Road traffic noise

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Road traffic noise

Abstract. Following the publication of the Wilson report in 1963 much attention has been drawn to solving problems connected with road traffic noise. In this article the relevant noise level standards are described and the phenomenon of noise from individual vehicles and traffic as a whole discussed. An account is given of how existing traffic noise is measured and the results are used for predicting noise levels in other circumstances, for example when planning new roads or building new housing developments.

1. Introduction

Road traffic noise is not a new phenomenon. Travelling is rarely a silent occupation, no matter what form of transport is being used; the sound of horses’ hooves on road surfaces has long been a familiar experience and few persons can deny that the noise of iron-tyred cart wheels rolling on cobbled roads is an annoyance. In more recent years many people have had their sleep disturbed by the grinding of the wheels of the late night tram.

However, these noises, characteristic of the past, were usually intermittent and rarely penetrated the residential districts, at least outside working hours. During the past two decades there has been a phenomenal increase in the number of vehicles on the road and a sharp rise in the use of heavy diesel lorries. Both cars and lorries, as well as buses, are sources of noise but the nuisance they cause is no longer confined to main roads and to industrial areas during working hours: it has spread to many, once quiet, residential areas, often used as short cuts giving rise to annoyance at night.

Governments and local authorities in most industrialized countries have, to varying degrees, expressed concern about the widespread increase in road traffic noise and appropriate action is often taken. In the United Kingdom a committee formed under the chairmanship of Sir Alan Wilson made a thorough investigation into the causes of different kinds of noise and how it can be reduced. Its findings were published in 1963 in a government paper known as the Wilson report (Wilson 1963). One conclusion reached was that, in built-up areas, road traffic noise presented the most serious problem.

Included in the Wilson report is an account of an investigation carried out jointly by the Building Research Station, the London County Council (as it then was), and the Central Office of Information. It showed that at 84% of more than 400 locations in Central London, where subjective investigations were made, road traffic noise predominated over all other forms of noise, including those originating from aircraft, industrial premises, constructional work and domestic sources.

The definition of noise, accepted by the Wilson committee, is ‘sound which is undesired by the recipient’. The report of the committee accepted that noise can be dangerous to health, where ‘health’ according to usage by the World Health Organization is a ‘state of complete physical, mental, and social well-being, and not merely an absence of infirmity’. There is no doubt that loss of sleep and disturbance of human activity as a result of road traffic noise does affect health in an adverse manner.

For a proper investigation of acoustical noise to be made, a suitable standard for noise level must be established. The main contribution to noise is a high acoustic intensity but
this alone may not always give rise to annoyance. Other factors include the frequency spectra, time of duration and degree of repetition. One may also have to consider contributions which, by themselves, might not cause annoyance. Much will depend on the type of activity carried out by the recipient and also on his state of mind at the time. Thus, whilst a particular sound might be regarded as being unobjectionable or even pleasant on one occasion, it may prove to be disturbing at some other time.

Although the final decision as to what constitutes a noise must be determined by subjective responses, that is, of loudness and pitch, a proper investigation requires objective measurements of the intensity and analyses of the frequencies.

2. Loudness

The intensity of sound waves is perceived by the ear as loudness and it has long been established that the relationship between the degree of loudness and intensity is a logarithmic one. This has led to the use of the decibel for which the sound level is given by

$$L = 10 \ln \frac{I}{I_0}$$

where $I$ is the measured intensity of the sound (usually in W m$^{-2}$) and $I_0$ a reference level, usually taken to be the threshold of audibility, in other words the minimum intensity detectable by a normal ear. At a frequency of 1000 Hz this is equal to $10^{-12}$ W m$^{-2}$. Although this relation is applicable only to a given frequency, realistic measurements of loudness must take into account the continuous range of frequencies to which the human ear can respond.

