IMPACT OF NOISE FROM URBAN RAILWAY OPERATIONS

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ABSTRACT

This thesis concerns the noise nuisance that results from the operation of urban railways and reports on a case-study of the impact of the Tyneside Metro on residents living in close proximity to the railway tracks. The study was based upon parallel related surveys in the vicinity of Wallsend and Walkergate, during the period August to November 1983: one, a subjective questionnaire survey of perceived noise-nuisance and the other, an objective set of measurements of the actual noise conditions prevailing there.

A review of the methods of current practice in the control or urban railway noise demonstrates that regular maintenance of the rails and train wheels is still the most effective way of keeping noise under control at source. Nevertheless, with high speeds of operation, considerable noise nuisance is likely to be experienced by residents nearby.

The Metro is the biggest source of noise and noise-nuisance for people exposed to noise levels of over 60 18H Leq dB(A), although the noise annoyance model constructed from the data showed that half of the annoyance felt by respondents could not be explained.

Other factors which affect annoyance include vibration, perception of other transport noises, the subjects' ages and whether or not they own the property they occupy. Metro is generally perceived to be quieter and to cause less vibration than the diesel trains (DMUs) which preceded it. The equivalent continuous noise level (Leq) appears to be the most practical of all the various noise indexes for measuring railway noise annoyance.

Finally, informal conversation with respondents in the course of a social survey can provide valuable insight into the mental and psychological processes of perception.

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CHAPTER ONE

INTRODUCTION

1.1 What is Noise?

Noise is (by definition) unwanted sound, sound which is undesired by the recipient. In other words, noise can be any sound which intrudes or disturbs or annoys. A sonorous melody pouring forth from a radio may be very pleasant to the listener in his dwelling, but it can be a nuisance to his neighbours who are trying to sleep; to them, it is unwanted and therefore, it is noise. Hence noise is a subjective phenomenon and the reaction of an individual is not to the intensity of the sound alone, but more to its message. Thus, sound-level measurements, on their own, have little or no meaning without accompanying social surveys to assess individual and community response to their noise environment.

1.2 Sources of Noise from an Urban Rail System

Noise from an urban rail system can reach the community from various sources, each emanating from different operations that make up the system. These include train operation, track maintenance, yard operations and activities, ventilation shafts, substation transformers and cooling fans, and station heating, ventilating and air conditioning (HVAC) systems. Noises from these operations propagate in two forms; they are airborne and/or groundborne. Airborne noise is transmitted directly from sources such as train operations on surface and elevated tracks. Groundborne noise (and vibration) is transmitted through the ground, from the tracks, especially those underground, to nearby buildings. The effect of walls, floors and ceilings vibrating produces a low frequency rumble, this sometimes causes windows and crockery to rattle, producing more noise known as "secondary radiation".

The extent of noise intrusion within the community depends largely on the types of vehicle operating on the system. Steel wheel on steel rail vehicles are the noisiest but can be relatively quiet when operating in near 'perfect' conditions, viz, with smooth wheels (resilient or damped) running on smooth continuous rails (CWR). Even under these conditions, however, squeal is unavoidable around tight curves. The related technology of rubber tyred vehicles, which include monorail, rubber tyred light transit and rapid transit (RTRT), emit less noise in general as they can negotiate curves (especially tight curves) more quietly. Mexico RTRT system, which has steel running surfaces, is said to be the quietest rapid transit system in the world (Vuchic, 1981). Finally, further away in technology from a conventional rail vehicle, is the magnetically levitated (maglev) vehicle which is different again in that it has no wheels and it is virtually silent-running. Each of these systems are in use in a number of cities, the latest of which (maglev) now operates in Birmingham, UK. But, by far the most widespread and common urban fixed-guideway system in the world today is the conventional steel wheel on steel rail system and so, with it, is the noise, often intense, which is generated by the interaction between the wheel and the rail while the vehicle is in motion.

1.3 Noise Control - Past and Present

Control of noise from the railways dates back to the late 1930's, though the method adopted in those early days was generally to placate those who complained rather than improve their lot. Since the traditional function of public transport was to provide low-cost transport, the authorities were reluctant to spend money on what was then considered a luxury. However, in the 1950's, some railway authorities in Europe and North America recognised that improvements in service and passenger comfort were long overdue and possibly, may even pay for themselves in increased revenue by increasing the use of public transport. To ensure a pleasant ride to passengers, noise control became an important consideration for those railway authorities.

A few selected examples of early control measures are listed below (Harris, 1957; Northwood and Paterson, 1956):

(a) London Underground. In 1937, a test section of the London Underground was treated with 1-inch drilled asbestos - felt absorptive tiles which resulted in noise reductions of 5 to 7 dB(A). This was carried out on all extensions from 1939 onwards.

(b) European Cities. In the 1950's, experimental work covering all phases of noise-control was underway on various systems in Europe. Paris Metro, for example, introduced rubber-tyred wheels on its RATP line to avoid the intense noise generated by the steel wheel on steel rail arrangement on older parts of the

Metro. Elsewhere in Europe, the steel wheel was retained and noise control features in use included: welded rails; rubber-mounted rails; rubber springs; rubber bumpers in the bogie assembly; vibration insulation of driving motors; sealed double windows; and vibration damping of wheels and rails.

(c) North American Rail Systems. The PCC streetcars were constructed with several features that contributed to quiet operation, most notably their resilient wheels which incorporated a rubber pad between the wheel rim and the hub. Other measures that were in use in the late 1940's included insulation pads in the bogie assembly; in-car absorption treatments (using mineral fibre blankets); reduction of openings to the outside and the use of more effective door seals. The Toronto Subway was among the first of its kind to be acoustically treated to meet a design-limit based on the Speech Interference level of 70 dB(A). Factors that contributed to the meeting of this criterion included: treatment of tunnel and platform walls with glass wool; use of welded rails; maintenance of smooth surfaces on rails and wheels; treated centre wall (in tunnel) with regular openings; hard cast-iron brake-shoe material to eliminate squeal and vehicle-floor insulation using a composite of cork and rubber. In 1956, the Toronto Rapid Transit System was described as the quietest subway in the world at that time.

Those few railway authorities that implemented some form of noise control on their system were particularly interested in the welfare of the passenger as a means of substantially increasing the use of public transport. This line of thought, on the part of railway operators, changed drastically in the early 1970's when environmentalists, anti-pollution lobbyists and subsequently, the general public started to question the "benefits" of large scale projects, including the construction of new rail systems (for example, in Japan and UK). Coincidently, rail passenger transport re-emerged as a serious competitor to road based public transport. Much faster Inter-city trains are being developed and lighter intra-urban rail systems are now being planned and built in many cities around the world. Railway noise (and vibration), up until that time tolerated if not actually deemed socially acceptable, thereafter has always featured on the complaints list at public meetings. Railway and transit authorities were persuaded to adopt stringent noise and vibration restrictions to pacify those communities exposed to high levels of noise. Not surprisingly, many of the studies conducted over the past decade have involved attempts to minimise intrusion to the wayside community.

The methods available for controlling noise from railway operations differ not only depending upon the type of noise source, but also upon the types of structure that exist on the system. There are three broad categories of structure, namely, surface (or at-grade), elevated (or aerial), and underground (or subway) structures. Though all three structures can have common acoustic treatments, elevated and underground structures need additional consideration due to further problems that are characteristic of those two structures. The noise radiated from lightweight elevated steel structures, for example, is a major community problem in many cities and it has been reported to be as much as 20 dB(A) higher than corresponding levels when the train runs on surface track (Nelson et al, 1982). This is primarily due to the secondary radiation emitted from the vibrating components of the elevated structure. On modern transit systems, elevated structures and bridges are either built entirely of concrete or have a concrete deck supported by a steel box girder. Much less noise is radiated by these types of structures. However, a problem often observed on modern elevated structures, especially composite structures with steel girders, is a tendency for the structures to radiate low frequency sound which can be a problem inside nearby buildings.

Underground structures, on the other hand, give rise to a different type of problem - groundborne noise and vibration. Though problems of a similar kind and magnitude can occur with surface and elevated structures, the impact on communities, generally is negligible because the airborne noise from trains, on these two types of structure, is usually much higher and masks that caused by groundborne vibration. Groundborne noise and vibration are caused by vibration originating at the wheel/rail interface and thereby propagating from the tunnel structure through the intervening soil and rock to nearby buildings. The resulting vibration may be perceptible, as physical motion, and the acoustic radiation by the building components may cause an audible low-frequency rumble.

The noise source of interest, in this study, is wheel/rail noise which predominates on most modern electric urban transit systems, like Tyne and Wear Metro. Propulsion and auxiliary equipment noise is not usually a problem on these systems and, therefore, it will not be discussed in any great detail in this thesis.

A summary of the means for noise control of urban rail systems for the three categories of structure is given below. Chapter 2 deals, in more detail, with some specific measures.

1.3.1 Control of Noise from Surface Track

Wheel/rail noise is the result of wheel/rail interaction during the passage of a train. This noise differs in character depending on the rail and wheel surface condition and also on the horizontal alignment of the rail. Generally, wheel/rail noise is classed as roar, squeal and impact. Roar noise is the audible consequence of micro-roughness (corrugations) on the surfaces of rails and wheels and is the dominant noise on straight continuous welded rail, in the absence of flat-spots on the wheels. Squeal is the term used to describe the high frequency sound caused by sliding when rail cars go round curves of small radii. Lastly, impact noise is characterised by the familiar "clickety-clack" that occurs when wheels encounter discontinuities on the rail, such as joints, switches and points, or when wheels with flat spots (so-called wheel-flats) roll over the rail.

The methods that are used for the control of noise from surface track, summarised in Tables 1.1 and 1.2, are effective for all three types of structure. The additional treatments for elevated and underground structures are discussed in the next two sections.

Other treatments that are used to reduce wayside noise from surface track include:

- acoustic absorption of the trackbed (for example, by using ballast); and
- vehicle speed reduction.

1.3.2 Control of Noise from Elevated Structures

Elevated structures can generally be divided into three broad classes - lightweight steel deck, concrete deck, and conventional ballast-and-tie on either concrete or steel deck. The noise radiated from these structures differs markedly, notably between the lightweight steel and the concrete deck. Due to the mass and inherent damping of concrete deck and ballasted (concrete or steel deck) elevated structures, their acoustic characteristics are close to those of surface track structures. As a result, the most effective noise reduction methods are essentially the same as for surface track. The possibilities for additional treatments for further reduction of noise is limited. In contrast, the control of noise from lightweight steel structures can be a difficult and complicated problem to tackle, primarily due to high noise radiation from structural steel components. For some old steel structures, there may be no practical and economical solution to the wayside noise problem and the only feasible policy may require that the structure be completely rebuilt or replaced.

Reduction of noise from elevated structures generally can be achieved by the following methods (Nelson et al, 1982):

(1) Source reduction. Reduce the energy input to the system by reducing wheel/rail forces and vibration.

(2) Vibration insulation. Introduce resilience between structural members to reduce energy flow into the structure.

(3) Vibration damping. Reduce the amplitudes of vibration by transforming vibrational energy into heat (damping).

(4) Mass addition. Increase the mass as, for a fixed amount of vibrational energy in a structure, this results in a proportional decrease in the vibrational velocity and hence in the radiated noise.

(5) Acoustic shielding. Block the noise path from the structure to the receiver.

(6) Acoustic absorption. Reduce the portion of the incident sound energy that is reflected by acoustical treatment of surfaces.

(7) Reduction of radiating area. Reduce the area that radiates noise so as to reduce the resulting noise levels. For example, a double-track structure radiates more noise than two separate, physically isolated structures carrying one track each.

1.3.3 Control of Groundborne Noise and Vibration

Groundborne noise and vibration can be a serious problem for an urban rail system that has extensive underground track-structure. Some of the methods that have been used (Kurzweil, 1977) to control it are:

- use of continuous rail;
- maintenance of wheel/rail surfaces (wheel turning and rail grinding);
- primary springing on bogies;

- resilient wheels;
- resilient rail fasteners;
- floating slabs;
- extra heavy tunnel structures;
- increasing tunnel depth;
- ballast mats for ballast-and-tie track;
- trenches or underground barriers;
- reduction of train speed; and
- building insulation.

The above mentioned control techniques are valid for existing transit systems as well as for new ones. However, mitigation measures are often costly and it is difficult to make significant acoustical improvements on existing rail facilities. The most efficient way of controlling noise and vibration (also the most practical and cost-effective) is by controlling it from the planning phase through to the revenue operation phase. Restraining measures include: (a) specifying acceptable noise and vibration levels in the purchase contracts of transit cars; (b) locating (wherever possible) the transit corridor, stations and special trackworks away from noise-sensitive areas; (c) choosing the appropriate rail structure (i.e. underground/surface/elevated) taking into account the effect the chosen structure will have on the acoustical environment of the area; (d) making maximum use of existing railway lines and road medians to confine and reduce the noise impact; (e) determining locations where abatement measures (such as floating slabs or noise-barriers) are required; (f) performing acoustical tests to evaluate how well facilities have complied with specifications, thereby identifying problems before serious complaints occur and devising strategies to handle complaints that do occur; and (g) developing the appropriate maintenance schedules or criteria to avoid significant increases in noise and vibration during operation.

1.4 The Importance of Controlling Noise

Noise from urban rail operations can be more than just annoying. It can startle people and interfere with a whole range of activities including conversation, sleep, listening to the radio or television, periods of relaxation, reading and so on. Excessive running noise diminishes the attractiveness of an urban rail system (for the passenger) as an alternative mode of transport to the private car and can be the cause of adverse economic impacts, such as a reduction in property values in areas subject to high noise levels. Permanent damage to hearing is most unlikely among the wayside community but high noise levels from trains can cause anxiety, fear and stress among certain individuals. Compared to other sources of transport noise such as road traffic and aircraft, railway noise has been found to be generally less annoying at similar noise levels (Vernet, 1979; De Jong, 1983; Knall and Schnemer, 1983; Fields and Walker, 1982). Nevertheless, to many wayside communities, railway noise is a significant cause of annoyance. The need to control noise from the railways, especially urban railways, is crucial to the well-being of many people at home, at work or outside in the garden. A quiet running rail system enhances the attraction of that system vis-a-vis its competitors and blends instead of intruding into the environment.

1.5 Problems of Measurement and Evaluation

Noise nuisance, if it is to be reduced or abated, must be assessed in some way or another. To assess noise exposure requires the use of some indicator that bears a meaningful relation to the subjective response of the public, both individually and collectively, to the nuisance caused by noise.

Existing indices that are used to evaluate railway noise, namely Leq and its derivatives (for example, Ldn), have their shortcomings but they have been regarded, until now, as the most suitable measures available in terms of correlation with subjective response, simplicity and international acceptability. The main disadvantages with this family of noise indices lie in the fact that: (a) they do not account for the effect of pure tones; and (b) they do not adequately account for rare loud events and impact noises (for example, from rail-joints). However, these disadvantages are shared by all current noise indices. The sole exception is the Effective Perceived Noise Level (EPNL), which is an index used to evaluate and compare the annoyance effect of aircraft noise and which make corrections to account for pure tones. However, the corrections are complex and they have not been validated for other noise sources nor for all noise levels (Schultz, 1979). At present, a time-averaged noise index (like Leq) is widely accepted as the best measure for railway noise-exposure; whereas the statistical ratings (like L10), used for road traffic noise, are quite inadequate for this purpose because the noise associated with running trains is only intermittent and usually lasts for less than 10 per cent of the total daily operating time.

The problems associated with conducting an interview survey are many and varied. Errors can creep in from the initial stage of designing the questionnaire to administering it (interviewer- and respondent-induced bias and inaccuracies respectively) to data coding and input. Besides these exogeneous factors that threaten the accuracy of a survey, it must be emphasised that 'surveys are not, and cannot be, a precise measuring instrument; that, despite its scientific base, it is not an exact science. In varying degrees, surveys underestimate the complexity of human behaviour and attitudes; they can paint only a sketchy picture of society since their results are subject to errors of commission and omission' (Hoinville, Jowell, et al, 1978).

A third, but nonetheless important factor that makes measurement and evaluation of noise nuisance difficult is the wide individual differences in susceptibility to the experience of noise. Some of these variations have been attributed to differences in the personality traits of various individuals, others are left unexplained.

The problems of measurement and evaluation will be discussed in greater detail in a subsequent chapter dealing with survey techniques.

1.6 Outline of Practical Case-Study

The primary aim of the study is to assess the effects of Metro noise on the wayside residential community. Consequently, the area of

Wallsend/Walkergate (Figure 1.1) was chosen as the study-area, since it is largely residential and densely populated, served by Metro and, unlike other sites, had not been exposed to any noise surveys or noise-related studies previously.

The fieldwork plan consisted of: (a) stratifying the area into noise zones, from which households/respondents could be randomly selected; (b) conducting a detailed questionnaire survey of chosen residents, by interview, about their acoustic environment in general and about noise from Metro in particular; and (c) measuring Metro noise levels at selected locations in the zoned area.

The following list of objectives were set for this case-study.

(1) To investigate recent research related to the impact and control of urban rail noise.

(2) To conduct a comprehensive noise measurement survey of the study area.

(3) To assess the residential community's reactions to Metro noise and, thereby, to answer the following questions:

  (a) is Metro noise a nuisance to residents?

  (b) what are the factors responsible for the frequently wide individual variations in noise susceptibility, as it applies to urban rail noise?

  (c) what noise index/indices are best related to annoyance caused by Metro noise?

  (e) besides noise, is vibration a problem? And how serious is it?

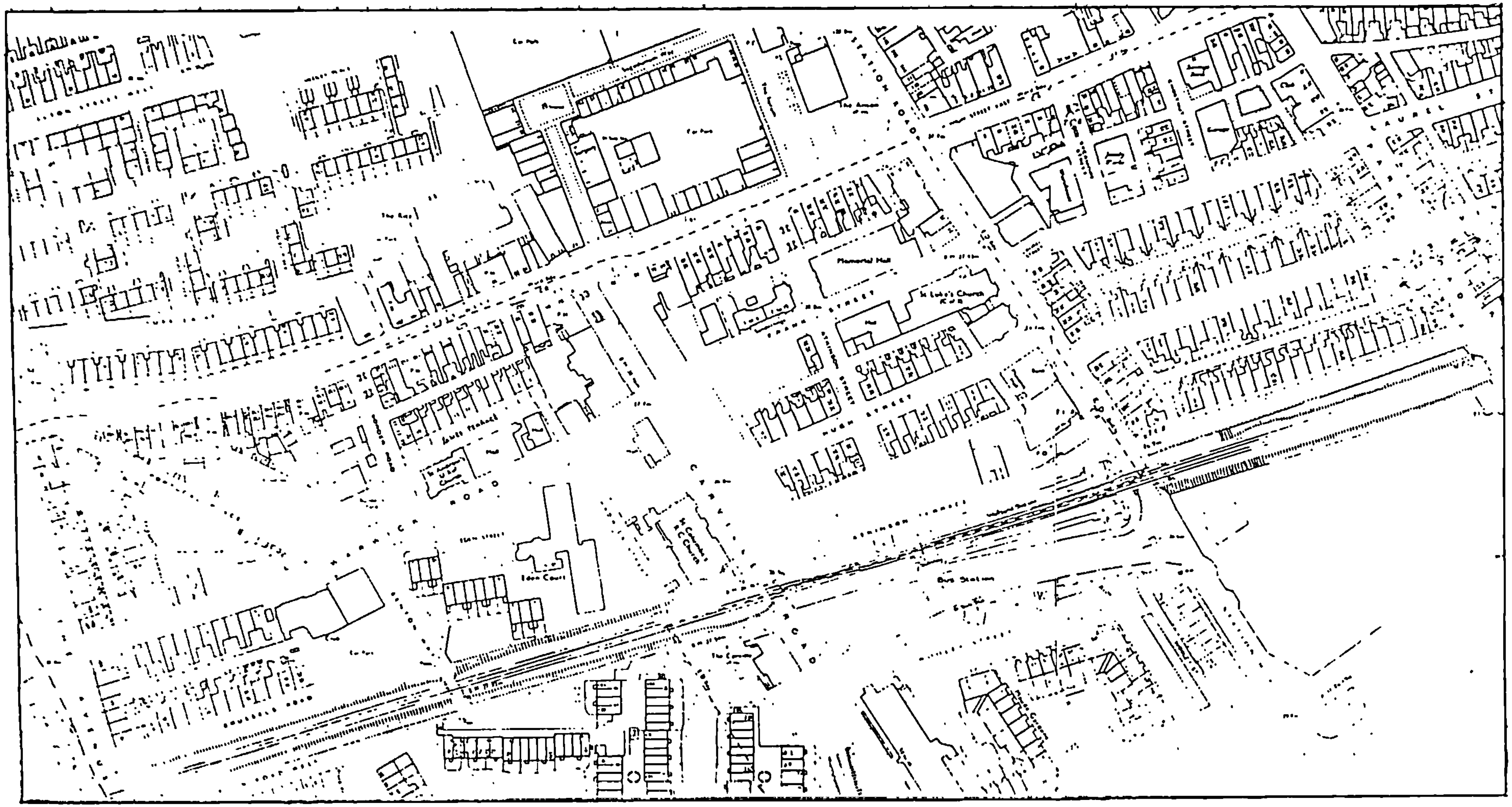


Figure : 1.1 Section of Study Area

(4) To suggest (i) means of alleviating noise related problems (if there are any) and (ii) precautionary measures to minimise noise intrusion.

1.7 Application of Results and Conclusions

Tyne and Wear Metro is the first urban railway system of its kind in the UK and it is hoped that this study of urban rail noise will be a useful reference document to operators and planners of Metro and of urban rail systems in general elsewhere. The results of the study have been used: (1) to examine the case of Tyne and Wear Metro and to lay out the positive and negative aspects of its operation in terms of its acoustic performance; (2) to suggest specific improvements regarding noise (and vibration) in planning a new urban rail system, in the light of the experience in Tyne and Wear.

TABLE 1.1 : Squeal noise - generic approaches and examples of control

1. Reduce lateral creep during train's negotiation of curve
   * Avoid short radius curves
   * Steerable bogies on trains
2. Alter friction-creep characteristics at wheel/rail interface
   * Rail or wheel tread "lubrication"
   * Specially treaded wheels or rails
3. Minimise resonant response of wheels
   * Damped wheels
   * Resilient wheels
4. Block sound radiation
   * Noise barriers (wayside)
   * Vehicle "skirts"

Source : Kurzweil (1983)

TABLE 1.2 : Impact and roar (rolling) noise - generic approaches and examples of control

1. Minimise wheel tread and rail surface discontinuities and roughness
   * Wheel turning
   * Rail grinding
   * Welded rails
   * Regular rail joint maintenance
2. Prevent wheel tread discontinuities
   * Slip/slide control
   * Composition tread brakes or disc brakes
3. Minimise wheel/rail response to surface irregularities
   * Resiliently treaded wheels
   * Resilient or damped rails
   * Reduce vehicle speed
4. Block sound radiation
   * Noise barriers (wayside)
   * Vehicle skirts

Source : Kurzweil (1983)

CHAPTER TWO

OVERVIEW OF URBAN RAIL NOISE AND VIBRATION

2.1 Introduction

Noise is an unavoidable side-effect of an urban rail system, as it is for all modes of urban transport. Although it is economically unfeasible (and technically impossible) to build noiseless rail systems, it is possible and practical to keep the total community noise exposure from urban rail systems well below that created by most other modes of transport, such as road traffic and aircraft. Since noise and vibration are not seen as directly related to the economics and efficiency of a rail system operation, they are often neglected until problems develop. Nevertheless, it is more efficient as well as more economical to anticipate acoustical problems and incorporate control solutions in the original design of the system; but when many of the older urban rail systems were constructed, only cursory consideration, if any, was given to noise and vibration. The results are evident. Urban railways have developed a reputation for exposing both the wayside communities and the rail commuters themselves to high levels of noise.

In designing new urban rail facilities or fitting new noise-control treatments to existing facilities, one must decide on acceptable maximum levels for noise and vibration. Obviously, the type of area, the human activities into which noise and vibration will intrude, the existing levels of noise and vibration, and the community's sensitivity to these nuisances must all be considered when developing the necessary criteria. Very restrictive criteria would be costly to achieve and, in some cases, impossible to fulfil. On the other hand, no standards at all or ones that are too lenient can result in the transport authority operating the system without regard to the nuisance, resulting perhaps in considerable community reaction. Japan's strong environmental lobby has recently bred an "anti-Shinkansen" group which has been remarkably successful in persuading the Japanese National Railways (JNR) to adopt stringent noise and vibration restrictions, even though there are no legal requirements to do so. At present, JNR spends about 10% of the average cost (£10 M/km) of track construction on noise-reduction measures to keep train sound to no higher than 85.dB(A) (Hayward, 1984) . Existing lines would face costlier modifications, if the same standard were to be applied.

Noise and vibration affect three groups within the community namely, people living close to the railway lines, commuters that use the system and employees of the system, especially repair-shop and line maintenance personnel. In the discussion that follows and throughout this thesis, the emphasis is primarily on the noise of an urban rail system as it affects the first group of people (viz. the residential communities) for whom the strictest criteria should apply, given that a residence is, above all, a restful place which needs to be protected against all sorts of intrusion, including noise.

2.2 Sources of Urban Rail Noise and Vibration

2.2.1 Wheel/Rail Interaction

Most of the noise radiated outwards towards a wayside community is generated by the motion of the wheels on the track and the noise from the propulsion equipment. However, for modern urban rail systems (like the Metro in Tyne and Wear) that operate at speeds less than 80 km/h, wheel-rail noise is the dominant source.

Wheel/rail interaction results in a noise that is generally divided into three distinct categories: 'squeal', 'impact' and 'roar'. These are considered below in more detail.

(a) Squeal is the term used to describe the intense high-frequency noise, consisting of one or more tones, heard when rail cars go round curves of small radius. Several factors can cause wheel squeal, three of which have been identified for the purpose of squeal control. These are:

(1) differential slip between inner and outer wheels on a solid axle which occurs because, on a sharp curve, the outer wheel has to cover more distance than the inner wheel. Hence the outer wheel will rotate faster than the inner wheel and this differential velocity is compensated by one or both of the wheels slipping on the rails;

(2) rubbing of wheel flanges against the rail; and

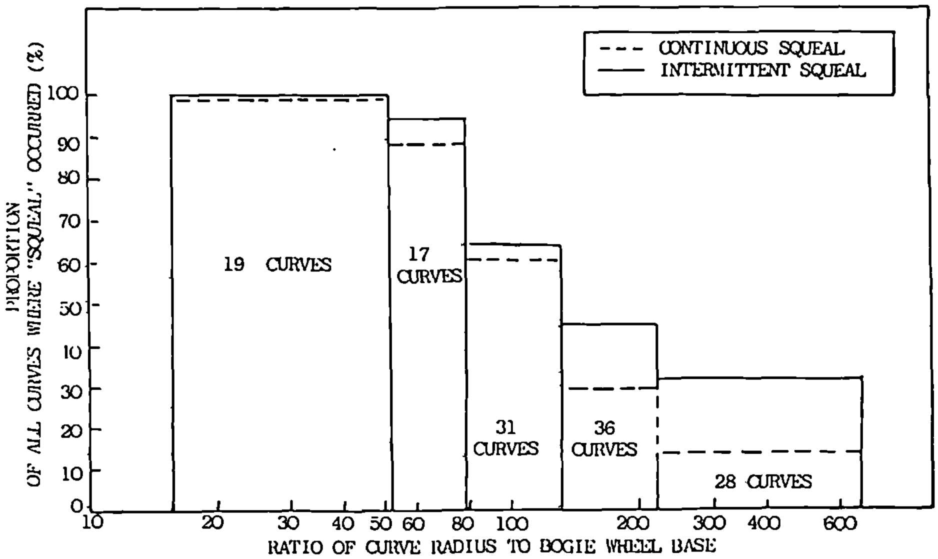
(3) lateral creep (crabbing) of the wheels across the rail head. As the rail car rounds the curve, its wheels (on both axles) cannot run at a tangent to the rails because they are constrained by

the car's rigid bogie. Hence, as the wheels roll along the rail, they must also creep laterally across the rail head in order to follow the curve, since the rigid axles are forced to remain parallel.

If the lateral creep, defined as the wheel's lateral velocity divided by the rolling velocity, is sufficiently large, a small transient excitation of the wheel will be reinforced by the friction forces at the wheel/rail interface. The wheel response will then grow until a stable amplitude is reached at one or more of the wheel's natural frequencies. This intense wheel vibration is then radiated as the familiar squeal noise. In typical rapid transit systems, curves of 700 ft (210 m) or less usually generate squeal.

One of the important findings of Rudd's original work was that squeal should not occur for curves with radii greater than approximately 100 times the bogie wheelbase of the vehicle. Remington, Dixon and Wittig, et al have examined the influence of the ratio of curve radius to bogie wheelbase on the occurrence of squeal on the Massachusetts Bay Transportation Authority (MBTA) in Boston, USA. Their data showed that for curves with a ratio of curve radius to bogie wheelbase of 50 or less, squeal is virtually guaranteed - whereas, if the ratio exceeds about 200, squeal is very unlikely. Figure 2.1 shows the relation between squeal occurrence and radius/wheelbase ratio.

(b) Impact noise is generated by discontinuities on the running surfaces of the wheels and rails. Flat spots on wheels, rail joints and special trackwork are all responsible for impact noise. The "clickety-clack" associated with trains that run on tracks with jointed rails is the familiar example of impact noise.



Source : Remington et al (1983)

Figure 2.1 : Field survey of curves on the MBTA where squeal noise occurs

Ver, Ventres and Myles (1976) have examined in some detail the noise resulting from wheels' impacts on rail-joints. They found that the change in level at a rail-joint was largely responsible for the impact noise. By contrast, gaps in the rail with no difference in level produce very little noise. They have also shown that, above a critical speed, the intensity of impact noise increases with increasing train speed for travel in the step-up direction, i.e. where the wheel travels from the lower level rail to the higher level rail, but is independent of the train speed for travel in the step-down direction. Below the critical speed, the impact noises of the two are equivalent. The critical speed, as defined by Ver, Ventres and Myles, is the speed above which the rail and the wheel came out of contact at a step-down joint. Finally, they found that wheel-flats can generate impact noise equivalent to step-down rail-joints, if the depth of the flat-spot equals the difference in level of the two rails at the joint.

Virtually all new rails in urban rail systems are now continuous welded rails (CWR), from which operating and acoustical benefits can be derived. However, even on systems with welded rails, there will be some impact noise at special trackwork, such as at switches and crossovers.

(c) Roar noise is the wheel/rail noise that predominates on straight track in the absence of discontinuities on the wheel and rail running surface, such as wheel-flats and rail-joints. Roar noise is attributed to the micro-scale roughness (corrugations) on the running surfaces of the wheel and rail, exciting both into vibration. In turn, this vibration is radiated as wheel/rail noise to the surrounding area.

Corrugation of the wheel tread, which (interestingly) does not seem to occur with disc-braked vehicles (Stanworth, 1983) can be removed by "turning" the wheels. A similar solution applies to rail corrugation - i.e. by grinding of the track-surface. However, both are short-term solutions since the corrugations quickly reappear. Perversely, if they are left untreated they can also sometimes disappear. The physics of this phenomenon is not yet fully understood.

Certainly there is no satisfactory explanation, up to now, of how corrugations on wheel treads and rails are initiated. It is suggested (Kaess, 1983) that the roughness of the rail-surface may have considerable influence upon the susceptibility to corrugation, but this has been refuted by S L Grassie in his paper 'Dynamic Loading of Track at Corrugation Frequencies' (Grassie, 1983). Clearly, the corrugation phenomenon is far from resolved but a solution to rail corrugation is vital if the full advantage of potentially quieter rolling stock is to be achieved.

2.2.2 Noise due to groundborne vibration

Groundborne vibration is generated by the interaction of steel wheels rolling on steel rails and transmitted through the rail fasteners to the track structure. The vibration radiated from the structure propagates through the soil to the foundations of adjacent buildings. The resulting vibration of the buildings may be perceptible, either as mechanical motion or/and as an audible low-frequency rumble created by the sympathetic vibration of the walls, ceilings and floors. Noise due to groundborne vibration is not usually a problem when airborne noise, from trains on surface or elevated structures, is relatively high. In cases where the noise from groundborne vibration is not masked by airborne noise, as is often the case with underground railways, the effects of the former become perceptible and can be the cause of considerable intrusion resulting in persistent complaints and demands for compensation. However, the problem of groundborne vibration must be looked at for each of the three basic railway track configurations - elevated, surface and underground - since the phenomenon is present in all three cases, with the underground receiving more attention, as explained earlier, even though the other configurations can produce similar vibration and noise levels.

Groundborne vibration from urban rail systems, transmitted into buildings, generally falls in the frequency range of 10 to 200 Hz and is usually concentrated in only one or two octaves. The typical octave band (rms) acceleration levels at the ground surface, at distances of 15 to 30 m from an underground railway are 50 to 70 dB (re 1 micro g*) with the peak frequency between 16 and 63 Hz (Saurenman et al, 1982). Studies conducted (Saurenman et al, 1983) at Washington DC rapid transport system (WMATA) and at the Metropolitan Atlanta Rapid Transit Authority (MARTA) in the USA,indicate that perceptible vibration between 10 Hz and 20 Hz to 30 Hz can be significant. This range is the low frequency range, at which vibration can make windows and dishes rattle and cause residents to fear the possibility of damage to their homes.

Factors influencing groundborne noise and vibration are shown, in Table 2.1, and a general list of the various components (sic) of community noise and vibration from a rail system is shown in Table 2.2.

Of all the sources of noise, from an urban rail system, that affect the wayside community, airborne noise is the worst offender except in cases where the tracks are predominantly underground. The former is certainly true in Tyne and Wear which has some 7 km of underground out of a total of 56 km of track. In addition, airborne noise from Tyne and Wear Metro is mainly from wheel-rail interaction, as

* $g = 39.4 \times 10^{-5}$ in/sec^2 or 10^{-5} m/sec^2

mentioned earlier. It is, therefore, with this in view that the discussion that follows, and indeed this whole thesis, concentrates on the control, measurement and subjective effects of airborne noise from rail systems and in particular wheel-rail noise.

TABLE 2.1 : Factors influencing groundborne noise and vibration

Factor	Influence
Vehicle primary suspension :	Very significant causing up to 10 or 15 dB differences in groundborne vibration levels.
Wheel/rail roughness and wheel flats:	Increases vibration by 6 to 15 dB.
Resilient wheels:	Decreases vibration above 40 to 50 Hz by 5 to 10 dB.
Rail fasteners:	Vibration level proportional to 20 log K above 50 Hz. K = rail support modulus.
Floating slab (14 Hz resonance):	Decreases vibration above 20 to 30 Hz by up to 20 or 30 dB.
Structure type:	Circular tunnels produce higher vibration levels than double-box subways at frequencies above 50 Hz.
Train speed:	Vibration increases by 4 to 6 dB per doubling of train speed.
Car body suspension:	No apparent effect.

