The effect of interruption of traffic flow on noise characteristics and annoyance

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The Effect of Interruption of Traffic Flow on Noise Characteristics and Annoyance

by

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A Master's Thesis

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Summary.

The study was divided into two main sections.The first was a physical study of noise characteristics at three major road intersections controlled by traffic lights.The second was a social survey combined with noise measurements at six sites with freely flowing traffic and six sites with traffic interrupted at an intersection controlled by traffic lights.

The object of the physical study was to determine the general trends in noise levels at intersections without a complex analysis of all the many factors involved.This was achieved by comparing actual values of L_{10},L_{50}, and L_{90} at various distances from the intersection, with values predicted by a reliable free flow method due to Delany, adapted for the intersection situation.Increase over prediction was plotted against distance from the intersection, and although scatter of results was high, linear regression analysis showed that the trend is for L_{90} to show the greatest increase over prediction close to the intersection, and for L_{10} to show the smallest increase, with these increases falling off linearly with distance from the intersection.

The second section of the study consisted of a questionnaire applied to a sample of the population at the twelve sites in order to determine whether the noise indices, 18 hour averaged L_{10}, L_{50}, L_{90} and Traffic Noise Index, would explain annoyance in the same manner for both free and interrupted flow situations.The questionnaire contained a series of questions covering various aspects of noise annoyance, which were used to give an overall annoyance score for each respondent. It was delivered by hand and returned postally.

At each free flow site noise measurements were taken at one position over the 18 hours between 0600 hrs.and 2400 hrs.,enabling the required indices to be calculated for each respondent's house. At the interrupted flow sites it was possible to obtain values of the indices for respondents' houses by combining 18 hour noise measurements close to and far from the intersection with the results of the physical study. Linear regression techniques were used to relate annoyance score to the indices.

L_{10} was shown to not behave consistently between the two flow situations, with dissatisfaction becoming the mean reaction at an L_{10} level of 75.6dB(A) for free flows, and 69.2dB(A) for interrupted flows.

L_{50} shows a more consistent behaviour between the two situations and is recommended if comparison of free and interrupted flow noise levels are to be carried out.

TNI behaved badly as an indicator of annoyance for free flows, possibly because of distortion due to the use of 18 hour average levels instead of the 24 hour levels around which it was designed. However, annoyance correlated well with it in the interrupted flow case, possibly because TNI takes into account level fluctuations which appear to be major sources of annoyance at intersections.

Contents.

1. Introduction.

1. Introduction.

1.1 Area of research - Traffic Noise Pollution.

The rapid growth in the use of private cars, and in the size of heavy lorries, which appears to have been little affected by the recent petrol shortage and price increases, is a serious threat to the environment in several ways. Quite often, road development has not kept pace with this growth, leading to unsuitable roads in towns and villages being subjected to heavy traffic flows. This leads to pollution in the form of concentrated exhaust gases, visual intrusion, danger to pedestrians, and noise. Although road development is steadily being carried out, the new systems, in the form of by-passes, improved ring-roads, and motorways, create their own problems. Traffic will sometimes be directed past areas previously unaffected by it. Motorways swallow up large amounts of the countryside along their length (although they can be important nature conservation areas in themselves, as the embankments, which are not often disturbed by man, provide a home for many small animals, which in turn creates a food supply for birds of prey).

Comparatively little work has been carried out until recently on causes, effects, and prevention of traffic noise pollution. This lack of concern has probably been due to two factors. The overall level of noise produced by traffic is increasing as power outputs of engines, and the numbers of vehicles on the road increase. However, a doubling of power at the noise source represents an increase in level which is only just discernable, and this doubling of power occurs approximately every ten years for traffic as a whole, therefore levels increase so slowly that there is likely to be continual acclimatisation process. The fact that levels are accepted does not mean that they are acceptable. Also, traffic noise does not affect all the population. Those who have never experienced constant high levels of noise throughout the day and night, are unlikely to appreciate the discomfort it causes, and are unlikely to be concerned for those who have to live with it. It is only the recent widely publicised openings of "Spaghetti Junction" at Birmingham, and the Westway in London, which have brought to the general public's attention the levels of noise and atmospheric pollution which some people have to suffer.

As early as 1948 a study by Chapman (1) showed that the most frequently reported external noises in British houses were from road traffic and domestic animals. Since then the total power output of traffic as a whole will have doubled approximately three times, which means that the percentage of the population experiencing annoyance from traffic noise is likely to have increased greatly. A Building Research Digest (2) of 1963 suggested that intrusive noise was most widespread in cities and that traffic noise was frequently the predominant source. The Central London Noise Survey (3) of 1966 showed that 36% of the 1008 people questioned were bothered by traffic noise, the next most annoying noise source being adult voices, which bothered 10% of the people questioned.

1.2 The Physical Study - Objectives.

Although a certain amount of work has been carried out in order to find relationships between traffic noise generation parameters, such as rate of flow, velocity of vehicles, percentage of heavy vehicles, and noise levels, this work has concentrated on freely flowing traffic. This is understandable, as the generation of noise by traffic is due to a complex combination of several factors, and reduction of the variables involved at the early stages of investigation is desirable.

However, the greatest areas of traffic noise annoyance are in highly populated urban situations, where flows are rarely free for any great distance. Therefore it would be of use to local authorities to be able to predict levels for situations such as intersections and other junctions with and without traffic lights, roundabouts, zebra crossings etc.

It was decided that the present study would concentrate on noise characteristics at light controlled intersections. Time constraints meant that all the variables involved could not be taken into account and related to noise levels, and so only traffic composition, flow rate, and velocity were to be considered. Although this would not allow the effects of vehicle concentrations and light sequencing to be studied, it was felt that a satisfactory indication of the trends in the change of noise characteristics would be obtained.

It was assumed that levels close to an intersection would show some change over free flow characteristics, with this change becoming smaller with distance away from the intersection, until free flow conditions were encountered. Therefore it was proposed to measure levels at different distances from the intersection. At the same time vehicle flow rate, average velocity, and percentage heavy vehicles were to be noted to enable a prediction of "free flow" level to be made. Predicted level and measured level were then to be compared in order to study the effects of the intersection on the noise levels.

1.3 The Survey - Objectives.

It is helpful to the planner to know the level of noise, as indicated by some noise index, above which the majority of people experiencing it can be said to be to some extent annoyed. However it is not known whether this level is the same for both free and interrupted flow situations, when a particular index is used. It was desired to calculate various commonly used noise indices for a large number of houses in both flow situations, and at the same time to assess the annoyance caused by the noise. This would enable rate of change of annoyance with level, as characterized by each index, to be compared for both flow situations. From this it could be determined whether any index would explain annoyance equally in both flow situations, by the fact that change of annoyance with level of noise was the same in both situations. The noise indices to be investigated were 18 hour averaged L_{10}, L_{50} and L_{90} and 18 hr. Traffic Noise Index. In order to obtain the number of noise measurements required in the interrupted flow situations, the results of the physical study were to be applied so that only two 18 hour measurements per site needed to be taken, rather than one for each house could then be extrapolated from the actual readings using the physical study findings.

Annoyance was to be gauged by applying a questionnaire, specifically designed for this survey, to one or two members of each household for which noise measurements were available.

2. Noise.

2. Noise.

2.1 Introduction.

Noise can be defined as unwanted sound. Sound is caused by pressure fluctuations in the air impinging on the ear drum of a listener. The fluctuations are transformed into movement of the eardrum, which is transmitted and amplified through the air filled middle ear by three bones, the malleus, incus and stapes. The stapes is in contact with the oval window of the cochlea. The cochlea is basically a coiled tube containing many nerve fibres, and filled with a fluid (perilymph). Movement at the oval window causes a fluid action within the cochlea, which is transformed into impulses by the nerve fibres, and transmitted to higher nerve centres, where they are perceived as sound of a certain pitch and loudness.

Sound level can be measured using an instrument which responds to the pressure fluctuations in the air. However, the physical level of a sound will not describe the annoyance it causes. The degree of "unwantedness", or noisiness of a sound depends largely on psychological factors which may vary greatly from individual to individual. For example, the level of music heard at an open air pop festival can give pleasure to the many young people who attend it, and cause extreme annoyance to the local residents.

2.2 Noise Units.

2.2.1 General Units.

The ear can register root-mean-square pressures ranging from $2 \times 10^{-5} N/m^2$ (any pressure fluctuations with rms values smaller than this being masked by internally generated noise in the ear), to $100 N/m^2$, which represents the pain threshold. If r.m.s. pressure values were used to measure sound levels, the scale would have such a large range that calculations and comparisons would be difficult. Sound pressure levels are therefore measured on a compressed logarithmic scale, known as the decibel scale (dB). Sound pressure level is 20 $\log_{10}$ of the ratio of the r.m.s. pressure of the sound, and a reference r.m.s. pressure, commonly taken as $2 \times 10^{-5} N/m^2$, representing the threshold of hearing at 1000 Hz.

On the decibel scale an increase of 3dB represents a barely perceptible change in level, while an increase of 10dB represents an approximate doubling of perceived loudness.

The apparent loudness of a sound is not only dependent on its r.m.s. pressure level, but also its frequency, because of the physiology of the ear. If a sound is heard at a constant dB level, but with a varying frequency, it will appear to be loudest at around 4000 Hz, dropping off at higher and lower frequencies. This has lead to the formulation of equal loudness curves, which show dB levels which appear to give the same loudness at different frequencies. The equal loudness curve which is equal to 40 dB at 1000 Hz is the 1 sone curve. The sone scale is linear, so that the 2 sone curve represents a level which appears twice as loud. However, as equal loudness curves apply to discrete frequencies they are of little use as they stand in normal noise situations where sounds are composed of a combination of frequencies. Therefore Stevens (4) proposed a method of summing sone levels for frequency bands within a noise spectrum. This gave loudness as:- $S^* = S_M + 0.15(\Sigma S - S_M)$

where S_M = max. number of sones in any one band

S = sones in all bands.

Bands are one-third octaves in this case, but alteration of the fractional portion 0.15 to 0.3 or 0.2 allows full or half octaves to be used.

It has become practice to express loudness in terms of logarithmic phons, which can be obtained from S^* above by:-

$$Lp = 40 + 33 \log_{10} S^*$$

where Lp = loudness in phons.

As human judgement of loudness does not depend solely on r.m.s. pressure level, it is useful for a sound level meter to show readings which relate to subjective perception of loudness. This is achieved by weighting its response at different frequencies. Resulting weighted levels are known as dB(A), dB(B), dB(C), and dB(D). The most widely accepted and recommended unit is the dB(A), whose weighting gives it characteristics relating to the 40 phon line.

Perceived noisiness, as opposed to noise annoyance, is defined by Kryter (5) as "the subjective impression of the unwantedness of a not unexpected, non pain or fear provoking sound as part of one's environment". It is thought that perceived noisiness can be taken as invariant between individuals for a given level of noisiness, therefore there are equal noisiness curves available, similar in format to equal loudness curves. The unit corresponding to the sone is the linear "noy", and the parallel unit to the phon is "perceived noise level" (L_{PN}), calculated in the same way.

2.2.2 Units used in measuring traffic noise.

The basic method of measuring traffic noise is to use percentile levels. These are written L_x, and represent the level in dB(A) which is exceeded for x% of a specified time period. These are most accurately measured by feeding the noise into a statistical distribution analyser, which samples it at regular intervals (e.g. 0.1 sec). This then indicates the level of the noise for each sampling, by increasing the count by one on the counter representing the level band within which the noise level occurs. This enables the statistical distribution of levels over time to be measured. If the distribution is measured cumulatively by the analyser, then a cumulative frequency plot can be drawn (from counter readings) allowing percentile levels to be calculated (see Appendix A).

The commonly used percentile levels are L_{90}, L_{50} and L_{10}, which represent 'average' background, mean, and peak levels respectively.

A method of measuring noise exposure at a particular site, which is often used, is to sample the noise statistically for about 10 minutes every hour between 0600 hrs. and 2400 hrs., and average arithmetically the 18 hourly values of L_{10} obtained. This method is recommended by the Noise Advisory Council (6), and is also the basis of the Land Compensation

Act traffic noise criteria (7).

The Wilson Committee recommendations for maximum levels within dwellings are stated in terms of plain L_{10} levels.

A more sophisticated unit, arrived at by application of a social survey (8), is the Traffic Noise Index:-

$$TNI = 4(L_{10} - L_{90}) + L_{90} - 30 \text{ (measured over 24 hrs.)}$$

This index, which adds a weighted measure of the range of noises to a measure of background level was found to correlate well with group mean dissatisfaction scores in the original survey.

It is hoped that eventually a single noise unit will be evolved that will enable noise from all sources to be measured and compared. The "equivalent energy level" unit (L_{EQ}) goes some way toward this. This is effectively a logarithmic average noise level over a specified time. This unit is recommended by the I.S.O. for use in residential, industrial and traffic situations.

Robinson (9) proposes the "noise pollution level" as the basis of a unified system. This is given as:-

$$L_{NP} = L_{EQ} + 2.56\sigma$$

where σ = standard deviation of the sound level. It represents the intensity of intruding sound combined with a weighted measure of the fluctuation in level. It has been found to be more faithful to human reaction than L_{EQ}, but it is more complex to determine.

2.3. The effects of noise.

2.3.1 Health.

High intensity noise can damage the ear mechanism, leading to temporary or permanent threshold shifts, where the threshold of hearing is at a higher level than before exposure. Temporary threshold shifts can occur after an 8 hour per day exposure to a noise at a level of

67dB(A), but permanent effects occur only with exposure to 80dB(A) or greater for long periods. Even 8 hours per day of exposure to a level of 90dB(A) is unlikely to cause significant hearing loss over a working life, according to the current British "Code of Practice for reducing the exposure of employed persons to noise" (10).

At very high intensity noise levels, the inner ear is protected by a stiffening of the ossicular chain in the middle ear, an escape of pressure through the eustachian tube joining the middle ear to the throat, or a rupturing of the eardrum. In the latter case reduced hearing is still possible due to bone conduction.

As levels close to a traffic stream do not often reach 90 dB(A), there is little chance of permanent hearing damage being caused by traffic noise.

However, traffic noise can damage health indirectly by preventing sleep. It would seem that sleep disturbance is due not only to mean level, but also the degree of fluctuation of level.

There is also some evidence that the stress caused by noise can affect mental health, although this is by no means conclusive (11).

2.3.2 Communication.

A major effect of traffic noise is interference with communication. This includes conversation, radio and television, telephone, live music, etc. In some situations it is only annoying, but it can also be dangerous as shouted commands or warnings may not be heard.

Background levels of around 45dB(A) are required for normal speech, radio, and T.V. to be comfortably heard. Telephone conversations become difficult above a level of around 55dB(A).

2.3.3 Task performance.

Although most investigations into the effects of noise on task performance have taken place at levels higher than those due to traffic, the results are of some interest.

It would seem that performance in low concentration tasks is improved by the stimulation provided by the noise, whereas high concentration tasks are made more difficult by its presence. A recent U.S. Army study has shown that people subjected to intermittant levels of 96dB(A) tend to perform better at first, and then their performance deteriorates (12).

As far as traffic noise is concerned, the frustration caused by the inability to change the situation could affect task performance.

2.3.4 Advertising Undesired Activities.

Although the noise heard by a listener may be fairly quiet, it may bring to mind some aspect of the noise source which creates an annoyance reaction.

The noise of an aeroplane passing overhead could make the listener frightened that it could crash onto his house. In the example of the pop festival quoted earlier, the music advertises to the local resident the fact that his area has been invaded by the type of people who he may not particularly like.

.It can be seen from the above, that noise annoyance is caused by a combination of many physiological and psychological factors. This makes measurement of annoyance extremely complex.

2.4 The Control of Traffic Noise.

2.4.1. The sources of vehicle noise and possible methods of reduction.

The most desirable method of reducing traffic noise is to reduce levels emitted by individual vehicles, as overall traffic noise levels are then reduced in all situations.

Exhaust Systems.

All vehicles must be fitted with some form of exhaust silencing. Private cars are generally the quietest vehicles on the road and little benefit would be obtained by improving their silencing. Typical silencers on heavy vehicles reduce exhaust noise by about 15 dB(A) if they are in good condition. As an extremely good silencer can only reduce noise by a further 3 dB(A), and standards of heavy vehicle maintenance are usually high, so ensuring that silencers are kept in good condition, concentration on silencer improvement is unlikely to be worthwhile.

The two types of vehicle which could benefit from improved silencing are motor-cycles and sports cars.

As exhaust noise is caused by the sudden release of gases when the exhaust valve opens, careful attention to the characteristics of the exhaust valve and its timing can considerably reduce exhaust noise.

Engine Noise.

In diesel engines the main noise source is the rapid pressure rise after combustion, and this tends to dominate mechanical noise. In the petrol engine this pressure rise is smoother, and so mechanical noise is a more important noise source. By changing cylinder pressure time patterns, the noise produced by the pressure rise can be reduced.

An effective way to reduce the engine noise emitted by a vehicle is to enclose the engine in a sealed compartment of insulating material which is lined with a sound absorbent. An alternative method is to place damping material on the engine itself,so reducing cooling problems associated with the enclosure method.

Cooling Fan.

The noise produced by the cooling fan can be reduced by taking care over its aerodynamic design. By changing blade spacing the level of harmonics can be distributed over the operating range. Fans which operate at reduced speeds, when engine speeds are high, are effective in controlling fan noise.