There are in existence several different ways of measuring loudness, including the use of phons and sones, but the criterion found to be most suitable for road traffic noise investigations is provided by the sound level meter (see figures 1 and 2) switched to A

![Figure 1. Block diagram of the sound level meter.](image1)

![Figure 2. Weighting networks of the sound level meter.](image2)
weighting, that is, loudness level is expressed in dBA. It has the advantage of simplicity and the instrument is very portable, comparatively cheap, and readily available.

When the sound level meter is used, one of three weighting networks, described by the letters A, B, and C, is switched into the circuit to provide the desired frequency response (see figure 2). The frequency responses for A, B, and C weightings approximate to those of the average human ear at loudness levels corresponding to intensities of 40, 70 and 100 dB, respectively, above $10^{-12}$ W m$^{-2}$ at 1000 Hz. It was originally intended that the choice of weighting be governed by the magnitude of the sound level to be measured, in other words A weighting for low levels, B weighting for medium levels and C weighting for high levels. However, for reasons given below, the use of A weighting is recommended for all road traffic noise measurements, irrespective of the sound level.

An early investigation of the relationship between subjective responses to road traffic noise, leading to the adoption of the dBA scale was made by Robinson et al (1961) of the NPL. They employed a jury of 19 listeners seated side by side on the nearside of the southbound carriageway of part of the London to Brighton road. They were asked to judge the noise emitted by individual passing vehicles in accordance with the scale illustrated in table 1. It is seen that columns A and F carry no descriptions. The subjects were instructed to regard these as extremes to provide a reference for the intermediate categories. The mean numerical value of the responses to each vehicle was related to the sound level as measured both in dBA and dBB and separate results for private cars and lorries were considered. Correlation between the subjective responses and objective measurements was found to be high for both cars and lorries with the A weighting, but not so high with the B weighting.

| Table 1. Scale used by Robinson et al (1961) for subjective assessments of road traffic noise |
|---|---|---|---|---|---|
| A | B | C | D | E | F |
| Quiet | Acceptable | Noisy | Excessively noisy |
| 0 | 2 | 4 | 6 | 8 | 10 |

Further tests were made at the MIRA proving ground at Nuneaton (Mills and Robinson 1963) with a larger jury (57) and using vehicles specially provided for the purpose. They were driven past the observers under a variety of conditions—different speeds, gear ratios, rates of acceleration, etc—totalling 150. Good correlation with A weighting was confirmed. Even better correlation with A weighting for heavy diesel trucks, using a sample numbering 100, was obtained by Hillquist (1967) in the USA.

3. Vehicle noise

Before discussing the objective measurements of noise produced by road traffic itself it is well to consider the noises emitted by individual vehicles. Much research into vehicle noise has been conducted by Priede and his colleagues at the ISVR Southampton and a survey of the findings has been published in a report issued by the Transport and Road Research Laboratory (1970). This is summarized below.

Under normal conditions the engine is the main source of noise in a motor vehicle. In the diesel engine where abrupt changes of pressure take place in the cylinders during the working cycles the noises produced by these pressure changes mask other mechanical
noises from the engine, for example from the pistons and fuel injectors. In the petrol engine, however, the pressure changes are less abrupt and the main noise originates from the associated mechanical components.

Engine noise has been found to vary with the engine speed in a logarithmic manner:

\[ L = A \ln N + K \]  

(2)

where \( L \) is the sound level in dBA, \( N \) the engine speed and \( A \) and \( K \) are constants.

The noise from an engine is also affected by the load, especially with petrol engines. Thus the difference between fully loaded and unloaded conditions may be as high as 10 dBA for petrol engines and less than 3 dBA for diesel engines. The noise is also affected by the size of the cylinder bore but not, apparently, by the cubic capacity. The resulting level is related to the bore diameter in a logarithmic manner similar to equation (2).

The spectra of engine noises are characteristic of resonances in the cavities and structures, for example high noise levels in the 1 to 3 kHz range of frequencies due to high sound pressure levels, characterized by 'diesel knock'.