Source: Saurenman et al, 1983

TABLE 2.2 : Components of community noise and vibration

Component	Comments
VEHICLE NOISE	
Wheel/Rail Noise	Noise radiated directly by the wheels and rails. Wheel/rail noise is often broken down into roar noise, impact noise, and wheel squeal noise.
* Propulsion Equipment	Noise from traction motors, reduction gears, and motor cooling fans. Usually, propulsion equipment noise is greater than wheel/rail noise at high speeds and comparable at medium speeds.
Auxiliary Equipment	Includes compressors, motor generator or alternator sets, HVAC equipment, braking systems. All add to overall train noise, but it is usually not an important component of community noise except near yards.
ELEVATED STRUCTURE	
Lightweight Steel Structures	Noise created by vibration of the structure. A very severe noise problem exists with many of the older lightweight structures.
All Concrete and Composite Concrete and Steel Aerial Structures	The overall noise level consists of two components, the noise radiated directly from the transit cars and the structure radiated noise. Typically car noise dominates at high frequencies and structure-radiated noise dominates at low frequencies.
GROUNDBORNE NOISE AND VIBRATION	Mechanical vibration of transit structure originating at the wheel/rail interface and transmitted to adjacent buildings. More common for subways but can also be a problem with surface and elevated structures. Airborne noise in subways does not contribute to groundborne noise and vibration.
CONSTRUCTION ACTIVITIES	Most construction equipment and activities have the potential of creating intrusive community noise and vibration.
VENTILATION SHAFTS	
Fans	The airborne noise of station and tunnel ventilation fans can reach the community through vent shafts and ducts.
Train Noise	The shafts provide an airborne path for train noise to reach the community.
TRACK MAINTENANCE EQUIPMENT	Rail grinding, ballast cleaning, etc. Track maintenance is often performed at night when residential communities are most sensitive to noise.
SUBSTATION TRANSFORMERS AND COOLING FANS	Substation noise is only a problem in the immediate vicinity of the substation.
YARD OPERATIONS AND ACTIVITIES	This includes train movements and equipment, horns, PA systems, trains coupling and uncoupling, maintenance activities.
STATION HVAC SYSTEMS	
Mechanical Equipment	The HVAC equipment noise transmitted to the outdoor can be a community noise problem.
Cooling Towers	Since cooling towers can be relatively noisy and are located outdoors they can be a noise problem.
PA Systems	Public announcements in above-ground stations can produce sound levels intrusive to neighbors.

* Propulsion noise in Tyne and Wear Metro is insignificant, compared to wheel/rail noise of Metro in operation. Only at slow speeds (20 km/hr and below) does propulsion noise make a significant contribution to the overall wayside noise (Bell and Leung, 1972)

Source : Saurenman et al, 1982.

2.3 Control of Wheel/Rail Noise and Vibration

The control of wheel/rail noise can be divided into 3 components - the treatments applied to the wheels, treatments to the rails and track and, finally, the treatments to the vehicle itself. This section presents a review of the methods available for the control of the three types of wheel/rail noise: squeal, impact and roar, under three sub-headings corresponding to the above-mentioned treatment areas. The discussion, that follows, draws heavily on Kurzweil's paper (Kurzweil, 1983) and the Remington et al report (1983) but makes reference to other significant contributions to the subject.

2.3.1 Wheel treatments

(1) Resilient Wheels

"Resilient wheels are wheels in which the metal tyre is structurally isolated from the wheel hub, generally by an elastomeric material" (Kurzweil, 1983). The elastomer (a) provides damping to the wheel, resulting in reduced vibrations of the wheel at its resonant frequencies (most notably those frequencies associated with squeal noise), and (b) isolates the vibrations of the wheel rim from the wheel hub, thus reducing the dynamic forces applied to the rail and also reducing acceleration of the axles, bogie and car body components. Resilient wheels are used quite extensively now, both in North America and in Europe. Typical cross-sections of currently available resilient wheels are shown in Figure 2.2.

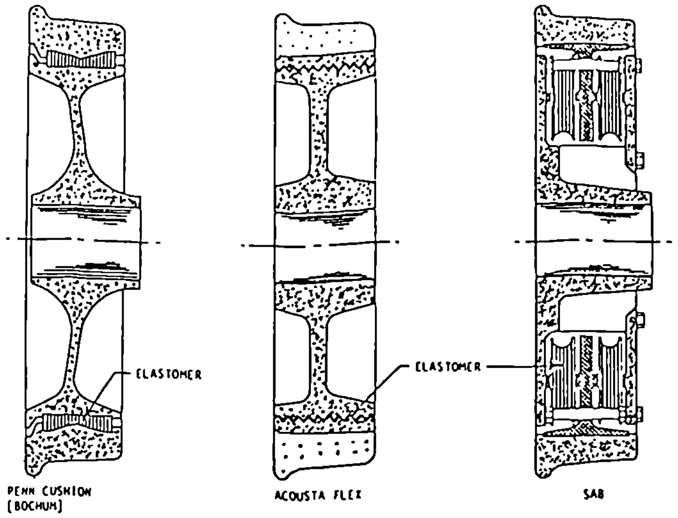


Figure 2.2 : Cross-sections of resilient wheels
Source : Saurenman et al, 1982.

Resilient wheels offer a number of benefits, according to Kurzweil, which "include: (1) noise reductions of squeal, roar and impact; (2) increased wheel life over that of standard wheels by up to 50%; (3) reduced ground vibration levels by 4-10 dB over the frequency range of 40 to 250 Hz; (4) reduced acceleration levels on axles, bogie components and undercar equipment by 6-20 dB; (5) reduced impact forces at joints, by up to 40%; and (6) reduced dynamic wheel/rail forces on continuous welded rail by about 20%" (Kurzweil, 1983). Kurzweil also suggests that resilient wheels "extend the life of the axle- and bogie-mounted components; require less frequent truing (sic) than standard wheels; increase rail life; reduce track and bogie maintenance requirements; and provide a smoother, more comfortable ride for the passenger(s)".

Resilient wheels' contribution to noise-reduction on straight tracks, namely roar and impact, is in the range of 0 to 2 dB(A) which is in itself regarded as insufficient to justify the extra cost of resilient wheels. However, they are very effective at controlling wheel squeal and provide numerous additional benefits as mentioned above, which make resilient wheels potentially more cost-effective than solid steel wheels for reasons other than noise-control. Problems that have been experienced with resilient wheels include failure of the elastomeric material due to initial manufacturing defects and/or overheating as a result of tread braking, and fatigue failures of the electrical shunts between the tyre and central plate of the wheel. Noise reductions observed on resilient wheels, as well as for other treatments mentioned in this section, are summarised in Table 2.3.

(2) Damped Wheels

Damping helps suppress the pure tone characteristic of wheel squeal, as was pointed out for resilient wheels. Rudd has shown theoretically (Rudd, 1976) that sufficient internal damping of the wheel will prevent squeal and that, if the internal wheel damping exceeds the maximum "negative damping" generated by the friction forces at the wheel/rail interface, no wheel squeal will occur. Damped wheels have comparable acoustical performance to resilient wheels and there are several damping treatments that have been developed and tested with considerable success. These include ring dampers, tuned dampers and constrained layer dampers, shown in Figure 2.3.

(a) and (b) Ring-damped wheels

The basic configuration of a ring-damped wheel, shown above Figures 2.3(a),(b) consists of a groove, machined into the tread of the wheel, into which sits the ring-damper. The damper is usually made of steel rods about 0.5 in diameter. Damping is provided as a result of the relative motion between the ring and the groove, that is, by the frictional resistance.

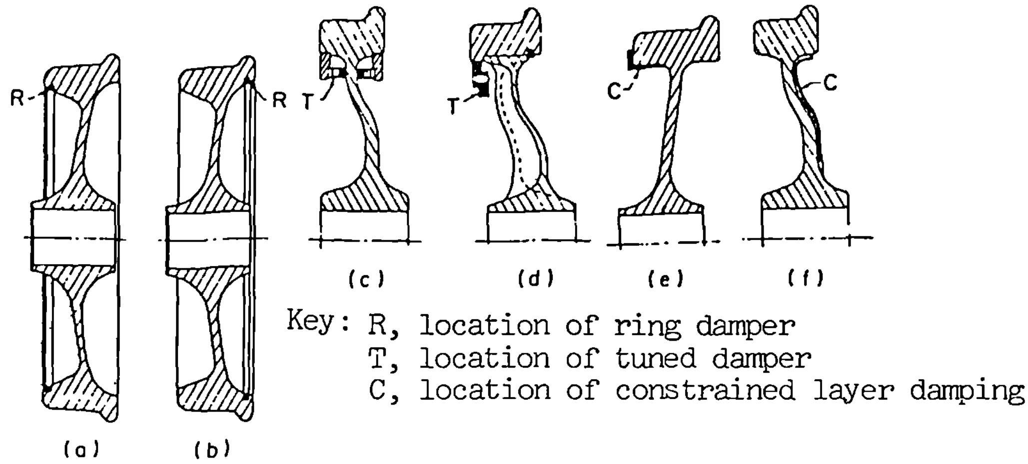


Figure 2.3 : Various damped wheel configurations
Source: Kurzweil (1983)

Ring-damped wheels could be one of the more cost-effective methods of controlling wheel-squeal but one important problem still needs to be solved. Ring-dampers tend to bind or adhere to the grooves, thus losing virtually all of their damping characteristics. It is not very certain whether the cause lies with the rusting of the rings or with the intrusion of foreign material, such as brake dust, in the grooves.

(c) and (d) Tuned-damper wheels

Resonant vibration absorbers achieve damping in these types of wheels. The absorbers consist of steel blades of different thicknesses, separated by plastic or elastomeric materials, which vibrate as cantilevered beams whose resonance frequencies are "tuned" to the resonant vibration frequencies of the wheel. The vibration energy of the wheel is absorbed by the blades and converted into heat in the elastomeric material. The axial or radial modes of the wheel can be damped by tuning the damper appropriately, thus optimising noise reduction for squeal or rolling noise, respectively (Kurzweil, 1983).

(e) and (f) Constrained-layer damped wheels

The constrained-layer damper behaves in the same manner as the tuned-damper in that the vibrational energy of the wheel is reduced through conversion to heat in the elastomeric constrained layers. The wheel can be rim-damped or web-damped. A drawback of this treatment is due to the covering of a portion of the wheel by the damper, which results in interference with visual inspection of the wheels, and with operation of the wheel turning machine (Shipley and Saurenman, 1978; Anon, 1978). This treatment is currently used on the Paris Metro (RATP).

(3) Resiliently Treaded Wheels

Resiliently treaded wheels are those that incorporate both an increased contact area and reduced contact stiffness between the wheel and the rail. These two mechanisms contribute to a reduction in wheel/rail noise in the following way: a more resilient tread has a lower contact stiffness which allows the tread to deform around irregularities on its own or on the rail's running surface, thereby reducing the excitation applied to the wheel and rail. The contact area between the wheel and rail acts like a filter, effectively filtering out those wheel and rail surface irregularities having wavelengths in the order of, or less than, the dimensions of the contact area. Thus, a larger contact area will more effectively filter out the excitation due to these irregularities.

There are two types of resiliently treaded wheels that are still at the experimental stage, a thin-tread wheel, shown in Figure 2.4 and a non-steel treaded wheel, such as the Nitinol/Tinel (nichel-titanium alloy) treaded wheel.

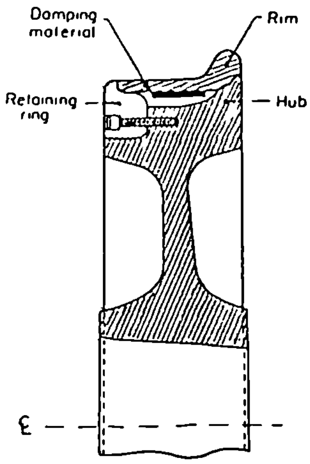


Figure 2.4 : Resiliently (thin) treaded wheel concept
Source : Kurzweil (1983)

(4) Wheel-Turning

Wheel-turning has long been used to restore the wheel tread and flange to its proper profile and to correct tread defects such as flats, shelling and spalling. The noise-reduction that can be obtained from wheel-turning depends on the condition of the wheels before turning and of the rails. Typical results of wheel-turning treatment are given in Table 2.3. In addition to reducing wheel/rail noise, wheel-turning promotes regular wear patterns which leads to longer life of the wheel, improves ride quality, reduces ground vibration levels above 100 Hz by up to 10 dB (Kurzweil, 1983) and is likely to reduce track and bogie component failures due to the removal of large defects from the wheel surface, resulting in a reduction of wheel/rail loads.

It is important, however, to develop suitable criteria for when to turn wheels. Too frequent turning will lead to reduced wheel life. The New York City Transit Authority (NYCTA) adopts the following criteria: (a) any wheel with a flat-spot of 1 inch or greater in length shall be reported for immediate turning; or (b) any wheel with a series of flat-spots of 3/4 inch to 1 inch in length in which the total length of all spots in one quadrant (one-quarter of the total circumference) of the tread is 4 inch or greater shall be reported, for turning as soon as is practical.

There is a need to review these and other suitable criteria so as to develop optimised criteria for wheel-turning for wheel/rail noise control.

2.3.2 Rail and Track Treatments

Rail and track treatments include the following:

* rail grinding
* rail welding
* joint maintenance
* rail or wheel-flange lubrication
* resilient rail-fasteners
* rail-surface treatment
* fitting of restraining rails on curves
* erection of acoustical barriers

(1) Rail Grinding

Rail grinding is a general railway operation, primarily for removing mill and weld imperfections from new rails and for "reprofiling" and removing corrugations, flaking, head cracks and rail burns (due to wheel-slip) from worn rails.

As with wheel turning, the effectiveness of rail grinding is highly dependent on the surface condition before grinding. In addition to noise-reduction of wheel/rail noise (shown in Table 2.3), rail grinding has been found to reduce ground vibration levels by 2-10 dB, rail and wheel failures and track and bogie maintenance requirements (Kurzweil, 1983).

There is a need, as with wheel turning, to develop criteria as to when and how to perform cost-effective rail grinding for noise control.

(2) Rail Welding

Welding rails is the most effective way of removing impact noise due to joints. Although the primary reasons for using welded rail is to reduce track maintenance, and therefore maintenance costs, there are clear acoustical benefits also. There is generally a noise reduction of between 2 and 10 dB(A) depending on the condition of the joints and the relative surface condition of the jointed and welded rails. Besides, the character of the sound is changed since the "clickety-clack" noise at the rail-joints, which many people find annoying, is removed.

Field-welded joints (as opposed to shop welding) sometimes pose a problem, due to occasional weld failure. Replacing worn or damaged sections of rail requires that the rail be cut and a new section fitted and rewelded. These maintenance problems, however, are offset by the elimination of joint maintenance and the reduced incidence of track degradation.

(3) Joint-Maintenance

Even where jointed track continues to be used, impact noise can be significantly reduced by proper and regular joint-maintenance. Badly maintained joints can lead to loosened bolts and fish plates, which then allow differential movement of the rail ends as well as broken bolts in some cases and battered rail ends. These, in turn, lead to more severe impacts from passing wheels, which accelerate ballast settling and significantly increase noise levels. Newly-laid smooth jointed track with tightly-bolted joints has shown to make no more noise than a welded joint (Kurzweil, 1983). Tests conducted by Shipley and Saurenman showed a total reduction of 2-5 dB(A) with proper rail-alignment and grinding of the joints.

(4) Rail or Wheel-Flange Lubrication

Lubrication of rails or wheels on curves is done mainly to reduce wear and not noise. Lubrication is applied to the gauge side of the rail, i.e. the side facing the restraining rail or the wheel-flange. Tests to determine the effectiveness of rail and wheel-flange lubrication in reducing wheel squeal have obtained contradictory results. However, it appears that applying lubricants on top of the rails can either reduce or eliminate squeal.

The problems associated with using lubricants, however, are numerous:

(a) the formation of wheel-flats and loss of traction at curves can result from grease on top of the rail;

(b) automatic lubricators require considerable maintenance to function properly;

(c) the viscosity and effectiveness of lubricants may vary with temperature and age; and

(d) water-based spray on top of rails, which evaporates so that traction is quickly regained, increases wear on the wheel and rail, it freezes in winter and can cause rot in the wooden ties, too.

Clearly, the application of lubricants to rails or flanges needs further consideration and research. Because of the site-specific nature of this treatment and the added benefit of reduced wheel and rail wear, rail lubrication appears to be a potentially cost-effective remedy for the problem of wheel squeal. The best solution would be to find a material that evaporates or disperses rapidly after application, that is non-toxic, non-flammable, non-corrosive, environmentally degradable and that does not freeze. This is a stringent list of requirements.

(5) Resilient Rail Fasteners

Resilient rail fasteners have shown best results (in reducing wayside noise) on elevated steel structures. The fasteners, if properly designed, both isolate the rail vibration from the supporting structure and increase the damping of the rail itself. Their effectiveness in reducing roar noise in general, however, is unclear and they are not expected to have any significant effect on wheel squeal.

(6) Rail Surface Treatment: Hard-faced rails

The hard-faced (Anti-Quietsch Schweissung) rail (Figure 2.5) is a rail specially treated for squeal suppression manufactured by Elektro-Thermit GmbH, in Essen, West Germany. The process involves the welding and subsequent grinding of special very hard, low-friction steel strips (Elekta 5 spezial), approximately 5 mm high by 12 mm wide, onto the rail head on sharp curves. The wheel runs on these strips and the claim is that no squeal noise is generated and rail wear is reduced.

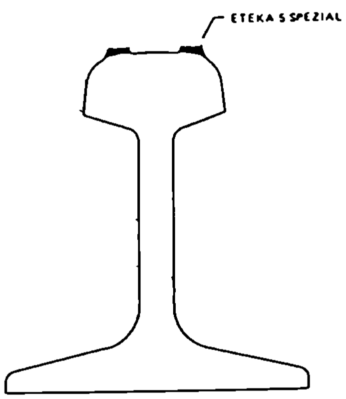


Figure 2.5 : Cross-section of a hard faced rail
Source : Remington et al, 1983.

Experiments conducted on the Stuttgart streetcar system in 1976 (Remington et al, 1983) resulted in the following: (a) the hard-faced rail did eliminate squeal, but after 3 to 4 months wheel-squeal recurred; and (b) the rails did not wear as long as had been claimed (i.e. over 2 years). The Frankfurt streetcar and subway system have had satisfactory results with the use of hard-faced rails but tests there are not complete.

The hard-faced rail has yet to prove itself. It appears that it does prevent squeal, but it is uncertain how quickly the rail takes to wear and how effectively it suppresses squeal with time.

(7) Fitting Restraining Rails on Curves

A restraining (check) rail is used to relieve the leading wheel of the pressure that is generated when its flange rubs against the side of the outside rail, during the passage of a vehicle round a curve. The check rail transfers the pressure to the back of the inner leading wheel flange, reducing wear of the outside rail and the risk of the outer leading wheel climbing over the rail. The effect of check rails on wheel squeal is not known. It should be noted that reducing the flange contact of the outside wheel, implies introducing another type of flange contact on the back of the inner wheel. The net effect of this on squeal needs further study.

(8) Erection of Acoustical Barriers

Acoustical barriers are often the only viable alternative for further reductions of wayside noise once the vehicle design, route alignment and structure configuration have been determined. Adequate barrier design is based upon relatively simple principles:

* The barrier must break the direct (line-of-sight) path between the noise source and the receiver, and block all possible indirect paths that the sound can travel from the source to the receiver (e.g. reflections).
* Openings in the barrier, for example, drainage holes, should be kept as small as possible. They provide "short-cut" paths for the sound.
* The barrier should be constructed of a material that is sufficiently heavy (thick and dense) to inhibit transmission of sound through the barrier.
* The most effective location for barriers is either close to the noise source, especially in built-up areas where there are many receivers living close by, or close to the receivers when the latter live some distance away from the railway.

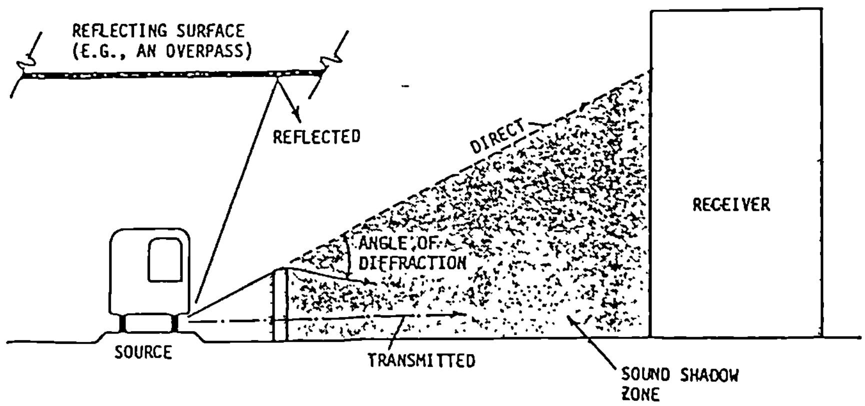


Figure 2.6 : Paths along which sound can travel from the source to the receiver

The main problems associated with the use of barriers (usually between 1.0 m and 2.5 m high) are: (a) reduced access to the track; (b) snow removal; and (c) possible increase in interior noise levels. However, an absorptive barrier (i.e. one lined on the side facing the train with acoustically absorptive material) minimises the effects of this problem. An absorptive barrier is typically 3-4 dB(A) more effective than a reflective barrier of the same dimensions.

2.3.3 Vehicle and Bogie Treatments

(1) Wheel Slip-slide Prevention

A slip-slide control system regulates the speed of each axle of a car and also regulates the rate at which each axle decelerates or accelerates. Its main function is to keep the velocity differential between axles (of a car) below an established threshold and to maintain the rate of change of velocity of each axle below another established threshold both for deceleration or acceleration.

Slip-slide control systems are used, on rail cars, to prevent the wheels from sliding on the rails. The system acts to minimise sliding during braking and spinning of the wheels during acceleration. The main effect of the slip-slide system is a reduction in the number of wheel-flat occurrences, thus reducing wayside noise levels. The NYCTA has reported a 50% reduction in the incidence of wheel-flats on cars equipped with these systems (Kurzweil, 1983).

(2) Articulated Metro-cars

Articulated bogies are still at the experimental stage of development. The bogie design incorporates a flexible arrangement that allows the rotation of one axle relative to the other. "The axles are either cross-linked or linked to the car body in such a manner that both axles can point toward the centre of a curve", (Kurzweil, 1983). An articulated bogie can thus negotiate a fairly tight curve without lateral slip (crabbing) of the wheels. The end result is the prevention or reduction of wheel squeal. Other benefits of articulated cars include reduced wheel and rail wear, reduced fuel consumption, due to reduced rolling resistance on curves, and elimination of wheel/rail lubrication on curves which additionally will reduce wheel-flats.

(3) Vehicle Skirts

Vehicle skirts are acoustical barriers attached to the sides of a rail car, extending down as far as possible to block the noise generated by the wheels and the undercar equipment. Because of skirt-clearance specifications, part of the wheel and all of the rail are usually exposed limiting the effectiveness of vehicle skirts in reducing wheel/rail noise. Tests performed in Europe, Japan and the USA have yielded wayside noise reduction in the range of 0 to 3 dB(A), both for absorptive and reflecting skirts. However, on rail systems whose propulsion noise is the dominant source at high speeds, vehicle skirts may provide reductions up to 10 dB(A) (Kurzweil, 1983). Vehicle skirts can create a few problems which include possible interference with inspection and maintenance of wheels and undercar equipment; an increase with in-car noise; absorption of contaminants such as oil or grease that may become a fire hazard; and a possible heat build-up underneath the car.

It is recommended that, in order to get maximum benefit from vehicle skirts, they should be used in conjunction with wayside barriers where an additional 5-10 dB(A) reduction can be obtained over that provided by the barrier alone.

(4) Braking Systems

The form of braking system used on a rail vehicle can greatly affect the surface roughness of the wheels and, hence, the noise. Hemsworth and Kurzweil both report marked difference in noise levels for rail systems using disc brakes and cast-iron tread brakes. Wheels braked with cast-iron tread brakes are about 10 dB(A) noisier than disc-braked wheels, and 5-7 dB(A) noisier than composition tread-braked wheels.

The cause of higher noise level with the use of cast-iron tread brakes is due to the formation of corrugations on the running surface of the wheels which increases the excitation of the wheels and rails. Disc brakes and composition brakes have shown little or no such corrugation.

(5) Vehicle Speed

Speed reduction will clearly result in lower wheel/rail noise. Halving the speed will produce a noise reduction of between 6 and 12 dB(A). Reducing speed is, however, rarely practical as a solution to a rail system providing a high level of service, but it is sometimes the only available means of control, to a railway authority, along a noise sensitive area.

A summary of wheel/rail noise control treatments discussed above is shown in Table 2.3.

2.3.4 Control of Groundborne Vibration

There is a large number of methods that can be used to control ground vibration. This section simply skims over the different options that are available and is confined to those that have had at least limited success. A more detailed description of these methods and vibration prediction methods can be obtained from the report by Nelson and Saurenman (1983).

Vibration control methods can be classified, as follows:

* wheel/rail maintenance
* vehicle design
* design of rail supports
* floating slab vibration isolation
* ballast mats
* design of underground structures
* location of tracks
* screening
* building insulation

The ideal situation for an urban railway authority is to be able to operate a railway system away from all noise and vibration sensitive areas. However, this will be in conflict with the primary aim of an urban rail system which is to transport passengers effectively and efficiently to and from their homes. Hence, the railway authority is

TABLE 2.3 : Summary of wheel/rail noise control treatments

Treatment	Wayside noise reduction*‡ (dB(A)) Squeal+	Impact	Roar
Resilient wheels	Reduces or eliminates	0-2	0-2
Damped wheels	Reduces or eliminates	0-6	0-6
Resiliently treaded wheels	Undetermined (thin-tread) Eliminates (Nitinol tread)	5-10	5-10
Wheel turning	2-5	Eliminates flats	2-6
Wheel/rail interface geometry	Undetermined	0	0
Maximise curve radii	Reduced likelihood of squeal	0	0
Rail grinding	0 (Unpredictable)	1-3 (Joints and welds)	2-9 Uncorrugated rail 8-15 Corrugated rail
Welded rail	0	Eliminates joints	0
Rail joint maintenance	0	2-5 (joints)	0
Rail (or wheel) lubrication	Reduces or eliminates	0	0
Resilient rail fasteners	0	3-6 Steel elevated	3-6 Steel elevated
Hardfaced rail	Reduces or eliminates	0	May prevent corrugation
Restraining rail (on curves)	Undetermined	Undetermined	Undetermined
Wayside barriers$ (3-6.5ft high)	5-15	5-15	5-15
Slip/slide control	0	Prevents most flats	0
Steerable bogies	Eliminates	0	0
Vehicle skirts	0-3	0-3	0-3
Composition (vs cast iron) tread brakes	0	Prevents small flats	5-7
Vehicle speed reduction	Reduces likelihood of squeal	6-12 per halving of speed	6-12 per halving of speed

* The reductions given in the table refer only to the source indicated and equal the overall noise reduction only when that source dominates the overall noise.

‡ In-car noise reductions are the same as wayside noise reductions only when the source affected dominates the overall in-car noise. For new, acoustically treated transit vehicles, wheel/rail noise does not dominate the in-car noise. The treatments in this case will typically result in smaller reductions in the cars than at the wayside.

\+ In the case of squeal, the actual noise reduction varies greatly, usually between 2 and 25 dB(A)

$ The wayside reduction depends on how much the top of the barrier extends above the direct line between the wheel and the wayside measurement location. Barriers should be lined with acoustically absorptive material to minimise any increase in in-car noise due to sound reflections off the barriers.

faced with a situation in which it has to provide a fast service to the catchment areas (mostly residential) without being too intrusive to buildings nearby.

One of the first steps to follow for controlling groundborne vibration is to minimise the wheel and rail irregularities. Replacing jointed rail with continuous welded rail and maintaining the wheel and rail contact surfaces in smooth and uniform condition will reduce both airborne noise and groundborne vibration. Nelson and Saurenman (1983) report a 6 to 10 dB reduction in vibration levels about 100 Hz for smooth standard wheels when compared with worn standard wheels. The vibration reduction obtained by rail grinding was less significant than for wheel turning, but well-maintained wheels and rails can result in up to 15 dB reduction in vibration levels.

Changes in vehicle design include decreasing the primary suspension stiffness of the vehicle bogie and introducing damping devices, such as resilient wheels. The primary suspension supports the bogie frame on the axles and reduction of the primary stiffness generally leads to a reduction of the dynamic load of the vehicle on the rail. Vibration reductions that can be achieved through the use of resilient wheels are quite significant. Compared to solid steel wheels, reduction of 4 to 8 dB for vibration from elevated structures, and 8 to 12 dB for underground structures over the frequency range of 31.5 Hz to 125 Hz have been achieved (Nelson and Saurenman, 1983). Pneumatic rubber tyres can further reduce groundborne vibration by up to 10 dB over the frequency range of about 50 Hz to 125 Hz (Saurenman et al, 1982).

Resilient direct-fixation fasteners (which refer to fasteners bolted directly to a continuous concrete trackbed without intervening ballast or wood ties) are a form of vibration isolation which can adequately control the problem of groundborne vibration for many existing situations. The reduction in vibration levels is due to (a) the lower rail support modulus (k) of resilient fasteners (i.e. k between 1000 lb/in^2 and 10000 lb/in^2) as compared to conventional rigid/non-resilient fasteners ($k > 20000$ lb/in^2); and (b) the elastomer pad that lies between the rail and the concrete trackbed. The recently designed elliptically-shaped "Cologne Egg" fastener, which has a ring of elastomer in shear bonded between two conically cast elements, is reported, by Nelson and Saurenman, to have achieved vibration reduction of 10 to 15 dB for the frequency range between 40 and 125 Hz. Besides resilient fasteners, there are also resiliently supported ties which provide further vibration damping and isolation.

Floating slabs are used in critical locations, where extra reduction of groundborne vibration is required beyond that provided by standard features such as well-maintained wheels and rails (continuous welded) or resilient rails supported on rigid inverts. The main reason for this restriction is due to the high cost of construction and installation of the slabs, although more recent designs are less expensive. The floating slab consists of a concrete slab supported on resilient pads and is similar, in principle, to the inertia bases on springs that are used to support stationary machines. The vibration isolation of floating slabs is provided by the mass of the slab acting as an inertia mass and the resilience of the support pads acting as support springs which, combined, reduce the transmission of the vibration forces to the surrounding track or/and underground structure. Estimates have been made based on measurement data for vibration reduction performances of continuous and discontinuous floating slabs relative to direct-fixation resilient fasteners. These show reductions of 10 dB to 30 dB, in the frequency range of about 25 Hz to 63 Hz, and reductions of 25 dB to 30 dB, in the frequency range of 63 Hz to 250 Hz for discontinuous floating slab (e.g. for the Toronto Transit Commission), whereas the reductions obtained on the continuous floating slab of the Washington Metropolitan Area Transit Authority (WMATA), were between 20 dB and 28 dB, in the frequency range of about 100 Hz to 500 Hz. There are strong indications that vibration attenuation, at different frequencies or frequency ranges, is related to the coupling of the mass-spring system of the slab with the vehicle suspension.

A ballast mat is a resilient layer of material placed under the ballast to provide vibration isolation from the train-track source to the surrounding environment. Ballast mats have been used mostly in Europe and in Japan and results of tests performed in Europe indicate vibration reduction between 5 and 15 dB can be achieved at frequencies between 63 and 250 Hz. However, there was little or no change in vibration level at 31.5 Hz and lower (Nelson and Saurenman, 1983). Ballast mats are normally used to control ballast pulverisation and improve electrical isolation and water drainage; they also reduce soil migration into the ballast and improve soil stability on earth embankments.

Groundborne vibration levels and spectra are strongly influenced by the type of railway structure - surface ballast and tie, underground or elevated structure. Since the relationship between the soil and the structure is different for each structure-type, the vibration coupling for each structure-type is fundamentally different. Very limited information is available concerning elevated and surface track structures and more information is required to confirm results of tests carried on underground tunnel structures. However, in each basic structure, vibration levels and spectra are affected by dimensional and mass parameters. From information available from Canada and the USA, it appears that heavier double-box concrete tunnels tend to produce lower vibration levels at frequencies above 125 Hz when compared with lightweight circular cross-section tunnels (Nelson and Saurenman, 1983). It may well be that, at low frequencies, the amplitude of underground vibration is controlled by soil stiffness whereas, at high frequencies, the amplitude is controlled by the tunnel mass. Much work on this subject remains to be done.

Vibration screening is a method of control analogous to controlling airborne noise by means of an acoustical barrier. Screens can either be open trenches and trenches filled with a lightweight waterproof filler (such as styrofoam) or solid walls made of sheet piles or concrete poured into trenches. In both cases, the basic idea is to provide an impedance mismatch in the soil so as to interrupt surface or Rayleigh wave propagation. For body waves (e.g. compression and shear) the screens must extend to greater depth than for surface waves. Hence, before deciding whether or not screening may be effective, the wave types and wavelength must be determined. Only little or sketchy data are available on the use of trenches and sheet piled barriers. It is suggested that additional work should be done on passive-screens (where the trenches are far from the source but near the site where the vibration amplitude is to be reduced) specifically, to identify the distance from an underground structure beyond which a passive screen may be effective.

Insulation of individual building structures consists of inserting vibration insulators, like natural rubber springs with steel reinforcement, between the foundation and structure. Buildings founded on soil are naturally insulated by the latter due to soil-compaction. However, buildings built on columns or foundations resting on stiff clays or bedrock may need some form of artificial insulation system. The use of vibration insulators in building structures have been used but not properly assessed because of the difficulty of doing so. However, such insulation can be very effective if well-designed.

The vibration control method, like the noise control method, that is finally adopted will depend on: (a) the severity of the problem and, therefore, the amount of attenuation required; (b) the cost of implementing the control measures; and (c) the effects of these changes on the environment. The importance of preliminary studies to assess the environmental impact of an urban rail system is crucial. Likewise, the need for integrating noise and vibration criteria in the design of the vehicles and the railway infrastructure at the planning stage and for regular monitoring of the system's performance cannot be over-stressed.

CHAPTER THREE

DISCUSSION OF SURVEY TECHNIQUES

Assessing the extent of a noise nuisance requires that the noise be rated in terms of (a) the disturbance it creates; and (b) its magnitude. A detailed social survey can be used to investigate the extent of the disturbance to a group of people and a simultaneous noise survey will reveal the levels of noise to which they are exposed. Results of these two types of survey can then be analysed statistically to determine the main factors that induce annoyance.