Tyre Design.

At speeds over 30 m.p.h. tyre noise can be a major noise source from passenger cars. Less noisy tyre compounds can reduce this, as can randomizing of the tread pattern to break up sound harmonics and frequencies. Certain types of tyre wear can produce holes which cause 'singing' of heavy vehicle tyres. Attention to tread design could change tyre wear characteristics and minimise this effect.

Transmission Noise.

Little is known about the mechanism of transmission noise production. However, inclusion of the gearbox in a sound proofed engine enclosure helps to cut down the noise produced.

Aerodynamic Noise.

Aerodynamic noise from vehicles is most likely to be caused by vortex shedding. Levels of noise produced do not significantly contribute to overall external vehicle noise, although they do contribute to internal levels.

2.4.2 Reduction of Traffic Noise by Alteration of the Traffic System.

Vehicles produce the greatest noise levels when they are accelerating, and the noise of deceleration and braking can also be high. An obvious way to reduce this is to smooth the traffic flow as much as possible. Synchronized traffic light systems can achieve this to a certain extent, although British road systems are not often ordered enough to lend themselves to this technique. One way systems also smooth traffic flow, but tend to take traffic along roads which were previously quiet. Increased smoothness of flow means higher speeds, and therefore higher tyre noise.

The complete removal of heavy traffic from urban centres can be achieved by installing ring roads and by-passes. However, care should be taken to not bring the heavy traffic close to residential areas which will be much more affected by the noise than the mainly non-residential buildings on the main roads in urban centres.

2.4.3 Reduction of Traffic Noise by Barriers.

The positioning of a barrier made of brick, concrete, timber, or piled up earth, between major roads and housing can often be the the most effective means of reducing noise levels, although the effectiveness of this method is sometimes overestimated.

The extent of noise reduction due to a barrier depends on the sound shadow which it casts. Although this shadow is not as clearly defined as a light shadow, due to diffraction around the top and ends of the barrier, its size is greatly affected by its proximity to the road, and its effective height. Effective height is the height of a normal drawn from the top of the barrier to a straight line joining the source and receiver.

Theory due to Maekawa (13) for a semi-infinite screen shows that reduction in noise level for a single frequency is dependent on wavelength. This reduction ranges from 0 dB at $N = -0.3$, where

N = (2 x path difference)/wavelength, to 33 dB at N = 100. Path difference is the difference between the direct distance between source and receiver, and the distance between source and receiver via the top of the screen. This means that the transmitted spectrum is altered, resulting in greater reductions in L_{10} compared with L_{90}, which gives a less peaky character to the noise. Experimental results (14) show that attenuation of L_{10} varies practically linearly from approximately 15 dB(A) at a path difference of 0.2m. to 22 dB(A) at a path difference of 1.2m.

Due to diffraction of sound around the top and sides of a barrier, the noise reduction due to the mass of the barrier need only be to a level below that of the diffracted sound. This means a reductionof 10 - 20 dB(A), which would require a barrier of weight 10 Kg per sq. metre, providing that this was strong enough to withstand the ambient wind loadings.

Wind can greatly affect the performance of a barrier, increasing the level transmitted if the wind blows from the source toward the receiver, especially at the high frequency end of the noise spectrum.

If a barrier is to be installed, the attenuation which may already exist due to the ground effect should be considered, as it could reduce the expected attenuation, due to the barrier. Also, consideration should be given to the rather dull appearance of long lengths of barrier, and the increase in level caused by reflection of noise back onto the road.

Where new housing is being developed, the combination of housing and barrier into a barrier block can be very effective. These single aspect housing blocks should be as continuous as possible, as small gaps reduce barrier effectiveness greatly. They should also be as close to the road as possible, so as to maximise the sound shadow and waste as little of the shielded side of the site as possible. By designing these blocks with sound insulated windows facing the traffic, and with bedrooms and living rooms on the side facing away from the traffic, there should be no extra annoyance for their residents.

2.4.4 The Effects of Road Design on Noise Propagation.

An extension of the use of barriers is the placing of the road in a cutting. The type of cutting which reduces noise most has vertical retaining walls, but these can reflect noise on to nearby dwellings. Cuttings with sloping grassed embankments don't produce this problem, but can still be comparatively effective in reducing noise levels.

The use of tunnels would effectively remove the noise source from the receiver environment, but apart from their high cost, several other problems would be produced. Ventilation systems would have to be designed so as not to pollute the atmosphere with concentrated exhaust fumes. The tunnel itself would have to be treated acoustically to reduce internal noise levels. The effects of vibration on buildings above the tunnel would have to be considered.

The elevation of a road above the ground, especially in conjunction with barriers beside the carriageway, can produce a considerable sound shadow in the immediate vicinity, although noise levels further from the road will be increased as the elevation decreases the ground absorption effect. The level directly below an elevated motorway is in the order of 20dB(A) below that at the edge. However if the elevated road is built over an existing road, then multiple reflections can considerably increase the noise. Houses near to elevated roads can sometimes be shaded from the sun for most of the day, and generally such structures do not enhance the visual attractiveness of an area.

As tyre/roadway interaction causes a high proportion of total noise at higher vehicle speeds, the road surface used can effect noise produced. By changing the road surface from rough to smooth asphalt, noise levels from this interaction can be reduced by 5dB(A). However, smoother surfaces do not have good resistance to skidding, and as this is of major importance, it is unlikely that noise reduction can be approached through road surface design.

Noise received is reduced with distance from a road. Close to the road individual vehicles can be heard clearly, and L_{10} and L_{90} levels show a marked difference, but as distance from the road increases, L_{10} and L_{90} converge, and a general drone can be heard. This is because individual vehicles act as point sources, and the level produced by them reduces theoretically at 6dB(A) per doubling of distance, whereas the traffic stream acts as a line source, and noise from it reduces at 3dB(A) per doubling of distance.

Reduction of received noise by spatial separation of housing and roads is usually uneconomic, but is sometimes the only solution. The benefits obtained from the noise reduction must be compared with the cost of the acquisition of the land.

2.4.5 The reduction of internal noise levels.

If it is impossible to reduce noise levels by any other means, internal levels can be reduced by architectural modification of a dwelling. This should be considered as a last resort, as it has no effect on the external noise environment.

A comparatively simple method of reducing annoyance is to use rooms facing away from the noise source for noise sensitive activities. Reductions of external level for rooms facing away from a main road in suburban houses can be in the order of 15 to 20dB(A).

Normal lightweight walls and roofs give a reduction in the order of 35dB(A) under external levels. This is satisfactory in most situations. However, airbricks and chimneys provide negligible attenuations, and closed external doors and windows can at best attenuate external levels by 25dB(A).

Chimneys are usually shielded from the sound source, and so provide no real problem. However, a single airbrick can be a major weak point, reducing the resistance of a wall by as much as a half. This problem can be reduced greatly by shielding the airbrick, or making it noise absorbent.

The reduction in noise due to a door can be increased by making the door very solid and improving its sealing when closed. However this is difficult in practice. Satisfactory reductions can be obtained by using a sealed porch with a second door, an open porch facing away from the source, or a wall between the door and the source.

An attenuation of 30dB(A) can be obtained using a sealed window of 10m.m. glass with a ventilation fan set into it. A double window with a staggered opening can provide attenuations of 20dB(A) when open, and 33dB(A) when closed. If these methods do not reduce internal levels sufficiently, then the most effective, but most expensive alternative is full double glazing. Attenuations in the order of 40dB(A) can be obtained using sealed panes at least 8 inches apart, with the reveals lined with a sound absorbent material. As windows cannot usually be opened, some form of ventilation system is required, adding to the cost. The increased solar gain due to these windows can be reduced by incorporating venetian blinds between the panes.

A certain amount of absorption can take place within a room if it is furnished, especially if the ceiling is low. A reduction of 6dB(A) can be obtained in a fully furnished and carpeted room, compared with an unfurnished room.

2.4.6 Recent Government recommendations and legislation relating to traffic noise.

The Wilson Committee 1963

In their final report in 1963 (15), the Wilson Committee made no specific recommendations about traffic noise levels. However they did make some tentative suggestions of levels which should not be exceeded in the living room or bedrooms of a private residence, for more than 10% of the time.

The suggested levels were 40dB(A) by day and 30dB(A) by night in country areas, 45dB(A) by day and 35 dB(A) by night in suburban areas, away from traffic routes, and 50dB(A) by day and 35dB(A) by night in busy urban areas. Precise definitions of "day" and "night" were not given.

As external noise can be expected to be attenuated by 20dB(A) if windows are closed, the implication of the 50dB(A) maximum level for busy urban areas is that the maximum external noise should be 70dB(A).

These criteria were widely accepted by planners, and adopted as 'desirable standards' by the G.L.C. in 1970.

Department of the Environment Circular 1973.

The circular to local authorities and joint planning boards, which was entitled "Planning and Noise" (16) defined the criteria which were to be used by the Secretaries of State in taking planning decisions, and urged local authorities to also use them. It recommended a liason between local planning authorities, highway authorities, and public health authorities when dealing with noise problems.

It suggested that noise sensitive development should be separated from major roads if possible, and if this could not be done, then it should be sited and designed to minimise noise. Also, residential areas should not be developed in areas likely to be subjected to high noise levels. The limit of the acceptable should be taken as an L_{10} value of 70dB(A), averaged over 18 hours, and measured 1 metre from the facade, as recommended by the Noise Advisory Council in 1971 (6). Acceptable levels should be taken as lower than this if possible.

The Department of the Environment's Design Bulletin 26 (17) was commended for its criteria, concerning new development. These were that sites likely to be subjected to L_{10} levels greater than 70dB(A) should not be used for development, but if there was no alternative, then barrier blocks should be utilised. No dwelling should have an interior L_{10} level greater than 50dB(A), 40dB(A) being a 'good' standard. The prediction method for noise levels set out in this bulletin was recommended, and prediction of levels for up to 15 years ahead was advised.

Motor Vehicles (Construction and Use) Regulations 1973.

These regulations (18) attack the traffic noise problem at source, by specifying noise levels not to be exceeded by vehicles, and standards of construction, maintenance, and driver behaviour, which are designed to limit noise emission.

Construction

Every internal combustion engined vehicle must be fitted with a silencing device which reduces the noise caused by escaping exhaust gases as much as may be reasonable.

Maximum levels of noise which may be emitted by new vehicles, when measured 1.2m. $\pm$ 0.1m. above the ground, and not less than 5.2m. from the nearest part of the carriageway on which the vehicle is travelling are specified. The level stated for a motor car is 85dB(A), and for a heavy goods vehicle or large passenger carrying vehicle it is 92dB(A). The meter used should be to the 1962 standard B.S.3539.

Use

A silencer must always be fitted between the engine exhaust and the atmosphere, and it must be maintained in good and efficient working order, and not altered so as to increase the noise emitted.

A vehicle must not be used on a road, if the level, measured as in the construction regulations, and with certain restrictions on the height of physical objects surrounding the microphone, exceeds a specified level, provided that the level of noise measured after the vehicle has left the measurement zone is 10dB(A) below the recorded peak. The level stated for a motor car is 88dB(A), and for a heavy goods vehicle or large passenger carrying vehicle, it is 92dB(A).

A vehicle must not be used in such a manner as to cause any excessive noise which could have been avoided by the exercise of reasonable care on the part of the driver.

Audible warning instruments must not be used, except in emergency, when a vehicle is stationary, or between 2300 and 0700 in a built up area.

Enforcement of the silencer regulations is straightforward as evidence of deterioration or tampering is enough to secure a prosecution, but roadside checks with a meter prove difficult as restrictions on the position of the microphone relative to the carriageway and reflecting objects, and on the presence of other vehicles during measurement, as well as the ease with which a driver may temporarily reduce noise output by easing off the throttle, do not make enforcement of the regulations cost effective.

The Noise Insulation Regulations 1973.

Powers under Section 20 of the Land Compensation Act (19) led to the formulation of the Noise Insulation Regulations (20). These are designed to reduce noise levels within homes, when new highway development has caused, or is likely to cause, unsatisfactory levels.

Dwellings are deemed eligible for compensation if the 18 hr. L_{10} level I metre from the most exposed window in the facade, either calculated by applying the method described in DoE Design Bulletin 26 (17), using predicted traffic flow rates and speeds for the next 15 years, or measured and adjusted to take account of probable changes in flow and speed over 15 years, exceeds 68dB(A). Measurements must be taken when the road is dry, and if a wind is blowing it must be away from the road and towards the microphone, and not register as a noise source,with the meter set for the traffic noise.

If a highway, or new carriageway on a highway, was first open to the public after 16th October 1972, the highway authority must make a grant for insulation work, or carry out the work, for all eligible dwellings and other residential buildings. The power to make grants or carry out insulation work is also provided if existing highways are altered.

Under the regulations, the insulation to be provided consists of double glazed windows in the affected facade and double doors in the exposed facade if feasible. The ventilation unit and ducting required by these alterations must also be installed. These measures can be expected to give an approximate 40dB(A) attenuation.

3. Traffic noise prediction methods.

3. Traffic Noise Prediction Methods.

Since 1963 several studies have taken place to attempt to relate traffic parameters such as vehicle flow rate, mean speed, percentage heavy vehicles, to the noise levels produced. These have been based on the method of measurement of the noise produced by a traffic flow with certain parameters, and relating the noise to those parameters.

3.1 National Physical Laboratory.

A report by Johnson and Saunders in 1968 (21), gave the results of a field study which took place between 1963-64. This had been primarily initiated to assess levels of noise which were current at the time, but traffic parameters were also measured.

Noise measurements were taken using a microphone connected to an amplifier level recorder, and statistical distribution analyser, set for a 0.1 second count. 15 minute readings were taken throughout the day when the roads were dry. 85 samples were obtained 25 ft. (approx. 7.5m.) from the centre of the nearside flow, and 1.2m. above the ground, at nine sites situated on five straight and level sections of major roads or motorways. At the same time velocities were measured using a radar meter, and flows were counted in terms of light vehicles, heavy vehicles, and motorcycles. Also, over 100 measurements were taken at distances up to 61m. from the various roads.

Analysis of the results gave an expression for L_{50} in the form:-

$$L_{50} = 51.5 + 10 \log_{10} Q/d + 30 \log_{10} \bar{V}/40 \text{dB(A)}.$$

Q = vehicles per hour.
d = distance from datum line in feet.
$\bar{V}$ = mean velocity in m.p.h.

The average measured traffic composition of 20% heavy vehicles was assumed.

The equation represents an increase of 3dB(A) for doubling of density, or halving of distance, and a 9dB(A) increase for doubling of velocity.

This result compares favourably with two equations put forward at the 5th International Congress on Acoustics, and a third by Rathé.

The equations, due to, (a) Nickson (22), (b) Lamure (23), and (c) Rathé (24) were:-

a) $L_{50} = 50 + 10 \log_{10} \frac{Q}{d}$ dB(A) at 40 m.p.h. with 10% heavy vehicles.

b) $L_{50} = 52 + 10 \log_{10} \frac{Q}{d}$ dB(A) for densities from 1200-5000v/h with not more than 15% heavy vehicles.

c) $L_{50} = 49 + 10 \log_{10} \frac{Q}{d}$ dB(A).

From the results a prediction chart was formed, with an associated system of correction factors for the acoustical environment. This included the attenuation rates indicated in Table 1. These rates were obtained from the measured data.

Table 1.

Average excess attenuation due to ground absorption.

Ground Surface	Attenuation rate (dB/100 ft.)
Short grass, rough earth	1.0
Very rough grass land, 2-3 ft. long grass or cornfield (light density growth)	2.0
Thick undergrowth, dense cornfield (fully grown)	5.0

A straight line was fitted to the data relating increase of level to change in percentage of heavy vehicles. This indicated an increase in L_{50} of 2dB(A) when the percentage of heavy vehicles increased from zero to 40%, so that the contribution from heavy vehicles would appear to be small.

Comparisons were carried out between measured values of L_{50} and values calculated using the prediction method that had been evolved. An overall standard deviation of 1.17dB(A) was obtained, but it must be noted that a small standard deviation would be expected between predictions and the noise measurements from which the prediction was evolved.

3.2 G.L.C. Urban Design Bulletin 1970.

This Bulletin (25), attempted to simplify the prediction of traffic noise by quoting levels of noise which could be expected from different types of road, and providing a series of protractors giving noise attenuation contours for different screening situations. However the method can be criticised for being too simple, giving recommended values of kerbside L_{10} as 83 dB(A) for motorways, and 76 dB(A) for class 1 roads, with no account taken of traffic conditions.

The shielding data was calculated assuming point sources of noise, although a line source is likely to be a closer approximation to the true situation. Also, attenuation due to a barrier had to be added to the attenuation due to propagation over open grassland, although in reality the barrier reduces the effect. These two factors would lead to very optimistic attenuation figures.

3.3 Building Research Station 1971.

B.R.S. Digest 135 (26) presented a detailed prediction method based on data obtained by Johnson and Saunders (13). The basic prediction was by means of a graph relating 18 hr. L_{10} at 30m. from the nearside edge of the carriageway to number of vehicles per 18 hour day. This level was for a point 1m. from the house facade, with a 75 km./hr. mean traffic velocity, and 20% heavy vehicles, together with a 10 km./hr. wind from source to receiver. The graph was obtained from the equation:-

$$L_{10} = 7.5 \log_{10} \text{(flow per 18 hours)} + 41.5,$$

for the above traffic conditions.