Engine noise can be reduced by suitable design of the engine and reductions of up to 10 dBA may be possible but it is more usual, for reasons of economy, to enclose completely the engine and transmission system.

Associated with engine noises are the sounds emitted from the inlet and exhaust, the fan, and for two-stroke engines the scavenger blower. Although the inlet and exhaust noises are reduced by the use of silencers, they are still significant. For this phenomenon there exists an empirical relation between the noise level and engine speed of the form of equation (2). Changing from conditions of no engine load to full load has been shown to produce a considerable increase in exhaust noise and for heavy diesel vehicles it may be as high as 20 dBA.

Cooling fans and scavenger blowers, both controlled by the engine, produce noise outputs which vary in a similar manner as those indicated by the earlier relationship.

The nature of the sound radiated by the transmission system is not well understood but the resulting noise is recognized to be loud enough to merit the soundproofing of the

![Figure 3. Generalized spectra for moving diesel trucks and passenger cars at 50 ft distance (Galloway et al 1969).](image)
Road traffic noise

Aerodynamic noise, although of possible annoyance to passengers, does not seem to be of any consequence to persons outside the vehicle.

Road surface and tyre noises are dependent on the speed of the vehicle, the type of tyre tread, the nature of the road surface and whether or not the surface is wet. Brake noise and horn noise, although a nuisance, occur only on occasion and then for short periods and thus do not contribute significantly to overall noise levels.

Other causes of vehicle noise are the vibrations of the structure and of the payload, which may include empty rattling containers. They can, on occasion, be troublesome but their characteristics vary so much with different vehicles that it is not easy to conduct investigations into their nature.

Additional sources of vehicle noise are two-stroke motor cycles and also high power motor cycles and sports cars often deliberately made noisier by irresponsible owners. Fortunately these are comparatively rare and, although they may constitute a nuisance, they contribute little towards the overall noise climate.

The spectra produced by vehicles varies from one vehicle to another. However, Galloway et al (1969) in the USA have analysed noises from large numbers of cars and diesel trucks of different types and typical spectra are given in figure 3. It is seen that in both cases peaks occur at low frequencies and there is a decrease in level with increase in frequency.

4. Traffic noise measurements

Measurements of noises emitted from individual vehicles, although useful in theoretical predictions of traffic noise levels, do not by themselves constitute evaluations of traffic noise. An effective investigation of this phenomenon must take into account the overall noise experienced at a given location for a continuous specified period. For this purpose the quantities $L_{10}$, $L_{50}$ and $L_{90}$ have been defined as the levels, in dBA, exceeded for 10, 50 and 90%, respectively, during the period under consideration and they are effectively the peak, average, and background levels.

Typically, a sound level meter set for A weighting and connected to a magnetic tape

![Figure 4. Schematic diagram of statistical distribution analyser (A-S Brüel and Kjaer 1967).](image)
recorder is set up at the required site and, after calibration against a defined level, provided by a piston-phone, a recording is made for a given period. The tape is later played back in the laboratory with its output fed through a pen recorder to a statistical distribution analyser, as shown in figure 4. This provides measurements at $L_{10}$, $L_{50}$ and $L_{90}$ in the following manner.

The writing arm of the pen recorder moves in response to the signals fed to it and an attachment arm slides over a number of equally spaced contacts, each connected to a digital counter. By switching the instrument to provide a cumulative count the contacts are connected to their neighbours by means of rectifiers, as shown. The sensitivity of the recorder can be adjusted by means of an attenuator to arrange that the levels corresponding to each contact are, say, 5 dB apart (eg 50, 55, 60... etc). Short pulses are fed at regular intervals (eg 0.1 s) through the attachment arm and are detected by those counters corresponding to the level for which contact is made and to the levels below this. Thus, if at a given instant the level is 75 dB, the pulse is detected by the counters connected to 75, 70, 65, 60, 55 and 50 dB contacts.