This chapter, divided in two parts, includes a discussion of the means available to conduct such surveys and an evaluation of the techniques and indicators that are currently used to measure both attitudes and noise levels.

PART I : SUBJECTIVE ASSESSMENT

3.1 Introduction

A sound, however loud, is not a nuisance if the receiver does not perceive it so. On the other hand, a sound which is not apparently loud, as measured by a noisemeter, can be a nuisance and cause considerable annoyance. The importance of a social survey in such a situation is utmost. Only an in-depth investigation can resolve the issue and determine the factors responsible for differences in response and susceptibility of individuals to any given sound.

The rest of Part I of this chapter is related to the interviewing method of collecting subjective response information. The reasons for choosing this method are straightforward, namely: (a) it offers the interviewer greater control over the administration of the questionnaire; (b) it yields the highest response rate; (c) it is, probably, the quickest way of obtaining the required information; and (d) the subject matter dictates the design and format of the questionnaire which, in turn, necessitates the interview approach.

The discussion begins with listing the advantages and disadvantages of interviews, followed by arguments in favour of a structured questionnaire format, an introduction to levels of measurement and the concepts of reliability, validity and reproducibility and finally, an evaluation of some techniques of attitude measurement.

3.2 Advantages of Interviews

1. Personal contact:

   It is generally agreed that people usually enjoy being interviewed (Gardner, 1978). Besides, the interviewer can generate rapport which she can use to handle complex and emotional topics. As opposed to filling in a written questionnaire, the respondent has an "attentive listener" to talk to. Appreciation can also be shown to the respondent.

2. Additional information:

   The information obtained in an interview can include detailed observations as well as unstructured records of behaviour and surroundings. These observations can be vital to the researcher to explain, for example, the indifferent reaction of a respondent with poor hearing ability to a loud noise. Observation of surroundings can be useful for social classification.

3. Greater flexibility:

   Interviews allow for probing and prompting. This advantage is most evident for open-ended questions where probing can result in far more detailed responses than otherwise would be achieved. Card sorting, and using photographs or pictorial illustrations as the material for questions can readily be handled by an interviewer.

4. High response rate and more complete data:

   Interview surveys can yield a response-rate close to 100 per cent. Postal surveys seldom achieve response-rates above about 40 per cent, unless the sample is of a special group instead of the general population or elaborate follow-up procedures are undertaken (Moser and Kalton, 1971). An interviewer can elicit replies from people who are illiterate or poorly-educated and she can reword or repeat some questions (if her instructions permit this) to improve the chance of them being clearly understood. She can also ensure that all questions are asked and that answers or other appropriate entries are made for all items. Interviews can be repeated as a check on reliability.

5. Greater control:

   An interviewer can control the sequence of questions and prevent the respondent from seeing all questions before answering any one of them, thus preserving the independence of different answers. The interviewer can make sure that the right person answers the questions, to conform with the design of the survey.

6. Spontaneity:

Interviews are most appropriate where spontaneous answers are wanted. Attitudes and expressed opinions may be more valid because the respondent must answer immediately, uninfluenced by discussion with others.

Interviews are also of advantage where questions testing an individual's knowledge are to be included.

Limitations of Interviews

1. Poor reliability:

The presence and influence of an interviewer can produce response-errors and bias leading to low reliability (which is a measure of the consistency of replies under comparable conditions). The interviewer may, by the way she asks the questions or interprets the answers, or through the effect of her personality upon the respondent, influence the responses that are made. This would then introduce an interviewer bias which may not be detected and would make comparability of results from different interviewers a difficult task. Subsequent quantitative analysis would then be misleading as the data would contain systematic errors of unknown magnitude (or direction).

2. Validity:

If a reply, whether consistent or not, does not reflect the true state of affairs, then its validity is low. The presence of an interviewer can affect validity in several ways: (a) a respondent may give answers that are not honest opinions and statements of fact to appear "respectable" to the interviewer; (b) he may state what he feels would be the interviewer's opinion, so as to ingratiate himself or to get the interview over quickly; or (c) a complete stranger (the interviewer) may inhibit the respondent to answer, truthfully and accurately, questions that may be personal or embarrassing.

3. Cost:

Interviews are relatively expensive (with respect to postal questionnaires) in terms of both money and time. These two factors may limit the survey to a smaller sample. In addition, the work is very tiring and requires special skills and training to avoid the limitations referred to above.

3.3 Structured vs Unstructured Interviewing

A structured interview is one that follows a set form. The questions to be asked are all predefined before the interview; the exact wording is used in each interview and the sequence of questions is strictly controlled. Except for planned randomisation or rotation of items (to minimise systematic biases), the sequence is the same for each interview. Most of the questions are of the closed type (though a few open-ended questions might be included) and the answers are recorded according to pre-coded categories in a standardised form. Less-structured interviews, on the other hand, range from allowing the interviewer to vary the sequence of questions, to explain their meaning, to add additional ones and even to change the wording, through to not using a questionnaire at all but having instead, a number of key points around which to build the interview. This last technique is referred to as unstructured, even though the data derived from it are capable of being analysed statistically by means of (for example) content analysis. The choice between the structured and less structured methods of interviewing depends on the aims of the survey. In practice, the chosen approach often includes both structured and unstructured interviews where the latter is used for exploratory purposes. Structured questionnaires are the norm in large scale surveys. Moser and Kalton (1971) argues that: "The case for formal interviewing is simple. Only if all respondents are asked exactly the same questions in the same order can one be sure that all the answers relate to the same thing and are strictly comparable. Then, and then only, is one justified in combining the results into statistical aggregates." Hence the use of a structured format in this study.

Table 3.1 (Forsyth, et al, 1984) summarises the appropriateness of various methods of eliciting attitudes, according to the purposes of the investigation.

3.4 Subjective Attitude Measurement Techniques: some considerations

The problem to which attitude measurement techniques are applied is that of ordering a series of items along some sort of dimension or continuum. In other words, they are methods of translating an individual's position, on a topic of interest, from a series of qualitative facts (attributes) to a series of numerical scores on

TABLE 3.1 : Appropriateness of various methods of investigation

Methods of Investigation / Purposes of Investigation	Group discussion	Sample survey. Fully structured questions	Survey sample open-ended questions	Intensive, in-depth, probing interviews	Large group testing with close matching (e.g. of ages, sexes, SEGs, etc.)
For creative think-tank research	**	+	+	+	+
To discover ideas or reactions that people actually have in relation to some issue	*	+	**	**	**
To discover basic aspects or dimensions of a problem or issue	*	+	*	*	*
To advance thinking about the feasibility of some proposition or idea	*	*	*	*	*
To guide the structuring of (subsequent) research	*	+	+	*	*
To establish population distributions on a quantitative basis	+	**	+	+	+
For experimental comparisons or studies (e.g. before and after)	+	*	+	+	**

Key: + this method not appropriate
* this method often appropriate
** this method particularly appropriate

Source : Forsyth et al, 1984.

appropriate rating-scales. The meaning of the scores will depend on the measurement level of the scale used. Stevens has defined four levels of measurement and these are mentioned here in increasing order of 'measurement sophistication':

A **nominal** measure classifies objects into groups (of two or more) without there being any implication of graduation or distance between the groups. It is simply a method of classifying them and there is no dimension associated with it. If numbers were assigned to the groups, no meaningful calculations could be performed using these numbers. An example is the numbering of football players.

The **ordinal** measure produces a ranking of the characteristic being 'measured' and, again, carries no implication of distance between successive positions. This kind of measure arises, for example, with ranking runners at the end of a race, the rank of the winner (position 1) does not indicate by how much, in time or distance, he was ahead of the second or third runners but only his relative position. Any set of numbers maintaining the order could equally have been used.

An **interval** measure has specified units of measurement along the scale (dimension), thus making it possible to interpret not only the order of the items measured but also the distances between them. The position of the zero point for this measure is a matter of convenience such that a constant can be added or subtracted to all the values without affecting the form of the measure; but multiplication or division cannot be performed on these values.

Temperatures measured in Celsius or Fahrenheit provide examples of interval scales: a 10^{o}C rise in temperature occurs whether the temperature changes from 10^{o}C to 20^{o}C or from 90^{o}C to 100^{o}C, but a temperature of 100^{o}C is in no sense "five times as hot" as 20^{o}C.

The **ratio** (or cardinal) level of measurement combines the properties of an interval measure with a fixed origin or zero point which permits absolute comparison. Examples of ratio scales are weights, lengths and times. Both differences in scores and the relative magnitude of scores can be compared with such a scale: the difference between 10 and 20 metres is the same as that between 30 and 40 metres, but, in addition, 40 metres is "twice as long" as 20 metres and 20 m is twice as long as 10 m.

Most attitude measuring techniques attempt no higher than the interval level of measurement but, nevertheless, this allows comparisons of attitude-change to be made in relation to other observed changes (e.g. noise-levels).

Reliability and Validity

Any measuring procedure must possess two basic desirable qualities. It must be reliable and it must be valid.

Fundamentally, **reliability** concerns the extent to which a measure or test yields the same results, under constant conditions, on repeated trials. But, because the conditions under which repeated measurements are made are never exactly equal, unreliability is always present to at least a limited (and often unknown) extent. However, repeated measurements of the same phenomenon do tend to be consistent from measurement to measurement. Thus, in practice, reliability refers to the tendency toward consistency found in repeated measurements of the same phenomenon.

Carmines and Zeller (1979) describe four methods of estimating the reliability of a measure: (a) the test-retest method; (b) the alternative-form method; (c) the split-half method; and (d) the internal consistency method. In their conclusion, they do not recommend either (a) the retest method or (c) the split-half approach to estimate reliability. A major objection to the retest method is that experience in the first testing will usually influence responses in the second testing. The main problem in their view with the split-half approach is that the correlation between the halves will differ somewhat depending on how the total number of items is divided into halves. The alternative-form method, like the retest method, requires administration of two tests with the same group of people. It is, they claim, a good technique to assess reliability if the difficulty of constructing two equivalent versions of a scale can be overcome. However, the internal consistency method provides an excellent technique for assessing reliability. It is directly related to the split half method and requires, similarly, administration of a single test. The most popular reliability estimate is given by Cronbach's alpha (Cronbach, 1951) which is the mean of all possible split-half coefficients. Thus, alpha is a unique estimate of reliability for each given test.

A measure must be more than reliable if it is to provide an accurate representation of some abstract concept, it must also be valid. Validity in this context means the success and extent to which the instrument measures what it purports to measure. This is a basic requirement that a measure needs to satisfy in order that differences between individuals' scores can be taken as representing true differences in the characteristic under study.

There are three basic types of validity: (a) content validity; (b) criterion - related validity; and (c) construct validity. Each of these types of validity takes a somewhat different approach in assessing the extent to which a measure is valid.

Content validity relates to the problem of obtaining a representative sample of items from the universe of content. The items should not only "contain the common thread of the attitude under study but, between them, they should also cover the full range of the attitude, and cover it in a balanced way", (Moser and Kalton, 1971, p.356). The assessment of content validity is essentially a matter of judgement and hence its insufficiency for assessing validity, since there is no agreed criterion for determining the extent to which a measure has attained content validity.

When a measure is developed as an indicator of some observable criterion, its validity can be investigated by seeing how good an indicator it is. There are two types of criterion-related validity - if the criterion exists in the present, then concurrent validity is concerned with how well the measure can describe the present situation, while predictive validity is related to how well the measure can forecast a future criterion. The performance of a measure is usually assessed by the degree of correspondence between the measure and the criterion, which is estimated by the size of their correlation.

"Construct validity is concerned with the extent to which a particular measure relates to other measures consistent with theoretically-derived hypotheses concerning the concepts (or constructs) that are being measured", (Carmines and Zeller). Construct validation involves three distinct steps: (a) the theoretical relationship between the concepts themselves must be specified; (b) the empirical relationship between the measures of the concepts must be examined; and (c) the empirical evidence must be interpreted in terms of how it clarifies the construct validity of the particular measure. Construct validation is dependent on theory and requires assumptions or evidence on how far attitudes and behaviour are related. It focuses on the extent to which a measure performs in accordance with theoretical expectations.

Some measures are required to have the additional property of reproducibility, which is the ability to reproduce an individual's responses to each item from a knowledge of his total score only. According to this quality, the respondent's total score would reveal which statements he agreed with and which he disagreed with. In practice, it is difficult to achieve reproducibility. This is a partial reflection of the fact that many measures are other than unidimensional.

3.5 An Evaluation of Some Techniques of Attitude Measurement

The aim of attitude measurement is to allow comparison of subjective judgements by giving numerical values to them. The idea behind this approach is that, instead of knowing simply whether or not a respondent is favourably disposed on an issue, one attempts 'to measure' his position, in terms of direction and intensity, on an attitude continuum. The assumption here is that there are underlying dimensions along which individual attitudes can be ranged. Measures can be composite or can consist of single items. Gender and hair-colour, for example, are each measured by a single observation, but many concepts are subject to varying interpretations, thus needing several items to measure them. When the scores of each item are combined, a composite measure results. For concepts, composite measures are generally preferred to single indicators since the former, by averaging over a set of indicators or items, "reduce the effects of idiosyncracies of particular respondents in respect to particular aspects of the attitude" (Moser and Kalton).

Composite measures can be broadly classed as indices and scales. These are both typically ordinal but differ in the ways scores are assigned to them. Adopting Babbie's definitions, an index is constructed through the simple accumulation of scores assigned to individual attributes, while a scale is constructed through the assignment of scores to patterns of attributes. Hence, by this definition, a scale differs from an index by taking advantage of any logical or empirical 'intensity structure' that may exist among the different items that are used to measure the variable or concept in question, and also, while a scale attempts to be unidimensional, an index tends to be multidimensional. Of the four measurement techniques discussed below, the Likert 'scale' and the semantic differential come under the category of indices while the other two, Thurstone and Guttman, are scales.

The Likert 'scale', developed by Rensis Likert in 1932, represents a straightforward means of constructing indices from questionnaire data. The method is based on the assumptions that: (a) each item has a similar intensity; (b) the set of items range over all the various aspects of the attitude; and (c) all the items belong to the same underlying dimension (i.e are unidimensional). The construction of a Likert 'scale' consists of a number of steps:

(1) Compose an "item pool". The success of the technique is enhanced by keeping the numbers of neutral and extreme items to a minimum.

(2) The item pool is administered to a sample of people representative of those whose attitudes are to be scored. They are required to express their degree of agreement or disagreement by choosing the category which best represents their own opinion. Five response categories are normally used and the descriptions usually used are "strongly agree", "agree", "undecided", "disagree" and "strongly disagree", with scores ranging from one to five.

(3) Each respondent is then assigned an overall score representing the summation of the scores he receives for responses to the individual items. Care must be taken in assigning scores such

that positive items are scored in the reverse order to negative ones (for example, assign a score of 5 to "strongly agree" for positive items and 5 to "strongly disagree" for negative items).

(4) The overall scores are then used in an 'item analysis' to select the 'best' items. Essentially, this consists of correlating the scores of individuals on each of the items with their total score (or total score less the score of the item involved). Items that correlate highest with the composite measure are retained and only those items are finally included in the index for analyses of the variable.

The Likert technique has both advantages and disadvantages. It is relatively easy to construct and provides fairly precise information on the respondent's degree of agreement/disagreement. In addition, it possesses qualities of unidimensionality and reliability. Since the items comprising a Likert 'scale' are themselves measures, they can usefully be analysed individually. However, each 'scale' is ordinal since the response categories are in rank order and this limits the use of statistical analyses to non-parametric level only. Another frequently mentioned limitation is its lack in reproducibility (this is a somewhat unfair criticism, given that the items are purposely chosen to be similar with respect to their content and intensity).

The Semantic Differential also produces data suitable for indexing. However, unlike the Likert method where there is a range of statements/items but only one standard form of response, with the semantic differential there is a range of areas of response but only one issue to evaluate. Osgood et al developed this technique for their measurement studies in semantics. Its construction involves: (a) determining the dimensions along which the issue or variable is to be judged; (b) finding two opposite terms representing the "polar extremes" along each dimension; and (c) deciding on the distance between the two opposite terms, a five or seven point equal interval scale is commonly used. The position of the poles is normally varied to avoid creating a biased pattern of responses. This can be achieved by placing a pair of opposite terms, for example, 'good/bad' running from left to right while another might run from 'unsatisfactory' on the left to 'satisfactory' on the right. On presentation, respondents are asked to place a checkmark in one of the spaces or ring a number to indicate their response choice. Their total score is then a simple summation of scores received for individual responses and it is a measure of their attitude to that issue. As with the Likert technique, consistent scoring must be observed with, for example, low scores at the unfavourable end and high scores at the favourable one.

The semantic differential technique has advantages similar to those of the Likert 'scale' - standardisation of categories, balance between positive and negative answers and it is simple to construct and understand. Moreover, it is a very flexible technique. Its use is not limited to attitude measurement only but is extended to provide profiles of consumer-goods, for example, cars, perfumes and for exploratory work.

Thurstone's method of 'equal-appearing intervals' provides a means of constructing a scale (as defined earlier). The Thurstone scale, therefore, differs from the Likert and semantic differential techniques in two ways: (a) the several items that make up the scale are assumed to have different intensities in terms of the variable under study; and (b) an important role is played by 'judges' in evaluating the relative strength of each item. The scale represents an attempt to form an interval scale of measurement.

A number of steps constitute the development of a Thurstone scale:

(1) As with Likert, a large number of items (statements) on the issue of interest, ranging from one extreme of favourableness to the other, are collected to form an item pool.

(2) A number of 'judges', usually around fifty, are asked individually to sort the items into a series of numbered piles, usually eleven, such that the piles reflect various degrees of favourableness on the attitude in question and that the interval between any two consecutive piles appears subjectively to be equal.

(3) Each item is given a scale value. This is done by assigning it the median position given to it by the group of judges which is determined from a cumulative frequency curve of each item's scores.

(4) The selection of items that will constitute the final scale is made such as to exclude any ambiguous items and to represent the full range of the scale.

Ambiguous items are identified by the extent to which the judges disagree on the placement of the item. The interquartile range, called the Q value by Thurstone (Goode and Hatt, 1952), is used to measure the scatter of judgements made. Using these ranges as a measure of ambiguity, items are selected so as to secure the best possible representation of the full continuum by items possessing the lowest possible Q values. The recommended number of items is about twenty (Moser and Kalton). The final list is then embodied in a questionnaire, in random order, which simply seeks the respondent's endorsement of the items with which he is in agreement. His score is then equal to the average (either mean or median) of the median values attached to the items he endorses.

The Thurstone scale is considered to have good reliability and validity if constructed with care. It is simple to administer and easy to use and easily understood by the respondent. However, it requires a great deal of labour and relies heavily on a group of 'judges' who, if careless and biased, can endanger the utility of the scale. Reproducibility is not good either, since an individual will agree only with items around his scale position while disagreeing with those more extreme on either side.

Thurstone scaling is not often used today primarily because of the laboriousness of the technique.

The Guttman scale is an ordinal scale. Like Thurstone scale, it is based on the fact that some items under consideration may prove to be more extreme indicators of the variable than others. However, the attainment of a high degree of unidimensionality is a major concern with Guttman scaling. Its construction involves the following phases:

(1) Define the total attitude (the universe of content) to be scaled. The objectives of the study should help in formulating the items to be included. Informal interviewing is a useful method of ensuring that no important aspect is missed. Between them, the items must range over the various aspects of the attitude.

(2) Select a sample of items, representative of the universe of content, for possible inclusion in the scale. These items are administered to a sample of persons (pilot sample).

(3) Examine the responses from (2) for 'scaleability', that is, check whether a scale structure exists in the pattern in which the respondents' answers arrange themselves. The requirement of a 'perfect' scale is that every respondent endorses all the items less extreme than the most extreme with which he agrees. A perfect scale is rarely achieved.

(4) Select the final set of items such that they cover the range of popularities or degree of endorsement. For a four-item scale, items with popularities close to 20, 40, 60 and 80 per cent can be chosen. Items with the same popularities only replicate each other and, therefore, only one of them needs to be included in the scale.

(5) Incorporate the chosen items in a survey questionnaire, preferably in random order, to be administered to the final sample.

Guttman scaling enjoys a high degree of unidimensionality and, unlike the Thurstone technique, it does not involve the subjective views of outside judges but relies heavily on answers from respondents. In addition, a Guttman scale has good reproducibility which implies that from an individual's total score, one can, with a fair level of precision, infer items with which he agreed and disagreed. This is not possible with either the Likert or Thurstone techniques.

A frequent criticism of Guttman scaling is its analytical complexity. This, however, has been considerably reduced with the use of statistical packages (for example, SPSS) on computers. More serious is the fact that "there is no guarantee that the items will scale and that items that do scale generally cover a narrow universe of content" (Moser and Kalton). 'Scaleability' is sample-dependent in that, although a set of items may form a Guttman scale among a sample of survey respondents, there is, no guarantee that they will form such a scale in another survey with a different sample.

PART II : OBJECTIVE MEASUREMENT

3.6 Introduction

Unwanted sound, namely that which disturbs, interferes or annoys is (by definition) noise; and, since noise can be a nuisance to the community, it needs to be assessed, abated and controlled. Paramount to the success of achieving these goals is the need to find a means of describing the magnitude of the noise problem, as it affects human beings - a noise descriptor which "as a numerical evaluation of the noise (preferably in terms of a single number) will bear a meaningful relation to the amount of disturbance caused to the public by the noise" (Schultz, 1972).

There are a number of noise descriptors currently in use to measure environmental noise. Among those, some relate to a specific sound source, some to a few specific sound sources and some that apply to all kinds of noise. The descriptors that are most frequently used to assess railway noise are of the third category and these will be discussed, in some detail, in the following pages. However, reference will be made to other descriptors when relevant and where necessary.

The discussion begins with a description of frequency weightings, which play an important part in noise measurement. Definitions and explanation of relevant acoustical terms are given in Appendix A.

3.7 Frequency Weighting : the response vs frequency relation

Since the ear is not equally sensitive at all frequencies, it is essential that this frequency discrimination is taken into account when measuring noise to which human beings are exposed. To obtain measurements from an instrument which purports to represent the response of the ear, so-called frequency-weighting networks are incorporated in the instrument. In a sound level meter, these networks alter its sensitivity with respect to frequency, so that the meter is less sensitive at frequencies where the ear is less sensitive and vice-versa.

There are four weighting networks included in standard sound level meters (although all four are not usually built into a single instrument) - the A, B, C and D weighting networks. Their response vs frequency characteristics are shown in Figure 3.1.

It is common practice to append the appropriate letter, in brackets, after the unit symbol as a reminder of the weighting being employed; for example, dB(A), dB(B), etc. Several different frequency weightings have been studied and proposed in the past for general use in the assessment of human response to noise (Schultz, 1972; Fields and Walker, 1980; Bennett and Pearsons, 1974). Today, the A-weighting is used almost exclusively, to assess transport and community noise, to specify emission limits and to set community noise standards throughout the world. No superior alternative has yet been found to warrant replacement of the A-weighting, since the

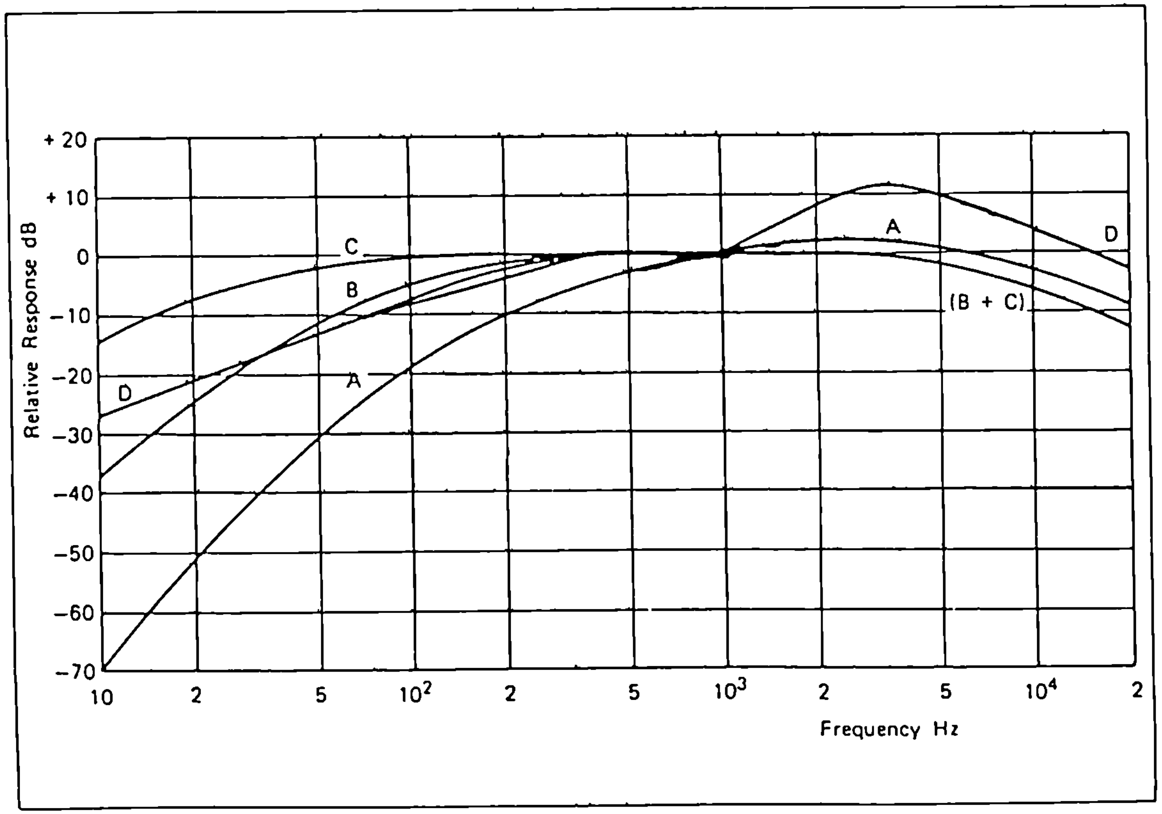


Figure 3.1 : Frequency response of weighting networks in a sound level meter

level correlates with human response better than the other weightings and as well as many more complex measures, such as the calculated perceived noise level or the loudness level, both derived from detailed spectral analysis (Botsford, 1969; Schultz, 1971; Fields and Walker, 1980). It is almost certain that unless another weighting is found, which shows a marked improvement over the A-weighting, there is unlikely to be any change in the status quo.

A persistent criticism of the A-weighting, however, is that it does not adequately account for low or very low frequencies, since its response decreases with decreasing frequency (Figure 3.1). Nevertheless, if it is agreed that the A-weighting correlates well with human hearing, then it should give a proper account of all the different frequencies to the overall aural sensation.

All measurements of noise in this study, therefore, are in dB(A), except where measurements were specifically made to be analysed for frequency content. The linear "unweighted" index was used on these occasions.

3.8 Indicators for Railway Noise

Noise from railway operations can be measured for two different purposes: (a) to determine the noise emission level with the aim of, for example, comparisons with other sources; and (b) to assess its effects on a group of individuals. In the first case, a simple average maximum A-weighted sound level during a train's passby is commonly used. More recently, the sound exposure level (SEL) has been used for direct comparisons of transient noises. SEL (defined in Appendix A) is an average-energy concept that takes both the duration of the passby and the magnitude of the noise into consideration. As for the evaluation of human response to railway noise, and noise in general, is concerned, the solution is not so simple. In this case, in addition to the magnitude of the noise, the indicator must take into account the number and duration of trains passing and, if possible, account also for temporal variation effects (if any) and the 'character' of the noise.

Schultz (1978) lists, in order of priority, seven requirements to which a community noise indicator should conform. These are, as follows:

(a) the measure of total noise exposure should be applicable in virtually all possible exposure conditions; it must apply to all kinds of noise sources and combinations of sources, so that the effects of different kinds of noise can be compared;

(b) the measure should correlate well with the known effects of noise on people;

(c) the required measurement equipment, with standardised characteristics, should be commercially available;

(d) the noise exposure at a given location, expressed in terms of the chosen noise measure, should be predictable within acceptable tolerances from a knowledge of the physical events that produce the noise;

(e) it should be simple, unambiguous, and easily understandable by users and the public in general;

(f) it should be usable for planning and monitoring, as well as for enforcement purposes; and

(g) the measure should be closely related to other methods currently in use.

Based on these seven requirements, it is clear that a large number of noise indicators fail to qualify as adequate descriptors of the noise emanating from trains. Among these are the indicators that cater for a specific noise source, such as the Traffic Noise Index (TNI) for rating urban street traffic noise, or the Noise and Number Index (NNI), the Noise Exposure Forecast (NEF) and the Composite Noise Rating (CNR), all used in the assessment of aircraft noise near airports (Schultz, 1971 and 1972).

Statistical descriptors, such as L_1, L_{10}, L_{50}, L_{90} (also defined in Appendix A), which have been widely and successfully used for urban road traffic noise are not suitable for discrete, individual noisy events of relatively infrequent occurrence, for example, train and aircraft noise. The reason is that, unless the cumulative duration of the discrete noisy events last for more than (say) 10 per cent of the observation period, they (the noisy events) will have no effect on the value of L_{10} (likewise for L_{50} or L_{90}), however loud those noisy events may be.

What is finally left by this process of elimination are measures that are based on energy-levels. One of these measures, the equivalent continuous sound level, L_{eq}, has been widely used for all kinds and combinations of noise sources including aircraft, road traffic and railway noise. It fulfills the seven requirements listed earlier and has proved to be a popular noise descriptor internationally. In the USA, a variant of L_{eq}, the day-night average sound level, (L_{dn}), is most often used. The latter differs from L_{eq} in having a built-in night-time noise penalty.

Fields and Walker adopted L_{eq} for their extensive survey of railway noise in Great Britain. Their choice, however, was made after close examination of the suitability of nine noise indicators, which included (among others) NNI, TNI, L_{10}, CNR, L_{eq} and L_{dn}, with respect to their ability to account for peak level of events, number of events, duration of events, frequency weighting, time of day effect (if any), ambient levels and fluctuations in the "time history" of the noise. Having found no evidence for a correction being needed for night-time noise level, their final choice was between different methods of combining single event levels and the number of events, viz, L_{eq}, NNI and CNR. They concluded that "the decision is made to use L_{eq} on the basis of the relationship with annoyance, the physical meaningful definition of L_{eq} and its wide use".

Logically and analytically, L_{eq} seems to be the best choice among the many indicators that exist (L_{dn}, here, is not considered as an independent indicator, but a variant, with essentially the same properties as L_{eq}). Its performance is assessed next and a few notable changes to L_{eq}, that have been proposed, are also discussed.

3.9 The Equivalent Continuous Sound Level (L_{eq}) - an assessment

The equivalent continuous sound level (L_{eq}) was developed in Germany and was introduced in 1965 as an indicator to evaluate the impact of aircraft noise on the communities living near airports (Burck et al, 1965). Its potential as a general noise descriptor was soon recognised in Europe and the USA so that, today, it is used in its own right in national and international standards. L_{eq} has been used to evaluate the subjective effects of noises as varied as road and rail traffic, industrial plants and playgrounds.

Its meaning, conceptually, is easy to grasp - L_{eq} represents the level of steady sound which, in a given situation and over a given time-interval, has the same amount of acoustical energy as does the actual time varying sound. Mathematically, it is defined, as follows:

$$L_{eq} = 10 \log_{10} \frac{1}{T} \int_0^T \left(\frac{P_A(t)}{P_o} \right)^2 dt \qquad (1)$$

where T is the total measurement time

$P_A(t)$ is the time-varying A-weighted acoustic pressure

and P_o is the reference acoustic pressure (20 μPa).

In practice, the following is often used:

$$L_{eq} = 10 \log_{10} \frac{1}{T} \int_{0}^{T} 10^{L_A(t)/10} \, dt \qquad (2)$$

where $L_A(t)$ is the time-varying A-weighted sound level

The time-interval, T, in the calculation of L_{eq} is a function of the type of noise environment under investigation. For events that take place throughout the day, for example the operation of inter-city passenger trains, the time interval is usually the whole 24 hours. For schools and workplaces, an 8-hour period would more accurately describe the noise exposure in such places. It is customary, in the UK, to designate a 24-hour L_{eq} as L_{eq}(24H) or L_{eq}(24 hour), while in the USA, the equivalent takes the form of $L_{eq(24)}$.

3.10 The Day-Night Level (L_{dn})

The variant of the equivalent continuous sound level is the day-night level, L_{dn}, which is simply the 24-hour L_{eq} with a 10 dB night-time penalty as defined below:

$$L_{dn} = 10 \log_{10} \frac{1}{24} \left[15 \left(10^{L_d/10}\right) + 9 \left(10^{(L_n + 10)/10}\right) \right] \qquad (3)$$

where L_d is the daytime (0700 to 2200) equivalent continuous sound level and L_n is the night-time (2200 to 0700) equivalent continuous sound level.

The day-night level was first adopted by the US Environmental Protection Agency (EPA) in 1974, as an improvement over L_{eq}. The weighting to the night-time noise was assigned "on the basis of results from complaint studies and social survey data that indicate a higher sensitivity to night-time noise" (Schultz, 1978).

These complaint studies and survey data were, however, mainly from aircraft and road traffic noise, especially the former. Thus, EPA simply extended this night-time correction to include rail traffic noise. Evidence as to the need for this adjustment has not yet been found. In the nationwide UK study on railway noise (Fields and Walker, 1980), night-time noise from rail traffic was examined subjectively to determine whether night-time events had a "disproportionate effect on annoyance". The authors concluded, as follows:

> "... if 24-hour L_{eq} is used as an explanatory variable, there is no evidence that the relative number of night-time events has any additional effect on night-time annoyance." (p.3.22);
>
> and:
>
> "Given present operating conditions, the evidence from this analysis does not support the use of a night-time weighting factor for railway noise conditions in Great Britain." (p.3.23).

The reasoning behind setting lower permissible noise emission levels at night is, however, clear. Since the background noise level is at its lowest at night, a train operating at usual speed will create a greater disturbance than in the daytime when the background noise levels are higher. Thus, setting more restrictive limits to night-time noise levels ensures less disruption to the environment and offers protection against relatively high levels of noise when most people are trying to sleep.

The argument about the adoption of the day-night level (L_{dn}) is whether any such adjustment to the equivalent continuous sound level (L_{eq}) is **actually** warranted. Results of studies on railway noise in the UK have not generally been in support of L_{dn}. A possible explanation may be that, besides the apparently greater acceptance by the community of noise from railways (compared to traffic noise), many fewer trains operate at night than during the day. For example, the ratio of day:night-time train frequency on the InterCity East Coast Main Line of British Rail is about 3 to 1 (typically 3 trains every 2 hours during the day compared to 1 every 2 hours or so at night). Fortunately, most of the high frequency urban rail services do not operate late at night or during the early hours of the morning.