Once this level had been obtained. it could be adjusted for change in traffic speed. gradient and distance from carriageway. Also the effects of attenuation over soft ground, and of barriers, as well as reflection effects due to buildings could be accounted for. These adjustments were provided by tabular or graphical means.

This method gives an increase of 4.5dB(A) in L_{10} per doubling of flow, an increase of 11dB(A) per doubling of speed, an increase of 1dB(A) for an increase of percentage heavy vehicles from 20% to 40%, and a decrease of 4dB(A) per doubling of distance from the carriageway.

More recent calculations (27) have shown that this method overestimates the effect of mean speed on L_{10}, and underestimates the effect of heavy vehicles. The shielding data is based on point sources, whereas traffic behaves more as a line source. Attenuation rates over soft ground are based on mean path height only, with no account taken of distance, which seems unlikely to be the case.

The more recent B.R.S. Digest 153 (28) updates the method with a few minor, but unexplained, alterations, but still contains the same limitations.

In spite of its limitations, the B.R.S. Digest 135 forms the basis of the Department of the Environment's Design Bulletin 26 (17). Predicted values of traffic parameters for the 15 years following the calculation are used to find 18 hr. L_{10} levels using the above method. The Bulletin also describes measurement procedures which should be adopted, and gives some possible solutions to the traffic noise problem.

3.4 National Physical Laboratory 1972.

Having taken noise measurements at a range of urban sites, Delany (27) found that actual levels did not compare well with those predicted using Johnson and Saunders' method (21). The actual effect of mean speed seemed to be half of that indicated by the prediction, and the contribution due to heavy vehicles seemed much greater than the prediction would indicate.

The original data obtained by Johnson and Saunders was reanalysed using a multiple regression technique. Additional measurements taken by Delany were added to the data.

The resulting equations were of the form:-

$$L = a + b \log v + c \log Q + dp$$

where L = percentile level at 7.5m. from centre of flow of nearside carriageway.

v = mean velocity km./h.

Q = vehicles/hour

p = percentage heavy vehicles

a,b,c,d are regression coefficients.

Centre of flow is defined as the mid-line of the road if it has two or three lanes, and the mid-line of the nearside two lanes, if the road has four or more lanes.

Table 2 indicates Delany's regression coefficients.

Table 2. Regression coefficients for noise level at the reference distance of 7.5m. from the traffic stream.

L dB(A)	a	b	c	d	Correlation coefficient r
L_{10}	17.56	16.36	8.97	0.118	0.92
L_{50}	-2.0	12.72	15.01	0.0941	0.91
L_{90}	-24.34	9.97	21.30	0.0755	0.89

The range of the variables covered by the field data was:-

v 50 - 101 km./h.

Q 780 - 4500 vehicles/h.

p 4 - 52%

Delany warns against extrapolation beyond these limits.

The regression coefficients show that L_{10} increases by 4.9dB(A) per doubling of speed, L_{50} increases by 3.9dB(A), and L_{90} increases by 3.0dB(A). L_{10} increases by 2.7dB(A) per doubling of flow, L_{50} by 4.5dB(A), and L_{90} by 6.1dB(A). L_{10} is most affected by the percentage of heavy vehicles.

Data on levels at various distances back from the stream with various surfaces was also analysed, and the results are given in Table 3.

Table 3. Mean attenuation rates for propagation over open ground (coefficient of log d, where d is the distance from the traffic stream).

L dB(A)	Concrete	Grassland	Cultivated Ground	Standing Corn
L_{10}	10.5	14.8	18.1	21.9
L_{50}	8.4	11.1	14.4	16.6
L_{90}	6.1	8.2	10.7	11.4

The range of distances covered was 7.5m. - 160m.

The above results were obtained by independent consideration of L_{10}, L_{50} and L_{90}. However these coefficients did not entirely reflect the Gaussian distribution of level which is known to be a good estimation of the real situation. Therefore the regression coefficients were relaxed slightly to linearise them, which brings them into line with the Gaussian distribution. Linearised prediction results were compared with measured noise levels. For open grassland situations the worst discrepancy was for L_{90}, where standard deviation was 1.42dB(A). However for the other propagation situations standard deviations reached high values for L_{90} (3.81 for cultivated ground), and only the coefficients for open grassland were given (Table 4).

Table 4. Summary of linearised regression coefficients for noise level prediction for propagation over open grassland.

L dB(A)	a	b	c	d	e (coefficient of log d)
L_{10}	31.0	16.2	8.9	0.117	14.7
L_{50}	7.1	13.0	15.1	0.096	11.4
L_{90}	-16.8	9.8	21.3	0.75	8.1

The standard deviations of the prediction error for L_{10}, L_{50}, L_{90} are given as 1.7, 1.49 and 1.63 respectively.

Delany followed this report with a practical prediction method for calculating L_{10} (29). This was based on the above results, with a few modifications, but the method was tabular and graphical, rather than by equations. The reference distance had been moved from 7.5m. to 10m. because the former distance had sometimes been too close to the stream, and the basic equation had been changed accordingly. Also, due to the general increase in intrinsic noise level since the data had been collected in 1963/64, the equation was adjusted so that L_{10} predictions increased by 1.2dB(A).

Basic L_{10} for 2000 vehicles/hour, 20% heavy vehicles, and 80 km./h. mean speed at 10m. from the stream was given as 80.6dB(A). This could be adjusted for change in parameters using tables. Attenuations for various road configurations could be calculated from a series of noise contours, as could attenuations due to side roads and barriers.

Accuracy of this practical method is given as being within ± 2dB(A) of measured values.

4. The Physical Study.

4. The Physical Study.

4.1 Proposed Method.

Using the results of this study it was desired to compare measured L_{10}, L_{50} and L_{90} levels at intersections controlled by traffic lights, with levels given by a free flow prediction method when traffic parameters for the sites were utilised. It was assumed that the difference between actual and predicted levels would decrease with distance from the intersection until free flow conditions occurred, when the difference would remain constant at zero.

The sites chosen had traffic flows which were heavy enough to ensure that any changes in character over free flow would be easily observed. Also, as several visits to each site had to be made, they were chosen so that they were within easy driving distance of Loughborough.

They were:-

1) Southfields Park, Loughborough, where the A6 Leicester to Derby road is crossed by part of Loughborough's one way system. (Buildings close to the road on one side, and a low wall bounding open ground on the other).

2) Tamworth, at the junction of the A453 Nottingham to Birmingham road, and the A5 (Watling Street). (Mainly hedges and fields).

3) Rothley, at the junction of the A6 and a minor road, the B5330. (Dwellings set back from the road on both sides.)

In the analysis, no account was to be taken of traffic light sequencing, the effect of vehicle concentrations on tail back, or the effect of vehicle concentrations on the light sequencing. This was because it was felt that the complex interaction between these three factors would involve a considerable amount of study and measurement, which would not be suitable for a work of this nature where the investigation of general trends at typical major road intersections was involved.

In order to obtain a range of values of vehicles per hour and percentage heavy vehicles, measurements were to be taken throughout the working day, but no measurements were to be taken during the quieter night period as flows would probably be too low to yield significant results.

4.2 The Prediction Method.

One of the prediction methods outlined in Chapter 3 was to be chosen for application to the interrupted flow sites. The main choice was between the two most up to date methods, Design Bulletin 26 (17), and the N.P.L. method of Delany (27) (29).

Account was taken of Delany's criticism of the alternative method, and it was therefore decided to apply his N.P.L. method. The original equations were used, as the practical method of the second report (29) did not lend itself to computer methods, and only gave L_{10}. Also, as the consolidated procedure from the first report was only considered accurate enough in the open grassland situation, and several types of surface were encountered at the sites, the original regression coefficients given in Tables 1 and 2 were used.

The prediction method, which was designed for the free flow situation, had to be adapted for intersections. The main flow (flow beside which the microphone was placed), and cross flow, were treated separately. As flows at intersections do not entirely go straight across, with some vehicles turning to right or left, it was difficult to define rate of flow for main or cross flow. Also, for most of the time one operator had to operate the equipment and measure vehicle flows alone, which would have made measurement of flows for all types of vehicle behaviour at the intersection a difficult task, probably leading to error. Therefore, total number of vehicles, divided into heavy or light vehicles, entering the intersection from all directions were counted. This total was then halved to give main flow and cross flow. This assumption was likely to be reasonable for sites 1 and 2, but for site 3 the ratio of main to cross flow was more in the order of 4:1. However, the equal flow assumption was utilised for all three sites, to provide some consistency of analytical procedure.

The predicted main and cross flow levels for each noise sample were obtained by substituting vehicle flow per hour and percentage heavy vehicles obtained during measurement into Delany's equations, using the assumed 1:1 traffic split. Average velocities for vehicles crossing the intersection were estimated on site and used in the prediction. Measurements were taken at 7.5m. from the centre of main traffic flow, as defined in Chapter 2, this being Delany's original reference distance, and at various distances from the centre of cross traffic flow. As the prediction using the 1:1 split gave levels for 7.5m. from the main flow, and 7.5m. from the cross flow, the contribution to total level due to the cross flow was obtained by using the relevant attenuation rate from Table 3, for d = distance from centre of cross flow to measurement position. The predicted level for the measurement position could then be obtained by combining the main flow contribution (prediction at reference distance) and cross flow contribution (prediction at reference distance corrected for distance from centre of cross flow to measurement position), by decibel addition (where two levels of x dB(A) give a total of $x + 3$ dB(A)). An example of this procedure is given in Appendix F.

4.3 Noise Measurements.

As stated above, a series of measurements were made at 7.5m. from the centre of flow of the main stream, and at varying distances back from the cross flow. These were between a point as close to the intersection as the configuration of the site allowed, and the point beyond which free flow conditions could be assumed. It was proposed to take five measurements at positions 20m. apart, but site constraints and characteristics caused some variation from this procedure, as described in section 4.5 below. Each noise sample consisted of a tape recording which lasted for six minutes, during which traffic flow and composition were noted, enabling flow per hour to be calculated.

To minimise the number of variables involved, only one road side out of the eight available at each intersection was used. This was always chosen so that vehicles approaching the intersection were nearest the microphone, so that the effects of tail back would be greatest.

The choice of which of the four appropriate stretches of road at each intersection to use was governed by its suitability for setting up the measuring equipment at the required distance from the traffic stream.

The final choice of stretches of road beside which to measure were:-

Site 1. On the A6, approaching Loughborough.

Site 2. On the A453, leaving Tamworth.

Site 3. On the A6, leaving Leicester.

4.4 Equipment.

The sound level meter used was a Brüel and Kjaer 2205 meter set at "A" weighting, with a 4117 piezo-electric microphone, covered with a foam windshield. This was connected to a Nagra 1V-S tape recorder, running at 7½ inches per second.

Each tape was calibrated when it was started, using a B and K calibrator which gave a 94dB(A) tone at 1000 Hz.

The meter was placed on a tripod 1.2m. above the ground.

4.5 Procedure on site.

Measurements were carried out over several days for each site, so that the tapes could be analysed between sets of readings. Roads had to be dry, and wind velocity had to be minimal for measurement to take place.

The first requirement was determination of the "free flow" point beyond which predicted levels and actual levels could be expected to be similar. The meter was set up at 7.5m. from the main stream, and at various distances back from the cross flow. As stated above, it was intended to start as near as possible to the cross flow, and progress back in 20m. steps to a point approximately 150m. from the cross flow. However, the actual distances varied due to site constraints such as trees, lamp posts, parked cars, traffic light control boxes etc., which could have affected readings if the microphone had been too close to them.

A six minute recording was taken three times at each position, with at least one of the recordings at a peak time and one off peak. At the same time, numbers of heavy and light vehicles entering the junction were noted and summed and multiplied by ten to give total flow per hour, as well as percentage heavy vehicles. Heavy vehicles were identified as anything larger than Ford Transit size. Average velocity across the intersection was estimated by driving with a traffic stream as it crossed, and noting speedometer reading. This was carried out several times throughout the day to take account of varying conditions. From this the following estimated velocities were obtained:-

Site 1.....40 km./h.

Site 2.....50 km./h.

Site 3.....60 km./h.

Although velocity for site 1 was below Delany's recommended limit of 50 km./h., it was felt that extrapolation was justified here, where the Delany formula was being used as the basis for a new study of a specific situation.

The traffic parameters were placed into Delany's equation, adapted as above for the intersection situation. The tapes were analysed as described in 4.6, and L_{10}, L_{50} and L_{90} levels obtained. These levels were then compared with predicted levels to obtain the point where they were within $\pm$ 2dB(A) of each other. L_{10} appeared to show an increase over prediction further from the intersection than L_{50} and L_{90}. Therefore the furthest point at which readings were taken was obtained by observing where L_{10} was within $\pm$ 2dB(A) of the prediction. Individual scatter was marked.

Two further recordings were then taken at each of the original positions, up to the "free flow" point, and the tapes analysed. Now, when actual level minus prediction was plotted against distance from the intersection, a definite linear tendency was observed, in spite of individual scatter. Positions where behaviour of the graph was in doubt due to scatter, or a change in character, had further readings taken at them to clarify the situation. Time constraints meant that some of the "fill in" positions had only two readings taken at them. Sites 2 and 3 had to have readings taken beyond the original "free flow" point, as it became obvious that the scatter of the original readings had been misleading.

Finally, 38 six minute samples were obtained at Site 1, 49 at Site 2, and 46 at Site 3, yielding a total of 133 samples.

4.6 Analysis of tapes.

The tapes were played back through an amplifier into a B and K 2305 level recorder, connected to a B and K 4420 Statistical Distribution Analyser. The analyser was used to give a cumulative frequency plot of the noise sample, in 5dB(A) groupings. From the frequency plot the L_{10},L_{50} and L_{90} percentile levels (see Appendix A), were obtained.

5. Results of the Physical Study.

5. Results of the Physical Study.

5.1 Individual results.

The individual values of actual L_{10}, L_{50} and L_{90} less predicted L_{10}, L_{50} and L_{90} which were obtained for the different positions at each of the three sites are shown in Appendix B. To indicate the type of range of vehicle flow and percentage heavy vehicles which was encountered, values of their means and standard deviations were calculated for all the sites. These were:-

Site	Mean v/h (s.d.)	Mean % heavy vehicles (s.d.)
Southfields	1440 (234)	16.5 (5)
Tamworth	983 (249)	28.3 (7.2)
Rothley	987 (133)	18.2 (3.8)

5.2 Regression analysis.

The results show a great deal of scatter, but when individual points, representing difference against distance from intersection, were plotted, the general linear trend was still observed. It was therefore decided to try to fit a straight line to the data points for L_{10}, L_{50} and L_{90} differences for each site. This was achieved by using linear regression methods (see Appendix A) to give the equation $y = mx + b$ of the best line through the points. Correlation coefficient, r, was obtained for each line. The results are shown in Table 5.

Table 5 shows that, although there is some consistency of behaviour between sites, there is not enough agreement for firm conclusions to be made.

L_{10} shows the greatest agreement between sites, with the regression coefficient of - 0.02 occurring for each. Value of the gradient is more significant than the constant, as the constant is affected by the value of velocity used in prediction. As velocity is estimated, error in estimation would be reflected in the constant (constant too large by 4.9dB(A) if velocity underestimated by half when calculating L_{10}).

Table 5. Values of regression coefficient m, constant b and correlation coefficient r obtained from linear regression of difference between actual level and predicted level against distance from intersection.

	Site	m	b	r	No. of cases
L_{10}	Southfields	- 0.02	4.82	- 0.31	38
	Tamworth	- 0.02	3.05	- 0.26	49
	Rothley	- 0.02	3.11	- 0.42	46
L_{50}	Southfields	- 0.01	3.93	- 0.10	37
	Tamworth	- 0.05	6.46	- 0.57	49
	Rothley	+ 0.07	0.42	+ 0.60	45
L_{90}	Southfields	0	7.25	0.01	37
	Tamworth	- 0.05	10.55	- 0.45	49
	Rothley	- 0.03	9.55	- 0.33	45

The low values of r (maximum possible value = $\pm$ 1) indicate the high degree of individual scatter. However the level of significance in the L_{10} case varies from just worse than 0.05 for Tamworth, to better than 0.01 for Rothley, showing that there was some justification in assuming the linear trend for L_{10}.

Results for L_{50} and L_{90} show that extension of the linear assumption to these cases is unlikely to be as valid as for L_{10}. Three of the six regression lines involved show the expected behaviour of negative gradient with a good level of significance, one shows the expected behaviour but with low correlation coefficient, one shows a positive gradient with a high correlation coefficient, and one shows zero gradient and practically zero correlation.

5.3 Combination of the three sites.

As the purpose of the study was to show general trends, and linear behaviour seemed to be a fair approximation in at least some of the cases, it was decided to carry out a linear regression analysis on results from all three sites grouped together. Assuming velocities were estimated accurately, this would yield a result for major roads with intersections where the noise receiver was away from any major reflecting object, as was the microphone at the three sites studied.

The regression analysis gave the results shown in Table 6.

Table 6. Regression analysis results for all sites.

	m	b	r	No. of cases
L_{10}	-0.01	3.21	- 0.21	133
L_{50}	-0.03	5.62	- 0.37	131
L_{90}	-0.03	9.55	- 0.31	131

The variation in number of cases was due to the attenuator setting on the meter being too high in two cases leading to a loss of L_{50} and L_{90} readings.