Table 2. Typical record of traffic noise count obtained from a statistical distribution analyser switched for cumulative counting

<table>
<thead>
<tr>
<th>dBA</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>75</th>
<th>80</th>
<th>85</th>
<th>90</th>
<th>95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>9999</td>
<td>9963</td>
<td>9618</td>
<td>8670</td>
<td>6830</td>
<td>4360</td>
<td>1739</td>
<td>437</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2 illustrates the readings of counters for a recording lasting 999.9 s (ie 16 min 39.9 s) for a pulse interval of 0.1 s. Because the traffic noise distribution has been shown to be gaussian in character these readings may be plotted on probability paper (see figure 5) to produce an approximately linear variation. Values of $L_{10}$, $L_{50}$ and $L_{90}$ can then be read straight off the graph, as shown.

![Figure 5](image)

Figure 5. Relationship between noise level in dBA and number of counts obtained from a cumulative statistical distribution analysis (as given by table 2).

Although the 999.9 s recording time fits in with the maximum count on the statistical distribution analyser for a pulse interval of 0.1 s it is often sufficient to record for only 99.9 s, that is 1 min 39.9 s, during which time enough vehicles may pass to permit the use of gaussian statistics; longer recording times may only be necessary during quiet periods, for example in the small hours of the morning.

In the London Noise Survey (Parkin et al 1968) conducted jointly by the LCC and the Building Research Establishment, recordings were made every hour for 2 minute periods...
throughout a 24-hour day. Figure 6 illustrates variations of $L_{10}$ and $L_{90}$ for a 24-hour period at two sites covered by the survey, one in a quiet open space with distant heavy traffic and the other near a busy main road and with construction work going on in the vicinity. Table 3 gives ranges of values of noise levels obtained in the London area for different types of locations where traffic noise predominates.

![Graph](image)

**Figure 6.** Measured variations of $L_{10}$ (full curve) and $L_{90}$ (broken curve) at hourly intervals throughout a 24-hour day (from the London Noise Survey (Parkin et al 1968)).

(a) Primrose Hill, NW8 (centre of open space 300 yards away from a road with heavy traffic.

(b) Walcott Street/Vincent Square, SW1 (main road 25 yards away and roadworks adjacent).

5. Traffic noise criteria

The results of various noise surveys have led to the establishment of criteria related to subjective responses of traffic noise over a given period. Expressions containing combinations of $L_{10}$, $L_{90}$ and (sometimes) $L_{50}$ have been evaluated and compared with subjective responses of annoyance under different conditions. One of these is called the traffic noise
Table 3. Noise level range at locations where traffic noise predominates (after Parkin et al 1968)

<table>
<thead>
<tr>
<th>Group</th>
<th>Location</th>
<th>Noise climate (ie for 80% of time)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Day dBA</td>
</tr>
<tr>
<td>A</td>
<td>Arterial roads with many heavy vehicles and buses (kerbside)</td>
<td>80–68</td>
</tr>
<tr>
<td>B</td>
<td>(i) Major roads with heavy traffic and buses</td>
<td>75–63</td>
</tr>
<tr>
<td></td>
<td>(ii) Side roads within 15–20 yd of A or B group roads</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>(i) Main residential roads</td>
<td>70–60</td>
</tr>
<tr>
<td></td>
<td>(ii) Side roads within 20–50 yd of heavy traffic routes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(iii) Courtyards of blocks of flats screened from direct view of heavy traffic</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Residential roads with local traffic only</td>
<td>65–57</td>
</tr>
<tr>
<td>E</td>
<td>(i) Minor roads</td>
<td>60–52</td>
</tr>
<tr>
<td></td>
<td>(ii) Gardens of houses with traffic routes more than 100 yd distant</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Parks, courtyards, gardens in residential areas well away from traffic routes</td>
<td>55–50</td>
</tr>
<tr>
<td>G</td>
<td>Places of few local noises and only very distant traffic noise</td>
<td>50–47</td>
</tr>
</tbody>
</table>