Whichever is the chosen noise descriptor, L_{eq} or L_{dn}, not surprisingly, they have the same limitations. Excluding doubts about night-time correction, the criticisms levelled at them are, as follows:

(a) they do not account for the effect of pure tones;

(b) rare loud events and impact noises may not be adequately accounted for; and

(c) the 'correctness' of the factor 10 multiplying the logarithm is questionable.

These criticisms are examined and discussed in turn, below.

(a) Pure Tones

The presence of recognisable pure tones in a noise is one of the factors (others include noise which is intermittent, irregular or rhythmic, or contains impulses) that may considerably increase the annoyance caused by that noise. To take account of all these factors is clearly a difficult task, especially when the large variability of individual responses and a wide range of noise types have to be considered.

Apart from the Effective Perceived Noise Level (EPNL), which is used to evaluate aircraft noise, all other community noise indicators share the limitation for not accounting for pure tone effects. Besides making the procedure complex, the presence of pure tones entails for its detection and subsequent inclusion in a noise indicator, corrections for pure tones that "have not been validated for all types of noise nor for all noise levels" (Schultz, 1978), except for aircraft noise.

The presence of pure tones in rail traffic noise is mostly concentrated in wheelsqueal that occurs on tight curves. Such sections of the track are usually given special remedial treatment and affect only a small fraction of the community. The presence of pure tones has, up to now, not been identified, from railway noise surveys, as an important contributory factor to annoyance. Hence, the incorporation of pure tone corrections in the community noise rating for rail traffic noise appears not to be necessary.

(b) Rare loud events and impact noises

The criticisms that L_{eq} does not adequately account for rare loud events and impact noises is, to some extent, valid. Though L_{eq} will register an increase in level due to, for example, a few train passes, it will, however, average those noisy events over the whole measurement period since L_{eq} is an average noise exposure indicator. It is often recommended that peak noise levels or average levels of single noisy events (for example, SEL) complement L_{eq} when describing an environment with intermittent loud events.

More importantly, what L_{eq} does not account for is the character of a sound. Similar to tonal effects, an audible and distinctive sound which is intermittent and rhythmic can increase annoyance. The familiar 'clickety-clack' of wheels going over joints in rails or over points is an example of such a sound. The evaluation by Fields and Walker of the effect of joint noise on annoyance shows no marked increase in annoyance when the value of the noise variable itself has been accounted for. They mention, however, that there is some evidence that, at high noise levels, the distinctive joint-noise does have a marked effect on annoyance which L_{eq} does not account for.

The problem of joint-noise is not generally considered a big one as, on most urban rail systems, they use continuous welded rail (cwr) on their network. The general trend is towards replacing jointed tracks with cwr which, not only brings clear acoustical benefits but, above all, reduces track maintenance costs and *vehicle-depreciation*.

(c) The K factor: pressure L_{eq} **vs conventional** L_{eq}

The factor 10, also known as the K factor, multiplying the logarithm in the right hand side of the expression for L_{eq} (Equation (1)) has been questioned by Flindell for its 'appropriateness' in relating to responses from multiple noise source environments. Flindell proposes the "pressure" L_{eq} as an improvement over the conventional L_{eq}, which is calculated on the basis of an integration of the intensity (i.e. sound pressure squared) of time-varying sounds. The "pressure" L_{eq} therefore, has a K factor of 20 and is defined, as follows:

$$L_{eq} = 20 \log_{10} \frac{1}{T} \int_0^T 10^{L(t)/20} \, dt \qquad (4)$$

where L(t) is the instantaneous sound pressure level, defined as

$$L(t) = 10 \log_{10} \left(\frac{P(t)}{Po}\right)^2$$

where P(t) is the instantaneous sound pressure and Po is the reference sound pressure (20 Pa).

Substituting L(t) in equation (4) yields a different form of relationship between pressure L_{eq} and acoustic pressure, namely

$$\text{Pressure } L_{eq} = 20 \log_{10} \frac{1}{T} \int_0^T \frac{P(t)}{Po} \, dt \qquad (5)$$

Comparing equation (5) with equation (1), reproduced below,

$$\text{Conventional } L_{eq} = 10 \log_{10} \frac{1}{T} \int_0^T \left(\frac{P(t)}{Po} \right)^2 dt \qquad (1)$$

shows that conventional L_{eq}, proportional to pressure squared, is biased towards high peak levels and that for similar time-varying acoustic pressures, conventional L_{eq} will be greater than pressure L_{eq}. Thus, it can be expected that road traffic noise will be unaffected by changing from conventional to pressure L_{eq} due to the relative "steadiness" of road traffic noise. Railway noise, on the other hand, which is characterised by short bursts of high noise levels with quiet periods between, will show a reduction when pressure L_{eq} is used instead of conventional L_{eq}.

Flindell argues that the conventional L_{eq} has been shown to be deficient in the area of multiple noise sources (also Powell, 1978) and that his 'pressure' L_{eq} reduces the discrepancy in annoyance-exposure response, wherever a noise environment has two or more contributing noise sources. The proposed index was tested using data presented by Fields and Walker, comparing road traffic and railway noise, and it was found that the difference in annoyance for similar exposure from the two noise sources, which resulted when conventional L_{eq} was used, was nearly eliminated with pressure L_{eq} as the exposure descriptor. However, the claim that pressure L_{eq} is a superior indicator to conventional L_{eq} has yet to be proved. The evidence, so far, is limited and indirect. The proposed index is, itself, the result of yet another disputed hypothesis that transport noise from different sources, i.e. road traffic, railways and aircraft, causes different degrees of annoyance at similar exposure levels (De Jong, 1983). Flindell's result is valid if, in fact, there is no difference in annoyance due to noise from different sources. However, if there exists a difference in perception leading to different degrees of annoyance for similar noise levels, then pressure L_{eq} will not detect it. As it has not been possible in this study to produce any evidence in support of either side in the contention. Conventional L_{eq} has been used throughout.

3.11 Noise Measurement: the inside-outside debate

Community noise measurements, in the UK and elsewhere, have generally been undertaken outside residences and the noise data are then related to the disturbance experienced by the community, either continually or during certain daily activities. Because it is assumed that an individual, on the whole, spends most of his time indoors, this has often raised the question of whether outdoor measurements are, in fact, appropriate to assess the community noise exposure and response. While it is true that the exterior and interior noise exposure can be markedly different, noisy indoor activities, at the same time, can totally transform what an individual is believed (by the researcher) to hear. What he actually hears may bear little or no relation to the noise that is measured externally. In such a situation, unless one is aware of what is actually going on inside and thus make an appropriate correction, it is not at all surprising that the individual's response to the outside stimulus is sometimes incomprehensible to the researcher. Pooled responses, however, will show some degree of correlation for the fact that a number of individuals actually do hear the outdoor noise, which could also be the dominant source of indoor noise during the noisier events. The question, then, is whether the microphone, if placed somewhere else (for example inside the dwelling) would represent a more realistic situation and hence improve on the generally low correlation between noise level and subjective response?

In a pilot experiment by Schultz (1973) investigating this question, two microphone positions indoors were tried - the first in a fixed indoor position and the second mounted near the ear of an occupant in the same dwelling. When compared, the exposure readings showed vast differences - the L_{10} levels differed by 17 dB, and the L_5 levels by 21 dB, even though the background levels, in both cases, were comparable. Thus, it appears that a fixed microphone, whether used indoors or outdoors, gives a poor account of the actual noise exposure of active occupants inside a dwelling. However, a recent Canadian study (Birnie et al, 1980) concludes that both indoor and outdoor effects of noise are important contributors to overall annoyance, and that neither set of effects could be eliminated without losing some explanation of the general annoyance.

Consequently, the present procedure of noise measurement outdoors remains the simplest, cheapest (in time and money) and most practical means of assessing community noise. A microphone-attached-to-respondent technique, surely, provides the most accurate method of ascertaining the actual noise exposure that individuals are subject to, but it raises other doubts. The practicability of such a method in a large-scale survey appears very limited indeed, notwithstanding the problem of detecting the contribution of the particular noise source(s) under study in the overall exposure and general annoyance. A comprehensive outdoor noise measurement programme supported by a corresponding detailed social survey, which includes questions on indoor and outdoor activities, should provide the researcher with sufficient information about the general feelings within the community towards the noise being surveyed.

3.12 Habituation

The cause of a poor correlation between an individual's response to noise and the measured noise level may not only be a result of measurement error (as described in 3.10), but also due to the influence of habituation, defined as the adaptation of the organism to the existing situation, to the noise environment. Some of the remarks made by respondents in this study bear evidence to this hypothesis.

Fields and Walker (1980) report that length of residence (sometimes used as a proxy for habituation) has little or no effect on annoyance. They found that people who had lived previously in another area were more bothered by railway noise than those who had always lived in the same area. This perhaps tallies with Aubree's (1975) finding that people who state that they have "got used" to railway noise react to the situation as a whole (including their area?) and not just to train noise. Aubree viewed self-reported habituation as a defence mechanism needed to cope with the noise, at least temporarily.

In the Netherlands, a longitudinal study (De Jong, 1983) carried out in 1977-78 to study the reactions of residents living in an area alongside a new railway found that only 31 per cent (133 respondents) of those interviewed before the line was opened were still in the area a year later. The study found that, of those remaining, the number who expressed annoyance four months after the line was opened was the same as that a year later. However, the proportion of highly annoyed respondents had dropped significantly.

It is not clear from these studies what relationship exists between annoyance and reported habituation or between annoyance and length of residence. Nevertheless, it seems likely that both length of residence and habituation contribute to a decrease in the initial degree of annoyance felt. The Dutch study also shows that effect of habituation is not to be equated with absence of annoyance.

CHAPTER FOUR

DESIGN AND APPROACH TO STUDY

4.1 Introduction

The format adopted in this research project relies, to a large extent, on an important and extensive study of the reactions to railway noise of all kinds in Great Britain carried out by Fields and Walker (1980). However, this study is solely concerned with a one type of rail system, a modern, high-frequency urban rail system which is the backbone of the public transport facilities in the area.

Differences in the questionnaire design to that adopted by Fields and Walker are of particular significance. To meet the requirements of this study and also to work within the time limit, their original questionnaire had to be reduced considerably in size. The relatively small area under study allowed noise levels and exposure actually to be measured and, thus, less reliance was placed upon predictive methods. These will be dealt with, in detail, in subsequent sections, where appropriate.

The general aim of this research is to assess the effects of urban railway noise on the residential environment. Specific objectives laid down for the study are:

(1) to investigate recent research related to the impact and control of rail noise in Europe and the USA;

(2) to measure the noise exposure and levels residents, living in the vicinity of the Metro line, are exposed to;

(3) to carry out a questionnaire survey of selected residents to assess their subjective responses to the measured sound levels;

(4) to examine the data from (2) and (3) to determine the kinds of relation that exist between them; and

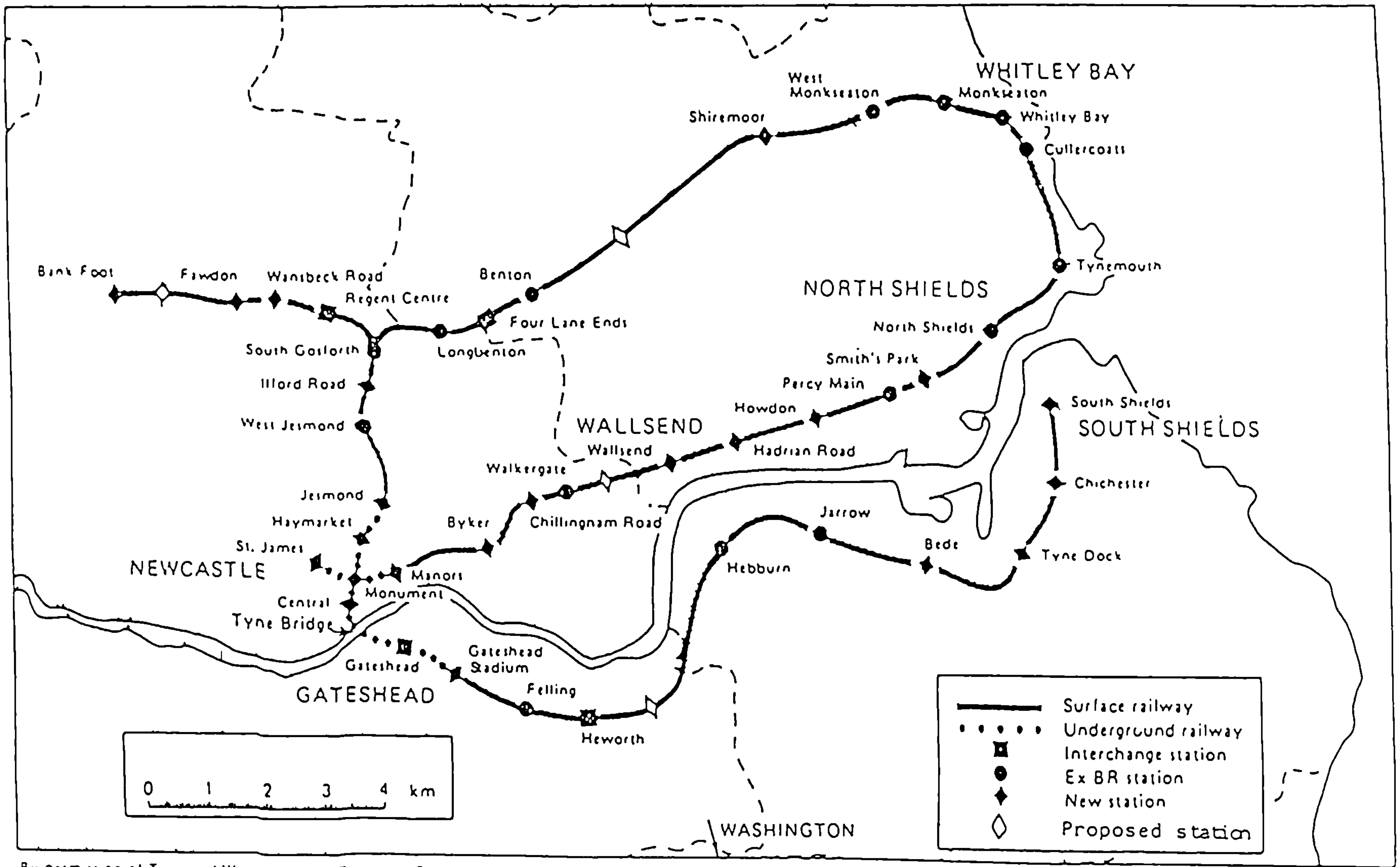
(5) to investigate other factors, besides noise, that may contribute to annoyance and/or disturbance caused by the Metro.

The objectives clearly refer to residents only and this exclude occupants of non-residential premises like shops and schools. The study looks particularly at the nuisance caused by noise from the Metro but other transportation noises, though not objectively measured, have been subjectively assessed.

The data for this research was collected over a period of four months from August to November in 1983, by the researcher and a colleague. A description of the study area, a discussion of the sample selection of households and residents and of the social survey and noise measurement programme follow.

4.2 The Study Area - Choice and Description

A number of areas adjoining the Metro line were considered for this study. A particular requirement was to find densely populated residential areas not subject directly or indirectly to previous investigations related to noise from the Metro. This constraint immediately eliminated the areas along Jesmond to South Gosforth Corridor (Figure 4.1), where it was felt that the well-informed residents would introduce a high degree of bias in their responses as



By permission of Tyne and Wear Passenger Transport Executive

Figure 4.1 : The Tyne and Wear Metro

a result of the publicity their complaints and petitions have received in the past, in addition to their previous exposure to noise and subjective surveys. Other promising locations were along the Walkergate-Wallsend-Hadrian Road section of the line which was opened in November 1982. After several visits to the area, it was decided that it satisfied the above-mentioned requirement adequately and that, even though there were other noise sources present (namely from road traffic and shipbuilding industries), noise from the Metro was the dominant source by far especially for those living in houses close to the line.

The chosen area of study shown partly in Figure 4.2, which comprises parts of Wallsend and of Walkergate, is located on the north side of the River Tyne. It has substantial industrial development along the banks of the river, dominated by shipbuilding and associated engineering. The railway line separates this industrialised zone from the residential and commercial (mainly shop) premises, which mostly lie to the north of the railway. About thirty per cent of the dwellings in the area were built before 1919, while the remainder of the housing stock is about equally divided between pre- and post-war age. The population density, at the time of the 1981 Census, was high at around 3000 per square kilometre.

The shipyard and associated heavy manufacturing industry between them dominate employment; the breakdown of employment patterns in 1981 (Holdsworth, 1983) were, as follows:

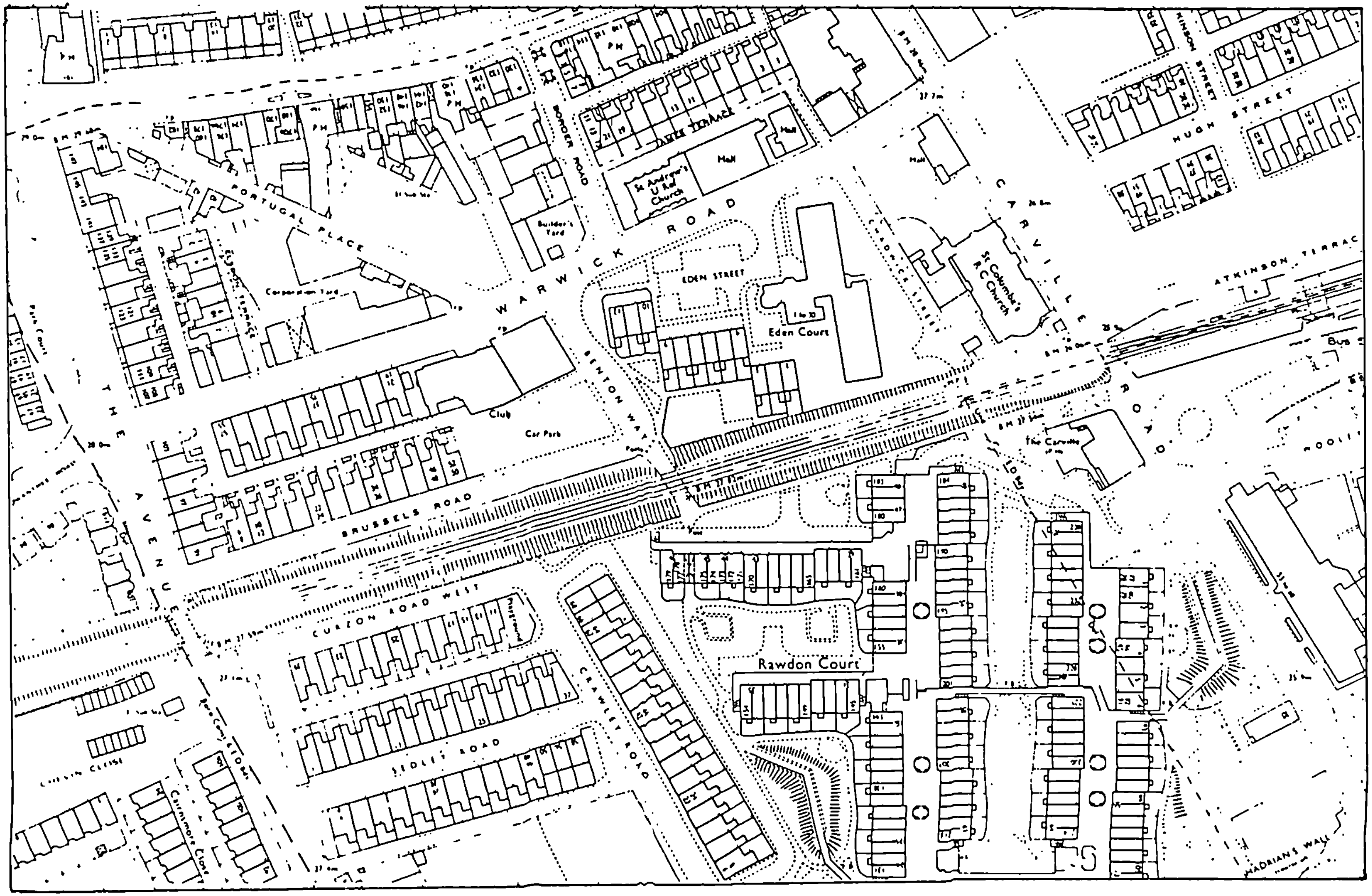


Figure 4.2 : A section of the study area

Table 4.1 Breakdown of employment patterns in the study area

Employment Sector	Proportion of Total Employment (%)
Agriculture	0
Energy and Water	2
Manufacturing	41
Construction	5
Distribution and Catering	19
Transport	6
Other services (Administration, Education, Personal Services, etc)	27
All employment sectors	100

Unemployment in the area of Wallsend has been increasing in the last few years, mainly as a result of the decline of shipbuilding, and is already at a serious level. In April 1981, male unemployment stood at 20.5%, and the female rate was 10.6%, an overall figure of 16.7% (Holdsworth, 1983).

Major investment has taken place in Wallsend to improve public transport service in the town. The main elements are:

(i) The completion of the Metro line from Tynemouth to St. James with new stations at:

(a) Wallsend;

(b) Hadrian Road; and

(c) Howdon.

(ii) A bus-Metro interchange built immediately to the south of Wallsend Metro station to allow passengers to transfer from bus to Metro easily.

(iii) Station Road bridge which has been raised to allow buses to serve the new bus station.

(iv) Bus routes in North Tyneside, including the study area, re-organised as part of the County Council's plan to develop a fully integrated bus/Metro transport system.

The re-organisation of the bus routes, as might be expected, has not been to the advantage of everyone. Even though only one bus route (service 313) to the centre of the City of Newcastle has been withdrawn, this, coupled with the rerouteing of other services have caused a certain amount of inconvenience to a number of residents (especially the elderly) who find that they either have to walk a longer distance to the nearest Metro station or wait longer at the nearest bus stop for trips to the city centre.

Wallsend suffers from a variety of environmental problems as this quotation illustrates:
"...noise from traffic and industry, dust and fumes from the same source, a run-down environment with poorly maintained buildings and unkempt open space, a shortage of trees, derelict, vacant sites and the mess that results from re-development areas." (Holdsworth, 1983).

The District Council is, however, committed to improve the affected areas and is carrying out, and plans to continue, various traffic management and environmental improvements such as removal and reduction of through traffic from residential areas, landscaping, and improvement of conditions for pedestrian safety in the shopping and residential areas.

A continuing decline in heavy industry, the end of coal mining and a general process of modernisation has considerably reduced the pollution especially the level of dust, fumes and noise for which the area was once notorious. The Council has declared the whole town of Wallsend a Smokeless Zone and the pollution control powers of the Council are used to monitor the levels of these pollutants.

Improvements in the older housing areas of the town have commenced and these include measures to plant trees, improve pavements and carriageways and other landscaping treatments.

4.3 Selection of Samples for the Surveys

In order to assess the response of a group of people to a stimulus, such as Metro noise, it is necessary to take into account a whole range of noise levels to which those individuals are exposed. Under such circumstances, a necessary requirement, from an analytical point of view, would be an adequate spread of the population in each band of noise levels of interest. This approach suggests the use of some sort of stratified sampling whereby households are grouped according to the levels of noise to which they are exposed. The random selection of households can then be made independently for each group, as explained later.

For practical reasons, not all residents could be included in the 'target' population and this was restricted to only those people who met the following criteria:

(a) that they were 18 years or older;

(b) that they actually live at the eligible address, i.e. spending at least four nights a week there. People who normally live at the address, but are temporarily away, are included provided they have not been away for six months or more. People who do not normally live at the address but are temporarily resident there are included if they have been there for six months or more. This criterion, therefore, excluded residents who had recently moved into the area, i.e. within the last three months;

(c) that the address where they live is a 'dwelling unit' as defined by the Social Survey Division of the Office of Population Censuses and Surveys; and

(d) that the dwelling unit in question is exposed to a peak noise level, from the Metro, of at least 65 dB(A) when measured at 1 metre from the facade on the noisiest side of the building.

Having set the criteria for the target population, the next step was actually to define the acoustical "boundary" of 65 dB(A) peak level in the area. This bound area was then divided into a number of zones containing dwelling units that were exposed to noise levels pertaining to each of the four noise bands, as defined below:

A - 85 dB(A) peak or higher

B - 81-85 dB(A) peak

C - 71-80 dB(A) peak

D - 65-70 dB(A) peak

This 'zoning' exercise was carried out by recording, on a map, peak noise levels during Metro passbys, with the help of a sound level meter. Equal noise band contours could then be drawn. Figure 4.3 shows how part of the area was divided into the four relevant noise-bands.

The sampling process followed the zoning exercise. As discussed earlier the procedure was to select a sub-sample, independently, for each noise band. This involved:

(a) counting the number of dwelling units in each noise zone, for example, the number of dwelling units in zones A, B, C, D; and

(b) randomly selecting, in turn, a number of dwelling units for each zone.

To determine the sample size from (b) above, two important factors had to be considered:

(1) the statistical requirements for computation and analysis purposes; and

(2) the limited resources available to carry out the survey.

The desired sample size, from a statistical point of view, depends to a great extent on the depth of analysis of the data in terms of their disaggregation. This, in turn, depends on the aims of the study. In this respect, the objectives of the study were planned to be achieved by a simple two-level disaggregation of the data. The limited resources of available time, money and manpower played as important a role as the statistical considerations in determining the sample

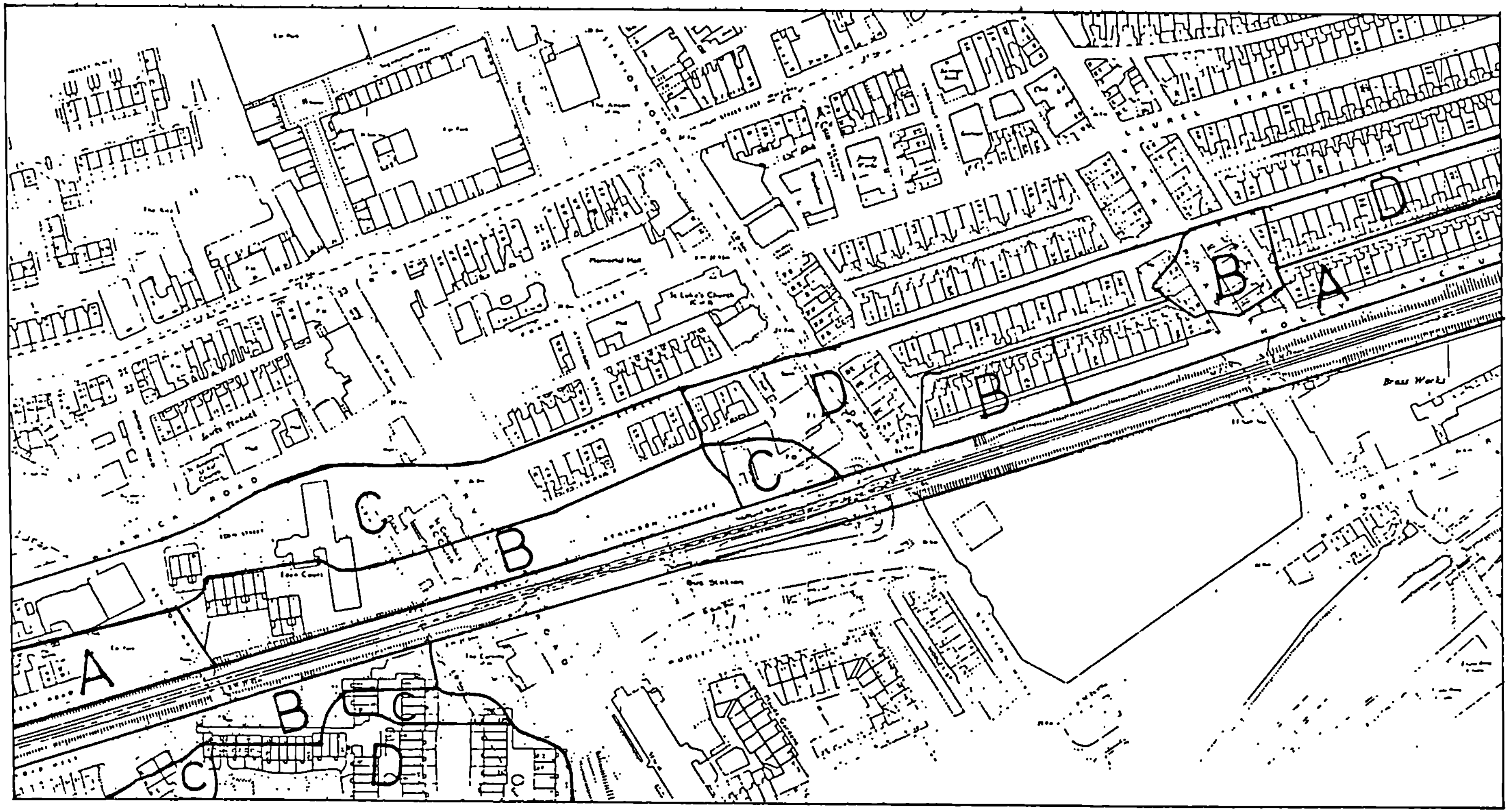


Figure 4.3 : Example of a section divided into noise zones

size. The fieldwork had to be carefully planned so that it would be practically feasible for a person to carry it out single-handed. In this calculation, account had to be taken of the average number of interviews an individual can efficiently conduct per day, tailing-off effects, difficulties of contact, appointment-at-convenience and other obstacles that slow down the fieldwork. A pilot survey, carried out to test the questionnaire, showed that it would take, on average, half-an-hour to conduct an interview and that, initially, six interviews could be conducted per day.

Table 4.2 shows the size of the population in each zone and the zonal sample size chosen, based on the two factors discussed above. It was estimated that, with a 70 per cent response, the total time would be close to one and a half times the initial rate of interviewing, that is, about seven weeks overall.

Table 4.2 Sample sizes within each noise zone

Noise zones	Total number of dwelling units	Sample size (no)	Proportion of total (%)
A	142	80	56
B	166	75	45
C	248	75	30
D	250	75	30
All zones	806	305	38

The selection of individuals was made by using the Kish selection table (Moser and Kalton, 1981) which gives all individuals in a household an equal chance of selection. A list of members in each household was obtained from the 1981 Electoral Register.

4.4 Social Survey Programme

A prominent feature in planning the social survey was the design and format of the questionnaire to be used to collect the desired information. After careful consideration of various questionnaires used in previous noise surveys in Great Britain, it was decided to adopt the questionnaire designed at the Institute of Sound and Vibration Research (ISVR) for the study on railway noise by Fields and Walker (1980). This ISVR questionnaire was itself developed on the basis of extensive literature search and which included many questions used in former noise surveys. However, this forty-five minutes questionnaire (which is estimated, in fact, to last over an hour) was too lengthy and contained many questions which were not relevant to the aims of this study. As a result, a shorter, adapted version was planned, which was expected to take about thirty minutes to administer. The flow diagram, Figure 4.4, shows the steps followed in designing this shorter questionnaire.

A small pilot survey was then carried out, outside the study area: (a) to check whether there was any ambiguity in the wording of questions; (b) to test the flow of the questionnaire, that is, to ensure that the sequence of questions enabled the interview to proceed smoothly both from the interviewer's and the respondent's point of view; (c) to determine the duration of an interview and to get an idea of the number of interviews that could be conducted efficiently in a day; and (d) to provide the interviewer with some experience of problems and difficulties that he would face when conducting the door-to-door interviews.

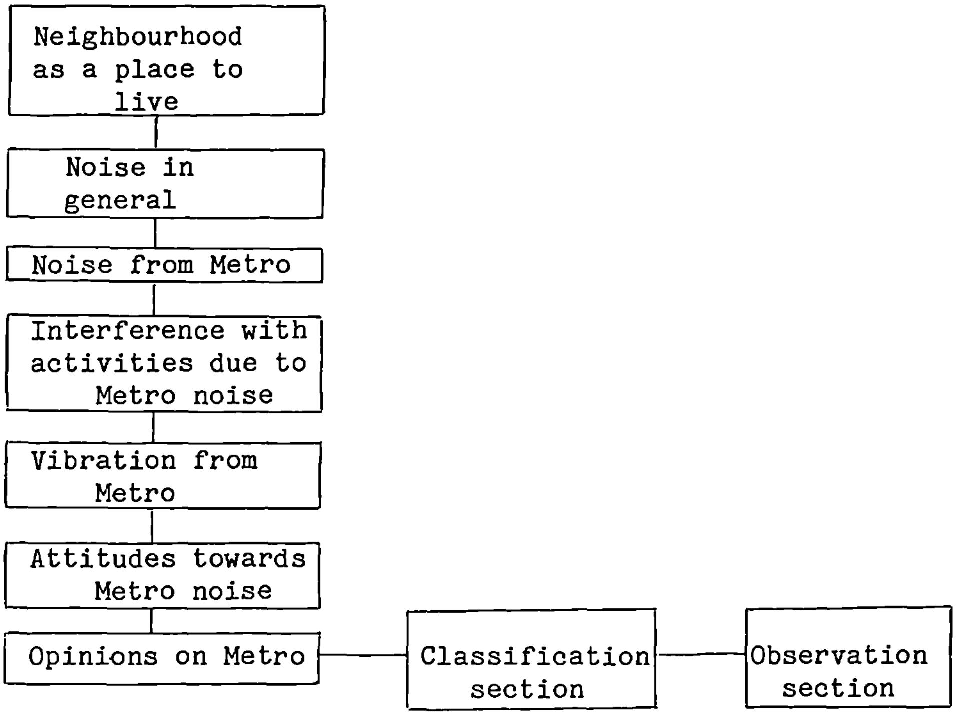


Figure 4.4 : Flow diagram on study's questionnaire

An examination of completed questionnaires from the pilot survey showed that there was no need to reword any questions except in cases where prompting words were needed or substitute words, like "Metro" or "Tyne and Wear PTE", were necessary to the context of this study. Similarly, the sequence of questions was shown to be correct and remained unchanged. A noteworthy observation, from the pilot survey and subsequently from the main survey, was the interpretation of the phrase 'quietness of the area' in questions 3(b) and 3(c) (Appendix B). The term 'quietness' here is the first reference made, in the questionnaire, to the acoustic environment of the respondent. To a number of people, this phrase was construed as meaning a trouble-free or peaceful area. The term was, however, retained because no substitute, as discreet but better in meaning, could be found for this early stage in the questionnaire.

Each interview lasted between twenty and thirty minutes but the total time spent with a respondent was sometimes up to forty five minutes. Even though eight interviews were completed during a single day by one person, six was a more feasible number. It was also recognised that: (a) a non-response, especially a discourteous one, could affect the morale of the interviewer and thereby reduce his output; and (b) that the number of interviews per day would fall further once the bulk of easily accessible respondents, such as housewives and other home-based respondents, had been interviewed.