The correlation coefficients indicate a high level of significance for all three lines (for 133 cases $r = \pm 0.22$ gives a significance level of 0.01), although individual scatter is high.

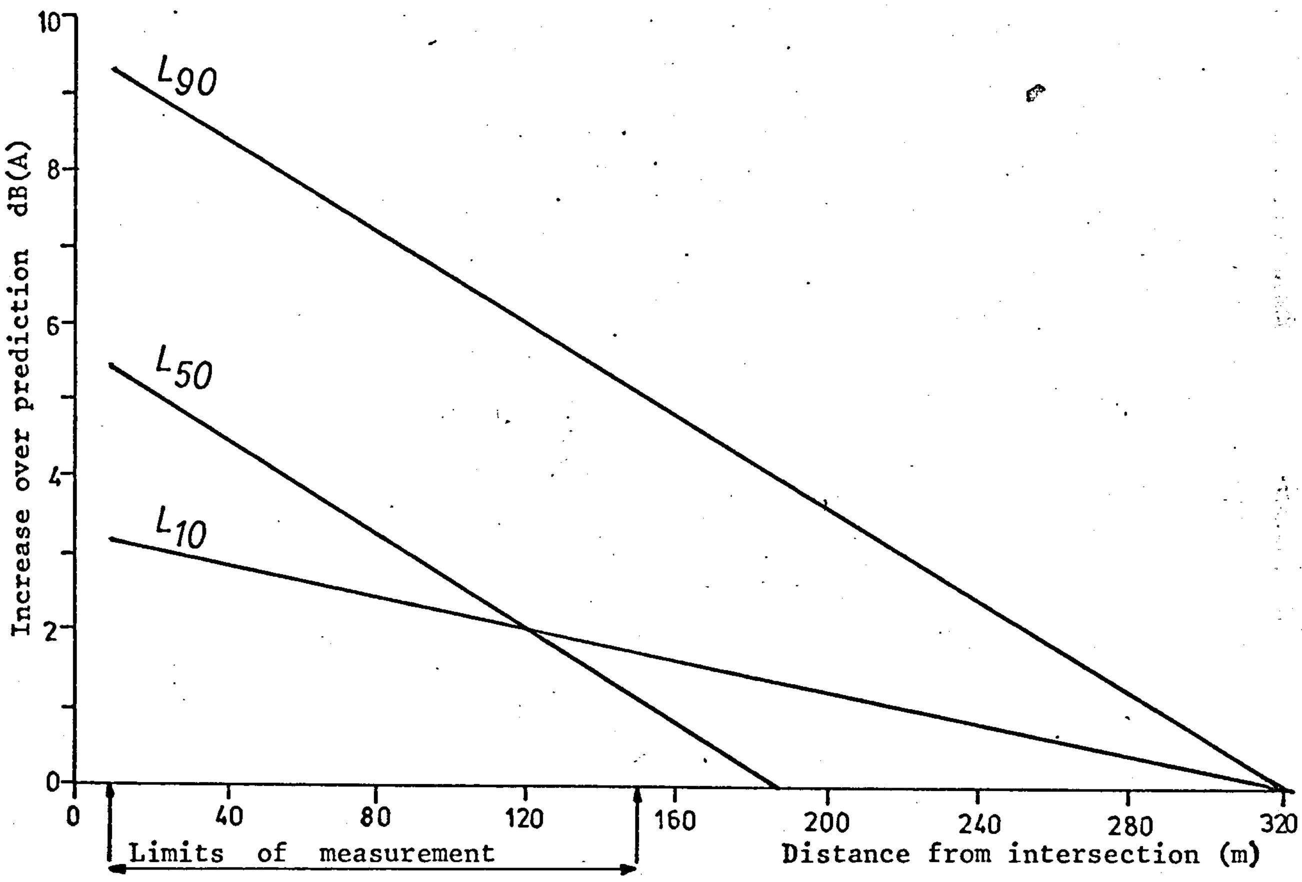
Fig. 1 shows the overall regression lines obtained by the analysis.

5.4 Discussion.

The results shown in Table 6 and Fig. 1 indicate that the linear assumption is an adequate model of the general trend in noise characteristics, although application to a specific case should be treated with caution.

The fact that the results are based on estimated velocities should be noted. Also linear extension of the regression lines beyond the 150m. point is assumed, but there are no measurements to back this up because the original fixing of "far" points was affected adversely by the high

Fig 1. Regression lines of increase of actual noise level over prediction against distance from centre of intersecting flow.(All sites combined)



degree of scatter of results. Therefore linear behaviour down to the "free flow" points is only an estimate based on behaviour up to the farthest measurement position from the intersection.

The increase in L_{50} and L_{90} observed in Fig. 1 is likely to be caused by stationary vehicles queuing at the lights with engines revving, thus raising background and mean levels close to the stop line. The increase in L_{10} can be ascribed to the effects of acceleration of vehicles away from the lights at a rate which is less than that for L_{50} and L_{90}, as vehicles are usually accelerating away from the lights beyond the point at which the traffic queue approaching the lights ends.

The noise output from an individual vehicle will decrease as it comes to a stop, unless changing down is carried in such a way as to raise engine speed greatly or if brakes are applied so as to cause a skid. This decrease of output would lower L_{10} levels, but the noise from accelerating vehicles leaving the intersection would appear to dominate this effect. Tyre noise is mainly a function of speed, and this is therefore a practically negligible contributor to levels for a vehicle accelerating from rest, although tyre squeal from hard acceleration, braking and cornering could occasionally contribute to levels.

Many factors influence noise characteristics at intersections. Already mentioned has been light sequencing and its relationship to vehicle concentration and tail-back. Driver behaviour, which varies greatly between individuals and types of vehicle, is also an important factor. If all vehicles tended to change gear at a certain position, the houses close to this position could be subjected to lower levels than at positions further from the intersection because of the vehicles coasting during the change. Some drivers will drive smoothly and anticipate the lights changing to red, while others will be caught out and brake hard, and others will accelerate when approaching a green light to ensure that they will get across. Tyre squeal due to insensitive driving has been mentioned above.

Taking into account the complex nature of noise at intersections, being due as it is to a series of individual vehicles, all with different noise characteristics and driver behaviour, which are either accelerating or braking, and which are affected by light sequencing and vehicle concentrations, it can be seen that the problem of analysis is a very complex one. The high degree of scatter found in the results of the study can be attributed to these complex factors to a certain extent. However, given that the effects of these variables have not been considered separately, but as a whole, the satisfactory correlation coefficients for the linear regression lines obtained for the three sites taken together give an adequate interim indication of noise characteristics at major road intersections in the absence of data from a more detailed study.

Further work is needed to test the validity of the findings of this study, and the author suggests that this should commence with the study in depth of characteristics at a single intersection. A multiple regression analysis relating noise levels to factors such as velocity, traffic composition, vehicle concentration, distance of measurement point from lights, length of tail-back, effect of tail-back on light sequencing etc., based on a large number of measurements at a single intersection, would yield valuable results. Simplifying the problem further, a possible approach would be to measure levels at a pedestrian controlled crossing with stop lights, on a normally freely flowing road, so as to compare free flow and interrupted flow levels for the same measurement position. The lights could be activated at will to provide the interrupted situation. A French study (30) has taken place on levels due to individual vehicles when accelerating or braking and an extension of this work to a flow of vehicles, either theoretically or experimentally would be useful.

6. Traffic Noise Surveys.

6. Traffic Noise Surveys.

6.1 Introduction.

Subjective response to traffic noise varies considerably between individuals. No one noise parameter has yet been defined which adequately explains noise annoyance and reduces the degree of individual scatter. A considerable amount of work on this has been carried out in several countries, but conclusions reached vary between studies. This work usually takes the form of a survey combined with noise measurements, so that reaction to noise as measured by survey results can be related to various noise parameters.

6.2 Previous surveys designed to relate annoyance to traffic noise exposure.

6.2.1 The Traffic Noise Index Survey.

In 1968, Griffiths and Langdon reported on a survey which was carried out in North West London to investigate the relationships between dissatisfaction and noise levels (8) at 14 sites.

The sites chosen were designed to have flows proportionally representative of traffic flows throughout Britain, on straight and level dual or single carriageways with free flow, and with no other noise source but traffic. Housing at the sites was chosen to be of one type so that standards of sound insulation, and social class of the occupants, could be taken as being comparatively invariant.

Noise levels were tape recorded 1 metre from the facade in front of the first floor windows for 100 seconds per hour for 24 hours. L_{10},L_{50} and L_{90} levels were obtained by feeding the recordings into a statistical distribution analyser.

Although the questionnaire consisted of several items, the results were based on a single seven point semantic differential scale labelled:- Definitely satisfactory - Definitely unsatisfactory, referring to the acoustical environment.

When the results were analysed, the mean L_{10} was found to be 69dB(A), with a range of 62dB(A) to 76dB(A), mean L_{50} was 61dB(A), with a range of 54dB(A) to 61dB(A), and mean L_{90} was 54dB(A), with a range of 48dB(A) to 54dB(A), which means that quieter sites in Great Britain were unlikely to be represented.

1200 people answered the questionnaire. Correlations between L_{10}, L_{50} and L_{90}, and dissatisfaction as measured by the seven point scale, were low. Taking the median dissatisfaction score per site and correlating it with L_{10}, L_{50} and L_{90} gave the higher coefficients of 0.51, 0.35 and 0.19 respectively, showing that individual variability was high among the respondents. The mid-point of the seven point scale seemed to have been used as a "don't know" response, and so all respondents with a score of 4 were excluded, leaving 77% of the original number of replies. Correlation coefficients between L_{10}, L_{50} and L_{90}, and dissatisfaction now increased to 0.6, 0.45 and 0.26 respectively, but they were still not highly significant.

It was thought that better correlations could be obtained if the variability of level, $(L_{10} - L_{90})$, was taken into account. High correlations between $(L_{10} - 0.75L_{90})$ and dissatisfaction were obtained. To make this index free from fractions and easier to work with, it was put into the form $4(L_{10} - L_{90}) + L_{90} - 30$, and called the Traffic Noise Index. Correlation coefficients between T.N.I. and median dissatisfaction were 0.81 with scores of 4 included, and 0.88 without them.

6.2.2 <u>The London Noise Survey</u>.

The survey entitled "Noise Annoyance in Central London" was carried out by McKennell and Hunt for the Building Research Station in 1961 (3).

257 locations were chosen randomly within 35 - 40 square miles of Charing Cross. Noise measurements were taken at these locations, and contours around each location within which noise exposure could be expected to be constant were defined. Within these contours a maximum of

five respondents was chosen. This gave a total of 1008 respondents at 226 sites, the remainder of the sites containing no dwellings.

The noise measurements gave L_{10} and L_{90} day time averages, L_{10} and L_{90} night time averages, and L_{10} values for 9-10 p.m. The hour of the morning when the noise level changed significantly from night to day values was also noted.

Annoyance scores obtained from several question responses were compared with associated noise pararmeters; no significant correlations were found. This was put down to a possible combination of the following three factors:-

1. As distance between microphone position and respondent's house could be as much as 100 yds, considerable attenuations could occur in certain circumstances. This had been taken into account, but it had been hoped that the averaging process over all the house positions considered would still allow a certain amount of correlation to occur.

2. Examination of the distribution of noise encountered showed that extremes of level were not significantly represented. This would be expected to reduce discriminative power of the measurements to a certain extent.

3. Personal susceptibility to noise varies considerably between individuals. This scatter would be expected to greatly affect results in this type of situation, where levels encountered are comparatively invariant.

6.2.3 Traffic Noise in Residential Areas (Sweden).

This report, produced by the National Swedish Institute for Building Research and the National Swedish Institute of Public Health in 1968 (31), compared questionnaire responses for various noise producing situations.

The main results were based on noise measurements and questionnaire responses at 59 areas of varying exposure to noise. 8 persons were chosen from each area (2 men and 2 women from each of the age groups

21-45, 46-75), to answer a questionnaire.

Interviews were "hidden". Traffic noise questions, from which the annoyance score was derived, were mixed with questions on general living conditions and other noise.

Noise measurements were taken using a distribution analyser for a period of 24 hours. Mean energy level (L_{EQ}), L_{10} and L_{50} values were obtained for the 24 hour period. Values of L_{EQ} ranged from 43dB(A) to 71dB(A).

Correlation coefficients between noise parameters and annoyance scores were all high. For 371 cases, with exposure taken in 2dB(A) steps, they were:-

L_{EQ}	0.96
L_{10}	0.86
L_{50}	0.82

This indicates the potential usefulness of the L_{EQ} unit, as it is not only shown here to be a good indicator of traffic noise annoyance, but its character also makes it suitable for use as the basis of a unified index to assess annoyance from all noise sources.

6.2.4 Annoyance caused by urban traffic (France).

A study was carried out in Paris and its suburbs by the Centre Scientifique et Technique du Batiment in 1971 (32).

Readings were taken for 48 hours continuously in front of 100 buildings. At the same time 700 people answered a questionnaire, giving a wide dispersion of replies. Measured levels of L_{50} ranged from 53dB(A) to 75dB(A).

A correlation coefficient of 0.37 between individual annoyance scores and L_{50} (corrected for the proportion of rooms per house exposed to noise, and individual degrees of satisfaction with the area), was reported. This compares favourably with the correlation coefficient of 0.29 between annoyance score and TNI if individual readings were used during the TNI survey.

Up to the appearance of this report, the CSTB had favoured L_{50} as a predictor of annoyance, as it correlated well with L_{10} and L_{EQ} which are apparently good indicators of annoyance themselves, and it was easy to predict accurately. The results of this survey justified the continued use of L_{50}, although the effectiveness of TNI was not discounted, as difference in correlation coefficient was not great.

It was thought by the authors that TNI behaved well for Griffiths and Langdon because it was suited to the high noise level situation on which a lot of their data was based. L_{50} was considered to be a better parameter in the urban situation however.

7. The Development of a Social Survey.

7. THE DEVELOPMENT OF A SOCIAL SURVEY

The following is a review of some of the factors which were taken into consideration when designing the present survey. It outlines various methods available to the surveyor when formulating layout, question content, method of analysis, and method of application of a survey. The works from which this material was obtained are referred to at the title of each section.

7.1 Questionnaire Design. (27,42,46)

A major task in social survey work is the design of the questionnaire to be used. Many factors have to be taken into account to ensure that the results obtained are meaningful.

The first consideration is whether the interview is to be unstructured or structured. In an unstructured interview, the subject is predetermined, but the interviewer is free to arrange the form and timing of his enquiries. This is useful at the early stages of research, in that the full scope of the problem to be dealt with can be determined, but it does not give comparable results between respondents.

In a structured interview the questions are definite, concrete, and preordained, and are prepared in advance, hence the differential in results between respondents is reduced. Questions can be open ended, where the respondent replies as he wishes, or closed, where he can reply in a predetermined number of ways, such as "Yes", "No", "Don't Know". Closed questions allow answers to be divided up into clearly defined categories which do not overlap, and are labelled, usually by a number. This is known as precoding. e.g.

1. Yes
2. No
3. Don't Know.

Precoding makes analysis of results easier, and encourages unambiguity in responses, but it leaves no room for replies that don't quite fit the categories.

The language used in formulating questions should be simple, with clear and straightforward syntax. Local phrases, and jargon, either technical or professional, should be avoided, as people tend to answer questions that they don't understand, rather than say so. Units of enumeration should be precisely stated. For example the question "How old are you?" could mean to the nearest birthday, so "How old were you at your last birthday?" is better. It is best to avoid subjective words such as good, bad, fair etc.

Clarity can be increased by keeping the questions as short as possible, which reduces the chances of overloading the respondent with information to digest or remember as the question proceeds.

Questions of a leading character, such as "Is Product A used most of the time?", should be avoided.

The layout of the questions is important. The early questions should put the respondent at ease, and therefore should be easy to understand and answer, and interest catching. Questions should then follow in a logical order, following the kind of course that a conversation would follow, grouping similar subjects together. Embarrassing or unpleasant questions should be left until fairly late in the questionnaire, where the respondent is more likely to be prepared to answer them, and if he refuses to continue, fewer questions are jeopardised. The list of questions should be as short as the information required allows, to reduce the chances of boredom occuring.

Before the final form of the questionnaire is decided upon, it is vital to run a pilot survey, firstly by circulating it in its proposed form to colleagues for their individual criticism of questions for clarity and ambiguity, and then by applying it in the field, to a number of people. This enables the surveyor to test the suitability of his introductory passage and interviewing technique, and how well the questions are understood, and how willing the respondents are to answer them.

7.2 Scaling Techniques. (33,34)

Although a person's attitude can be gauged to a certain extent by his response to a single question, this could lead to a false impression as attitudes are made up of many aspects, and the particular aspect dealt with in the question could be heavily weighted, making his response untypical of his attitude as a whole. This is why scales which approach an attitude from several angles are desirable, in order to reduce this type of bias.

7.2.1 Level of Measurement.

Before a questionnaire is designed, the level of measurement required must be considered, as this controls the format and type of the questions, how the data is collected, and the method of analysis to be adopted.

Measurement levels, in order of sophistication are:-

Nominal, where individuals are classified into two or more groups, without any indication of gradation or distance between groups. If numbers are used to classify groups, these cannot be used in calculations.

Ordinal, where individuals are ranked along the continuum being scaled, without distance between scale positions being implied.

Interval, where units of measure are equal, but the position of the zero point is arbitrary, so a score of 10 does not necessarily indicate twice as strong an attitude as a score of 5.