The noise index (TNI) and is given by

\[ TNI = 4(L_{10} - L_{90}) + L_{90} - 30. \]  

Another, which also takes into account noise from sources other than road traffic (e.g., aircraft and railway trains) is called the noise pollution level \( L_{NP} \) which may be expressed approximately as

\[ L_{NP} = L_{90} + d + 0.018d^2 \]  

where \( d = L_{10} - L_{90} \). By inclusion of both \( L_{10} \) and \( L_{90} \) these criteria take into account the variability as well as the intensity of traffic noise. In equations (3) and (4) the values given of \( L_{10} \) and \( L_{90} \) are the averages taken over a period of 24 hours.

Determinations of TNI and \( L_{NP} \) are somewhat troublesome, because of the difficulty in evaluating \( L_{90} \) with any certainty, and Scholes and Sargent (1971) found that the mean value of \( L_{10} \) measured during the period from 0600 to 2400 hours during a working day at a distance of 1 m from a facade correlates satisfactorily with subjective measurements even though not quite as well as TNI and \( L_{NP} \). Consequently the Noise Advisory Council has now recommended the adoption of this simplified criterion for rating the disturbance caused by road traffic noise.

6. Prediction of traffic noise levels

With a knowledge of the predicted noise level at a given site, acoustic insulation can be made to provide a tolerable level for occupants of buildings in the vicinity of that site. This knowledge can also be used when planning new buildings from the point of view of reducing internal noise. The Wilson report recommended that the values of \( L_{10} \), shown in
table 4, should not be exceeded inside living rooms and bedrooms. It also recommended that the upper background noise limit to be tolerated in buildings in which communication by speech is of great importance should be 55 dBA.

Table 4. Values of $L_{10}$ which should not be exceeded inside living rooms and bedrooms, as recommended by the Wilson committee (Wilson 1963)

<table>
<thead>
<tr>
<th>Situation</th>
<th>Day dBA</th>
<th>Night dBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country areas</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Suburban areas, away from main routes</td>
<td>45</td>
<td>35</td>
</tr>
<tr>
<td>Busy urban areas</td>
<td>50</td>
<td>35</td>
</tr>
</tbody>
</table>

When planning for noise reduction in existing buildings an estimated average value of $L_{10}$ from 0600 to 1800 hours at 1 m from the facade of the building may be obtained and the insulating properties of the walls and windows considered. Although the walls themselves might provide adequate insulation, noise may enter the building through windows. In a room having a conventional single window the noise reduction is from 5-15 dBA when open and from 20-25 dBA when closed, depending on the position of the recipient. On the other hand a closed double window of proper design can provide an insulation of 30-35 dBA, which is roughly the same as that provided by an outside wall.

The sound level at the facade of the building depends on the distance from the traffic. In extreme cases we may expect, for $L_{10}$, a series of individual vehicles each acting as a point source for which attenuation should take place in accordance with the inverse square law, that is 6 dB for doubling of distance, and, for $L_{90}$, the source is a line consisting of the traffic speed for which attenuation takes place in accordance with the inverse first power law, that is 3 dB for doubling of distance. In practice this is not so because much depends on the distance of the observer from the road. The further one goes back from the road the closer a row of point sources approximates to a line source. In practice one finds something like a 3 to 4 dB attenuation in $L_{10}$ and a 2 to 2.5 dB attenuation in $L_{90}$, respectively, for doubling of distance. This problem has been investigated to some depth by Delany et al (1971).

Further reductions in noise may occur as a result of the presence of barriers, either existing ones provided by intervening buildings and walls or purpose-built ones. Unlike light radiation, an obstacle will deflect rather than cut off acoustic radiation. However, a deflected beam of sound has a longer path length than a direct one and is likely to suffer greater attenuation with distance. Figure 7(a) shows how a barrier at the side of a road in a cutting may prove ineffectual with respect to noise reflected at the far side of the road. It is seen in figure 7(b) how for elevated roads the noise affects the upper floors of nearby houses more than the lower floors.