The experience gained from conducting the pilot survey was vital and of utmost importance to the researcher, as a morale-booster and as a firm basis on which to tackle the main survey.

On the technical side, the survey revealed the problem of introducing the study as an "environmental study". This made the respondent either very inquisitive or rather indifferent. In the former case, he or she would question the interviewer about the exact nature of the study, while in the latter case little interest was shown. Neither response was desired by the interviewer who was not supposed to disclose that the questions related to a noise study. To counteract this, therefore, the survey was introduced as being "a general study of the area", i.e. about the conditions of roads and pavements, shopping facilities, provision of open spaces etc, and for which the opinions of the respondent were being sought. This proved successful in minimising interviewees' bias. The questionnaire finally adopted is presented in Appendix B; a copy of the letter of introduction which the interviewer carried with him is also included.

The following procedure was adopted throughout the main survey. On calling on a respondent, the interviewer would:

(i) introduce himself as being a student from the University and involved in a project related to his course;

(ii) explain how the respondent came to be selected for interview;

(iii) state the purpose of the survey, as discussed earlier;

(iv) explain the confidential nature of the enquiry;

(v) request cooperation, stressing the importance of each successful interview in achieving the goals of the project; and

(vi) give an indication of the likely duration of the interview.

If requested or if the interviewer felt necessary, the respondent was shown the letter of authorisation. The Police were also informed of the survey taking place and of its nature.

In cases of non-response, that individual was not replaced by any other person of the same household. However, if the respondent had moved away (or passed away) and the house was vacant or there were new occupants, then the following method was observed. In the former case, another household was randomly chosen in that zone and an individual selected; while, in the latter case, a person of similar gender to the original candidate was chosen, provided that person had lived at that address for more than three months. If the condition for the three months residence was not satisfied, a new address was chosen.

Recalls were made to a particular address at three different times on a week-day - morning, lunch-time and late afternoon (around six o'clock) - until contact was made. Failing that, such visits were paid again on a different day of the week and, finally, a weekend visit (as a last resort). Provided some information was obtained, say, from neighbours, about the whereabouts of that individual, a reply-paid appointment slip-cum-letter (Appendix B) was left at that particular address. This letter was also sent: (a) to individuals who had refused an interview, but who gave the impression they might be persuaded at a later date; and (b) to those few people to whom access was not possible because the person contacted was unsympathetic to the study. Appointments were made and kept with respondents irrespective of time or day of week, as long as it was possible (especially if a means of transport was available) for the interviewer to do so.

4.5 Noise Measurement Programme

The noise survey began soon after completion of the social survey. The aim was to measure the noise of the Metro, passing through the area, at various predetermined locations, near to the selected addresses. Hence, measurement sites had to be chosen prior to the start of the survey.

With the help of maps, measured peak noise levels of Metro passbys during the zoning exercise and several visits to the area, a number of measurement sites were selected. Since many of the dwelling units are terraced flats, it was possible to select a number of sites which comprised between 3 and 7 adjacent addresses, all of which were estimated to have similar noise exposure. The same technique was used for houses along the parallel rows of streets perpendicular to the railway line. A single measurement position was chosen at each measurement site which, mostly, was at one of the addresses at which interviews had been conducted. Measurements were carried out at 82 sites, in all.

Most of the equipment used during the survey was available from within the Department of Civil Engineering, with the exception of the anemometer, which was borrowed from the Building Science section of the Architecture Department. The integrating sound level meter, Bruel and Kjaer 2230, had just been acquired by the Department and its capability and portability were of great help throughout the survey. With two sound level meters, B & K 2230 and B & K 2203, and the latter connected to the statistical analyser, it was possible for two persons to make noise measurements at two different sites at the same time.

Since most of the equipment is bulky, it was transported in a Department van. During the few occasions when this means of transport was not available, the lightness of the B & K 2230 sound level meter enabled fieldwork to go on. Figure 4.5 shows the equipment arrangement in the van.

Equipment used during the survey was, as follows:

- sound level meters (B & K 2203, 2230)
- condensor microphones (B & K 4145, 4155)
- statistical analyser (B & K 4426)
- alphanumeric printer (B & K 4123)
- tape recorder (UHER 4400)
- calibrator (B & K 4230)
- anemometer
- dehumidifier (B & K UA 0310)
- 12v DC power supply
- windshield
- tripod and extension pole
- extension cables
- stop watch
- batteries and spare instrumentation
- measuring tape
- maps
- data sheets
- polythene sheets

Weather conditions dictated when noise measurements were not possible. Wet conditions and/or wind speeds greater than 5 ms^{-1} prevented work going ahead. Luckily, such conditions were seldom experienced and progress was rarely hampered.

On arrival, the exact measurement site was located and the equipment was set up. Noise measurements were made for durations of between twenty and thirty minutes, during which, noise levels of (on average) eight Metro passbys were noted. The next measurement site was then visited. At each site, the microphone was positioned at the side of the house exposed to the loudest Metro noise, provided there were living room or bedroom windows on that side. Otherwise, the side of the house with windows which were assumed to belong to living or bedroom accommodation and exposed to the next highest level of Metro noise was chosen. The microphone was placed at a height of 3 metres for first floor terraced flats and 1.5 metres for ground floor flats. It was positioned about 1 metre from the facade. This last requirement was easily met in most cases, since most houses in the area are built actually fronting onto the streets. In the few cases where this was not so, permission of the house owner was sought to set up in their garden.

Noise measurements were made by reading sound levels during Metro passbys and during lulls between. The sound level meter was kept running continuously during the measurement period, which allowed individual passby levels to be noted as well as the total noise level. Recordings of Metro passbys were also made for frequency content analysis, the linear response (dB) being used on these occasions.

The main problem encountered during the survey was that due to the adverse weather conditions. In addition, road vehicles passing close to the microphone, and interference from passers-by and animals (especially the barking of dogs) were the principal culprits. Aircraft noise was not particularly disruptive. On occasions, when the wind speed was close to 5 ms^{-1}, measurements were restricted to a single site since two persons were then required to man the equipment - arrangement shown in Figure 4.5 - with one person taking readings inside the van and the other preventing the tripod and pole from toppling over.

The noise data collected at each site, all given in dB(A), were, as follows:

(1) the maximum A-weighted sound level reached during a Metro passby for the near and far tracks;

(2) the sound exposure level (SEL) of each passby for both near and far tracks; and

(3) the equivalent continuous sound level (L_{eq}) during the sampling period.

The data at each site were recorded on a 'Noise Measurement Sheet' as shown in Figure 4.6. They were then summarised for each measurement site by calculating the logarithmic mean of measures (1) and (2), i.e. the near and far maximum A-weighted sound levels and the near and far sound exposure levels. These summary data, together with information about the number of Metro trains operating at different times of the day were then combined to allow the 18-hour and 24-hour exposure levels to be determined. Calculations to obtain the summary noise measures are shown in Appendix A. Finally, Table 4.3 shows the frequency of Metro trains passing through the study area on a typical day, between Monday and Saturday.

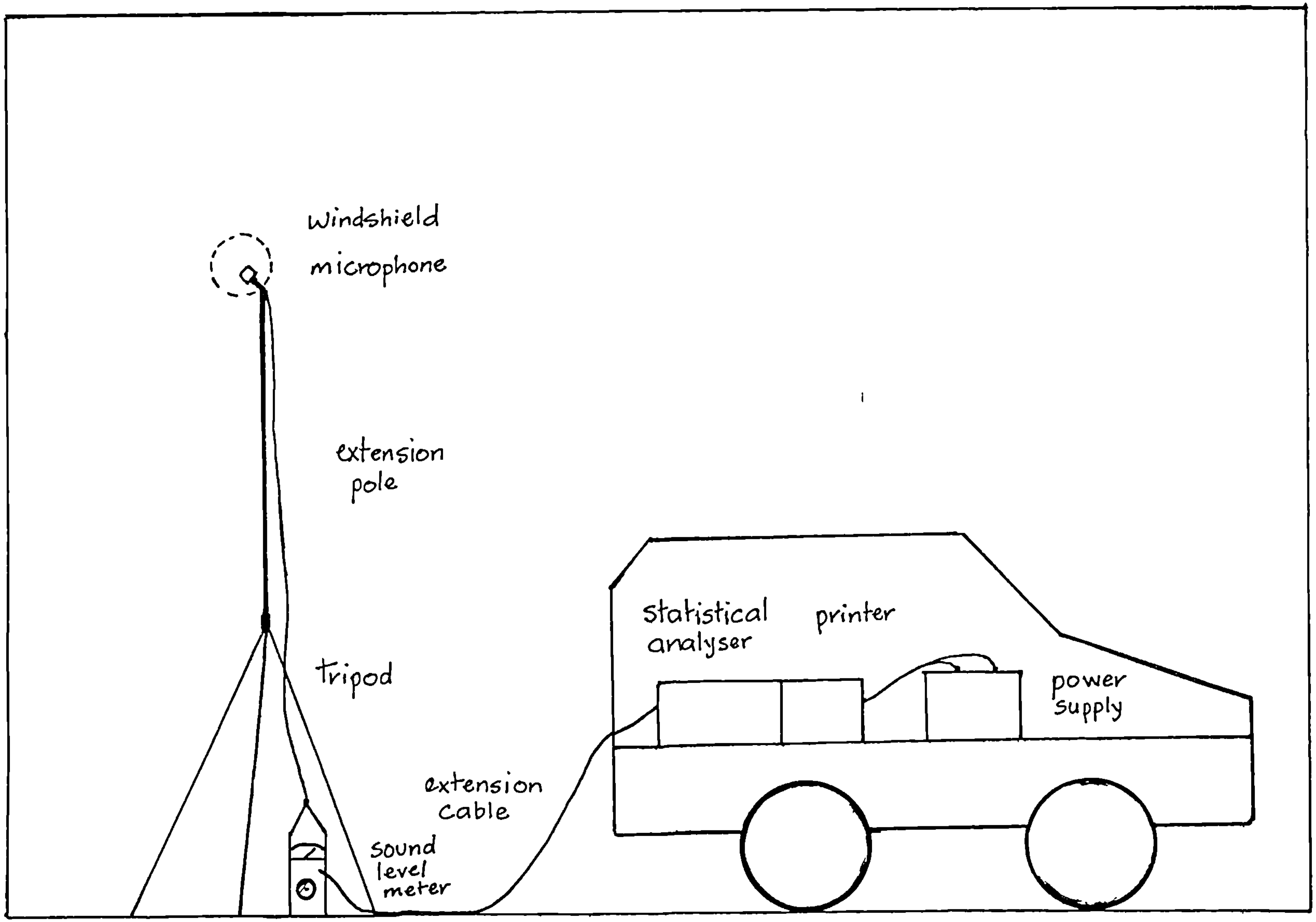


Figure 4.5 : Schematic diagram of major items of equipment used during noise survey

NOISE MEASUREMENT SHEET

Address : 146 Holly Avenue

Date : 9/11/83

Site Description :

Rail 1 JR 2 JR with points

(3) CWR 4 CWR with points

Sleepers (1) concrete 2 wood

Cutting / Embankment ✓

Is Metro visible from microphone position?

(1) yes 2 no

Wind

(1) none 2 steady 3 variable

Speed < 5 ms^{-1} 1 yes 2 no

Weather

Temperature (°C) 14°C

Cloud cover 1 overcast (2) mainly clear 3 all clear

SLM attenuator setting for calibration : (90)

SLM attenuator setting for measurement : (90)

Predominant source of noise : METRO Other noise sources : ROAD TRAFFIC

Start/end time	$L_{max(near)}$	$L_{max(far)}$	$SEL_{(near)}$	$SEL_{(far)}$	L_{eq}	No. of trains
11.33 a.m. 11.55 a.m.	90.6 91.0 90.6 90.8	81.4 83.0 82.0 81.7	94.7 95.0 94.5 94.8	86.2 87.8 87.0 87.0	71.6	8

Figure 4.6 : Data sheet

Table 4.3 Frequency of service of Metro in survey area

Operating periods of the day	Frequency of service (trains/hour)	No of passbys observed
05.33-06.20	6	4
06.20-06.55	18	9
06.55-18.20	24	274
18.20-18.45	18	9
18.45-23.55	12	62
Total time = 18hrs 22 min	Total passbys =	358

CHAPTER FIVE

PRECIS OF SURVEY RESULTS

This chapter presents the main results of the social survey. Some tabulations of the responses to the questionnaire which have not been presented in this chapter are shown in Appendix C.

5.1 Response Rate

The overall response rate, that is excluding visits to vacant premises, people who have passed away and non-existent addresses, is 74 per cent. The effective sample size for all noise zones was 274 and the resulting successful interviews numbered 203.

Even though the zonal response rate ranged from 72 per cent (Zone A) to 78 per cent (Zone D) for the social survey ('before' response), the final percentage for each zone had changed from what it was after the noise survey was conducted ('after' response). This change was especially marked for Zone A and B as a result of higher measured peak noise levels from Metro afterwards than when the area was initially surveyed to establish the noise zones. This unexpected and unexplained rise in emitted noise levels increased the sample size of households in zone A at the expense of those in zone B. This effect was much less noticeable for Zone C, which also had the widest noise range, 70 to 80 dB(A). Zone D was not affected.

Some minor readjustments were also effected as a result of estimation error while drawing the noise boundaries. The 'before' and 'after' zonal figures are shown in Table 5.1.

TABLE 5.1 : Breakdown of response in each zone

	Sample number of housholds in each zone			
Zone	A	B	C	D
No. of households	68	71	67	68
No. of respondents ('before')	49	55	50	53
No. of respondents ('after')	61	39	46	57

Refusals accounted for 28 per cent of non-response, the breakdown of which was, as follows:

Refusals	20
Unsuitable for interview	10
Away from home	8
No contact/out at time of call	33
	71

Several possible reasons account for the non-response. These include: (1) the time of year (August/September) which coincided with the holiday season; (2) the increased exposure of residential communities to door-to-door interviews from such varied sources as commercial agencies and spiritual and religious groups (information from residents established that salespersons had visited the area earlier in the year and introduced themselves as survey interviewers to gain access to the house); and (3) the difficulty sometimes experienced by the interviewer when confronted by a respondent, or by a relative of the latter, who wished to know 'exactly' what the survey was about. If the area or the area's environment, as the subject of the survey was introduced, did not interest that individual, the call could be unsuccessful. It is, of course, not possible to know whether the refusal rate would have been less if the respondents were better informed of the exact nature of the survey.

5.2 Respondents' General Impression of Their Area

Early in the questionnaire, respondents were asked to mention things they liked and disliked about their area. 'Neighbourhood amenities' was the most often favourable, mention by 71% of respondents; followed by 'location' 45% and 'Metro services' 41%.

Among dislikes, 30% of respondents said they 'Dislike Nothing', with 'Metro Noise' mentioned by 12%. Of those who mentioned 'Metro Noise', 84% come from the zones exposed to higher levels (A and B) and no one mentioned it from the lowest of the exposed zones, D.

In terms of their commitment to the area, 58% of respondents said they had never felt like moving from the area. Of the 42% that were moving out or planning to do so, 65% gave better housing as their motive. No one had considered moving out as a result of Metro noise.

Respondents rated the area where they live in the following way: 95% rated 'Being close to shops' at least "good"; 90% also rated its location ('Near to places you need to go to') and 'Public Transport services', at least "good"; 77% felt the 'Way roads and streets are kept' was "average" and lower. Overall, 59% rated their neighbourhood at least "good".

5.3 General Reactions of Respondents to Noise in Their Area

Rating their area with respect to quietness, 58% of respondents said it was 'average' to 'very poor'. Of the 42% who rated the quietness of their area at least 'good', nearly half (46%) were, surprisingly, from the two highest exposed groups (in zones A and B). Respondents in zone C represented the highest percentage (10%) who rated quietness in the area as 'very poor'. The figures shown in Table 5.2 partly explain this response in that particular zone.
A series of questions was asked about specific noises heard by respondents. Those who heard a noise were then asked whether they were bothered by it. The responses are summarised in Table 5.2 below. 'Other' refers to other noises and included mainly dogs barking, loud music from club or pub and Metro maintenance work, especially ballast tamping which is carried out late at night.

Respondents were asked, of those noises that bothered them, which they regarded as the biggest and then the next biggest nuisance. A breakdown of responses in the 4 zones is shown in Table 5.3. The figures are percentages of those who said they were bothered by a

TABLE 5.2 : Reaction of respondents to noise in their area

(% respondents)

Noise source	Zone				All zones
	A	B	C	D	
Metro	33	41	30	5	26
People/ children	20	23	37	23	25
Building works	16	10	30	19	19
Road traffic	13	26	20	18	18
Factories/ machinery	20	8	17	9	14
Neighbours	12	5	24	11	13
Aircraft	5	8	7	11	7
Other	18	15	15	9	14

(No. of respondents)

Sample size	61	39	46	57	203

TABLE 5.3 : The nuisance of noise

(* see key)

Noise source	Zone A	Zone B	Zone C	Zone D	All zones
Metro	(20) 55 / 40	(16) 88 / 6	(14) 71 / 21	(3) 33 / 33	(53) 68 / 25
Road traffic	(8) 38 / 25	(10) 40 / 50	(9) 22 / 33	(10) 60 / 30	(37) 41 / 35
Neighbours	(7) 57 / 14	(2) 50 / 0	(11) 36 / 27	(6) 27 / 27	(26) 46 / 27
Aircraft	(3) 33 / 66	(3) 0 / 66	(3) 0 / 33	(6) 17 / 50	(15) 13 / 53
Building works	(10) 30 / 20	(4) 25 / 0	(14) 29 / 36	(11) 64 / 36	(39) 38 / 28
Factories/ machinery	(12) 50 / 33	(3) 33 / 33	(8) 13 / 25	(5) 0 / 40	(28) 29 / 32
People/ children	(12) 50 / 8	(9) 11 / 44	(17) 12 / 24	(13) 46 / 23	(51) 29 / 24
Other	(11) 39 / 0	(6) 67 / 17	(7) 43 / 14	(5) 80 / 0	(29) 62 / 7

(No. of respondents)

	A	B	C	D	All zones
Sample size	61	39	46	57	203

* key: No. of respondents who are bothered by noise → (20); 55 ← % biggest nuisance; 40 ← % next biggest nuisance

particular noise. As the table shows, of the people who were bothered by Metro noise, 93% considered it to be the biggest (68%) or next biggest (25%) nuisance, followed by road traffic noise (41% and 35% respectively). Also of interest, are the 25% who said they were bothered by 'Children and other people outside' (Table 5.2); in comparison to Metro noise (26%), only 53% regarded noise from other people as the two biggest nuisances.

5.4 Specific Reactions to Metro Noise

All respondents were shown a card (Figure 5.1) and they were asked to choose a number which most closely reflected their feelings about the amount of noise from Metro, road traffic and aeroplanes and, for those who had lived in the area sufficiently long, diesel multiple units trains (DMUs) too. Table C1 (Appendix C) gives the breakdown of response in each zone. Table 5.4 illustrates the average score-value for each zone-type.

Figure 5.1 : Prompt Card

CARD D

Definitely satisfactory	1
	2
	3
	4
	5
	6
Definitely unsatisfactory	7

The scores were tested between the zones and between groups within each zone for hypotheses about differences in mean scores. Non-parametric tests, such as Kruskal-Wallis, Wilcoxon signed-rank and Mann-Whitney, suitable for ordinal data were carried out on the scores in Tables 5.4(a), (b) and (c). Tests at parametric level, such as T-test and one-way analysis of variance, which assume interval properties of the scale, were also performed. As Figures 5.2 to 5.11 show, tests at both levels proved consistent in their outcome, thereby indicating that the assumption of interval properties of the 7-point scale is a reasonable one. Hence, more powerful parametric tests could be used to reinforce the results obtained from the non-parametric tests.

To summarise the results illustrated in Figures 5.2 to 5.11:

Figure 5.2: There were no significant differences, at the 5 per cent level, for the more exposed zones in the rating of Metro noise on the 7-point satisfaction scale. Scores of residents in zone D, however, were significantly different from the rest.

Figure 5.3: The rating of noise from DMU trains showed still less disagreement. At the 10 per cent, and even at the 5 per cent level, none of the zonal scores differed significantly from each other, indicating lesser difference (cf. Figure 5.2) in score values between the more exposed zones and the least exposed Zone D.

TABLE 5.4(a) : Average scores of respondents for each zone on three different noise sources

(Mean score)

Noise source	Zone			
	A	B	C	D
Metro	3.8	4.2	3.6	2.4
Road traffic	2.7	3.5	3.0	2.6
Aeroplanes	1.9	2.3	2.0	2.3

(No. of respondents)

Sample size	61	39	45	53

TABLE 5.4(b) : A comparison of average scores (DMU v Metro) for those exposed to both DMU and Metro noise

(Mean score)

Noise source	Zone			
	A	B	C	D
DMU	4.1	4.4	3.8	3.4
Metro	3.5	4.0	3.6	2.3

(No. of respondents)

Sample size	45	33	28	38

TABLE 5.4(c) : A comparison of average scores between zones for those exposed to Metro noise only

(Mean score)

Noise source	Zone			
	A	B	C	D
Metro	4.5	4.7	3.6	2.7

(No. of respondents)

Sample size	16	6	17	15

Figure 5.[illegible] : Tests for differences in mean scores, on Metro noise, between zones

KRUSKAL-WALLIS ONE-WAY ANALYSIS OF VARIANCE

SCALEM - Metro noise rating on 1 to 7 point scale
BY
ZONES

Zone	Cases	Mean rank
A	61	108.40
B	39	121.46
C	45	104.08
D	53	69.21
Total	198	

			Corrected for Ties	
Cases	Chi-Square	Significance	Chi-Square	Significance
198	22.2997	0.0001	22.9596	0.0000

ANALYSIS OF VARIANCE - SCHEFFE PROCEDURE

Mean score	Zone	A	B	C	D
3.7541	A				*
4.1538	B				*
3.6444	C				*
2.4340	D				

Key: * denotes pairs of zones whose scores are significantly different at the 5% level

Figure 5.3 : Tests for differences in mean scores, on DMU noise, between zones

KRUSKAL-WALLIS ONE-WAY ANALYSIS OF VARIANCE

SCALEDMU - DMU noise rating on 1 to 7 point scale
BY
ZONES

Zone	Cases	Mean rank
A	45	79.50
B	33	86.18
C	29	71.98
D	42	63.48
Total	149	

			Corrected for Ties	
Cases	Chi-Square	Significance	Chi-Square	Significance
149	5.8410	0.1196	5.9742	0.1129

ANALYSIS OF VARIANCE - SCHEFFE PROCEDURE

Mean score	Zone	A	B	C	D
4.1333	A				
4.4242	B				
3.7500	C				
3.4737	D				

No two zones were found to be significantly different at the 5% level

Figures 5.4 to 5.7: Ratings of Metro noise from those who had lived in the area when DMU trains were in operation (Group 1) were tested against those who had not (Group 2). These tests were carried out separately for each zone. It was found that, at the 5 per cent level, scores of the two groups did not differ significantly in any of the zones. However, scores in zone A were significantly different, at the 10 per cent level, indicating some difference in reaction to Metro noise in that zone for the two groups.

Figures 5.8 to 5.11: Residents' perception of noise from DMU trains was compared to that of Metro for each zone. Residents in zones A and D showed the biggest difference in their perception of noise from the two rail systems. Residents in all zones generally perceive Metro as the quieter system.

From the results above, it appears (Table 5.4(a)) that residents in zones A, B and C (mean scores 3.8, 4.2 and 3.6 respectively) are nearly equally sensitive to noise from Metro even though, on average, there was a difference of 10 dB(A) in peak noise level between zone A and zone C. Residents in zone D are the least affected and their mean score of 2.4 reflects this. Noise from DMU trains was generally perceived as being more disruptive than noise from Metro by people in all zones, as the scores in Table 5.4(b) show; marked significant shifts (higher to lower) in mean score-values were registered for the highest, zone A (4.1 to 3.5), and the lowest, zone D (3.4 to 2.3) exposed zones. Unlike the case of noise from Metro, where there is a significant difference between the scores of zones A, B and C and

Figure 5.4 : Tests for differences in mean scores, on Metro noise, in Zone A between those exposed to DMU noise (Group 1) and those not exposed (Group 2)

MANN-WHITNEY U - WILCOXON RANK SUM W TEST

SCALEM - Metro noise rating on 1 to 7 point scale
BY INHSEDMU - Living here when DMU was in service?

Response	Cases	Mean rank
INHSEDMU = 1 'Yes'	45	28.66
INHSEDMU = 2 'No'	16	37.59
Total	61	

		Corrected for Ties	
U	W	Z	2-Tailed Prob
254.5	601.5	-1.7537	0.0795

T-TEST

Group 1 - INHSEDMU = 1
Group 2 - INHSEDMU = 2

							Pooled variance estimate		
Variable	Number of cases	Mean	Standard deviation	Standard error	F Value	2-Tail prob	T Value	Degrees of freedom	2-Tail prob
SCALEM									
Group 1	45	3.4889	1.842	0.275	1.30	0.489	-1.82	59	0.074
Group 2	16	4.5000	2.098	0.524					

Figure 5.5 : Tests for differences in mean scores, on Metro noise, in Zone B between those exposed to DMU noise (Group 1) and those not exposed (Group 2)

MANN-WHITNEY U - WILCOXON RANK SUM W TEST

SCALEM - Metro noise rating on 1 to 7 point scale
BY INHSEDMU - Living here when DMU was in service?

Response	Cases	Mean rank
INHSEDMU = 1 'Yes'	33	19.48
INHSEDMU = 2 'No'	6	22.83
Total	39	

		Corrected for Ties	
U	W	Z	2-Tailed Prob
82.0	137.0	- 0.6717	0.5018

T-TEST

Group 1 - INHSEDMU = 1
Group 2 - INHSEDMU = 2

							Pooled variance estimate		
Variable	Number of cases	Mean	Standard deviation	Standard error	F Value	2-Tail prob	T Value	Degrees of freedom	2-Tail prob
SCALEM									
Group 1	33	4.0606	1.694	0.295	1.75	0.297	-0.77	37	0.445
Group 2	6	4.6667	2.251	0.919					

Figure 5.6 : Tests for differences in mean scores, on Metro noise, in Zone C between those exposed to DMU noise (Group 1) and those not exposed (Group 2)

MANN-WHITNEY U - WILCOXON RANK SUM W TEST

SCALEM - Metro noise rating on 1 to 7 point scale
BY INHSEDMU - Living here when DMU was in service?

Response	Cases	Mean rank
INHSEDMU = 1 'Yes'	28	23.32
INHSEDMU = 2 'No'	17	22.47
Total	45	

		Corrected for Ties	
U	W	Z	2-Tailed Prob
229.0	382.0	-0.2143	0.8303

T-TEST

Group 1 - INHSEDMU = 1
Group 2 - INHSEDMU = 2

Variable	Number of cases	Mean	Standard deviation	Standard error	F Value	2-Tail prob	Pooled variance estimate: T Value	Degrees of freedom	2-Tail prob
SCALEM									
Group 1	28	3.6429	1.909	0.361	1.54	0.247	-0.01	43	0.995
Group 2	17	3.6471	2.448	0.594					

Figure 5.7 : Tests for differences in mean scores, on Metro noise, in Zone D between those exposed to DMU noise (Group 1) and those not exposed (Group 2)

MANN-WHITNEY U - WILCOXON RANK SUM W TEST

SCALEM - Metro noise rating on 1 to 7 point scale
BY INHSEDMU - Living here when DMU was in service?

Response	Cases	Mean rank
INHSEDMU = 1 'Yes'	38	25.59
INHSEDMU = 2 'No'	15	30.57
Total	53	

		Corrected for Ties	
U	W	Z	2-Tailed Prob
231.5	458.5	-1.0919	0.2749

T-TEST

Group 1 - INHSEDMU = 1
Group 2 - INHSEDMU = 2

Variable	Number of cases	Mean	Standard deviation	Standard error	F Value	2-Tail prob	Pooled variance estimate: T Value	Degrees of freedom	2-Tail prob
SCALEM									
Group 1	38	2.3421	1.214	0.197	1.35	0.562	-0.91	51	0.367
Group 2	16	2.6667	1.047	0.270					

Figure 5.8 : Tests for differences in mean scores between Metro noise (SCALEM) and DMU noise (SCALEDMU) for respondents in Zone A

WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

Mean rank	Cases			
13.38	13	-	Ranks	(SCALEDMU < SCALEM)
19.35	20	+	Ranks	(SCALEDMU > SCALEM)
	12		Ties	(SCALEDMU = SCALEM)
Total	45			

Z = -1.9029 2-Tailed Probability = 0.0571

PAIRED T-TEST

Variable	Number of cases	Mean	Standard deviation	Standard error	Difference in mean	Standard deviation	Standard error	T Value	Degrees of freedom	2-Tail prob
SCALEM	45	3.4889	1.842	0.275	- 0.6444	2.298	0.343	-1.88	44	0.067
SCALEDMU	45	4.1333	2.138	0.319						

Figure 5.9 : Tests for differences in mean scores between Metro noise (SCALEM) and DMU noise (SCALEDMU) for respondents in Zone B

WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

Mean rank	Cases			
15.05	11	-	Ranks	(SCALEDMU < SCALEM)
14.15	17	+	Ranks	(SCALEDMU > SCALEM)
	5		Ties	(SCALEDMU = SCALEM)
Total	33			

Z = -0.8539 2-Tailed Probability = .3931

PAIRED T-TEST

Variable	Number of cases	Mean	Standard deviation	Standard error	Difference in mean	Standard deviation	Standard error	T Value	Degrees of freedom	2-Tail prob
SCALEM	33	4.0606	1.694	0.295	- 0.3636	2.596	0.452	-0.80	3[illegible]	0.4[illegible]7
SCALEDMU	33	4.4242	1.768	0.308						

Figure 5.10 : Tests for differences in mean scores between Metro noise (SCALEM) and DMU noise (SCALEDMU) for respondents in Zone C

WILCOXON MARCHED-PAIRS SIGNED-RANKS TEST

Mean rank	Cases		
8.83	9	- Ranks	(SCALEDMU < SCALEM)
10.17	9	+ Ranks	(SCALEDMU > SCALEM)
	10	Ties	(SCALEDMU = SCALEM)
Total	28		

Z = -0.2613 2-Tailed Probability = .7939

PAIRED T-TEST

Variable	Number of cases	Mean	Standard deviation	Standard error	Difference in mean	Standard deviation	Standard error	T Value	Degrees of freedom	2-Tail prob
SCALEM	28	3.6429	1.909	0.361	- 0.1071	1.988	0.376	-0.29	27	0.776
SCALEDMU	28	3.7500	1.798	0.340						

Figure 5.11 : Tests for differences in mean scores between Metro noise (SCALEM) and DMU noise (SCALEDMU) for respondents in Zone D

WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

Mean rank	Cases		
7.00	3	- Ranks	(SCALEDMU < SCALEM)
13.29	21	+ Ranks	(SCALEDMU > SCALEM)
	14	Ties	(SCALEDMU = SCALEM)
Total	38		

Z = -3.6857 2-Tailed Probability = 0.0002

PAIRED T-TEST

Variable	Number of cases	Mean	Standard deviation	Standard error	Difference in mean	Standard deviation	Standard error	T Value	Degrees of freedom	2-Tail prob
SCALEM	38	2.3421	1.214	0.197	- 1.1316	1.663	0.270	-4.19	37	0.000
SCALEDMU	38	3.4737	1.751	0.284						

zone D, this discrimination is not apparent, statistically, in the case of noise from DMUs. Numerically, the trend is a decrease in satisfaction as noise levels increase. Residents in zone B, however, scored consistently higher in all cases.

Just over a fifth (23%) of the residents interviewed said they found noise from Metro 'more annoying at times'; 83 per cent of them said evening (18.00-24.00) was the worst time, while 17 per cent said the morning (5.30-9.00) was. By comparison, 73 per cent of all respondents felt the noise was either 'always the same' or 'not annoying at all'.

Respondents were asked a number of questions about whether noise from Metro caused annoyance through interference with certain activities. The responses, shown in percentages for each zone separately, are shown in Table 5.5. When asked if they kept their doors or windows shut because of noise from Metro, 18%, 15%, 24% and 2% replied positively in zones A, B, C and D respectively.

Of all respondents, 86% had "got used to" the noise from Metro, 6% had not, another 6% were not sure, while 2% of the sample (zone D) said they did not hear the noise at all. The average length of time taken to get used to the noise was approximately 10 weeks for respondents in zones A, B, C and 6 weeks for residents in zone D. The range of times stated was from a year to less than a week. Nearly half of those who had got used to noise from Metro said they were 'never bothered'.

TABLE 5.5 : Interference by Metro noise with activities indoors

(% respondents, * see key)

Interference by Metro noise	Zone A	Zone B	Zone C	Zone D	All zones
Interference with listening to radio, TV and Hi-Fi	54 43 7	54 46 10	37 30 17	7 2 0	37 29 8
Interference with conversation	51 30 3	26 18 5	17 17 4	0 0 0	24 16 3
Wakes up	33 16 3	21 8 5	35 24 11	4 4 0	23 13 4
Startles	5 5 3	8 8 3	7 7 4	0 0 0	4 4 3

(No. of respondents)

Sample size	61	39	46	57	203

* Key:

54	← experience interference
43	← at least 'a little annoyed'
7	← 'very annoyed'

5.5 Specific Reactions to Metro-caused Vibration

All respondents were asked if they experienced any form of vibration, such as rattle/shake, during a Metro passby and, if so, how annoyed were they by it. Their responses are shown in Table 5.6. In addition, several respondents mentioned that vibration from DMU trains had been more severe and this was confirmed, to the researcher, by residents in the least exposed group (zone D) who were not experiencing any vibration from Metro, but who claimed they had previously from DMU trains. Vibration caused by road traffic and aeroplanes was also discussed.

When asked what it was that they had noticed vibrating (shaking or rattling), 44% of respondents who experienced vibration from Metro (in the overall sample) mentioned feeling the floor/house/bed/chair move, followed by 'windows/doors' (30%), 'glasses/crockery' (23%) and 'pictures/mirrors on walls' (10%). This order was also maintained at the zonal level.

The perceived damaging effects of vibration from Metro were expressed, by respondents who experience the vibration, in the following way: 50% in zone A, 25% in zone B, 58% in zone C and 14% in zone D believed damage could be done to their property. Some forms of structural damage, such as cracking to foundations, floors, walls and ceilings, were most feared. There was even mention of 'house collapse' as a possibility by two respondents in zone A!