Ratio, which is similar to the interval level, but with a fixed origin.

7.2.2 Attitude Scales.

The Technique of Equal-Appearing Intervals.

This method, developed by L.L.Thurstone (36), requires the use of a number of judges in its construction.

A number of statements expressing attitudes about a particular issue are gathered, and each is written on a slip of paper. A complete set of statements is given to each judge, who is told to sort the slips into a number of piles, usually 7 or 11, which form a graduated series of attitudes from extremely favourable to extremely unfavourable. The results from all the judges are tabulated, so that the number of times each statement is included in each of the piles can be determined. From these results a cumulative frequency plot for each statement can be drawn, with cumulative proportions plotted against scale categories (1-7 or 1-11), and median and quartile values can then be found. The median value gives the scale value of the particular statement, and the difference between the quartile values gives the coefficient of ambiguity, which increases with ambiguity.

The final scale consists of 15 to 20 of the least ambiguous statements, placed in random order. The attitude score is obtained by taking the arithmetic mean of the scale values of the statements that have been endorsed by the respondent or the median value of the endorsed statements.

This type of scale is sometimes referred to as a differential scale, because the respondent tends to agree only with items around his scale position, disagreeing with the extremes on either side of his scale position.

Preparation of the scale is time consuming and laborious, and relies on the judges' attitudes, which are not necessarily those of the respondents.

The Technique of Summated Ratings.

Although this technique, frequently known as the Likert technique, is similar to the Thurstone method, it dispenses with the judging system and its dangers of bias.

A number of statements is gathered, with each statement having several possible response categories which show various strengths of agreement or disagreement:-

e.g.

Response:-	Strongly approve	Approve	Undecided	Disapprove	Strongly disapprove
Weight:-	1	2	3	4	5

A large number of subjects are each given all the statements to check. Each subject's total score is calculated by adding the individual scores for each statement, and then by drawing a plot of cumulative proportions against total scores for all respondents, total scores can be arranged in quartiles. Discriminative power for each statement is found by obtaining the difference between average scores in the highest and lowest quartile:-

e.g.

Response	Weight	Highest Quartile		Lowest Quartile	
		f	f x wt	f	f x wt
Agree	3	8	24	1	3
Don't Know	2	2	4	3	6
Disagree	1	1	1	7	7
Total		11	29	11	16
Mean			2.64		1.45

Item scale value difference = 2.64 - 1.45 = 1.19

The scale value differences for each item are arranged in rank order. The final draft of the questionnaire should be made up from statements having a relatively high discriminative value.

The main scoring method is known as the arbitrary method, where the scores for each statement are summed for each respondent. Some indication of the unidimensionality of the various statements can be obtained by calculating correlations between item scores and total scores.

The Semantic Differential Scale.

This type of scale was developed by Osgood (37), for the examination of the meaning of various concepts. A scale consisting of several points is used, with adjectives which are polar opposites at each end. Each scale position is assigned a score:-

e.g.

Good 5	4	3	2	1 Bad

An attitude scale can be formed by deciding the description of the issue to be evaluated and forming various adjective pairs for it. The total score is obtained by summing the scores for each adjective pair.

Guttman Scales.

Guttman scales seek to attain a high degree of unidimensionality.

Firstly the universe of content to be scaled is defined, and a sample of items which represent the universe are administered to a sample of the population. Responses are then subjected to "scalogram analysis", which tests the scaleability of the items, which indicates to what extent they belong to the same dimension.

The following example is taken from Moser and Kalton (34), and is a test of arithmetic ability, being a list in order of difficulty of calculations:-

(1) 3 + 4 =

(2) 29 + 37 =

(3) 47 + 59 - 17 =

(4) (33 x 17) - 15 =

(5) (46 x 15) / (26 - 19 + 3) =

It would be expected that anyone who answers a particular question correctly would have answered the previous questions correctly. Therefore six patterns of answer can be anticipated (+ = correct, - = incorrect):-

(1)	(2)	(3)	(4)	(5)	Score
+	+	+	+	+	5
+	+	+	+	-	4
+	+	+	-	-	3
+	+	-	-	-	2
+	-	-	-	-	1
-	-	-	-	-	0

The above diagram is known as a scalogram. If a set of n items is perfectly scalable, then there will be only (n + 1) response patterns, and an individual's total score indicates which items he agreed or disagreed with.

In reality the perfect scale rarely occurs, and so items are rearranged so that they are as close to the perfect pattern as possible. For example, ++-++ is closest to +++++, and so has a scale score of 5, with one error of reproducibility.

A measure of the success of this rearrangement is the coefficient of reproducibility which is defined as:-

$$\text{Rep} = 1 - \frac{\text{total number of errors}}{\text{total number of responses}}$$

Total number of responses is the total number of items in the scale multiplied by the number of respondents.

An acceptable level for Rep is .9+

The Guttman technique can be criticised for its analytical complexity and the fact that items cannot be guaranteed to scale. The items which do scale will usually cover a narrow universe of content. Because of this, the Guttman technique is more appropriate for scaling ordered behaviour, rather than broader based attitudes. It provides only an ordinal level of measurement, as do the Likert and Thurstone techniques.

7.2.3 Reliability of a Scale.

A scale is reliable to the extent that repeat measurements made by it under constant conditions will give the same result.

The split half reliability method takes two or more matched groups of items from the questionnaire, and degree of correlation between the groups is calculated. As this correlation does not apply to the full survey, but only to a fraction of it, the reliability for the complete test can be obtained form the Spearman Brown formula which gives "stepped up" reliability (r_w):-

$$r_w = \frac{nr_p}{1 + (n-1)r_p}$$

r_p = correlation between parts

n = number of parts

The above formula shows that as n increases, reliability also increases, and so the higher the number of items in a scale, the more reliable it becomes.

7.2.4 Validity of a Scale.

Validity is an indication of the success of the scale in measuring what it sets out to measure, and is very hard to determine.

Content validity is largely assessed by the judgement of the surveyor, or a team of judges, and is intended to verify that the items in a questionnaire each refer to the attitude under study, and that between them they cover the whole of the attitude in a balanced way.

7.3 Mailed Questionnaires.(34)

The main potential problem in the use of mailed questionnaires is non-response. Originally this made the use of them unpopular, but recent high responses to mailed surveys show that they have a definite potential.

Mailed surveys can be a lot cheaper than other methods, as mail costs replace the interviewer's salaries and expenses. However if response rate is low, cost per questionnaire can be higher than the cost of using interviewers.

A widely spread population can be covered at no extra cost. In 1967, a postal survey of senior psychiatrists in England and Wales, a fairly widely spread and thin population, yielded a 92% response rate (38).

Time taken to carry out the survey is not necessarily reduced, as it can take a month or more for all the responses to be returned, unless there is some form of incentive to encourage a quick return.

Interviewer error and bias is eliminated by using mailed surveys. The respondent can answer at his leisure, and so has more time to think about his answers. Embarrassing questions are more likely to be answered if there is no interviewer present, and the problem of missing people who are not at home is avoided.

As the interviewer is not present to clear up any confusion, special attention must be paid to the clarity of the language and instructions which are used, and ambiguity, vagueness, and technical expressions must be avoided.

Answers cannot be obtained spontaneously, as the respondent has the opportunity to discuss them with others, nor can they be treated as independent, as the respondent can see the questionnaire as a whole when answering a specific question. The surveyor cannot even be sure that the desired respondent is the person who has filled in the questionnaire.

Response rates can be anything between 10% and 90%. A postal Government Social Survey in 1957 showed a response rate of 93% from the general population, and since then several surveys have shown responses in the 80% - 90% range.

The three major influences on response rate are sponsorship, population, and subject matter. Scott (39) sent the same questionnaire to 3 comparable samples, with the same introductory letter, but each sample's sponsor was different. The three organizations used were the Central Office of Information, the London School of Economics, and the British Market Research Bureau, with response rates after 4 weeks being 93%, 89% and 90% respectively, showing a slight gain for the most respectable body.

All that a surveyor can do about the population is to decide whether it is suitable for a mail questionnaire, and whether response rate will be high enough.

The subject matter dictates the length of the survey, but there is little evidence to say that a longer questionnaire means a lower response rate.

The choice of questions is fairly flexible, and as an incentive to completion, interesting "throw away" questions, and space for comments, can be added. However, one awkward question, either difficult, embarrassing, or unpleasant, could severely affect the response rate.

In the place of the interviewer's opening speech, a covering letter must be sent with a mailed questionnaire, in order to explain clearly why, and by whom, the survey is being undertaken, why the addressee has been selected, and why he should reply.

8. The Present Survey.

8. The Present Survey.

8.1 Choice of Scaling Technique.

Although the Guttman scaling technique seeks to attain a high degree of unidimensionality, it leads to complex analysis. It is best suited for application to ordered behaviour, which is not the case in noise annoyance studies where individual scatter is high. It only provides an ordinal level of measurement, which is no better than the less complex Thurstone and Likert techniques (see 7.2.2. above).

A report by Edwards and Ollerhead (40) suggests that the Guttman Scale technique is not as reliable as it is generally thought to be, and therefore comparisons between Guttman Scale responses for different surveys cannot carry much weight.

Of the Thurstone and Likert techniques, the Likert method dispenses with the Thurstone method's panel of judges, which can create bias. Therefore it was decided to use a Likert scale in the survey work, so that total annoyance scores for individuals could be found by a straightforward summation of their item scores.

8.2 The pilot survey.

8.2.1 Design.

It was necessary to run a pilot survey for several reasons. It enabled various interviewing techniques to be assessed. The respondents' comprehension of the various items could be judged. The Likert technique requires that the questionnaire items are answered by a number of subjects so that discriminative values of items may be calculated, and this was provided by the pilot survey.

It was decided that the interviewer would put the questions to the respondent and either give him a card with possible response categories on it , tell the respondent the various categories and ask which one represented his response best, or allow the respondent to answer in his own words so that the interviewer would have to decide which category was closest to the response. This latter method allowed the interviewer to see whether response categories represented all possible answers fully, and to assess the ease with which a respondent confronted with several categories could decide which one represented his own view best.

The pilot questionnaire (see Appendix C) was designed so that most aspects of noise annoyance, and noise related annoyance (i.e. other annoyance caused by traffic which the respondent is made more aware of by the noise of the traffic), were covered.

The first seven questions classified the respondent in terms of age, name, sex, length of residence in house, family composition, and occupation of head of household. The subject numbers were given in order as questionnaires were completed.

Questions 8 and 9 were unprompted questions determining general likes and dislikes about the area. These were designed to eliminate respondents who were not at all bothered by traffic, or who were affected by aircraft noise, and to discover if the respondent would spontaneously mention some form of traffic noise annoyance.

Question 10 asked how often noise from passing traffic was heard. It was hoped that response to this question would indicate annoyance as well as awareness of the noise, as it was thought that a person who was very annoyed by the noise would to a certain extent listen out for it, or not be able to "switch off" to it. Also, people indicating no traffic noise annoyance by answering "almost never" could be eliminated.

Questions 11 and 12 were designed to indicate the character of the noise and the type of vehicles which caused most annoyance. Question 13 split the day up into several periods in order to ascertain when traffic noise was at its most annoying.

Questions 14 to 17 covered various aspects of communication interference. As approximately 97% of households in Britain possess either T.V. or radio it was thought that interference with these could be a major factor in noise annoyance. Although fewer households possess telephones, the question was included in order to see how those people who did own them were affected by noise.

Questions 18 to 22 covered sleep disturbance, with three questions asking how often disturbance occurred at various times of the night, one asking if bed times were affected by the noise, and one asking if choice of position of bedroom was affected by the noise.

Question 23 asked how often traffic caused the house to vibrate. Questions 24, 25, and 26 asked questions which were noise related rather than being straightforward annoyance questions. They involved accidents to pedestrians, accidents involving cars, and the presence of exhaust fumes in the house.

Question 27 asked how much quieter the respondent would prefer the noise. Question 28 attempted to put a monetary value on noise annoyance by asking how much compensation would be considered fair for putting up with the noise. Question 29 asked how satisfied overall the respondent was with his noise environment, and took the form of a 5 point semantic differential scale reading from "definitely satisfactory" to "definitely unsatisfactory".

The final part of the questionnaire was filled in by the interviewer, and dealt with classification of the respondent's house in terms of address, distance from traffic stream, type of traffic flow, and whether it was on a bus route. Any evidence of hearing deficiency in the respondent was noted.

The pilot survey was applied by the author at four sites. These sites represented the kind of situations where the final survey was to be applied, i.e. two major roads with intersections and traffic lights (Leicester Rd., Loughborough and Loughborough Rd., Rothley), and two major roads with free flow (Loughborough Rd., Quorn and Rykneld Rd., Derby). 30 people were interviewed, selection simply being by interviewing any adults who answered the door within the selected groups of houses. Random sampling was not important at this stage, as long as a certain variety of types of respondent was obtained. Noise measurements were not taken.

8.2.2 Application of the Pilot Survey.

It was proposed to make the pilot survey "hidden". The first few questions did not refer specifically to noise, and the fact that this was a noise survey was not stated, so that potential bias due to the respondent trying to give the "right" answers was eliminated in the early stages.

The interviewer introduced himself in the following manner:- "Good morning. We are interviewing a large number of people to find out what they think of the area they live in. Do you think that you could spare five minutes to answer a few questions?"

If the interviewer was asked what the information was for he would say that it would be of future use in town planning. Potential refusals were told that the work was important, and that a refusal to answer could jeopardise the whole survey.

The first seven questionnaires were applied without cards. Although respondents appeared to understand the questions satisfactorarily, their answers tended to be mainly "Yes" or "No" which did not produce the required graduation in responses. Cards showing the possible responses were used where applicable for the rest of the respondents.

Asking name and age seemed to arouse some hostility, and as knowing these served little purpose at this stage these questions were omitted. The other personal questions, length of residence, family structure and occupation of head of household, were left until the end so as to minimise the effect of any hostility on the required responses. Further interviews remained too lengthy and so the questions on occupation and family structure were eventually dropped.

Generally little difficulty was experienced in obtaining responses, and the individual questions seemed clear enough for the respondents.

14 men and 16 women were interviewed.

During interviewing it was felt that the "time of day most annoyed" question had response categories which were too wide and which didn't have provision for rush hours only. The "choice of room in which you sleep" question seemed to be affected more by family circumstances than by noise, as a large family would always have to have somebody sleeping near to the road. Vibration was mentioned spontaneously in response to Question 11 by 14 out of the 30 respondents.

It was found that there was some justification in including noise related annoyance questions with pure noise annoyance questions to form an annoyance scale. People who were obviously very disturbed by the noise gave high annoyance responses to the noise related annoyance questions, especially the "fumes" question and the accident questions, although this was more reflected in conversation with the interviewer than by response to the item.

The idea of putting a monetary value on noise annoyance was abandoned as response was poor. Women usually said that their husband would have to answer the question, and men had great difficulty in arriving at a figure.

It had been hoped to estimate noise levels using the information from Questions 31-35, but when this was attempted the noise estimates were too crude, and without enough variance for meaningful interpretation.

8.2.3 Likert analysis of pilot survey.

A total score for each respondent was obtained by summing the scores for Questions 10, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29. Each had 5 point scales, with 5 indicating maximum annoyance. The "no radio or T.V." response was never given.

Using the technique outlined in section 7.2.2 above, the discriminative values were obtained for the individual questions; and presented in rank order in Table 7 .

Table 7 . Pilot Survey. Scale value differences for items given in rank order.

		Question	Scale value difference.
1.	Q.20.	"Waking at night"	2.8
2.	Q.21.	"Waking in morning"	2.4
3	Q.25.	"Accidents between cars"	2.1
4.	Q.23.	"Vibration"	2.0
5	Q.10.	"Do you hear noise from traffic"	2.0
6.	Q.24.	"Accidents to pedestrians"	1.8
7.	Q.27.	"Preferred level"	1.8
8.	Q.19.	"Going to sleep at night"	1.6
9.	Q.29.	"Overall satisfaction"	1.6
10.	Q.14.	"Listening to Radio/T.V.	1.5
11.	Q.26.	"Fumes"	1.4
12.	Q.17.	"Conversation"	1.3
13.	Q.22.	"Choice of bedroom"	1.0
14.	Q.18	"Bed time"	0.9
15.	Q.15	"Electrical interference, Radio/T.V.	0

It was desired to form the final questionnaire from the ten questions giving the highest discriminative value. However the three sleep questions were included in this ten. As there was a possibility that these questions were really only asking the same question three times in different ways a linear regression analysis was carried out between them. If the regression coefficients m and b were close to 1 and 0 respectively (regression equation: $y = mx + b$) then the questions could be taken as being the same and therefore combined into a single question.

Questions 19 and 20, $y = 0.53x + 0.57$ $(r = 0.57)$

Questions 19 and 21, $y = 0.68x + 0.84$ $(r = 0.61)$

Questions 20 and 21, $y = 0.59x + 0.90$ $(r = 0.51)$

Correlations gave high significance levels for 30 cases, showing that responses were related. However the regression coefficients indicated that the three questions did not ask the same question in different ways. They were therefore all included in the final questionnaire.

The same procedure carried out for the two accident questions yielded a regression equation of $y = 0.75x + 0.86$ ($r = 0.83$). It was decided that the value of $m = 0.75$ was close enough to 1 to justify a combination of the two questions into a single accident fear question. The "fumes" question was therefore included in the ten items to make up the final scale, as it had previously been at the 11th. position.

