annoyance as the basis of noise control programmes. The annoyance that humans feel when faced with noise is the most common outward symptom of stress building up inside. Therefore, these symptoms could be considered as indications of possible more serious health problems.

Among the direct and most obvious effects of noise on awake subjects, annoyance, in general, interferes negatively with the individual's speech communication, on their concentration ability, and consequently on performance of tasks. However, a direct measure of the relationship of noise–annoyance in the case of traffic noise is not easy to establish due to the problem having more dimensions than just physically measurable acoustical variables. Other factors having no direct connection to the cause of noise itself or to the auditory receptor of the exposed subject, like socio-cultural position and attitude towards the noise source, are also to be accounted for and make the matter more complicated. Variables influencing the subjective judgement of a situation where noise prevails from traffic, like the weight of running vehicles, traffic fluidity and time of the day, may also contribute to the degree of annoyance and to sleep disturbances during the night with resulting after-effects the following day. However, some recent reviews suggest that despite different measurement techniques, which are used within different cultures, the noise–reaction relationships show in general some similarities. These relationships show some strength when analyses are carried out on data groupings made on a noise exposure basis rather than on individual data. Factors such as noise sensitivity and attitude towards the noisy situation, presumably which have some potential effect on modifying noise reactions, account for more variation within data surveys than do noise exposure parameters. Another important aspect in the studies of noise effects on people is the design of suitable interview procedures to be undertaken by the subjects. The acquisition of the data requires the selection of good estimation procedures for the data analysis in view of establishing reliable models for describing noise–annoyance relationships. The models undergo tests and are then validated before finally being adopted.

From the extensive work during the few last decades on the subject of annoyance resulting from exposure to traffic noise, it is interesting to point out that the outcomes of some of the investigations have been controversial, i.e. that subjects may react differently to similar noise situations. Possible reasons for these discrepancies have been attributed to the intervening conditions under which the investigations were performed. Hence, it is imperative to consider the differences between the nature of the studies, either they are conducted on the field in the homes of the respondants, or in the laboratory under artificial experimental conditions. Another contribution to these sometimes antagonist results is, as mentioned earlier, the ignorance of subjective factors connected to individual differences in the perception of noisy environments by the subjects.

The development of a large number of quantitative noise scores from the early 1970s had to allow for a versatile number of tools to make objective evaluations of specific noise situations. Traffic noise measures of daily averaged sound levels have caused much concern. Although the proliferation of these noise-rating indices has the common goal of predicting the general adverse human response, it has, at least during its early development, further complicated the development of noise abatement and control programmes. Nevertheless, the noise index that appears most often in the literature on noise–annoyance relationships is still L_{eq}, though several late reports suggest it should be used with some caution when it comes to drawing conclusions for general purposes. In this respect, it is interesting to glance at various WHO recommendations concerning noise exposure where several different noise indices are used with different noise sources (Table 1).

The combination of different sources, e.g. road traffic plus train, requires perhaps a separate consideration, but the L_{eq} is again the candidate for retention of a model based on a normalized index between the sources. The relative simplicity of evaluating L_{eq} from the time history of the noise signal is perhaps a major reason for its selection from many related noise-rating indices. These indices belong to a group based on the assumption that average sound levels over equal time periods produce equivalent adverse effects. However, it is known that, especially in the case of road traffic, noise may show great variability in sound level during the period of observation. Hence, in the absence of better predictors, researchers in environmental noise believe there to be have some convincing grounds for the continuing use of the L_{eq} index. Furthermore, and as recommended by some late studies, it is suggested that this index would accomplish more concrete objectives if complemented with some scheme accounting for the short-time

TABLE 1
Noise levels recommended by the World Health Organization (Berglund & Linduall, 1995)

Descriptor	Limit	Situation or effect
$L_{eq,24}$ (A)	70 dBA	Negligible risk of hearing impairment
$L_{eq,8}$ (A)	75 dBA	Negligible risk of hearing impairment
L_{eq} (A)	30 dBA	Excellent speech intelligibility
L_{eq} (A)	55 dBA	Fairly good speech intelligibility
L_{eq} (A)	30 dBA	No sleep disturbance (inside bedroom)
L_{max} (A)	45 dBA	No sleep disturbance (peaks inside bedroom)
L_{eq} (A)	45 dBA	No sleep disturbance (outside bedroom)
$L_{eq,4}$ (A)	90 dBA	Discotheques and other ballrooms
L_{eq} (A)	45 dBA	Residential areas, outdoors, night-time
L (A)	80 dBA	Toys (at the position of a child's ear)
L_{peak} (C)	130 dBC	Toys (at the position of a child's ear)
L_{eq} (A)	35 dBA	Hospital room
L_{max} (A)	45 dBA	Hospital room (peaks)
L_{eq} (A)	55 dBA	Residential areas, outdoors, daytime

sharp sound level variations occurring within a prolonged noise event.

Despite the different natures of the studies on induced traffic noise annoyance, and that they were conducted across different social, cultural and urban environments and for noise emanating from different means of transportation, it has lately been possible to develop models that predict the acuity of annoyance following diurnal noise exposure. In the study conducted by Finegold *et al.* (1994), the Day to Night Level, (*DNL*) was the parameter which gave the best correlation for the percentage of highly annoyed individuals, and again this descriptor is a refined version of the L_{eq} index. The *DNL* accounts also for exposure to nocturnal noise and gives it a higher score than that of daytime. Moreover, the problem of noise exposure during nighttime may also be considered from another perspective in that deprevation of sleep may have mood-inducing consequences for people the following day, and therefore on their performance of daily tasks.

Human bodies react automatically and unconsciously to loud noises. In a world where people are constantly exposed to noise, the cumulative effects of noise on people may be quite extensive. People do not become accustomed to noise and biological reactions are always subject to change. These changes, even at noise levels below those associated with hearing damage, are predictable and may be regular. Researchers are still debating whether the cumulative reactions to noise may lead to 'diseases of adaptation', i.e. diseases of stress, such as asthma, ulcer, headaches, depression and blood pressure. The contribution of noise to such physical disorders is again influenced by factors such as socio-economic belonging, age and sensitivity to noise.

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