TABLE 5.6 : Annoyance due to vibration

(% respondents, * see key)

Vibration source	Zone				All zones
	A	B	C	D	
Metro	56 26 8	51 28 5	41 28 9	12 4 0	39 21 5
Road traffic	25 13 5	31 26 8	22 15 13	19 14 2	24 16 7
Aircraft	0 0 0	8 5 0	9 7 4	11 5 0	6 4 1

(No. of respondents)

Sample size	61	39	46	57	203

* Key:

56	← Experience vibration
26	← at least 'a little annoyed'
8	← 'very annoyed'

The same group of respondents were asked whether they regarded vibration caused by Metro as a problem and, if they did, which as between noise and vibration they considered a bigger problem. Their responses are shown in Tables 5.7(a) and 5.7(b). It appears that vibration is a bigger problem for respondents exposed to high noise levels (zone A) who, in general, may also be exposed to high vibration levels. However, the sample sizes for the various zones are too small to draw any conclusion from the response. For those who perceive it, vibration from Metro mostly causes 'worry' and 'irritation and bother'.

5.6 Attitudes to Metro Noise

Of all the respondents, 72% in zone A, 67% in zone B, 48% in zone C and 14% in zone D said they thought something should be done to reduce noise from Metro. The responsibility for this, they felt, lay with the operators (Tyne and Wear PTE) and the local authority (Tyne and Wear County Council).

Respondents were asked whether, during the time they had lived in the area, they had noticed any change in the amount of noise from the railway. This question was meant to find out:

(1) from those respondents who have been exposed to noise from both Metro and DMU trains, how they judged the two systems; and

(2) from those who have only been exposed to noise from Metro, how they judged the current situation.

TABLE 5.7(a) : The problem of vibration from Metro

(% respondents)

Is vibration from Metro a problem?	Zone				All zones
	A	B	C	D	
Problem	47	15	47	14	36
Not a problem	53	85	53	86	64
Totals	100	100	100	100	100

(No. of respondents)

Sample size*	34	20	19	7	80

* refers to respondents who experience vibration from Metro

TABLE 5.7(b) : Comparing the problems of noise and vibration from Metro

(% respondents)

Which is a bigger problem?	Zone				All zones
	A	B	C	D	
Vibration	63	33	22	0	45
Noise	31	67	56	0	41
Same	6	0	22	100	14
Totals	100	100	100	100	100

(No. of respondents)

Sample size*	16	3	9	1	29

* refers to respondents for whom vibration from Metro is a problem

From the responses shown in Table 5.8(a) and (b), there does not seem to be any definite trend in attitudes. A possible explanation may be that some people judged 'amount of noise' to mean exposure. In which case, due to the higher frequency of service of Metro, they would have perceived an increase in noise with the new system. By contrast, if some took 'amount of noise' to mean peak level, then they would have perceived the change as a decrease from the DMUs to Metro. In general, more respondents in zones A and C thought the amount of noise had either stayed the same or increased while, in zones B and D, the response was about equally divided between those who perceived the noise had either increased or stayed the same, and those who felt it had decreased.

Most respondents who have been exposed to noise from Metro only saw no change in their noise environment. A few, however, compared the situation as it was when Metro first began operation in the area (November 1982), i.e. between Tynemouth and St. James with that when the interview was held (September 1983), which included a new "Metroline" service between St. James and North Shields, opened in March 1983. Those respondents who did so generally perceived an increase in noise.

5.7 Opinions on Metro

Of all respondents in the area, 52% said Metro fares were 'about right' or 'cheap', 22% said they were expensive, 13% had free travel

TABLE 5.8(a) : Perceived change in noise levels, Metro v DMU

(% respondents)

Any change in noise	Zone				All zones
	A	B	C	D	
Increased	31	30	24	13	25
Stayed the same	36	24	41	32	42
Decreased	33	46	35	55	33
Totals	100	100	100	100	100

(No. of respondents)

Sample size*	45	33	29	40	147

* refers to those respondents who have been exposed to noise from both DMU and Metro

TABLE 5.8(b) : Perceived change in noise levels of Metro

(% respondents)

Any change in noise?	Zone				All zones
	A	B	C	D	
Increased	31	17	29	0	29
Stayed the same	69	83	71	93	78
Decreased	0	0	0	7	2
Totals	100	100	100	100	100

(No. of respondents)

Sample size*	16	6	17	15	54

* refers to those respondents who have been exposed to Metro noise only

passes, while the rest were non-users.

Of all Metro users, 97% rated the service at least 'good' and 3% rated it 'fair'.

Owner-occupiers were asked if they thought Metro had caused any change in the value of their property and, if so, whether they thought the change was considerable or negligible. Responses, shown in Table 5.9, indicate that among those who thought there had been a change, most felt it had been a decrease. This was, in most cases, attributed to high noise levels. Those who said they anticipated an increase in the value of their property attributed it to the fact that their property was close to a Metro station.

In general, most of those respondents who thought their property had depreciated in value either had no idea at all of their depreciation (i.e. 'don't know') or said the decrease was 'considerable'. On the other hand, those who thought the value had increased generally said it was 'negligible'.

Nearly 50% of respondents found some aspects of Metro unsafe but the same percentage found nothing unsatisfactory at all. The former mentioned, among other things, poor fencing along tracks (26%), fast-closing of the automatic Metro doors (21%), turnstile-type exit barriers dangerous for children (19%) and open level-crossings with ordinary roads (14%).

TABLE 5.9 : Perceived change in property values for owner-occupiers as a result of noise from Metro

(% respondents)

Any change in property values?	Zone A	Zone B	Zone C	Zone D	All zones
Increase	8	6	9	10	9
No change	48	69	64	80	63
Decrease	44	25	27	10	28
Totals	100	100	100	100	100

(No. of respondents)

Sample size*	25	16	11	19	71

* refers to respondents who are owner-occupiers

TABLE 5.10 : Range of measured noise levels

(dB(A))

Noise index	Zone A	Zone B	Zone C	Zone D
L_{max} dB(A)	85.8→92.9	79.9→86.8	70.9→79.3	58.1→73.0
SEL dB(A)	89.1→96.4	84.7→90.8	75.2→84.0	65.0→79.5
L_{eq}(18H) dB(A)	64.1→71.2	60.5→66.0	51.3→62.0	43.5→56.1

5.8 General Questions on Metro

Only 3% of respondents (6 in all, equally divided between zones A and B) had complained or signed a petition concerning noise from Metro, 0.5% (1) had complained about Metro vibration, and 2% (4) about other Metro-related problems including flashes from the pantograph, noise from late night maintenance work (tamping), bad fencing and (in one case) rats! These low figures confirm reports from various noise studies that the actual amount of formal complaints or petitions is a poor indicator of community dissatisfaction.

On frequency of use, 60% of respondents used Metro at least once a week, 28% 'rarely' and 12% of the sample had never used it. On ease of access, 75% of respondents were within 5 minutes walking distance of the nearest Metro station. The range of walking time was from less than 1 minute (some zones A and B) to 15 minutes (some zones C and D).

5.9 Noise Survey Results

Figure 5.12 shows a graphical picture of the range of noise levels measured during the noise survey. The overlapping of noise levels between zones illustrates mostly the increase in emission level recorded during the survey as explained in Section 5.1, but it also reflects the fact that two sites which are exposed to similar peak noise levels can experience very different exposure levels measured, for example, by Leq because one is shielded by adjacent buildings while the other is not. The corresponding numerical values are shown in Table 5.10.

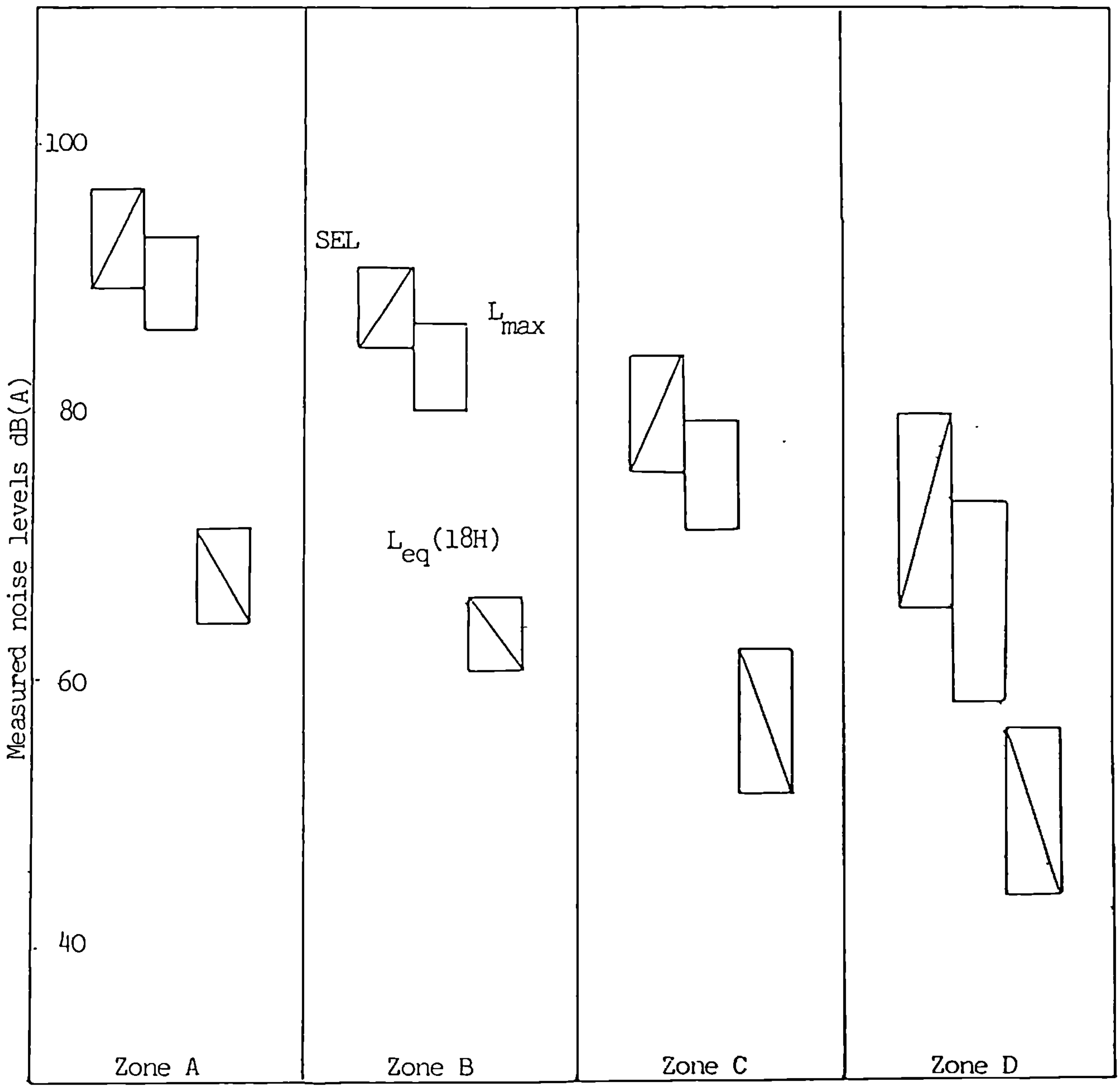


Figure 5.12 : Range of measured noise levels in each zone

CHAPTER SIX

REACTIONS TO METRO NOISE

This chapter deals first with simple distributions of the answers to single questions which describe the effects on people of Metro noise, in terms of 18 hour Leq dB(A). Later, a statistically constructed noise annoyance index (NAI), used as the "measure" of annoyance, will be described. Its relation to selected independent variables, using the method of multiple linear regression, is then examined.

6.1 Activity Interference

A measure of disturbance commonly used in general studies of transport noise is the extent of interference with activities in the home. Table 6.1 and Figure 6.1 show the reported incidence of disturbances and annoyance therefrom, in cumulative percentages, for four types of activities. The following results can be noted:

(1) below 55 Leq dB(A), reported incidence of interference with the 4 indoor activities is minimal. In fact, none of the respondents reported being startled or having difficulty with conducting conversation;

(2) reported disturbance and annoyance increase rapidly with noise level. For example, only 3% of people report any interference with conversation at levels below 60 Leq dB(A), whereas above 65 Leq dB(A) the percentage is 26%. The rate for the other three activities range from a threefold to a fivefold increase at similar noise levels;

TABLE 6.1 : Disturbance to indoor activities (data for Figure 6.1)

(% respondents)

Disturbance	Metro noise level 18 hour L_{eq} dB(A)				
	≤ 50	≤ 55	≤ 60	≤ 65	≤ 72
Startled	- -	- -	1 1	2 2	5 5
Woken up	1 1	3 2	8 6	12 9	24 15
Interference with listening to radio or TV	1 1	4 1	9 6	17 14	39 30
Interference with conversation	- -	- -	3 3	8 7	26 17

No of respondents	28	68	91	121	198

Note: All percentages are rounded to nearest integer

Key: 24 ← % reporting disturbance; 15 ← % expressing annoyance

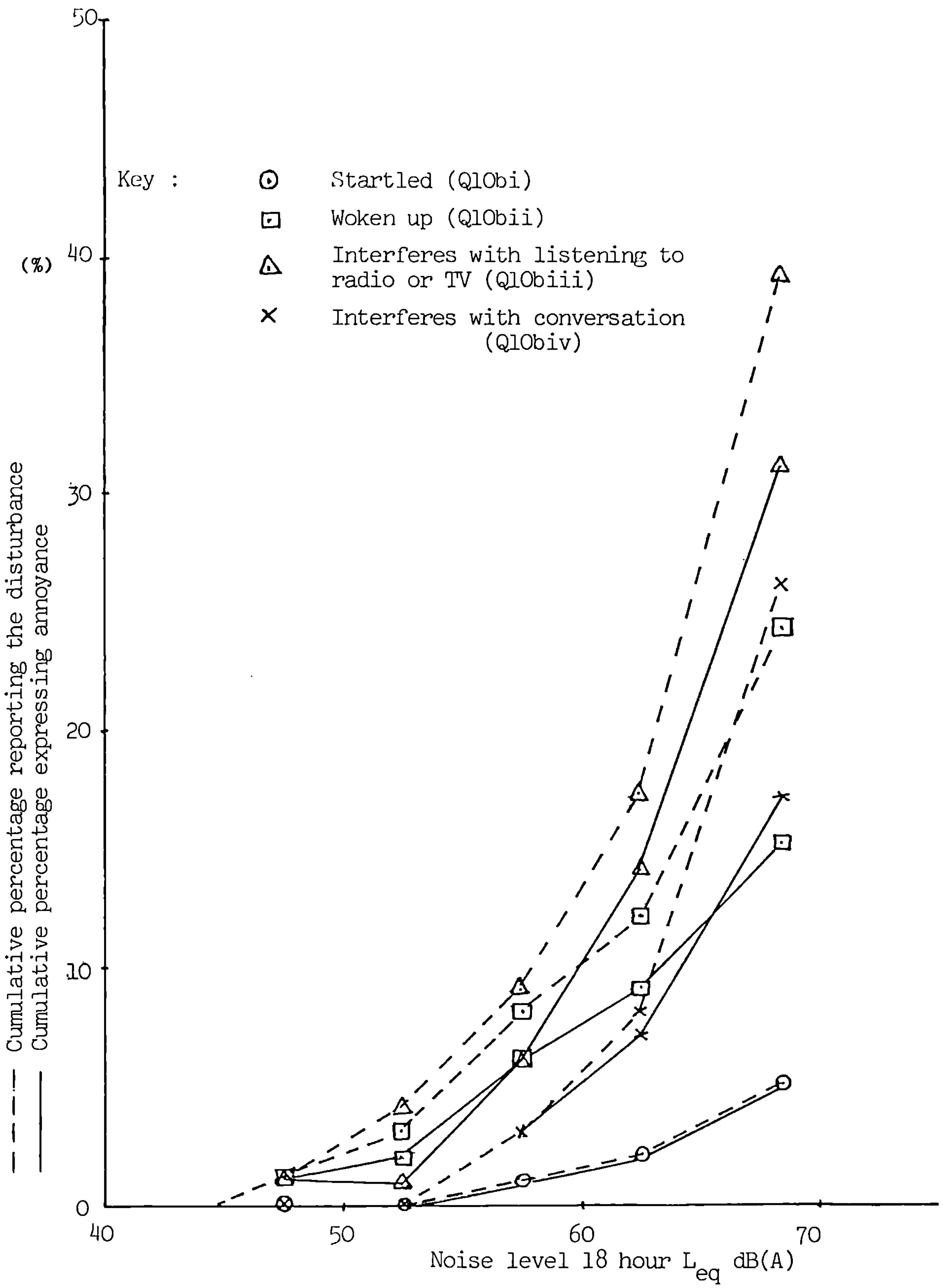


Figure 6.1 : Disturbance to indoor activities due to noise from Metro

(3) interference with an activity is not simply related to noise level but also to the type of activity. For example, there are no reports of people being startled or of interference with conversation below 55 Leq dB(A), while there are some reports of people being woken up and interference with listening to radio or television below 50 Leq dB(A). Similarly, while only 5% report being startled above 65 Leq dB(A), 39% report interference with listening to radio or television at the same noise level; and

(4) the percentage of those who report being both disturbed and annoyed (at least 'a little annoyed') varies between 62%, for those woken up, to 100% for those who claimed to be startled.

6.2 Metro Noise: What is it and what should be done about it?

Dissatisfaction with noise from Metro is not limited only to those who are bothered by the noise. As Figure 6.2 shows, even though some 27% of residents report being bothered by noise from Metro, as many as 51% would like to see some reduction in the noise levels.

The trend, as with activity interference, is a rapid increase in dissatisfaction with noise level. The increase is approximately twofold with every 5 dB(A) rise in noise levels.

6.3 Behavioural Reactions

Reactions to the effects of Metro noise in terms of altered behaviour

Proportion of respondents	Metro noise level 18 hour L_{eq} dB(A)				
	≤ 50	≤ 55	≤ 60	≤ 65	≤ 72
Bothered by Metro noise	0.5%	2%	6%	15%	27%
Who think Metro noise should be reduced	2%	6%	12%	24%	51%

Sample size = 198

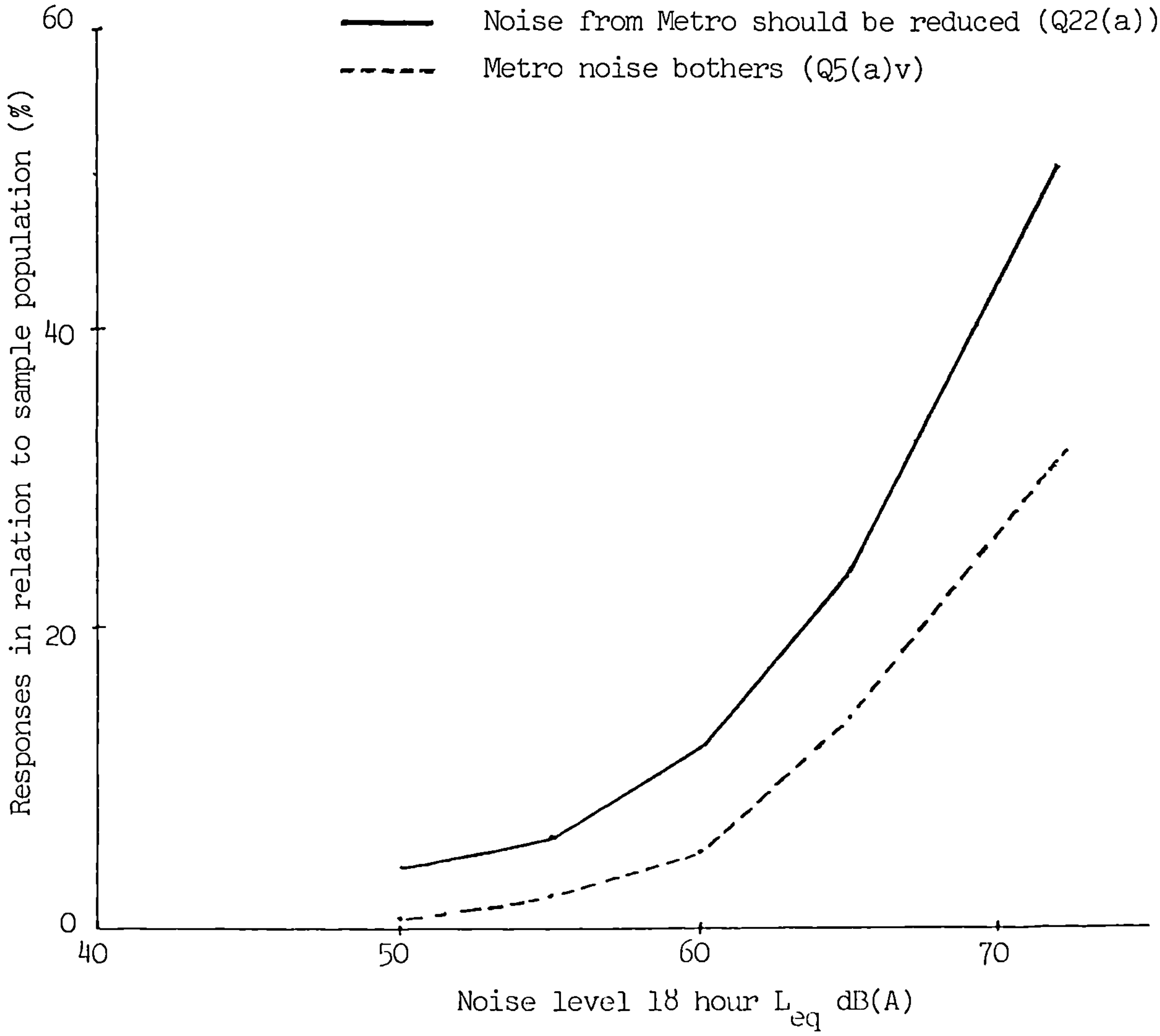


Figure 6.2 : Dissatisfaction with levels of noise from Metro

of residents were in general few. While no one said they were planning to move out of the area as a result of noise from Metro, only 1 resident in 9 mentioned Metro noise as their reason for installing double-glazing. The most often reported behavioural reaction was the closing of doors and windows, this reaction being reported by 19% of respondents at the highest noise level. At that same level, however, only 6% had ever made a formal complaint to the PTE about Metro noise.

6.4 General Reactions

The attitude of residents to railway noise in general was also investigated, whereby respondents were asked if they would like to live where they could sometimes hear some noise from the railway (Q24). About half of the respondents replied 'Yes'. Further analysis, using the Chi-Square test with a 5% level of confidence, revealed the following information about their choice.

(1) It seems to be independent of:

- (a) the noise level actually experienced; and
- (b) whether or not they are bothered by the noise from Metro.

(2) It is dependent, on the other hand, on:

- (a) age, where those above the age of 45 years showed greater preference for some railway noise than their younger counterparts (61% compared to 37%);
- (b) sex, where greater preference was expressed by females (56%) than males (37%); and
- (c) dissatisfaction with prevailing noise levels from Metro,

i.e. those who would like to see some reduction in noise level from Metro were less willing to live with some noise from the railway than those who did not - 38% as against 59%.

6.5 The Concept of Annoyance

Annoyance is a general concept which is not easily measured. Even though a number of surveys have assumed that a person's degree of annoyance can be more simply and more reliably determined from his or her response to a direct question, asking how annoyed he or she is by the noise under investigation (McKennel, 1973; Grandjean et al, 1973; Sorensen et al, 1973), other studies (Leonard and Borsky, 1973; NASA Report CR-1761, 1977; McKennel, 1973) have suggested that non-acoustical variables can play an important role in determining individuals' annoyance. However, the usual practice in the UK is that annoyance due to noise is measured using a constructed index, built up from a combination of the subject's answers to a number of questions each of which are closely related to the concept of annoyance. This approach, also used in this study, averages scores over a set of responses and is purposely designed to reduce the effects of idiosyncracies of particular respondents in respect of particular aspects of the 'attitude' (Moser and Kalton, 1981).

It is important at this stage to describe the steps involved in the construction of the noise annoyance index (NAI) and the implications for subsequent analyses of the subjective response data using this measure.

6.6 Constructing a Noise Annoyance Index (NAI)

The Noise Annoyance Index (NAI) is taken as the mean of the respondents' scores for a given number of questions, selected from a larger total, which at their face value bear most directly on annoyance. The chosen questions (Qs 5b(v), 6, 9(a), 12(a), 20(b), 22(a) and 23) are reproduced in Appendix D, along with the details on how the answers to each question were scored. NAI is a 7-point index, increasing in intensity from point 1 to point 7. The steps followed in the construction of the NAI are:

(1) choose items that seem relevant to the measurement of annoyance with Metro noise. For example, all items chosen for the analysis are direct questions on opinions or reactions to noise from Metro or the railway;

(2) test each item for:

   (a) its construct validity -

   a factor analysis (using the Principal Component method of factor extraction) was carried out on the eight items to confirm their validity: i.e. to verify step (1); and

   (b) its reliability -

   the Internal Consistency method was used to test reliability. An alpha coefficient (Cronbach's alpha) value of not less than 0.8 was set as a requirement; and

(3) reject items that are not highly loaded on the principal factor(s) and that reduce overall reliability.

Following the above procedure, eight questions were originally chosen. One, however, (Q24) which asked whether, given a choice, one would prefer living in a place where there was some railway noise or not, was dropped from the list, because, besides reducing overall reliability, it was also the only item that was highly loaded onto a second principal factor. The removal of this item resulted in the extraction of a single factor and an increase in the value of the alpha coefficient. The unsuitability of the responses to Q24 with respect to the other seven questions is clearly reflected in that item's correlation with other items individually and collectively, as shown in the output of the validity and reliability tests (Appendix D).

The remaining seven items were combined by scoring each from 1 to 7 and then averaging the scores to form an index that represents the concept of overall annoyance due to noise. An alternative, more complex method of combining items based on weights derived from factor analysis of the data was also used. No improvement in either reliability or validity was gained by this method and hence, the simpler scoring method is used throughout.

Finally, an assumption essential in proceeding to the next set of analyses, viz linear regression, is to treat NAI (which has only ordinal properties) as a measure with interval properties. This assumption was tested by correlating NAI with noise level (18-hour Leq) using (a) Pearson's product-moment correlation (requires assumptions of normality and interval properties) and (b) Spearman's rank correlation (for ordinal data). The results of these two tests ($r_{Pearson} = 0.42$; $r_{Spearman} = 0.43$) showed that the assumption is a reasonable one.

NAI is also assumed to have equal intervals between adjacent points on a continuous scale. This is a common assumption in most, if not all, noise studies and investigation related to this assumption has shown it to be, in almost all cases, reasonable (Phillips, 1978).

6.7 Factors Affecting Annoyance

Annoyance with noise differs from one individual to the other, of course, and it is not uncommon to find neighbours whose reactions to a noise source of similar intensity to be at opposed extremes. This section looks at individuals' various characteristics that could affect annoyance. Other possible factors are also investigated, none more relevant than noise level itself, which is discussed below.

(1) Noise Level

In order to examine the relationship between noise exposure and annoyance, it is essential to use a noise indicator that best represents the noise source. In Chapter 3, it was argued that measures based on energy levels are the most appropriate. This was substantiated by comparing energy-based measures (L_{eq} and L_{de}) with the Noise and Number Index (NNI), for example, with respect to their correlation with NAI. Both NNI and L_{de} are easily computed from available noise data. L_{de} is equivalent to L_{dn}, where 10 dB is added to evening time (1800 to 2400) levels, while the daytime (0600 to 1800) levels are unaltered. Comparison of correlation coefficients for the three indices against NAI showed no significant difference between them (r_{Leq} = 0.42; r_{Lde} = 0.42; r_{NNI} = 0.41). This is not surprising since a large amount of variance in annoyance (82%) is left unexplained when using noise data alone. Given the inconclusive result of the test, the choice is heavily biassed towards Leq, due to the fact that it satisfies the requirements laid down in Section 3.8.

Having chosen Leq as the noise index, it is now possible to examine the relationship between expressed annoyance and measured noise level (L_{eq}). Two ways of looking at this are pursued: (a) by comparison of differences in means of annoyance scores in various specified noise groups; and (b) by bivariate regression of annoyance with noise level. Tables 6.2(a) and 6.2(b) summarise the results of the one-way analysis of variance (ANOVA) test for differences in means. As shown, the maximum average group score on the 7-point annoyance scale (NAI) is 4.2 (Group 4). However, the maximum score in each group is much higher than their averages, ranging from 5.7 (Group 1) to 7.0 (Groups 4 and 5), which indicates that considerable annoyance with Metro noise can be felt even at relatively low noise levels. A comparison of the mean scores of the five groups shows that, while there are no significant differences (at the 5% level) among the three higher noise groups, the scores of the two lower noise groups (1 and 2) are significantly lower than the rest.

TABLE 6.2(a) : Average annoyance scores of different noise groups

Group	Noise range L_{eq} dB(A)	No. of respondents	Minimum score	Mean score	Maximum score
1	43-50	32	1.0	2.2	5.7
2	50-55	41	1.0	2.5	6.0
3	55-61	32	1.4	3.5	6.7
4	61-67	40	1.4	4.2	7.0
5	67-73	58	1.4	3.8	7.0

TABLE 6.2(b) : Comparison of mean scores for expressed annoyance

		Group				
Mean score	Group	1	2	3	4	5
2.2	1					
2.5	2					
3.5	3	*	*			
4.2	4	*	*			
3.8	5	*	*			

Key: * denotes pairs of groups significantly different at the 5% level

From the values of mean scores calculated for the five noise groups (Table 6.2(a)), an annoyance/noise level curve can be drawn as shown in Figure 6.3. This curve, which gives a rough graphical picture of how NAI varies with Leq, was also drawn for males and females separately. As Figure 6.3 shows, there is a similar relationship between the variables in all 3 curves. Perversely, this figure indicates a decrease in annoyance, with noise, above a level of around 64 Leq dB(A). However, it is not possible, at this stage, to conclude that Figure 6.3 represents the best noise/annoyance relationship. Groupings of noise levels in a different way from that shown in Table 6.2(a) would probably alter the annoyance - noise level curve shown in Figure 6.3. This was checked by altering the range of noise levels to obtain a 4-point curve and a 6-point curve (compared to the 5-point curve of Figure 6.3). The results were, as follows: (a) the basic shape of the curve in Figure 6.3 was retained in both cases; and (b) the level at which annoyance decreased with noise was around 60.5 Leq dB(A). The above findings, though far from conclusive, nevertheless provide a base on which regression analyses can be carried out. The shape of the curve, on the other hand, helps in choosing the type of model that would best fit the data.

The implication from Figure 6.3 is that the annoyance - noise level relationship may be non-linear. With this in mind, it was decided to test some specific models on the data, by regressing linear, quadratic and logarithmic transformations of noise levels (L_{eq}) on the index of noise annoyance (NAI) and also on the logarithmic transformation of NAI. Figure 6.4 shows the scatterplot of the

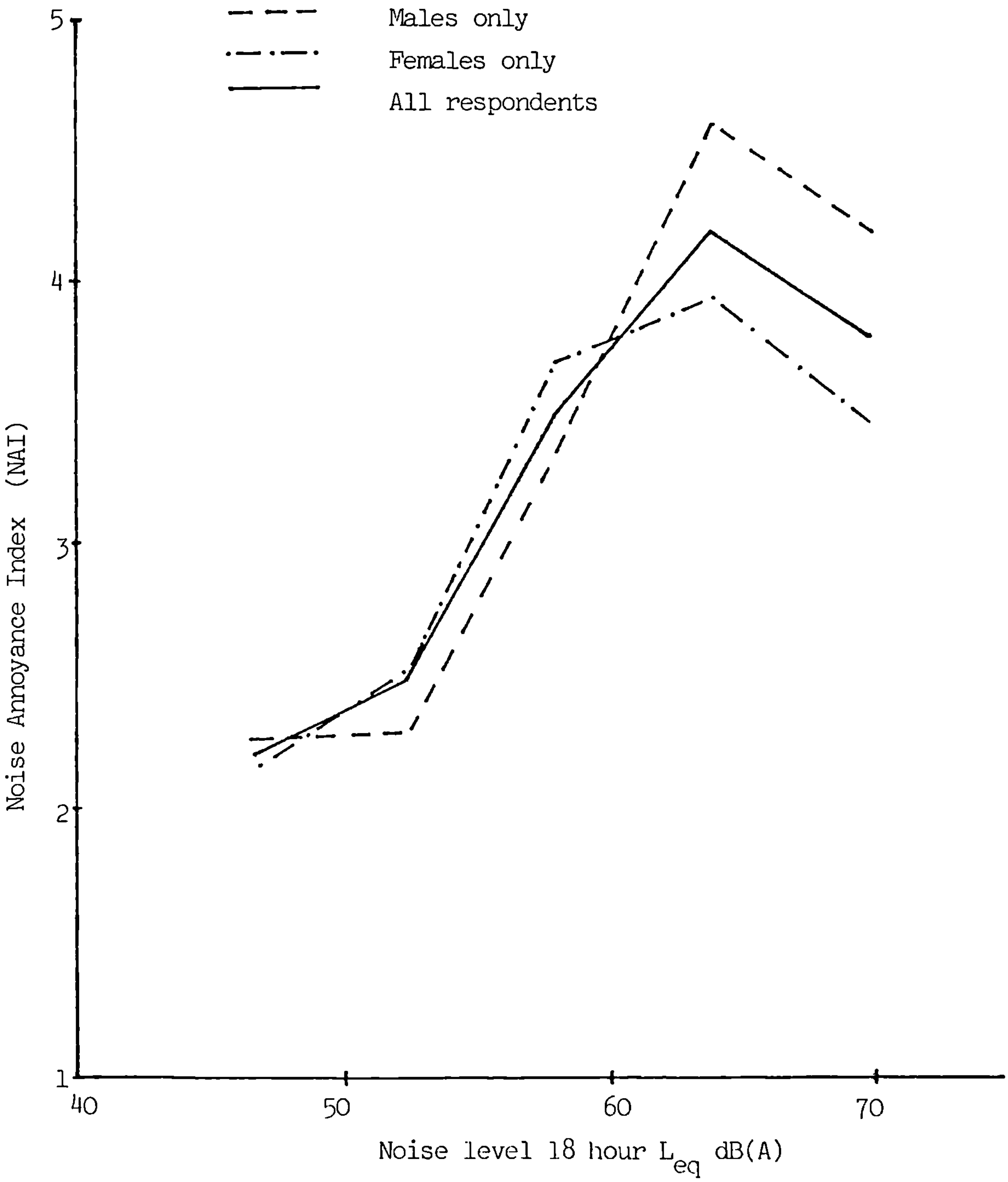
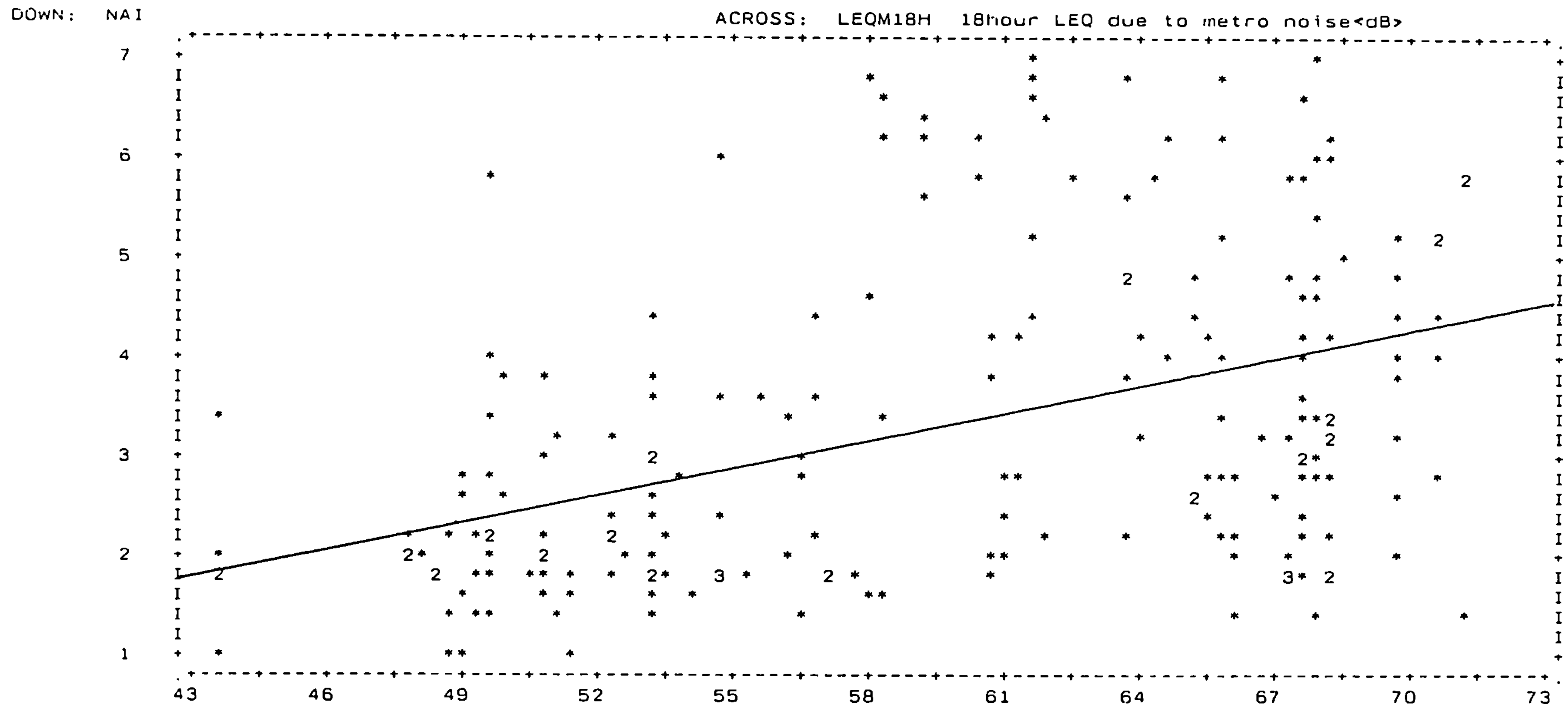


Figure 6.3 : Annoyance - Noise level curve plotted from mean scores



STATISTICS..