8.3 The Main Questionnaire.

8.3.1 Design.

The questionnaire content followed on from the results of the pilot survey. (Appendix D).

The ten questions which gave the highest discriminative powers, including the combined accident question, were included. The overall satisfaction question was reworded to make it apply only to traffic noise, and easier to understand. It now read "How satisfied are you overall with the traffic noise around here?", with five response categories, the central position being labelled "neutral".

"Subject number" was filled in by the author before the questionnaire was applied. Question 2, "Do you hear aircraft noise?" was designed to indicate whether any of the sites chosen were subjected to significant aircraft noise which would affect the results.

Questions 3-10 were obtained from the Likert analysis of the pilot survey.

Question 11 dealt with the visual intrusion of traffic. It was felt that this should be included to make the list of noise related questions complete. Although it had not been subjected to a Likert analysis, it was felt that the response to it could be left out of the final total if its performance as an indicator of annoyance was not satisfactory.

Question 12 was the "preferred level" question as used in the pilot, and Question 13 was the "overall satisfaction" question which had been reworded.

Question 14 was designed to discover if any characteristic of the traffic noise was a dominant producer of annoyance. It was left till the end so that the respondent could get the noise situation clear in his mind before answering this question.

Question 15 showed length of residence of the respondent. If length of residence was under six months, then that particular respondent was ignored, as a person newly moved to a noisy area could give high annoyance responses due to a temporary sense of "shock" at the higher levels.

All items forming the attitude scale had five point responses, with five indicating maximum annoyance. A score of six on Question 4 indicated that the respondent had no radio or T.V.

Age, occupation, and family composition questions were not included as the possible hostility that they could cause was not compensated for by their limited usefulness in the present survey.

8.3.2 Method of application.

In order to save time taken over interviewing, and to ensure that the required respondent was contacted, it was decided to deliver the questionnaire postally. In order to save money delivery was carried out by hand while noise measurements were being taken. Each questionnaire was delivered in an envelope addressed using a sticky label computer programme, together with a return envelope which was stamped.

In order to make the questionnaire as attractive as possible, it was printed on coloured paper. Space was left for comments in order to make the respondent feel that he had some degree of communication with the surveyor. Questions were answered by ticking the pre-coded box next to the relevant response category.

A letter of introduction from the Head of Department was included on the form, explaining why the survey was taking place, and asking for the respondent's assistance.

The main method used for ensuring a fast and high response was to give the respondent the opportunity to take part in a £25 draw. The questionnaire had to be returned within two days in order to qualify. Return dates were written in the blank space in the introductory letter before the questionnaire was delivered. First class stamps were used on the return envelopes. If the respondent did not wish to give his name and address he did not have to, unless he wished to enter the draw, as identification was by the subject number.

As several of the questions had "almost always" - "almost never" responses, the order of these responses was reversed for successive questions so that the respondent would be more encouraged to study each possible set of responses in turn.

In case it was thought that the questionnaire was linked with a possible new road scheme, a note stating that this was independent research was included.

8.3.3 Choice of sites.

Six sites with free flow were required, together with six sites with flows interrupted at traffic lights. Fairly heavy flows were required in order to produce levels in the region where annoyance is more likely to occur. Housing had to be fairly dense and close to the road. Sites had to be grouped in pairs so that two sites could be covered by the noise measurement team in one day. Twelve suitable sites within a half hour drive of the university were eventually found, although several of them had a certain amount of incline over some of their length. This would have to be ignored if results from all free flow sites, and all interrupted flow sites were to be treated as a whole, especially as little is known about the effects of gradients on noise levels.

The sites were:-

1. Melton Rd, Tollerton (A606) Free flow - the main road from Nottingham to Melton.
2. Loughborough Rd, Ruddington (A60) Interrupted flow - the main road from Loughborough to Nottingham.
3. Corden Avenue, Derby (B5019) Interrupted flow - a narrow road which took a great deal of heavy traffic at the time of the survey.
4. Rykneld Rd, Derby (A38) Free flow - the main Derby to Birmingham road, since by-passed.
5. Middleton Boulevard, Nottingham. Free flow - Nottingham outer ring road.
6. Western Boulevard, Nottingham. Interrupted flow - Nottingham outer ring road.
7. Loughborough Rd, Rothley (A6) Interrupted flow - main Leicester to Loughborough road.
8. Leicester Rd, Mountsorrel (A6) Free flow.
9. The Portwey, Leicester (A6030) Interrupted flow - Leicester ring road.
10. Tailby Avenue, Leicester (A6030) Interrupted flow.
11. Markfield Rd, Groby (A50) Free flow - main road from Leicester to Burton.
12. Groby Rd, Glenfield (A50) Free flow.

8.3.4 Sampling.

The sample was obtained using electoral registers. The number of people chosen at each site varied with the total number of people available. This number varied between 25 and 40 per site. It was hoped that a degree of random sampling was attained by the following method: If within the limits chosen for the site there lived N people, and it was desired to choose n of them as respondents, then every N/nth. person (to nearest whole number) on the list was chosen. The register usually lists houses by the position in which they actually stand.

Occupants of houses are listed alphabetically so increasing the random nature of choice by this method.

The fact that adults only are listed on the registers ensured that no children had questionnaires sent to them. There is a certain amount of risk with electoral register sampling that people chosen have moved or are deceased. Use of the most recent registers minimised this.

The sex of respondents was noted as they were chosen.

Each chosen person was allocated a subject number for identification of the house and its position.

8.3.5 Delivery.

The questionnaires were personally delivered at each site while the noise measurements were taking place. At the same time distance of each house's mid-facade from the Delany reference line for the carriageway was noted. Distance to the Delany reference line for the intersecting road was also noted.

If possible due to limited time, a personal interview was carried out by the author once per site, at a randomly chosen house. This enabled some feel for the type of responses which could be expected, to be obtained. Also any failings in the new form of the questionnaire could become apparent.

8.3.6 Response Rate.

Questionnaires which were returned usually arrived within a week of delivery. Altogether 377 questionnaires were delivered at the 12 sites, and 261 were returned. This represents a 69.2% response rate. This is a satisfactory level, and was probably due to the inclusion of the draw, although the fact that the sites chosen had fairly high noise levels leading to high annoyance is likely to have also affected response rate.

Of the 261 responses, two were not used as length of residence was less than six months. 9 personal interviews were carried out giving a total of 268 completed questionnaires. 129 were for interrupted flows, and 139 were for free flows.

8.3.7 Preparation for analysis.

In order for the data obtained to be analysed and linked with noise levels it had to be punched onto computer cards, Each card represented one respondent, and on to this was punched the subject number, and each item score, with one column representing one item.

9.Noise Measurements for the Survey.

9. Noise Measurements for the Survey.

9.1 Requirements.

Noise characteristics, as indicated by L_{10}, L_{50} and L_{90} levels, were required for typical weekdays between 0600 hrs. and 2400 hrs. at each site.For free flow sites one measurement position only was required, as levels were assumed to be unchanged with position parallel to the road, and to be the same for both sides of the road at the same distance from the traffic stream. For interrupted flow sites one position was required as close to the intersection as possible, bearing in mind parking problems on busy roads, and one position was required away from the lights at a point where free flow could be assumed. This was to be judged by observing the point at which heavy vehicles had stopped accelerating through the gears.

Samples of the noise were to be taken for 10 minutes per position per hour, as were traffic counts. Sites were grouped in pairs, which meant that at most four samples had to be taken per hour (two interrupted flow sites - readings on opposite sides of the roads for interrupted flows were obtained by measuring on one side in one hour, and on the opposite side in the next). Because of this heavy work load it was not expected that measurements could be taken at the same time within the hour for each position. Therefore the team were told to attempt to obtain one ten minute sample per position within each hour division, if at all possible, stressing the importance of the 0600-0700 and 2300-2400 readings which were likely to affect the 18 hr. average levels considerably as they would probably be significantly quieter than readings taken at other times.

Measurements were to be taken at 7.5m. from the Delany reference line, this position being chosen because Delany's prediction method (27) was to be used in calculating levels at individual houses, and this method is based on the 7.5m. distance. The Delany reference line was the middle of the road for 2 or 3 lane roads, and the centre of the inside two lanes for roads with 4 or more lanes.

9.2 Equipment and organization.

A Brüel and Kjaer 2205 meter with a B and K 4117 piezo-electric microphone was used on "A" weighting. This was connected to an on-line statistical distribution analyser manufactured by Loughborough Consultants Ltd. The analyser had 16 channels set 2dB(A) apart, which gave it a range of 32dB(A). Calibration was by means of a 4230 calibrator which gave a constant 1000 Hz. tone at 94.0dB(A). Power was supplied to the analyser by a 12v. car battery.

Each day was divided into three shifts so that the work could be shared between a team of three. During the first shift questionnaires were delivered and houses measured for position relative to traffic streams.

Typical weekdays were taken as Monday to Thursday inclusive.

9.3 Procedure on site.

When the first member of the team arrived at the first site at 0600 hrs. suitable parking positions for vehicles were chosen. The analyser and battery remained in the vehicle and only the meter on its tripod was removed so as to make time taken per position as short as possible. At interrupted flow sites four microphone positions had to be chosen, with sites on opposite sides of the road at the same distance from the reference line for intersecting traffic. Sites close to the intersection generally had to be further from it than was desired due to the parking difficulty. The use of a long lead from meter to analyser would have improved matters, but one was not available at the time. The distance from the reference line of the intersecting flow was measured for the "near" and "far" positions at interrupted flow sites.

The meter was set at a height of 1.2m. on its tripod and placed 7.5m. from the reference line. The analyser was then calibrated, by setting it to read +4.0 with the meter attenuator set at 90dB(A). The meter was set at a range where readings for vehicles were comfortably within the scale, a windshield was placed over the microphone, and the analyser switched on after being set for a ten minute sample and a 0.1 second sampling rate.

While the analyser was running traffic flow was counted for six minutes, multiplied by ten to give hourly flow, and noted on a data sheet. Light and heavy vehicles were counted separately in order to calculate total flow and the percentage of heavy vehicles. Both sides of the road were included in the count. In all cases flow past the meter was counted only, with cross flows being ignored at the near point to an intersection as this would be too confusing for the operator in the short time available. When the analyser had stopped, the readings from each channel were noted on the data sheet, together with date, site, time of starting reading, meter attenuator setting, and position and side of road at interrupted flow sites.

As quickly as possible the equipment was packed up and driven to the next position or site and the procedure repeated, so that all 2, 3 or 4 positions in a pair of sites could be covered within the hour. This was carried on throughout the day with shift changes at 1200 hrs. and 1800 hrs.

Average speeds of flow were estimated by observation of the traffic, and by driving past the site several times within a traffic stream and noting speedometer reading.

During the morning shift the questionnaires were delivered, house positions relative to traffic streams noted, and personal interviews carried out if time allowed.

Measurements were carried out during January 1975. Unfortunately frequent bad weather affected the data collection. Wet roads alter the spectrum of traffic noise, and rain was not good for the meter, so it was impossible to measure during rain or in the period following it. Because of this some measurements had to be repeated, assuming that typical weekdays shared the same 18 hr. noise characteristics, and even then it was not always possible to obtain 18 readings throughout the day. However two consecutive hourly readings were never missed, and at least one of the two "quiet periods" was always covered at each site, and this was thought to be adequate for the purposes of this survey.

9.4 Variation of levels for both sides of the road at intersections.

Measurements of levels were carried out on both sides of the road at the Ruddington and Corden Avenue intersections. This was because it was hoped to use the results of the earlier work given in Chapter 5 to calculate levels at individual houses between the measurement points, and this work had dealt only with the side of the road where the near stream approached the intersection. It was therefore required to see if there was any significant difference between characteristics for either side of the road.

Fig. 2. shows the noise levels obtained for both sides of the road at the Ruddington "near" position. It can be seen that the lines follow each other very closely, indicating little difference in noise characteristics throughout the day. The other three sets of readings obtained at these sites showed the same tendency, and so levels for both sides of the road were combined.

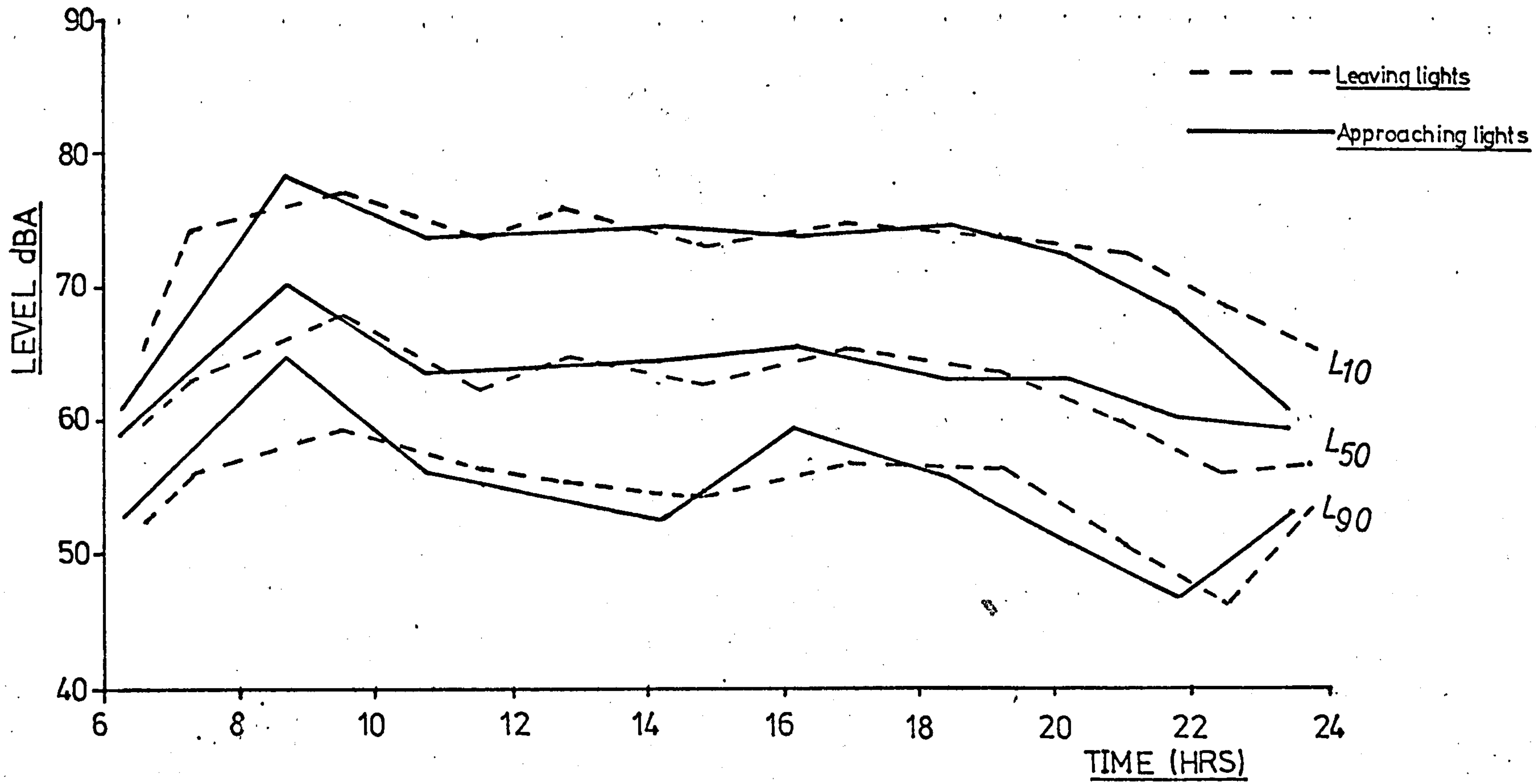
It was assumed that the other 4 intersection sites would share the same characteristics, and so readings for these were taken on one side of the road only.

9.5 Calculation of 18 hour average levels at houses.

From each set of analyser readings was drawn a cumulative frequency plot. From this the L_{10}, L_{50}, and L_{90} percentile levels were obtained. This provided a series of measured values of levels throughout the day at the six free flow, and twelve interrupted flow positions. If, due to poor weather conditions, one early or late reading was missed, then it was assumed that these were the same as each other, and the missing value was put in.

Appendix E shows the values of L_{10}, L_{50}, L_{90}, vehicle flow per hour,

Fig.2 RUDDINGTON 45m. —— 18hour noise levels for both sides of road.



and percentage heavy vehicles measured throughout the day. The flows can be seen to have a tendency to peak around 0800 hrs. and 1700 hrs, representing the rush hours. Smaller midday peaks are also apparent between 1200 and 1400 hrs. However no great difference between peaks and median levels is in evidence. This is probably due to the fact that roads chosen were main roads and by-passes which would take fairly constant levels of traffic throughout the day.

L_{10} levels remain comparatively invarient as flow varies, changing a little in response to large flow variations, as L_{10} is generally due to peaks in level caused by individual loud vehicles. L_{10} appears to also respond to peaks in percentage heavy vehicles, because an increase in the presence of heavy vehicles means an increase in loud noise sources.

L_{90} levels, representing general background noise, follow vehicle flow rates closely, and vary considerably as flow rate changes, as an increase in the number of vehicles flowing will always affect the general level.

At interrupted flow sites the tendency would seem to be that L_{10} levels follow each other closely for "near" and "far" positions, L_{50} levels at the "far" position are slightly below those for the "near" position, and this effect increases for L_{90} levels. Although this was expected from the results of the physical study, the effect was not as great as those results would indicate.