![Figure 7](image-url)
Before one can predict the likely traffic noise levels in roads at the planning stage a
knowledge is required of the factors influencing them at a given time and also the esti-
mated traffic pattern during a 24-hour (or 18-hour) period. Noise levels and indexes (eg
$L_{10}$, $L_{50}$ and $L_{90}$) depend on the following factors:

(i) traffic density
(ii) traffic composition (ie the percentage of heavy vehicles)
(iii) mean speed of the traffic
(iv) gradient of the road
(v) width of the road
(vi) nature and condition of the road surface
(vii) weather
(viii) nature of the traffic flow
(ix) nature of the physical surroundings (eg the presence of high buildings).

Stephenson and Vulkan (1968) (see also Vulkan 1971) made a comprehensive survey of
the effects of traffic density on $L_{10}$ and $L_{50}$ at kerbside positions in urban roads of the
London area with varying percentages of heavy vehicles, and their results for $L_{10}$ are
shown in figure 8. Measurements were made on level roads where traffic was flowing
smoothly at speeds between 20 and 30 mph (32 to 48 km hr$^{-1}$) during periods of fine
weather. The sites chosen were located well away from traffic hazards such as parked
cars, intersections, pedestrian crossings and traffic signals, to ensure a steady flow. The
number of chosen sites (140 on urban roads) was large enough to average out variabilities
such as road width, physical surrounds, speed, and road surfaces. With regard to the
latter, it should be noted that most urban main roads have asphalt surfaces, although it
has been shown that tyre noise is slightly higher on concrete surfaces.

Noise levels are also affected by the speed of the traffic and Delany (1972) has shown as
a result of large numbers of measurements that for freely flowing traffic within the speed
range 50 to 100 km hr$^{-1}$ doubling of velocity produces increases of about 5 dBA, 4 dBA
and 3 dBA in $L_{10}$, $L_{50}$ and $L_{90}$ respectively.

One would expect that road traffic noise would be affected by gradients and a few
investigations have shown that, in general, increases in noise levels should take place with

![Figure 8. Variations of $L_{10}$ with traffic density and different percentages of heavy traffic (as indicated) (Vulkan 1970).](image-url)
increase in slope. Exactly how the increase depends on gradient has not yet been properly established. However, some preliminary work has been carried out by Grover and Blitz (1971) from which observed variations of $L_{50}$ with gradient are given in figure 9. The author is at present engaged, under contract with the Transport and Road Research Laboratory, in a more detailed investigation of this phenomenon and it is hoped that results will be published in the near future.

![Figure 9. Variation of $L_{50}$ with gradient in urban roads for a traffic density of 1200 per hour (Grover and Blitz 1971).](image)

Having established how a noise index, for example $L_{10}$, varies with the parameters discussed above, it should be possible to predict its value at a given location from a knowledge of the characteristics of the traffic flow. Thus one should be able, for instance, to forecast traffic noise behaviour before a road is actually built.

7. Conclusions

Little has been mentioned in this article as to how traffic noise can be reduced. The solution to this problem lies mainly in the hands of the motor manufacturers and the architects and planners. The work of the acoustician is to provide information to these people to enable them to act accordingly. However, the most effective method of reducing road traffic noise is to replace the internal combustion engine by some means of silent traction such as an electric motor. Until this is possible it is the responsibility of the motor manufacturers to produce quieter engines and transmission units. They have, in fact, gone a long way in this direction, especially in the design of private cars where often the greater part of the noise comes from the sound produced by the tyres on the road surface. However, there are many difficulties to overcome but their efforts can well be spurred on by pressure of public opinion and the subsequent introduction of more stringent regulations regarding vehicle noise.

Acknowledgments

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