CORRELATION (R)-	.42845	R SQUARED -	.18357	SIGNIFICANCE -	.00000
STD ERR OF EST -	1.43819	INTERCEPT (A) -	-1.93694	SLOPE (B) -	.08785

Figure 6.4 : Plot of NAI against L_{eq}

linear regression of Leq on NAI and onto which the "best fit" line is drawn. There is a wide variation in response especially at higher noise levels as one would expect. The results of the analyses of the three models are displayed in Table 6.3, in which the values of the multiple correlation coefficients R are presented. The log-linear model provides the best fit for the data and has the highest R value. Besides, it is also the best model, in that it violates least the assumption of normality (i.e. the normal distribution of the residuals of observed data) required when the regression technique is used. Figure 6.5 shows the comparison of the normal probability plots for the linear, quadratic and log-linear models to that expected under the assumption of normality - i.e. a 45^{o} line. The assumption of constant variance is also slightly violated but is met equally by the three models.

Based on the log-linear model then, predicted noise annoyance as a function of noise level alone, is given by:

$$\log(NAI) = -0.277 + 0.013\ L_{eq}(18H)\ dB(A)$$

It is clear, from the values of the coefficients in Table 6.3, that noise level alone is not a good predictor of noise annoyance, since only about 22% of the observed variability in annoyance can be explained by the noise level variable.

Thus, the next step involves determining which other factors can explain the noise annoyance effect further. Multiple linear regression (MLR) extends bivariate regression and allows for the incorporation of several independent variables. Before discussing

TABLE 6.3 : Comparison of various models for noise/annoyance

Statistical output	Model			
	NAI v L_{eq}	NAI v L_{eq}, L_{eq}^2	NAI v $\log(L_{eq})$	Log(NAI) v L_{eq}
Correlation coefficient R	0.428	0.452	0.435	0.465
Explained variability R^2	0.184	0.204	0.189	0.216

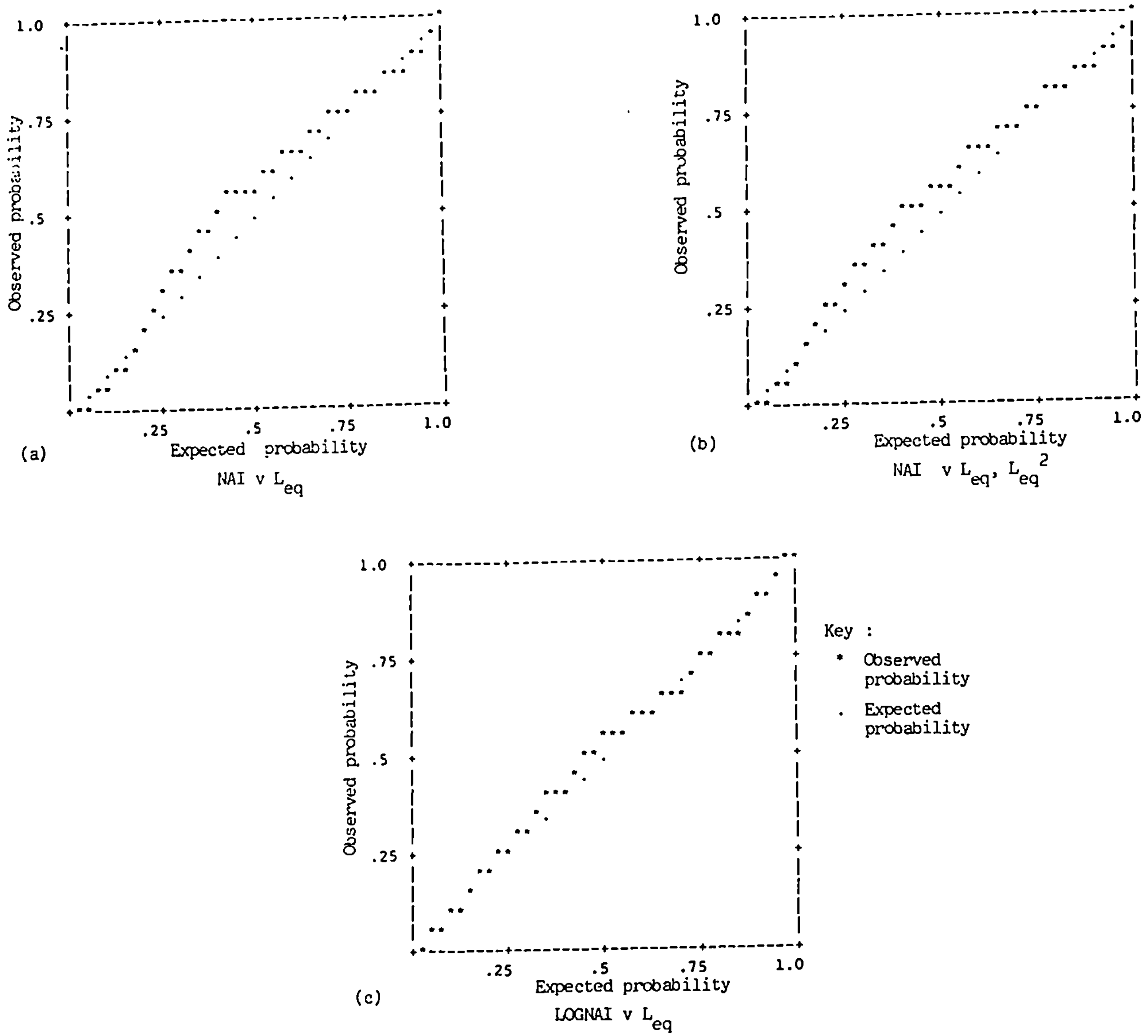


Figure 6.5 : Plots of cumulative probability distributions of standardised residuals

the MLR analysis and the results obtained, some discussion of the variables selected for inclusion in the analysis is needed.

(2) Other Factors

In fact, twelve other variables were chosen to be examined and these were grouped into three categories: (a) those based on personal characteristics; (b) those based on characteristics of the area; and (c) others (a miscellaneous category).

(a) Personal Characteristics

These include age and sex of the respondent, his or her socio-economic class, whether he/she owns a car, a house/flat and whether he/she is in employment (full-time or part-time).

(b) Area Characteristics

Two area conditions are examined: (i) perceived ambient noise (Q6) and (ii) perceived environmental quality.

(c) Other

There are four variables in this category, namely: annoyance with vibration caused by Metro (Q14(a),(b)); exposure to DMU noise (Q7), perceived safety of Metro (Q30(a)) and frequency of use of Metro (Q25(a)).

Details concerning the level of measurement and the coding of these variables are given in Table 6.4.

As mentioned earlier, the question that arises is what other factors can further explain the variance in annoyance remaining (around 78%) after accounting for noise from Metro (L_{eq} (18H)). Multiple linear regression (MLR), described in Appendix E, is a commonly used and powerful technique to determine those factors. It is a technique by

TABLE 6.4 : Variables included in multiple linear regression

Variable (variable name as in SPSSx runs)	Level of measurement	Type of coding		Footnote
(a) Personal characteristics				
Age (AGE)	Interval	18 years	90 years	
Sex (SEX)	Nominal	1 male	2 female	
Socio-economic class (SOCECO)	Ordinal	1 (DE) 2(C2) 3(C1)	4(AB)	As per standard industrial classification system (SICS)
Car (CAR)	Nominal	1 owner	2 non-owner	
Tenure (TENURE)	Nominal	1 owner-occupier	2 rented/free	
Activity (ASTATUSR)	Nominal	1 in employment (F/P time)	2 not working	
(b) Area characteristics				
Perceived ambient noise (BGNOISE)	Ordinal	1 definitely satisfactory	7 definitely unsatisfactory	BGNOISE is the mean of scores on rating of road traffic and aircraft noise (Q6)
Environmental quality of area (NGHBHOOD)	Ordinal	1 very good	5 very poor	NGHBHOOD is the mean of scores on all items of Q3(c)
(c) Other				
Annoyance with Metro-caused vibration (METROVI)	Ordinal	1 no vibration	5 very annoyed	
Living in the same house when DMU was in operation (INHSEDMU)	Nominal	1 yes	2 no	
Metro safety (SAFETY)	Nominal	1 not safe	2 safe	
Frequency of use of Metro (MUSE)	Nominal	1 at least once per week	2 rarely/never	

which the linear relationship between a set of independent variables and a dependent variable is established taking into account the inter-relationships among the independent variables. The analysis of the fourteen variables (including Leq) using MLR is discussed next.

The approach adopted in the MLR analysis is to start with the linear form of both the dependent variable (NAI) and the independent variables and to follow the 4 steps laid down below.

(a) Force-enter all variables that satisfy the minimum tolerance criterion* of 0.01 set by SPSSX (the statistical computer package used for analyses throughout this study).
A correlation matrix of all the variables entered (Table 6.5) can be obtained and the summary statistics of the equation, with all the variables, will provide an estimate of the maximum variance in annoyance that can be explained.

(2) Perform a stepwise regression with all the variables as in step (1). Examine the residuals left after the linear model is fitted, to detect possible violations of assumptions of linearity, normality and homogeneity of variance which are required to be met when using MLR to fit a particular model.

(3) Formulate an alternative model if there is evidence of serious violation of assumptions. Repeat step (2).

(4) Choose the model that best fits the data and least violates the required assumptions.

The results of the multiple regression analyses are presented in Table 6.6 and residual analyses, performed on the models to verify

TABLE 6.5 : Correlation matrix for all variables selected for regression

	NAI	LEQMI8H	INHSEDMU	METROVI	SAFETY	AGE	SEX	SOCECO	CAR	TENURE	ASTATUSR	NGNOISE	NGHBHOOD	MUSE
NAI	1.000													
LEQMI8H	.431	1.000												
INHSEDMU	.151	-.039	1.000											
METROVI	.503	.294	.124	1.000										
SAFETY	-.088	.146	-.211	-.012	1.000									
AGE	-.261	.044	-.412	-.201	.333	1.000								
SEX	-.039	.128	-.082	.066	.093	.101	1.000							
SOCECO	.120	.208	.019	.160	-.077	-.200	-.057	1.000						
CAR	-.014	-.061	.048	-.056	-.066	.162	-.033	-.264	1.000					
TENURE	-.108	-.089	.122	-.070	-.036	-.066	-.031	-.443	.276	1.000				
ASTATUSR	-.036	.047	-.129	-.123	.025	.403	.176	-.205	.230	.190	1.000			
NGNOISE	.294	.019	-.099	.156	-.016	-.008	-.050	-.100	.149	.072	.023	1.000		
NGHBHOOD	.257	.080	.106	.220	-.085	-.101	-.013	-.078	-.042	.106	.054	.166	1.000	
MUSE	-.084	-.067	-.198	-.117	.123	.342	.025	.020	-.210	.055	.103	.042	.026	1.000

TABLE 6.6 : Results of MLR analyses

	Model (number of cases)			
Details of MLR	NAI v All variables (200)	NAI v All variables (200)	Log(NAI) v All variables (200)	Log(NAI) v All variables (200)
Type of regression	Forced entry	Stepwise	Forced entry	Stepwise
Variables selected by regression	All	LEQMI8H, METROVI BGNOISE, AGE	All	LEQMI8H, METROVI BGNOISE, AGE, TENURE
Multiple R	0.694	0.658	0.717	0.693
R^2	0.482	0.433	0.514	0.480
Adjusted R^2	0.445	0.421	0.480	0.467

assumptions of normality and homogeneity of variances, are presented in the form of normal probability plots and scatterplots of standardised residuals (Figure 6.6).

It is clear once again, from the statistics in Table 6.6 and from the plots in Figure 6.6, that the log-linear model provides a better fit than the others for the data. However, the variance of residuals, as shown in the scatterplots, is not constant for either form of model. Attempts at stabilising the variance, by trying different transformations of the dependent variable (NAI), did not succeed. Besides the logarithmic transformation, the square root, reciprocal and arcsin transforms were also tested.

Among the set of variables included in the log-linear regression model, the following five variables were selected as good predictors of annoyance: (a) noise level (LEQMI8H); (b) degree of annoyance with vibration from Metro (METROVI); (c) degree of dissatisfaction with noise from road traffic and aircraft (BGNOISE); (d) age of respondent (AGE) and (e) whether or not the respondent is an owner-occupier (TENURE). Statistics related to variables in the regression equation are given in Table 6.7.

6.8 Interpreting the Noise Annoyance Model

The regression equation produced that relates the predicted logarithm of noise annoyance to the independent variables is, as follows:

LOGNAI = -0.14 + 0.01 (LEQMI8H) + 0.05 (METROVI) + 0.04 (BGNOISE)

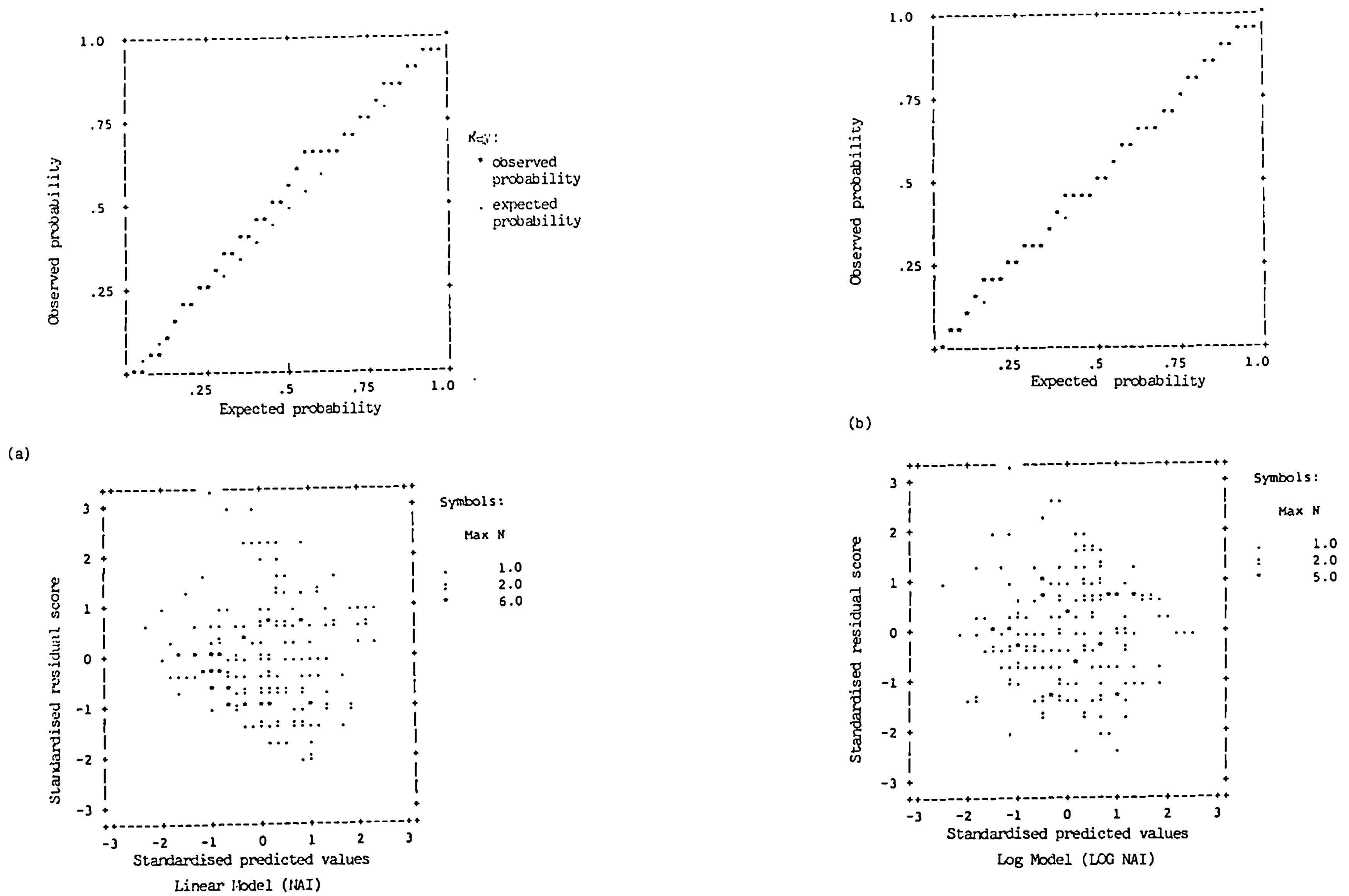


Figure 6.6 : Plots of residuals from regression models

-0.003 (AGE) - 0.05 (TENURE)

The interpretation of the multiple regression equation estimated above suggests several findings. First, it can still only explain about 50% of the observed variability in annoyance. Comparing the BETA coefficients in Table 6.7, the prevailing noise level (Leq) appears to be the best single predictor of noise annoyance amongst the variables included in the regression. Annoyance with vibration from Metro, dissatisfaction with noise from road traffic and aircraft and age appear to be variables of roughly equal importance. Tenure is also related to noise annoyance but is the least important of the five variables. As one would expect, annoyance with noise from Metro is high when noise levels are high and when there is corresponding annoyance with the vibration from Metro and with other transport noise. Noise annoyance is also greater for younger people and for owner-occupiers.

Finally, to illustrate the use of the noise annoyance equation, a hypothetical case is considered and, for various L_{eq} levels, the relevant noise annoyance scores are computed. Suppose, for example, a person aged forty, who owns his own house and is neither annoyed nor totally satisfied with the vibration he experiences from Metro and the ambient noise level respectively; such a person, according to the annoyance equation and at the various noise exposure from Metro (Figure 6.7), would have an index score as shown. Total satisfaction (NAI = 1.0) would be reached only if there was no noise at all (LEQMI8H = 0), i.e. as if no Metro existed, while extreme

TABLE 6.7 : Variable statistics in the regression model

	Statistics of the regression model				
Variable	B	SE B	BETA	T	SIG T
Leq (18H)	0.01038	0.00147	0.38514	7.051	0.0000
Metro-vibration	0.04939	0.01018	0.27383	4.851	0.0000
Background noise	0.04438	0.00868	0.26902	5.110	0.0000
Age	-0.00270	0.00059	-0.24236	-4.542	0.0000
Tenure	-0.04975	0.02276	-0.11446	-2.186	0.0300
(Constant)	-0.14002	0.09999	n/a	-1.400	0.1630

or

(a)	METROVI = 3
(b)	BGNOISE = 4
(c)	AGE = 40
(d)	TENURE = 1

at

LEQMI8H dB (A)		NAI
40	→	2.5
50	→	3.2
60	→	4.0
70	→	5.0
80	→	6.3
85	→	7.0

Figure 6.7 : Estimating annoyance levels

dissatisfaction (NAI = 7.0) would be expressed at about 84.5 L_{eq} and above. Between these extremes, the index would reflect annoyance in a way that would vary with the circumstances most closely related to noise perception.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

The aim of this study has been primarily to assess the impact of noise from the Tyne and Wear Metro on the wayside residential community. An interesting background to this study was provided by the existence previously of British Rail's DMU trains which served the region before the Metro and the fact that, between the phasing out period of the DMUs and the introduction of Metro, there were nearly two years when the region's only public transport was the bus service.

During the four-month case-study in a residential area of Tyne and Wear, the reactions of just over 200 residents to noise from Metro were surveyed. The findings of the study are given in the next section.

7.2 Conclusions

1. The Metro is the biggest source of noise nuisance for people living in houses bordering the rail tracks (typically, above 60 Leq (18H) dB(A)), when compared to other transportation and neighbourhood noises. However, the noise affects only four residents in ten. Some people are also annoyed by Metro

noise because it disturbs sleep, conversation and television viewing.

2. The Metro can be surprisingly noisy. Peak levels of over 90 dB(A) have been recorded (92.9 dB(A)) at facades some 15 metres away from the tracks, while the corresponding exposure levels were over 70 Leq (18H) dB(A) (71.2 dB(A)). Metro trains running on wheel-flats could increase the noise level by 2 to 3 decibels.

3. Leq dB(A) appears to be the most practical noise index for measuring railway noise annoyance (NAI), when compared to the Noise and Number Index (NNI) and Lde, a variant of Day-Night exposure level, Ldn.

4. Besides noise itself, annoyance tends to increase the more annoyed people are with vibration caused by Metro and the more dissatisfied they are with other transportation noises. Age is also a contributory factor to annoyance, in that older people are less annoyed than younger ones. It also appears that owner-occupiers are more annoyed than those who rent their accommodation.

5. Vibration from Metro is experienced by over half of residents living in houses bordering the railway tracks. A number of them believe that the vibration is or can be the cause of some form of structural damage to their property. It

appears, from conversation with residents, that vibration is less now than when DMUs were in operation.

6. Residents previously exposed to DMU noise and living in the highest noise (Metro) exposure zone (64 to 71 18H Leq dB(A)), on average, rate the noise from Metro more favourably than those who have not been exposed previously to DMU noise. Though Metro is generally perceived to be quieter than the DMUs, the difference is not always significant in statistical terms.

7.3 Recommendations

1. Loud noises, different from the "normal running" noise of a train are easily noticed. This observation applies, for example, to Metro trains with bad wheel-flats or with abnormal propulsion noises. Regular maintenance of the rolling stock is necessary to avoid these occurrences and this, together with regular track maintenance (e.g. grinding and tamping), can achieve effective overall control of noise. The maintenance programme would require a set of criteria specifying, for example, the minimum length and number of wheel-flats, the maximum roughness of the rails and so on, in order to decide when wheel and/or rail grinding should be carried out.

2. Work late at night on the tracks using tamping and track-aligning machines was often mentioned by residents as their worst noise experience. One of the reasons for the strongly expressed views about this intrusion was the fact that residents were not informed of this essential night-time operation. It is strongly recommended that ample notice is given to residents well before such maintenance work starts.

3. It is the view of the author that regular maintenance of a railway system and adjoining property together with good and timely public relations, could greatly enhance the image of an urban rail system and reduce the nuisances which can be caused.

4. As far as advice for any authority contemplating a "new" Metro using existing railway alignment through existing residential areas is concerned, several important recommendations can be made:

   * Develop noise and vibration goals - a review of practices by existing operators in the UK and abroad could provide a start;
   * Set specifications for vehicle noise and vibration to which manufacturers must comply;
   * Carry an investigation on the experiences of similar urban rail systems regarding noise and vibration;
   * Carry a thorough testing of rolling stock on test-track

and under conditions as close as will be experienced during operations (e.g. using jointed rails, continuous welded rails and on tight bends) and tighten specifications if required; and

* Encourage community involvement in Public Hearings and meetings at the planning stages and maintain a close link with community representatives especially to deal with complaints from residents arising at the initial stage of operation.

7.4 Other Points Arising from the Surveys

During the course of the survey, through informal conversation with respondents and their families, a few of the remarks made were noted by the interviewer and it is felt that their importance is worthy of mention. It could even be claimed that they provide an insight into the mental and psychological processes of perception.

(a) Because Metro is generally regarded as an excellent means of transport, some people judge the noise from Metro less severely than others, to the point where the attitude sometimes prevails that "one shouldn't really complain".

(b) "If you listen, you'll hear it" was one interesting comment from a respondent, which may well explain the sometimes total lack of concern on the part of residents who live in a noisy area and yet are used to the noise. Questioned by the respondent as to how many trains had passed by (in fact, 4) in the quarter hour that the interview had been going on, the interviewer was unable to answer, owing to the fact that he had been concentrating on the interview and had failed to register the passing of the trains.

(c) There was some indication that people reorganise the use of their rooms to avoid high noise exposure, such as using the back room as their bedroom.

(d) There does not seem to be any resident who "chose" to live near the railway line. They have either been brought up in the area or their present accommodation was the only kind available to them (e.g. as Council tenants).

7.5 Further Research

Some people get used to railway noise and some do not; of those who don't, some people are bothered by it and some are not. There seems to exist certain characteristics in people which determine their susceptibility to noise; for example, their age, length of residence etc. However, there are non-personal and non-acoustic factors that also affect their perception. An investigation into the effect of a well-planned programme of public relations by the urban railway operator could yield fruitful results in reducing residents' perception of railway noise as a nuisance. The public relations could take the form of regular meetings between a residents' representative group and the operator which would be closely monitored by the researcher over a considerable period.

Vibration from Metro appears to be a bigger problem in terms of perception than noise. It would be of interest to measure the actual level of vibration caused by Metro and to assess the airborne and the groundborne contributions. Such an exercise would help not only in quantifying the stimulus but also help in finding a solution where the problem is regarded as acute. The study could also investigate the relationship between vibration levels, the form and structure of the residence and type of foundation.

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APPENDIX A

DEFINITIONS OF ACOUSTICAL TERMS

A1 <u>Sound Exposure Level</u> (SEL)

SEL is an average energy concept, which integrates the total sound energy over the measurement period, as with Leq, but instead of averaging over the whole measurement period, a reference duration of 1 second is used. SEL has two main applications: (1) direct comparisons of transient noises; and (2) as a means of calculating the corresponding Leq for a given exposure duration. SEL is defined as follows:

$$SEL = 10 \log_{10} \frac{1}{T_{ref}} \int_0^T \left(\frac{p^{(t)}}{p_o} \right)^2 dt$$

where, T_{ref} = reference duration of 1 second

$p^{(t)}$ = A-weighted sound pressure

p_o = reference sound pressure of 20 Pa

Individual SEL values are added logarithmically to calculate Leq :

$$Leq = 10 \log_{10} \frac{1}{T} \sum_{i=1}^{n} 10^{SELi/10}$$

where, n is the total number of events in time T (in seconds)

SELi is the single sound exposure level for the ith event.

A2 <u>L_N</u>

The 'Fast' A-weighted sound level exceeded by a fluctuating sound level for N% of the measurement period. For example, L_{10} represents the sound level which is exceeded 10% of the time during which measurements are taken.

A3 Noise and Number Index (NNI)

NNI was developed specifically for aircraft noise. It takes into account both the average peak noise level, measured in PNdB, and the number of events occurring during the measurement period. NNI is defined as follows :

$$NNI = L_{apn} + 15 \log_{10} N - 80$$

where, N = number of pass-bys reaching the required level of 80 PNdB.

$$L_{apn} = 10 \log_{10} \left(\left(\frac{1}{N}\right) \sum_{i}^{N} 10^{L/10} \right)$$

where, L = peak noise level in PNdB.

The equivalent NNI expression using dBA (dBA = PNdB-13) is

$$NNI = L_{Amax} + 15 \log_{10} N - 67$$

where, L_{Amax} = maximum A-weighted sound level

N = number of pass-bys reaching 67 dB(A) and above.

67 dBA = 'cut-off' NNI level

A4 Traffic Noise Index (TNI)

TNI is the A-weighted sound level, measured over a 24-hour period, which is defined as

$$TNI = 4 (L_{10} - L_{90}) - 30$$

where, L_{10}, L_{90} = levels exceeded for 10 and 90% of the time respectively, in dBA.

TNI places emphasis on the fact that significant annoyance is attributable to the variation of the noise level with time. The term $(L_{10} - L_{90})$ is sometimes called the 'noise climate'.

A5 Effective Perceived noise level - EPNL

EPNL is the corrected Perceived Noise Level (PNL) which takes into account the duration of aircraft flyover and the tonal content of noise. PNL is a rating for single aircraft flyovers which is based on a concept of perceived 'noisiness' which originally assumed the judgement of a jury, and resulted from extensive subjective experiments to determine the relationship between 'noisiness', 'annoyance' and the physical characteristics of aircraft noise. PNL is now calculated from a frequency analysis in third-octave-bands measured every half second, which are weighted and summed to give a perceived noisiness value (in noys) for each time interval. This value is converted to give the Perceived Noise Level (in PNdB), by means of a standard table.

The steps involved in calculating EPNL are :

1. For each spectrum, the sound pressure level in each 1/3 octave band from 50 to 10000 H_Z is converted to perceived noisiness values (in noys) by means of equal 'noisiness' contours.
2. For each spectrum, the noy values of all the 1/3 octave bands are then combined according to the formula

$$N = n_{max} + 0.15 \left(\sum n - n_{max} \right)$$

where n_{max} = greatest value of n

$\sum n$ = sum of the noisiness values in all the bands.

3. N (in noys) is converted to the perceived noise level (in PNdB)

$$PNL = 40 + \frac{10\log_{10} N}{\log_{10} 2}$$

4. The perceived noise level is then corrected (if needed) to account for the increased annoyance attributable to the tonal content of the noise and the duration of the flyover.

Tone-correction is made on the basis of the magnitude of the tone and its frequency. A tone correction graph is used for this purpose. Thus,

PNL + tone correction = tone-corrected PNL.

To account for the influence of time, the tone-corrected effective perceived noise level EPNL has been defined by the expression

$$\text{Tone-corrected EPNL} = 10\log_{10} \frac{1}{10} \int_{t_1}^{t_2} 10^{\frac{L_{TPN}}{10}} dt.$$

where L_{TPN} = tone-corrected perceived noise level

t_1 = instant when the noise level first exceeds a specific value, usually 10 dB below the maximum

t_2 = instant when the noise level last decreases to below the above-mentioned value.

A6 Composite Noise Rating (CNR)

CNR was introduced in 1957 to evaluate the noise impact of military aircraft operations on neighbouring communities. The CNR method develops contours based on daily aircraft operations around an airport that are, in effect, equal noise level exposures using the perceived noise level, the number of daytime and night-time flight operations and a 10 dB night-time penalty. In developing the contours, the aircraft are grouped in classes according to type, engine size and performance.

CNR has also been adapted to evaluate railway noise (Fields and Walker, 1980). The exposure values were computed as follows :

$$CNR = 10\log_{10} \sum_j \text{antilog} \left(\frac{CNR_j}{10} \right)$$

where $CNR_j = PNL_j + 10 \log_{10} (N_{Dj} + 20 N_{Nj}) - 12$

j is a single class of operation producing a particular noise characteristic at some reference point.

N_{Dj} and N_{Nj} are the number of occurrences in that class during the periods 0600-2100 and 2100-0600 respectively, and

PNL_j is the energy mean (logarithmic) maximum perceived level for that train class.

A7 Noise Exposure Forecast (NEF)

NEF is the total summation, on an energy basis over a 24-hour period, weighted for the time of day, of effective noise level (EPNL) minus a constant of 88.

$$NEF = 10\log_{10}\left[\sum_{i=1}^{N} \text{antilog}\left(\frac{EPNL_{Di}}{10}\right) + 16.67\sum_{i=1}^{N} \text{antilog}\left(\frac{EPNL_{Ni}}{10}\right)\right] - 88$$

where $EPNL_{Di}$, $EPNL_{Ni}$ are the EPNL of the ith event during daytime and night-time events respectively;

N is the number of events during each period.

APPENDIX B

SOCIAL SURVEY QUESTIONNAIRE

UNIVERSITY OF
NEWCASTLE UPON TYNE

DEPARTMENT OF
CIVIL ENGINEERING

CLAREMONT ROAD
NEWCASTLE UPON TYNE
NE1 7RU
Newcastle upon Tyne (0632) 328511

Professor of Civil and Hydraulic Engineering and Head of Department [illegible]

Tyne and Wear Professor of Environmental Control Engineering [illegible]

Professor of Transport Engineering and Director of the Transport Operations Research Group [illegible]

Professor of Structural Engineering [illegible]

Please send to

DIVISION OF TRANSPORT ENGINEERING (Claremont Tower, [illegible] Floor)

20 July, 1983.

Dear resident,

As part of a continuing study of the urban environment, the Division of Transport Engineering in this Department is conducting a survey at a number of locations in Tyne and Wear. The purpose of the study is to understand the problems and measure environmental conditions in different types of residential area. In this way, it is hoped that a better understanding can be obtained of the external influences on the quality of residential neighbourhoods. This will involve interviews with local residents as well as measuring prevailing conditions. I shall be most grateful if you would assist us in this important study.