For free flow sites the levels for each site were averaged to give 18 hr. L_{10}, L_{50} and L_{90} values. As distance of individual houses from the traffic flow reference line was known, these values were attenuated using Delany's attenuation coefficients (27) for the type of ground which predominated between microphone and house, so that levels which would exist at the mid-facade of each house were obtained. Actual readings measured 1 m. from the facade would he expected to be in the order of 3dB(A) greater than these figures, due to reflection, but it was decided that levels without reflection would be considered throughout, as these indicate actual levels impinging on the facade.

For interrupted flow sites the procedure was considerably more complicated. An average increase over Delany predictions for each position was required, so that the results given in Chapter 5 could be utilised. Therefore for each individual reading a Delany prediction of L_{10}, L_{50} and L_{90} was carried out using measured vehicle flow and percentage heavy vehicles, together with the estimated value of average velocity. Flows across the intersection were assumed equal to flows past the meter, as in the earlier work, and levels due to main flow and cross flow were combined by decibel addition. These predictions were compared with the actual values, and differences were noted. In this way an average difference between actual levels and predictions was obtained for both positions at each interrupted flow site.

The Delany prediction of average level was now required at each respondent's house. This was calculated by predicting levels due to the main flow only, at 7.5 m. from the flow, using all flow per hour and percentage heavy vehicle readings for the site and averaging the levels so obtained. This average was then attenuated using Delany's coefficients to give the predicted contribution at the house due to the main flow. The predicted levels at 7.5 m. from the cross flow reference line were assumed to be the same as the main flow predictions. These were then attenuated to give levels at the centre of the house facade due to the cross flow. The two contributions were then combined by decibel addition to give the Delany prediction of average L_{10},L_{50} and L_{90} levels at the middle of the house facade facing the traffic flow.

It was now intended to increase the Delany predictions by an amount calculated using the results of the physical study as shown in Chapter 5. The overall result had been that L_{10}, L_{50} and L_{90} levels are greater than Delany predictions at interrupted flow sites, with this addition to the prediction decreasing linearly with distance from the intersection. This result had been obtained by combining results from three major road sites which displayed this characteristic to varying degrees. Also these results were based on estimated velocities, so it was decided to use only the rates of decrease as given by the overall results of the physical study, rather than absolute values obtained.

As shown in Fig. 3, average increases over Delany predictions for the two positions were plotted on a graph of increase over Delany prediction against distance from intersection. Lines with gradients obtained from the overall results of the physical study were drawn through the relevant points. Ideally, if the noise measurements for the survey matched those of the physical study, a single line of the correct gradient would join the two points for a particular index. However some discrepencies occurred, and it was decided that a mean line of correct gradient would be drawn between the two lines for each index. This mean line indicated the amount by which the Delany predictions of average L_{10}, L_{50} and L_{90} should be increased due to the interruption of flow, depending on distance from the centre of flow of the intersecting road.

Figs. 4 to 8 indicate the mean lines which were obtained for the remainder of the sites by the above method.

The increase in level over Delany prediction was obtained for each house from the graphs and added to predicted average levels. The new values of average L_{10}, L_{50} and L_{90} levels represented 18 hr. average levels which would be expected if measurements had been taken at every house, neglecting the effects of reflection.

This somewhat lengthy procedure was made easier by the use of the Loughborough University ICL 1904 computer.

9.6 Preparation for analysis.

Values of Traffic Noise Index were calculated for all respondents from 18 hr. values of L_{10} and L_{90} ($TNI = 4(L_{10} - L_{90}) + L_{90} - 30$). TNI should be based on 24 hr. readings, but as insufficient data was available, this 18 hr. TNI was included, in order to determine its effectiveness as an indicator of annoyance.

Each respondent was already represented by a punched card which gave his questionnaire scores. Values of 18 hr. average L_{10}, L_{50}, L_{90} and TNI at his house were added to the card to complete the information about the respondent.

Fig.3. THE PORTWEY. Increase over prediction against distance from intersection showing lines with gradient obtained from the physical study drawn through values at "near" and "far" points - hence mean lines.

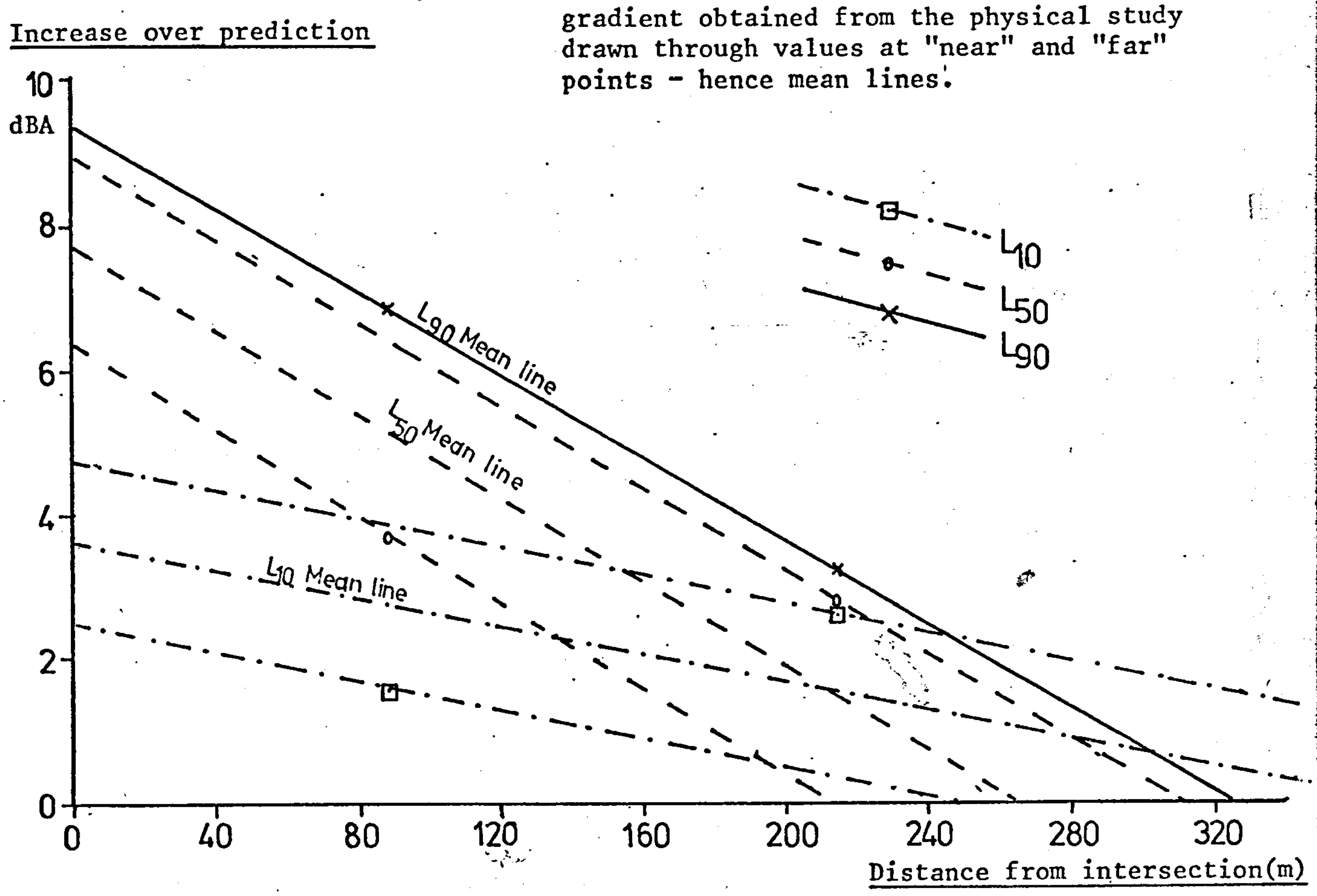


Fig.4. RUDDINGTON.

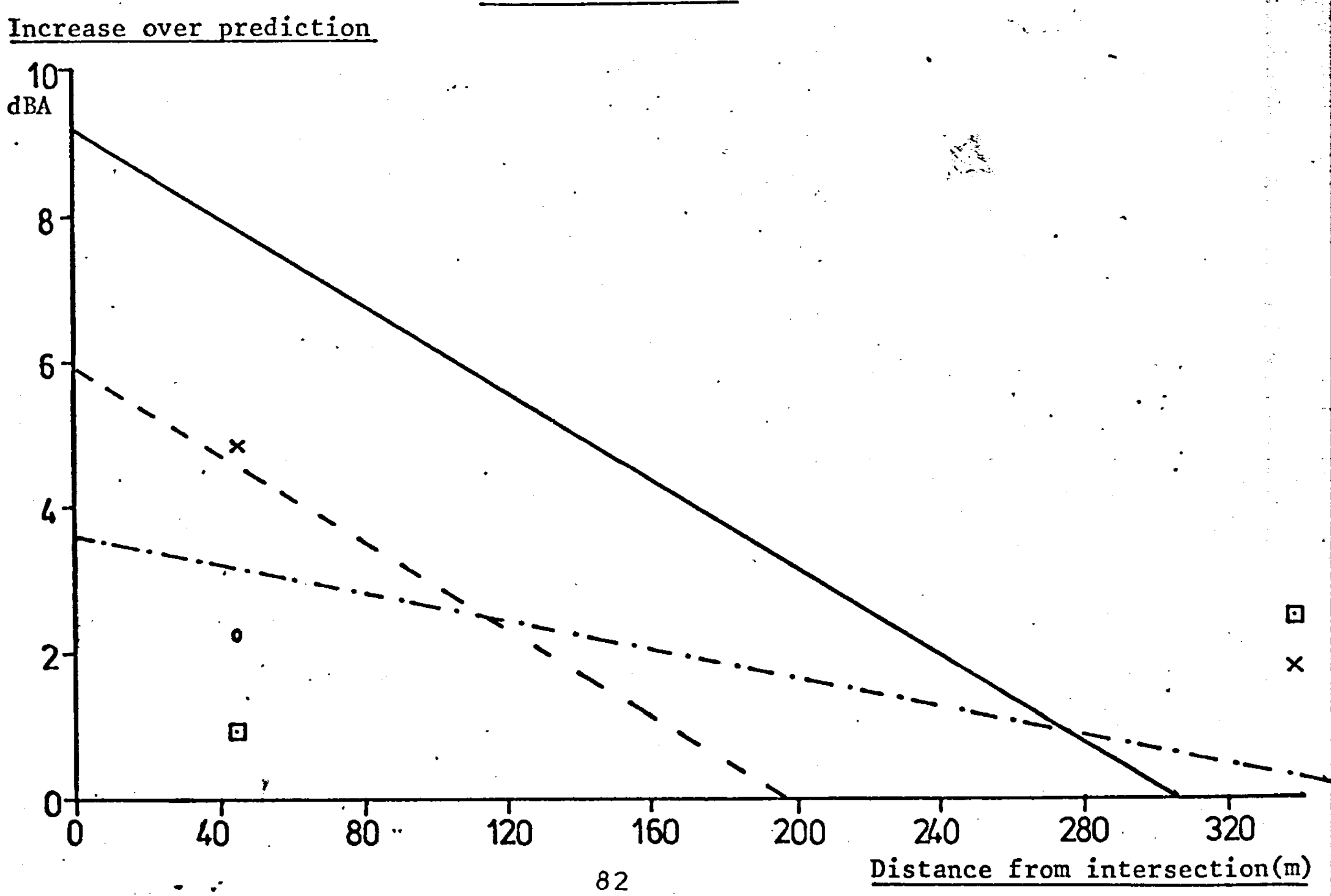


Fig.5. ROTHLEY

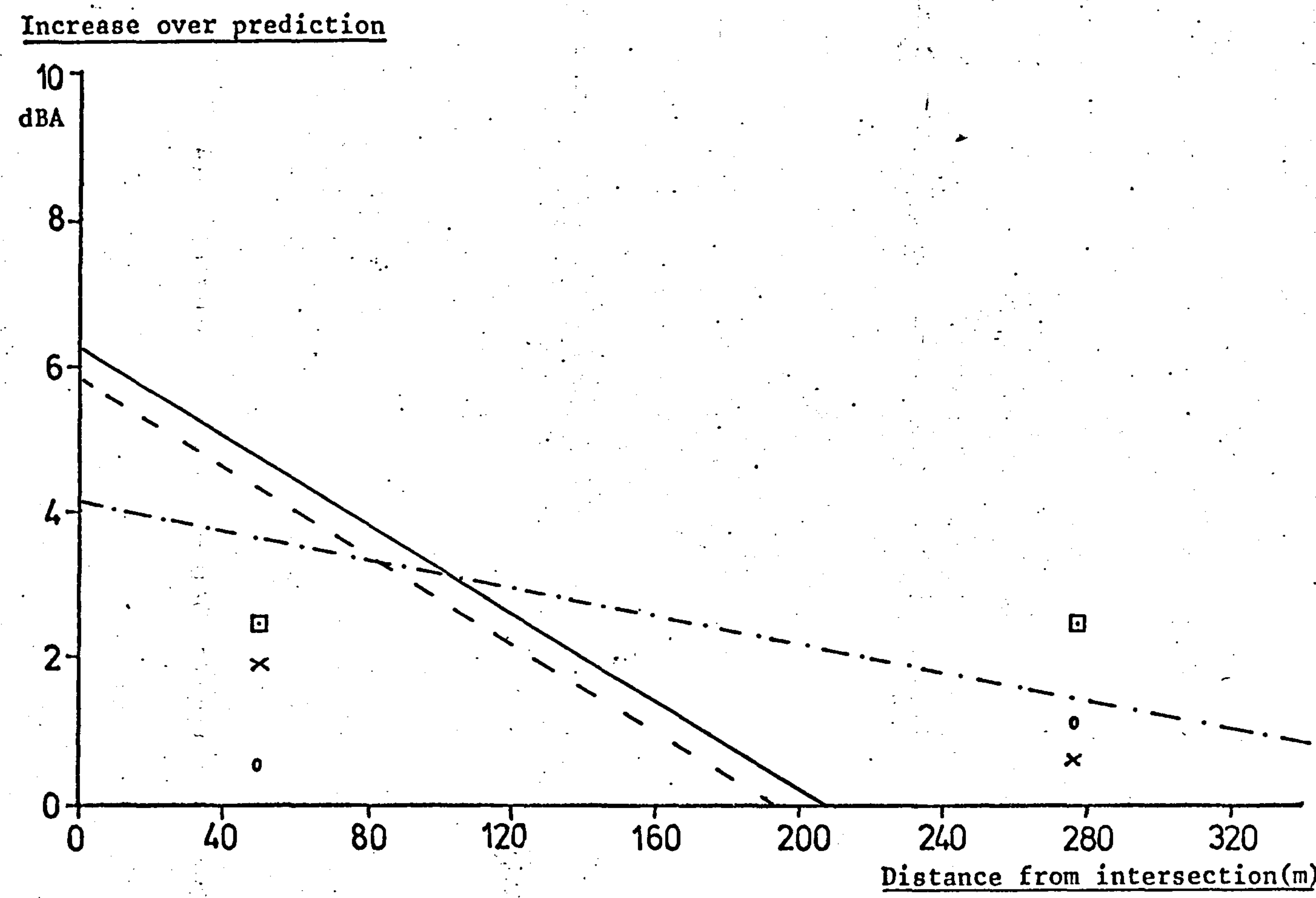


Fig.6. WESTERN BOULEVARD.