Finally, I give you my assurance that any information you give will be treated in confidence and that any results published will be in such a form that no individual who has provided information can ever be identified.

Yours sincerely,

Peter J. Hills
Research Supervisor

University of Newcastle upon Tyne

ENVIRONMENT STUDY

		Record No.	(1-4)
		Card (1)	(5)
Area ______________		Date	(7-12)
Street ______________		Area No.	(13-15)
Time Interview started ______		Address No.	(16-18)
Time Interview ended ______		Street Code	(19-21)

		Col /Code	Skip to
	(As I mentioned before) we are interested in your opinions on this area, that is, the two, three streets around here.	(22)	
		(SPARE)	
1a)	Is there anything you particularly <u>like</u> about living in this area? (PROBE: "Anything else?" UNTIL FINAL "NO")	(23)	
		(24)	
		(25)	
		(26)	
		(27)	
		(28)	
		(29)	
		(30)	
b)	Is there anything you particularly <u>dislike</u> about living in this area? (PROBE: "Anything else?" UNTIL FINAL "NO")	(31)	
		(32)	
		(33)	
		(34)	
		(35)	
		(36)	
		(37)	
		(38)	

	Col /Code	Skip to
2a) Do you have any plans to move, in the next year or so?	(39)	
Yes	1	
Possibly (Volunteered)	2	
No	3	Q3
b) If 'Yes' or 'Possibly' Why are you thinking of moving away from this house/flat?	(40)	
	(41)	
	(42)	
	(43)	
	(44)	
3a) If you choose a new place to live, what are the two or three most important things you look for? (DO NOT PROBE)	(45)	
	(46)	
	(47)	
	(48)	
	(49)	
	(50)	

b) Now, in choosing a place to live, how important is .... being close to shops to you personally? (SHOW CARD A)

RECORD FOR EACH ITEM UNDER (b): How important is .... AND RECORD IN GRID ASK ALL a) ITEMS FIRST

c) How would you rate this area where you live in terms of the following?

Firstly, how would you rate it on .... being close to shops?

RECORD IN GRID UNDER c) (SHOW CARD B)

	(b) Importance				(c) Rating of the area						Col /Code	Skip to
READ OUT	very	some-what	A little	No	very good	Good	Average	Poor	very Poor	Don't know		
Being close to shops	4	3	2	1	5	4	3	2	1	6	(51-52)	
The quality of local schools	4	3	2	1	5	4	3	2	1	6	(53-54)	
The way roads and streets are kept up	4	3	2	1	5	4	3	2	1	6	(55-56)	
The appearance of houses & buildings	4	3	2	1	5	4	3	2	1	6	(57-58)	
The quietness of the area	4	3	2	1	5	4	3	2	1	6	(59-60)	
How nice the neighbours are	4	3	2	1	5	4	3	2	1	6	(61-62)	
Having parks & open spaces	4	3	2	1	5	4	3	2	1	6	(63-64)	
Nearness to places you need to go to	4	3	2	1	5	4	3	2	1	6	(65-66)	
Public Transport Services	4	3	2	1	5	4	3	2	1	6	(67-68)	

		Col/Code	Skip to
4a) Are any windows in this house/flat double-glazed?		(69)	
	Yes	1	
	No	2	Q5

IF YES
b) Why did you have them double-glazed? (RECORD ANSWER IN GRID)

IF MORE THAN ONE REASON
c) What was the most important reason?

	Reasons	Most Important
	(70)	(71)
To preserve heat	A	1
To cut down traffic noise	B	2
To cut down metro noise	C	3
To cut down industry noise	D	4
other (specify) ______	E	5
Double-glazed before moved in	F	
Don't know	G	6

	Col/Code
SPARE	(72-80)
Record No.	(1-4)
Card (2)	(5)

5a) Right, Could you please tell me if you hear any of these noises when you are indoors?

(READ FROM GRID)

	(a) Yes	(a) No	(b) Bothers	(b) Dont Bothers	(c) Biggest nuisance	(d) Next Biggest nuisance	Col/Code	Skip to
Aircraft	A	0	1	2	A	A	(b)	
Factories or Machinery	A	0	1	2	B	B	(6-14)	
Car, Lorries and Other road traffic	A	0	1	2	C	C	(c)	
Children and other People outside	A	0	1	2	D	D	(15)	
Metro	A	0	1	2	E	E	(d)	
Building Works	A	0	1	2	F	F	(16)	
Noise from Neighbours such as TV, Radio, household appliances, talking when inside or slamming doors	A	0	1	2	G	G		
Any other Noises (specify) ______	A	0	1	2	H	H		
______	A	0	1	2	I	I		

FOR EACH NOISE MENTIONED AT 5a)

b) Does noise from .... bother or disturb or annoy you at all? RECORD IN GRID.

IF MORE THAN ONE BOTHERS AT 5b)

c) Of the noises that bother you (READ OUT). Which on the whole is the biggest nuisance to you, taking account of how often they occur as well as of how annoying they are at the time?

d) IF MORE THAN TWO BOTHER

Which is the next biggest nuisance? RECORD IN GRID

		Col/ Code	Skip to
6)	Please look at this card (SHOW CARD D) and tell me how you feel about the amount of noise from .... Metro trains(READ ITEMS)		
	(RECORD FOR EACH ITEM IN TURN)		

	Definitely Satisfactory						Definitely Unsatisfactory	Col/ Code
Metro	1	2	3	4	5	6	7	(17)
Cars, lorries & other road traffic	1	2	3	4	5	6	7	(18)
Aeroplanes	1	2	3	4	5	6	7	(19)

		Col/ Code	Skip to
7)	Were you living in this house when the diesel trains (DMU's) were running?	(20)	
	Yes	1	
	No	2	Q9a
8)	IF YES TO Q7		
	Thinking back to the time when the diesel trains were running, can you tell me how you feel, looking at this card (SHOW CARD D), about the amount of noise from the trains then?	(21)	
	Definitely Satisfactory	1	
		2	
		3	
		4	
		5	
		6	
	Definitely Unsatisfactory	7	

University of Newcastle upon Tyne

		Col/ Code	Skip to
9a)	Do you find noise from the Metro more annoying at certain times of the day or is it always the same?	(22)	
	More annoying at certain times	1	
	Always the same	2	[illegible]
	IF MORE ANNOYING AT CERTAIN TIMES		
b)	At what time do you find the noise most annoying? (RECORD VERBATIM)	(23)	
10a)	Does the Metro ever .... (READ FROM GRID)		
	IF YES		
b)	When it .... how annoyed does this make you feel? (SHOW CARD C) ASK (a) THEN (b) FOR EACH ITEM IN TURN		

	(a)			(b) HOW ANNOYED				Col/ Code
	YES	NO	N/A	VERY	MODERATE	A LITTLE	NOT AT ALL	
i) Startle You?	7	5		4	3	2	1	(24)
ii) Wake you up?	7	5		4	3	2	1	(25)
iii) Interfere with listening to radio or T.V.?	7	5	6	4	3	2	1	(26)
iv) Interfere with conversation?	7	5		4	3	2	1	(27)
								(28)
v) Interfere with or disturb any other activity?	7	5		4	3	2	1	(29)
(SPECIFY ALL. ASK b), OF MOST ANNOYING)								
____________								(30)
____________								(31)
____________								(32)
vi) Interfere with your sleep in any other way?	7	5		4	3	2	1	(33)

		Col/ Code	Skip to
11	Are there any particular types of noise from the Metro that are especially annoying such as a clanging, or squeal, or clickety clack, or low rumble or some other sort of sound?	(34)	
	No particular types of noise bother	0	

	Yes	No	Col/ Code
clanging	1	2	(35)
squeal	1	2	(36)
clickety clack	1	2	(37)
low rumble	1	2	(38)
others (specify) ________	1	2	(39)
(RECORD REDPONDENTS WORDS) ________			(40)
________			(41)

		Col/ Code	Skip to
12a)	Do you keep your doors or windows shut because of noise from the Metro trains?	(42)	
	Yes	1	
	No	2	Q13
	IF YES		
b)	Do they make you keep your doors or windows shut at night, or during the day, or both?	(43)	
	Night only	1	Q13
	Day only	2	
	Both	3	
	IF DAY		
c)	Do you keep them shut all the time during the day or only occasionally?	(44)	
	All the time	1	
	Only occasionally	2	
13)	Do you have any idea of how many Metro trains pass by in an hour?	(45-46)	
	(a typical hour during the middle of a week-day)		
	Don't know	99	
	Estimated Number ☐☐		

ASK ALL

14a) Do you notice anything shake, vibrate or rattle, in your house, when .... aeroplanes fly above (RECORD FOR EACH ITEM)

FOR EACH MODE THAT CAUSES VIBRATION

b) When this happens, how annoyed does it make you feel? (SHOW CARD C)

Ask (a) Then (b) FOR EACH MODE IN TURN

	YES	NO	VERY	MODERATE	A LITTLE	NOT AT ALL	Col/ Code
Aeroplanes fly above	6	5	4	3	2	1	(47)
Metro trains pass by	6	5	4	3	2	1	(48)
Car, lorries or buses pass by	6	5	4	3	2	1	(49)
Anything else? (specify) ________	6	5	4	3	2	1	(50)

IF VIBRATION DUE TO METRO — OTHERWISE Q19

15) Now, speaking of Metro trains:
What is it that you have noticed shaking or vibrating or rattling?

(PROBE: "Anything else?" UNTIL FINAL "NO") DO NOT PROMPT.

	Yes	No	Col/ Code
Windows/doors	1	2	(51)
Glasses/crockery	1	2	(52)
Pictures or Mirrors on walls	1	2	(53)
feel floor/houses/bed/chair	1	2	(54)
other (specify) ________	1	2	(55)

		Col/ Code
16)	Do you think anything may be damaged by the vibrating or shaking, or not?	(56)
	No	1
	Yes (specify) ________	2
	Qualified Yes (eg may be)(specify) ________	3

		Col/ Code	Skip to
17a	Would you say that the vibration caused by the Metro is a problem or not?	(57)	
	Problem	1	
	Not a Problem	2	Q18a
b	IF PROBLEM which is the bigger problem, the vibration or the noise from the Metro?	(58)	
	Vibration bigger	1	
	Noise bigger	2	
	Same	3	
18a	Does the vibration from Metro trains bother you in any particular way?	(59)	
	No	1	
	Yes	2	
	Qualified Yes (eg sometimes)	3	
b	IF YES (2 OR 3) In what way does it bother you?	(60)	
		(61)	
		(62)	
		(63)	
		(64)	
19	Can I just check, you said you did/did not hear Metro noise here?	(65)	
	Hears Metro	1	
	Does not hear	2	Q23
20a	IF HEARS METRO Have you got used to the noise from Metro trains?	(66)	
	Yes	1	
	Yes, (qualified)	2	
	No	3	Q21
	IF YES About how long did it take you to get used to the noise from Metro trains? (IN DAYS, WEEKS, MONTHS OR YEARS)	(67)	
	Was never bothered	1	
	(Don't know/Do not remember)	2	

		Yes	No	Col/ Code	Skip to
21	Have you or any member of your family, living here, ever complained to the T/W PTE or signed any petition concerning noise or any other problem associated with Metro trains?			(68)	
	Yes			1	
	No			2	Q22
b)	IF YES What was the problem you complained about?				
	Metro Noise	1	2	(69)	
	Metro Vibration	1	2	(70)	
	Others (specify) ________	1	2	(71)	
	________	1	2	(72)	
22a)	Do you think anything should be done to reduce noise from the trains, around here?			(73)	
	Yes			1	
	No			2	
	Dont know			3	
b)	Who would you say is in a position to do something about Metro noise? (DO NOT PROMPT)				
	The people who run the Metro	1	2	(74)	
	The manufacturer of Metro trains	1	2	(75)	
	Other (specify) ________	1	2	(76)	
	________	1	2	(77)	
	Don't know	1	2	(78)	
23	During the time you have lived here, has the amount of noise from the railway increased, decreased or stayed about the same?			(79)	
	Increased			1	
	Decreased			2	
	Stayed about same			3	
	Not been here long enough			4	
	D.K/Do not remember			5	

No.	Question	Response	Col/Code	Skip to
24	If you had the choice, would you rather live in a place where there was no railway noise at all, or in a place where you could sometimes hear some noise from the railway?		(80)	
		No railway noise	1	
		Some railway noise	2	
		Record No	(1-4)	
	Now, changing the subject	Card No(3)	(5)	
25a	How often do you use the Metro?		(6)	
		Everyday	1	Q26
		Most days/very often	2	Q26
		Once a week	3	
		Rarely	4	
		Never	5	
b	Do any other members of your household use the Metro regularly?		(7)	
		Yes	1	
		No	2	
	IF 'NEVER' TO Q 25a) GO TO Q29			
26	How long does it usually take you to get to the Metro Station from here? (by method of transport most often used)	Mins ☐☐	(8-9)	
27	What do you think of the price of Metro tickets? Would you say it is (Read list)		(10)	
		Much too expensive	1	
		Rather expensive	2	
		About right	3	
		Quite cheap	4	
		Very cheap	5	
28	How would you rate the service which Metro provides for the public? Would you say it is (Read list)		(11)	
		Excellent	1	
		Good	2	
		Fair	3	
		Poor	4	
		Very Poor	5	

No.	Question	Response	Col/Code	Skip to
29a)	Do you think Metro has caused any change in the value of your property/house?		(12)	
		Yes (specify) increase	1	
		decrease	2	
		No change	3	Q30
		Not applicable (eg Tenants)	4	Q30
	IF YES TO Q30a)		(13)	
b)	Would you say the decrease/increase is considerable or negligible?			
		Considerable	1	
		Negligible	2	
		Don't know	3	
30a)	Are there any aspects of the Metro which, you find, are not particularly safe?		(14)	
		Yes	1	
		No	2	Q31
	IF YES			
b)	Could you tell me what they are?		(15)	
			(16)	
			(17)	
			(18)	
			(19)	
c)	How concerned would you say you are about these problems, would you say you are (READ OUT)		(20)	
		Very concerned	1	
		quite concerned	2	
		not concerned	3	
31	Is there anything about the Metro that we have not talked about and that you would like to mention?		(21)	
			(22)	
			(23)	
			(24)	
			(25)	

CLASSIFICATION SECTION

TENURE	(26)		**Col/ Code**	**Skip to**
Owner-occupied	1			
Rent, private	2			
Rent, Council	3			
Rent free	4			
TYPE OF HOUSE	(27)			
Whole house - detached	1			
- semi-detached	2			
- terraced	3			
Flat/Maisonette	4			
Rooms	5			
Other (specify) ______	6			
CAR OWNERSHIP	(28)			
Do you or don't anyone in your household have the use of a car or van?				
Yes	1			
No	2			
SEX OF RESPONDENT	(29)			
Male	1			
Female	2			
RESPONDENTS MARITAL STATUS	(30)			
Single	1			
Married	2			
Separated/Widowed/Divorced	3			

RESPONDENTS AGE		
Exact Age [ ][ ]	(31-32)	
	(33)	
18-24	1	
25-34	2	
35-44	3	
45-59	4	
60-64	5	
65+	6	
ACTIVITY STATUS OF RESPONDENT	(34)	
A) Working full time (30 hours +)	1	
Working part time (10-30 hours)	2	
Seeking work	3	C
Retired/sick	4	C
Non-working housewife	5	C
Full-time student	6	C
Other ______	7	C
OCCUPATION OF RESPONDENT		
B) Name/Title of job ______		
ACTIVITY STATUS OF H O H		
C) IF NOT RESPONDENT		
Working full time (30 hours +)	1	D
Working part-time (10-30 hours)	2	D
Seeking work	3	
Retired/Sick	4	
Non-working housewife	5	
Full-time student	6	
Other ______	7	
OCCUPATION OF H O H		
D) Name/Title of job ______		

OBSERVATION PAGE

1. Did the respondents hearing capacity seem to be
   a) normal
   b) moderately diminished
   c) severely diminished

2. Did the respondent have more difficulty than most respondents in understanding the questions?
   YES
   NO

3. Which questions were difficult?

4. Did the respondent want to finish the interview as soon as possible?
   YES
   NO

5. Did the respondent seem especially interested in a particular topic?
   YES (specify topic)

6. Did respondent feel stronger on the.
   a) metro noise
   b) metro service

7. Was respondent interested in the study?

8. During the interview did you notice the metro noise?

9. How did this affect the interview.
   a) v. little
   b) some
   c) a lot

10. How long did the interview take? mins.

UNIVERSITY OF
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Professor of Civil and Hydraulic Engineering and Head of Department P NOVAK
Tyne and Wear Professor of Environmental Control Engineering M B PESCOD
* Professor of Transport Engineering and Director of the Transport Operations Research Group PETER J HILLS
Professor of Structural Engineering F K KONG

Please reply to
DIVISION OF TRANSPORT ENGINEERING Claremont Tower (7th Floor)

12 September 1983

Dear Resident,

The Division of Transport Engineering is carrying out a questionnaire survey in Wallsend/Walker which will enable you to express your feelings about your area and which will help us to understand and, hopefully, overcome some of its problems.

You have been chosen to be one of the respondents, but we have not been able to contact you when we paid several visits to your address. Your opinions are of utmost importance to this study and, therefore, we would be most grateful if you could fill in the appointment section below so that we can contact you at a convenient time.

The questionnaire is simple and short and I give you my assurance that any information you give will be treated in confidence.

I thank you in anticipation of your help towards this important study.

Yours sincerely,

P.J. Hills
Professor of Transport Engineering

Please tear here

APPOINTMENT SECTION

A convenient time for the interview would be .... o'clock on

......................(day) .... September, 1983

NAME ....

ADDRESS ....

....

APPENDIX C

RESULTS OF SOCIAL SURVEY

		ZONE A			ZONE B			ZONE C			ZONE D		
		Metro	Road traffic	Aircraft	Metro	Road traffic	Aircraft	Metro	Road traffic	Aircraft	Metro	Road traffic	Aircraft
Definitely satisfactory	1	11	16	31	2	4	11	10	13	22	14	17	20
	2	5	15	14	5	8	13	6	11	12	14	18	18
	3	14	14	10	9	8	8	5	5	4	15	4	7
	4	10	7	4	7	10	5	11	6	5	9	7	6
	5	7	6	1	7	5	2	2	4	3	1	5	2
	6	7	1	1	3	2	-	4	5	-	-	2	1
Definitely unsatisfactory	7	7	2	-	6	2	-	7	2	-	-	2	1

Note : Figures refer to number of respondents

TABLE C1 : Breakdown of response to Q6 - - Perception of noise from Metro/road traffic/aircraft

(No. of respondents)

		ZONE			
		A	B	C	D
Definitely satisfactory	1	7	1	4	8
	2	5	5	4	7
	3	8	3	4	7
	4	4	10	7	7
	5	6	4	4	10
	6	6	4	5	-
Definitely unsatisfactory	7	9	6	1	3

TABLE C2 : Breakdown of response to Q8 - - Perception of noise from DMUs

(No. of respondents)

Response	ZONE			
	A	B	C	D
Never bothered	17	15	18	33
Don't know/ Don't remember	3	2	-	-
1 week	7	3	5	4
1 week to 1 month	11	3	9	9
1 month to 3 months	11	7	6	4
3 months to 1 year	7	4	2	2
1 year	-	-	2	-
Missing	5	5	4	5

TABLE C3 : Breakdown of response to Q20b) - - Length of time taken to get used to noise from Metro

(No. of respondents)

Response	ZONE			
	A	B	C	D
Reduce noise from Metro	44	26	22	8
Don't need to reduce noise from Metro	16	12	23	45
Don't know	1	1	-	-
Missing	-	-	1	4

TABLE C4 : Response to Q22a) - - Should noise from Metro be reduced

(No. of respondents)

Response	ZONE			
	A	B	C	D
Some aspects of Metro are not safe	22	16	26	31
Metro is a totally safe system	37	20	15	23
Don't know	-	1	-	-
Missing	2	2	5	3

TABLE C5 : Response to Q30a) - - Safety of Metro

(No. of respondents)

Unsafe aspects of Metro	ZONE			
	A	B	C	D
Station barriers	1	4	7	6
Open crossings	3	3	3	4
Metro doors	3	2	8	7
Track fencing	8	6	3	8
Train-platform trap	4	1	-	1
Hooligans	2	-	4	3
Other	1	3	3	3

Note : A respondent can find more than one aspect unsafe.

TABLE C6 : Response to Q30b) - - Unsafe aspects of Metro

Note : All figures refer to number of respondents

	Zone A	Zone B	Zone C	Zone D
Sample size	61	39	46	57

(a) Tenure

	Zone A	Zone B	Zone C	Zone D
Owner-occupied	25	16	11	19
Rent, private	34	15	15	17
Rent, Council	2	8	18	19
Rent, free	-	-	2	2

(b) House Type

	Zone A	Zone B	Zone C	Zone D
Detached house	1	3	1	2
Semi-detached house	2	5	2	3
Terraced house	13	22	9	21
Flat/ maisonette	45	9	33	31
Rooms	-	-	1	-

(c) Car Ownership

	Zone A	Zone B	Zone C	Zone D
Yes	22	11	11	15
No	39	28	35	42

(d) Marital Status

	Zone A	Zone B	Zone C	Zone D
Single	9	8	3	11
Married	32	24	31	31
Sep Wid/Div	20	7	12	15

(e) Sex

	Zone A	Zone B	Zone C	Zone D
Male	22	12	20	30
Female	39	27	26	27

	Zone A	Zone B	Zone C	Zone D
Sample size	61	39	46	57

(f) Age Group

	Zone A	Zone B	Zone C	Zone D
18 - 24	7	6	8	8
25 - 34	13	9	11	14
35 - 44	7	5	9	6
45 - 59	14	9	10	13
60 - 64	6	1	7	4
65+	14	9	1	12

(g) Working Status

	Zone A	Zone B	Zone C	Zone D
Full-time	17	12	11	21
Part-time	11	7	6	7
Housewife	14	10	8	7
Others	19	10	21	22

(h) Socio-Economic Group

	Zone A	Zone B	Zone C	Zone D
Professional and Non-manual	16	12	6	14
Skilled manual	36	20	27	21
Semi-skilled manual	7	4	12	21
Unskilled, housewives and others	2	3	1	1

TABLE C7 : Sample Classification

APPENDIX D

RELIABILITY AND VALIDITY TESTS

THE NOISE ANNOYANCE INDEX (NAI)

D1 As described in Chapter 3 (Section 3.4), an index must possess two basic desirable qualities. It must be reliable and it must be valid, SPSSx offers the facility to carry out both tests on the items selected for inclusion in the index. A list of items (questions) is given below together with their codes as used in the analysis, after which the way in which the scale (NAI) was constructed is described.

D2 Q5b) v) Does noise from Metro both or disturb or annoy you at all?

(1) don't hear (2) don't bother (3) bothers

Q6 Please look at this card (SHOW CARD D) and tell me how you feel about the amount of noise from Metro trains.

Definitely satisfactory	1
	2
	3
	4
	5
	6
Definitely unsatisfactory	7

Q9a) Do you find noise from the Metro more annoying at certain times of the day or is it always the same?

Always the same	1
More annoying at certain times	2

Q12a) Do you keep your doors or windows shut because of noise from Metro trains?

No	1
Yes	2

Q20b) About how long did it take you to get used to the noise from Metro trains?

Never bothered	1
Don't know/don't remember	2
Less than 1 week	3
1 week to 1 month	4
1 month to 3 months	5
3 months to 1 year	6
Greater than 1 year	7

Q22a) Do you think anything should be done to reduce noise from the trains around here?

No	1
Don't know	2
Yes	3

Q23 During the time you have lived here, has the amount of noise from the railway increased,decreased or stayed about the same?

Decreased, don't know, not been here long enough	1
Stayed about the same	2
Increased	3

Q24 If you had the choice, would you rather live in a place where there was no railway noise at all, or in a place where you could sometimes hear some noises from the railway?

Some railway noise	1
No railway noise	2

D3 Since the numerical codes of responses to questions listed in Section D2 vary from 2-point scales (Q's 12a), 24) to 7-point scales (Q's 6, 20b)), it was necessary to transform them to a common base in order to perform the reliability test, and later, to average the scores when constructing the annoyance index. All (except Q's 6, 20b)) were transformed to 7-point scales as shown below :

Q5b) v)	(((Q5b) v) - 1)/2) x 6) + 1
Q9a)	(((Q9a) - 1)/1) x 6) + 1
Q12a)	(((Q12a) - 1)/1) x 6) + 1
Q22a)	(((Q22a) - 1)/2) x 6) + 1
Q23	(((Q23 - 1)/2) x 6) + 1
Q24	(((Q24 - 1)/1) x 6) + 1

D4 The output of the validity and reliability tests using the SPSSx procedures 'FACTOR' and 'RELIABILITY', respectively is reproduced in this section. The goal of axes rotation is to enhance the interpretation of the factors. Rotation does not affect the goodness of fit of a factor solution.

Variables one, two, three, four, five, nine, eleven and twelve in Figure D1 refer to Q's 5b) v), 6, 22a), 23, 24, 9a), 20b), 12a), respectively.

---------- F A C T O R   A N A L Y S I S ----------

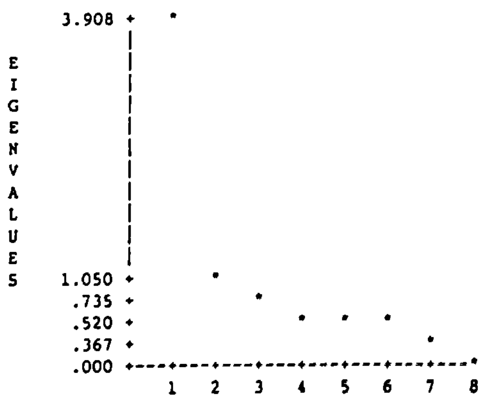
ANALYSIS NUMBER 1 PAIRWISE DELETION OF CASES WITH MISSING VALUES

CORRELATION MATRIX:

	ONE	TWO	THREE	FOUR	FIVE	NINE	ELEVEN
ONE	1.00000						
TWO	.73346	1.00000					
THREE	.46407	.59751	1.00000				
FOUR	.40004	.44972	.35623	1.00000			
FIVE	.04834	.23293	.20867	.18765	1.00000		
NINE	.57634	.56413	.32772	.27095	.10400	1.00000	
ELEVEN	.56993	.57804	.43562	.32185	.07055	.42479	1.00000
TWELVE	.57115	.57151	.38051	.39956	.08398	.41900	.43610

	TWELVE
TWELVE	1.00000

EXTRACTION 1 FOR ANALYSIS 1, PRINCIPAL-COMPONENTS ANALYSIS (PC)



PC EXTRACTED 2 FACTORS.

FACTOR MATRIX:

	FACTOR 1	FACTOR 2
ONE	.84099	-.22675
TWO	.88567	.03749
THREE	.68785	.20439
FOUR	.59667	.24712
FIVE	.23608	.90286
NINE	.69074	-.18075
ELEVEN	.72556	-.17193
TWELVE	.72642	-.12955

FINAL STATISTICS:

VARIABLE	COMMUNALITY	*	FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
		*				
ONE	.75867	*	1	3.90782	48.8	48.8
TWO	.78583	*	2	1.04983	13.1	62.0
THREE	.51491	*				
FOUR	.41708	*				
FIVE	.87089	*				
NINE	.50980	*				
ELEVEN	.55600	*				
TWELVE	.54447	*				

VARIMAX ROTATION 1 FOR EXTRACTION 1 IN ANALYSIS 1 - KAISER NORMALIZATION.

VARIMAX CONVERGED IN 3 ITERATIONS.

ROTATED FACTOR MATRIX:

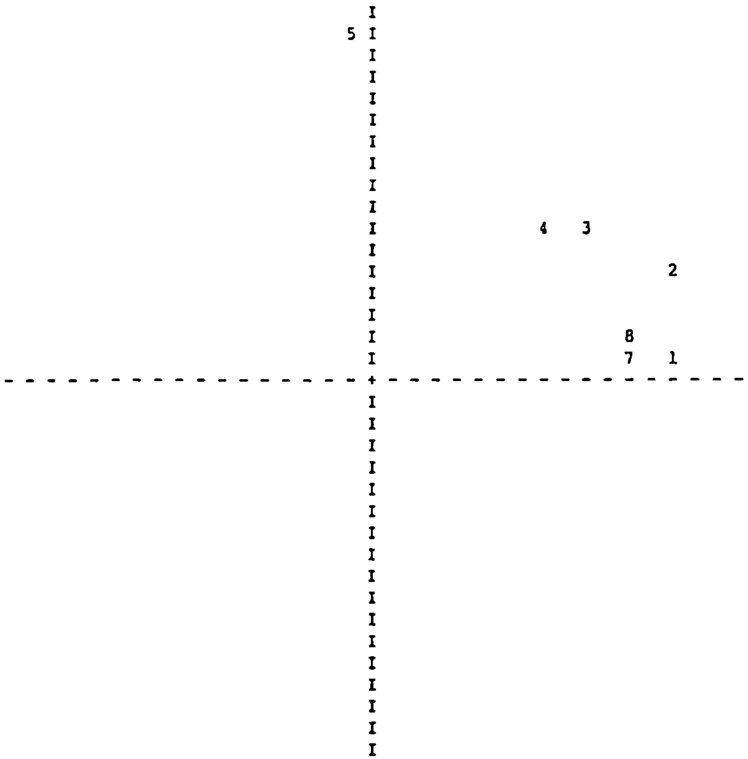
	FACTOR 1	FACTOR 2
ONE	.87067	.02462
TWO	.83750	.29055
THREE	.60004	.39353
FOUR	.50042	.40824
FIVE	-.03347	.93261
NINE	.71355	.02548
ELEVEN	.74436	.04394
TWELVE	.73300	.08477

Figure D1 : SPSSx Computer Output

FACTOR TRANSFORMATION MATRIX:

	FACTOR 1	FACTOR 2
FACTOR 1	.95778	.28751
FACTOR 2	-.28751	.95778

HORIZONTAL FACTOR 1 VERTICAL FACTOR 2



SYMBOL	VARIABLE	COORDINATES	SYMBOL	VARIABLE	COORDINATES
1	ONE	(.87067, .02462)	2	TWO	(.83750, .29055)
3	THREE	(.60004, .39353)	4	FOUR	(.50042, .40824)
5	FIVE	(-.03347, .93261)	6	NINE	(.71355, .02548)
7	ELEVEN	(.74436, .04394)	8	TWELVE	(.73300, .08477)

R E L I A B I L I T Y   A N A L Y S I S

1. ONE
2. TWO
3. THREE
4. FOUR
5. FIVE
6. NINE
7. ELEVEN
8. TWELVE

\# OF CASES = 180.0

INTER-ITEM CORRELATIONS	MEAN	MINIMUM	MAXIMUM	RANGE	MAX/MIN	VARIANCE
	.3748	.0419	.7306	.6887	17.4200	.0326

ITEM-TOTAL STATISTICS

	SCALE MEAN IF ITEM DELETED	SCALE VARIANCE IF ITEM DELETED	CORRECTED ITEM-TOTAL CORRELATION	SQUARED MULTIPLE CORRELATION	ALPHA IF ITEM DELETED
ONE	22.8611	118.1985	.6879	.6274	.7584
TWO	24.2167	105.9584	.7880	.6798	.7304
THREE	23.5778	97.1503	.5705	.3803	.7567
FOUR	23.8444	114.7019	.4518	.2288	.7742
FIVE	23.4944	118.8435	.1833	.1017	.8318
NINE	25.2278	105.3165	.5311	.3882	.7618
ELEVEN	24.6111	111.0658	.5661	.4022	.7581
TWELVE	25.7944	111.1028	.5448	.3659	.7607

RELIABILITY COEFFICIENTS 8 ITEMS
ALPHA = .7904 STANDARDIZED ITEM ALPHA = .8274

Figure D1 continued ..

APPENDIX E

MULTIPLE LINEAR REGRESSION

E1 Multiple Linear Regression (MLR) is a powerful statistical technique which can be used to summarise data, as well as to quantify relationship between a dependent variable and several independent variables. MLR is an extension of simple linear regression which establishes the linear relationship between a dependent variable and one independent variable.

The regression analyses performed in this study were carried out using the advanced statistical computer package SPSSx, as were the rest of analyses. SPSSx offers three procedures for selecting variables in a regression model: forward selection, backward elimination and stepwise selection. The last of these procedures was chosen in this study because it is essentially a combination of the backward and forward procedures. A brief description of the stepwise selection procedure is given below:

The first independent variable considered for entry into the equation is the one with the largest positive or negative correlation with the dependent variable. The F-test for the hypothesis that the coefficient of the entered variable is zero is then calculated. To determine whether this variable (and each succeeding variable) is entered, the F value is compared to an established criterion, that is, the minimum value of the F statistic (called F-in) that a variable must achieve in order to enter the equation. The default value for F-in in SPSSx is 3.84. Alternatively, the probability associated with the F statistic can be specified. If the first variable fails to meet entry requirements, the procedure terminates with no independent variables in the equation. If it passes the criterion, the second variable is selected based on the highest partial correlation. If it passes the entry criterion, it also enters the equation. At this point, the first variable is examined to see whether it should be removed according to a removal criteria (called F-out), similar to the entry criterion described earlier. To prevent the same variable from being repeatedly entered and removed, the entry criterion F-in must be greater than the removal criterion, F-out. The default value for F-out in SPSSx is 2.71. In the next step, variables not in the equation are examined for entry. After each step, variables already in the equation are examined for removal. Variables are removed until none remain that meet the removal criterion. Variable selection terminates when no more variables meet entry and removal criteria.

E2 Multicollinearity is the result of high linear correlation among independent variables in a regression analysis. Such correlations only suggest that variables are duplicating each other without improving the overall fit of the model. Multicollinear variables can be detected by the presence of large coefficients in the correlation matrix. However, multicollinearity can sometimes exist without any of the correlation coefficients being very large. Another commonly used indicator for interdependency between variables, therefore, is tolerance.

Tolerance is the proportion of variability in an independent variable not explained by the other independent variables. It is calculated as $1 - R_i^2$, where R_i^2 is the squared multiple correlation when the ith independent variable is considered the dependent variable and the regression equation between it and the other independent variables is calculated. Before an independent variable is entered into the equation, whatever procedure of variable selection is used, its tolerance with other independent variables already in the equation is calculated. If either the tolerance of the variable or the tolerance of any other variable is less than 0.01, the default value in SPSSx, the variable is not entered unless the tolerance criterion has been altered.