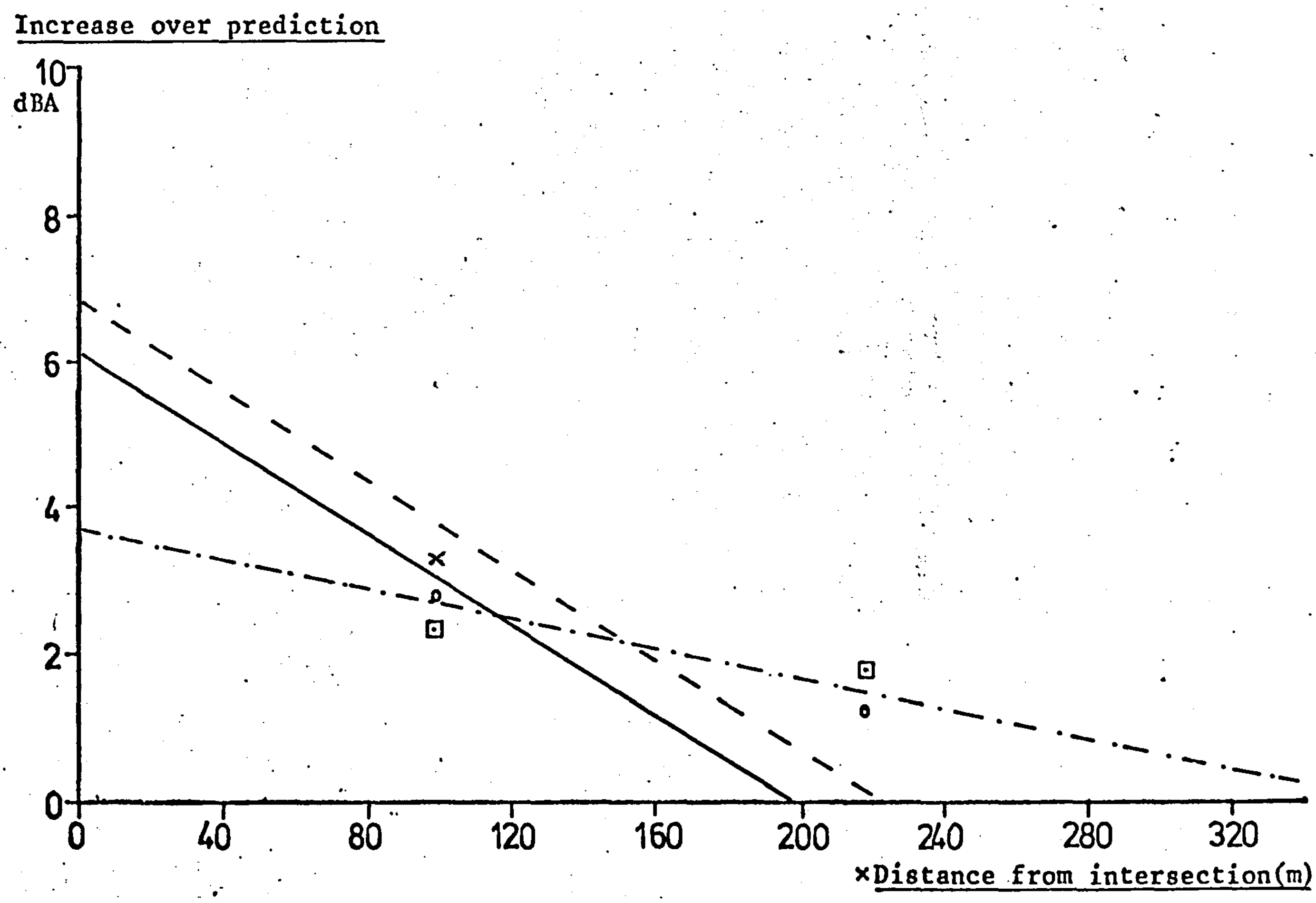


Fig.7. TAILBY AVENUE.

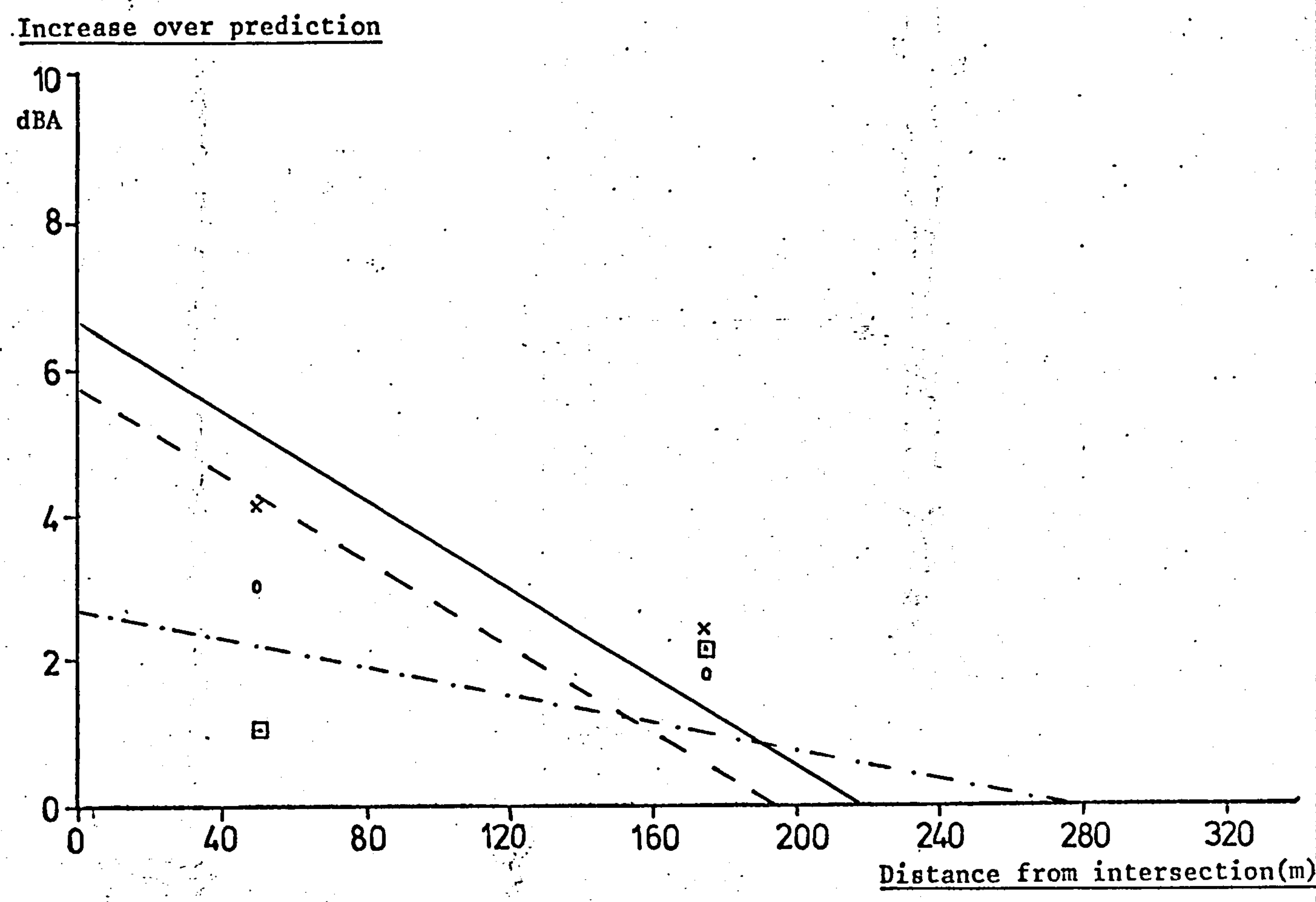
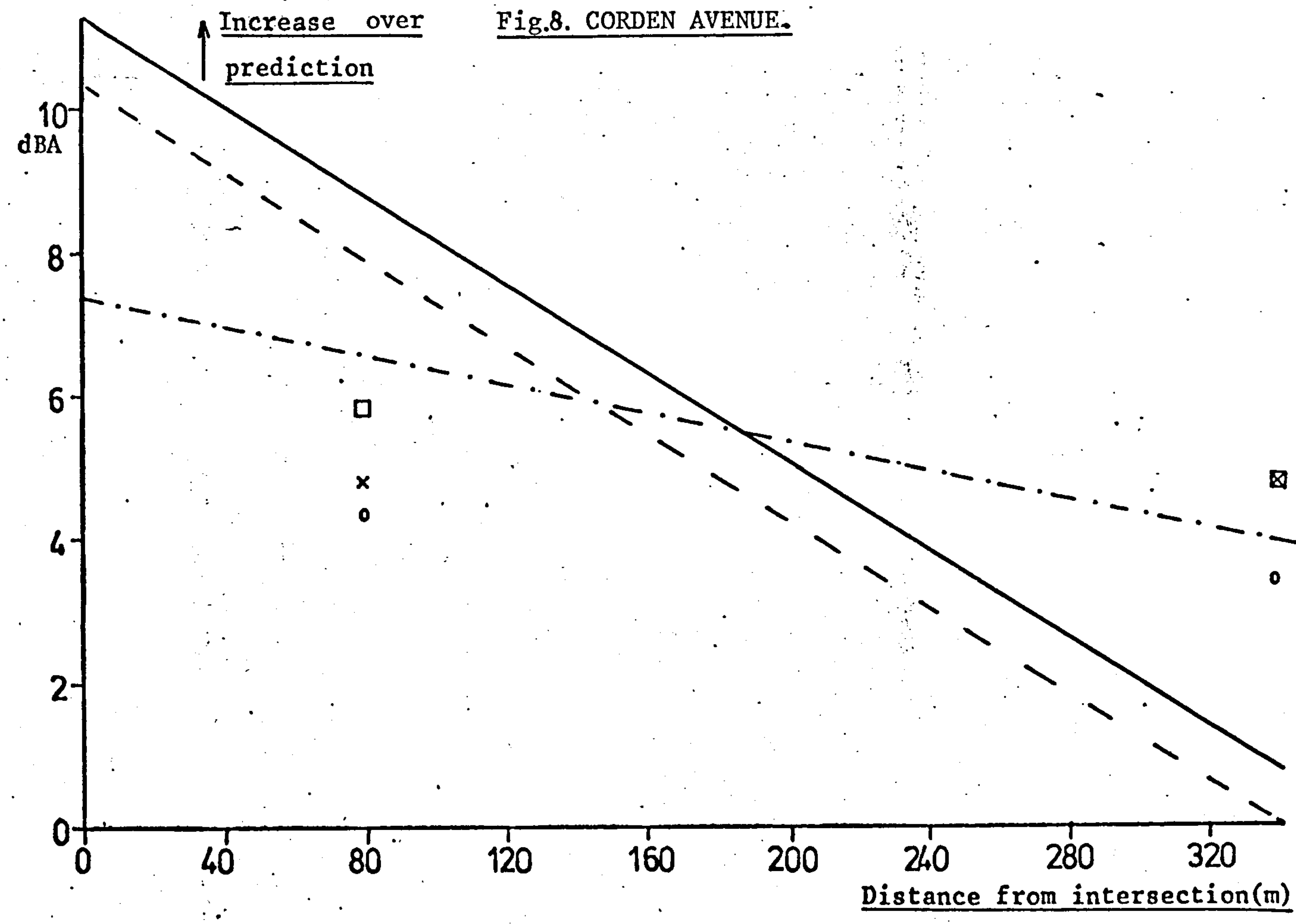


Fig.8. CORDEN AVENUE.



10. Survey Results.

10. Survey Results.

10.1 Introduction

The data was now ready for analysis. One card had been prepared for each respondent. Each card had punched on it the subject's identification number, his individual question scores, and values of 18 hr. averaged L_{10}, L_{50}, L_{90} and TN1 calculated for the nearest point of his house to the traffic stream.

In order to determine whether relationships existed between questionnaire responses and noise indices, a correlation analysis was carried out. Although the level of measurement attained by the Likert technique is ordinal and rank-order correlation analysis should strictly be used, tentative use of the linear Pearson method is permissable in this type of situation (41) (42), This is useful in that regression lines may also be calculated using this method (see Appendix A). Correlation coefficients quoted in the following results will therefore all be due to Pearson analysis.

A convenient method of carrying out the full regression analysis on the data was provided by the Statistical Package for the Social Sciences (S.P.S.S.) available on the "ICL 1906 A" computer at Nottingham University. This package, developed in the USA (43), enables several statistical methods to be applied to data, without having to write a full programme. The various sub-programmes may be called up using comparatively simple language. An example of an S.P.S.S. regression analysis is given in Appendix G.

The primary regression analysis was carried out between the individual item responses and noise indices L_{10}, L_{50}, L_{90} and TN1. Various totals which could possibly be used as an overall annoyance score were also computed for each respondent. These were the straightforward total of Questions 3 - 11, the total without the visual intrusion score, the total with the sum of the three sleep question responses averaged so that they contributed to the final score as a single question, and the total of scores involving noise and vibration annoyance only. The use of the total with averaged sleep was designed to minimise the predominance of sleep disturbance found in the other totals.

The data was divided into two subfiles, interrupted flow and free flow, and the analysis was carried out on each in turn, enabling relationships between annoyance scores and noise indices for each flow situation to be investigated.

10.2 Relationships between questionnaire responses and noise indices.

This section considers relationships obtained from the S.P.S.S. analysis which show a level of significance of .05 or better. Reference is made to the regression and correlation coefficients as presented in Tables 8 to 11 and in Figs 9 to 18.

The somewhat limited range of noise levels as shown by their means and standard deviations should be noted.

Question 3. Do you hear noise from passing traffic? (Fig. 9)

This question was not considered to be just an indicator of the presence of noise, but also a gauge of annoyance, as a person who is not disturbed by noise will be much less aware of its presence, being able to "switch off" to a certain extent.

Generally mean scores are high and gradients on the graph are all positive as would be expected.

For interrupted flows the highest correlation (.32) is with L_{10}, for free flows the highest correlation (.24) is with L_{90}, although in this case the coefficients are very close to one another. This would seem to indicate that awareness of the presence of traffic noise is most dependent on peaks for interrupted flows, and on the general background level for free flows.

On the graph, the larger gradient in the L_{90} case for the free flow condition shows that annoyance is greater for a given L_{90} in free flow, especially at higher values of L_{90}. This is possibly due to the fact that, as L_{90} increases in an interrupted flow, the peaks,

Table 8 Correlation coefficients between annoyance scores and noise indices, with means and standard deviations of variables

Free flow 139 cases

Mean	S.D.	Dependent variable	L_{10}	L_{50}	L_{90}	TNI
		Mean dB(A)	69.92	61.05	53.67	88.52
		S.D. dB(A)	2.52	1.92	2.18	8.60
4.61	0.82	Q3. Traffic noise	.21	.22	.24	.05
2.27	1.16	Q4. Radio/T.V.	.12	.12	.07	.06
2.35	1.27	Q5. Going to sleep	.16	.16	.13	.05
2.21	1.13	Q6. Waking at night	.12	.07	.02	.10
3.01	1.49	Q7. Waking morning	.07	.04	.05	.01
2.98	1.09	Q8. Vibration	.23	.22	.09	.20
3.14	1.52	Q9. Accidents	.01	.08	.10	.08
1.78	1.06	Q10. Fumes	.15	.16	.07	.11
3.64	1.43	Q11. Vis. intrusion	.07	.17	.27	-.13
3.06	1.21	Q12. Preferred level	.09	.16	.23	.07
3.49	1.05	Q13. Overall satisfaction	.12	.16	.22	.03
7.58	3.36	Sleep total	.13	.10	.08	.06
25.99	7.16	Total	.17	.20	.18	.05
20.94	5.40	Total with av. sleep	.18	.23	.20	.04
17.44	4.95	Noise total	.20	.18	.13	.11
22.35	6.36	Total less vis. intrusion	.18	.19	.14	.08

Significance level of .05 at correlation coefficient of .16

Significance level of .01 at correlation coefficient of .21

Table 9 Regression coefficients and constants from regression analysis between annoyance scores and noise indices (values of m, b, in equation y = mx + b)

Free flow

Dependent variable	L_{10}		L_{50}		L_{90}		TNI	
	m	b	m	b	m	b	m	b
Q3. Traffic noise	.07	-.16	.09	-1.22	.09	-.22	.01	4.14
Q4. Radio/T.V.	.05	-1.5	.07	-2.35	.04	.08	.01	1.55
Q5. Going to sleep	.08	-3.14	.11	-4.18	.08	-1.85	.01	1.65
Q6. Waking at night	.05	-1.48	.04	-.27	.01	1.56	.01	1.00
Q7. Waking morning	.04	.06	.03	1.22	.04	.97	0	2.71
Q8. Vibration	.10	-4.00	.13	-4.75	.04	.67	.03	.75
Q9. Accidents	-.01	3.51	.07	-.93	.07	.62	-.01	4.42
Q10. Fumes	.06	-2.47	.09	-3.61	.03	.02	.07	-2.55
Q11. Vis. intrusion	.04	.67	.13	-4.23	.18	-5.90	-.02	3.52
Sleep total	.17	-4.56	.18	-3.22	.13	.68	.03	5.36
Total	.49	-8.50	.76	-20.32	.58	-5.31	.04	22.35
Total with av. sleep	.38	-5.47	.64	-18.17	.50	-5.76	.02	18.79
Noise total	.40	-10.20	.47	-11.50	.30	1.20	.06	11.80
Total less vis. intrusion	.45	-9.18	.63	-16.09	.41	.59	.06	16.84
Q12. Preferred level	.04	-.03	.10	-2.95	.13	-3.83	-.01	3.89
Q13. Overall satisfaction	.05	-.08	.09	-1.81	.11	-2.17	0	3.84

Table 10 Correlation coefficients between annoyance scores and noise indices, with means and standard deviations of variables

Interrupted flow 129 cases

		Mean dB(A)	67.57	59.67	52.35	82.85
		S.D. dB(A)	3.07	3.87	3.99	7.56
Mean	S.D.	Dependent variable	L_{10}	L_{50}	L_{90}	TNI
4.52	0.77	Q3. Traffic noise	.32	.31	.22	.25
2.57	1.37	Q4. Radio/T.V.	.43	.34	.23	.36
2.51	1.32	Q5. Going to sleep	.33	.33	.22	.23
2.22	1.24	Q6. Waking at night	.25	.19	.11	.28
3.02	1.55	Q7. Waking morning	.31	.26	.18	.21
3.12	1.24	Q8. Vibration	.59	.52	.37	.38
2.97	1.35	Q9. Accidents	.06	.08	.07	.02
1.92	1.23	Q10. Fumes	.47	.42	.30	.29
3.43	1.42	Q11. Vis. intrusion	.30	.23	.15	.23
3.01	1.20	Q12. Preferred level	.44	.38	.20	.42
3.40	1.20	Q13. Overall satisfaction	.48	.38	.28	.37
7.74	3.64	Sleep total	.34	.30	.19	.26
26.28	8.06	Total	.48	.42	.29	.34
21.12	6.01	Total with av. sleep	.51	.44	.31	.36
17.96	5.73	Noise total	.49	.42	.29	.37
22.85	7.25	Total less vis. intrusion	.48	.42	.29	.34

Significance level of .05 at correlation coefficient of .17

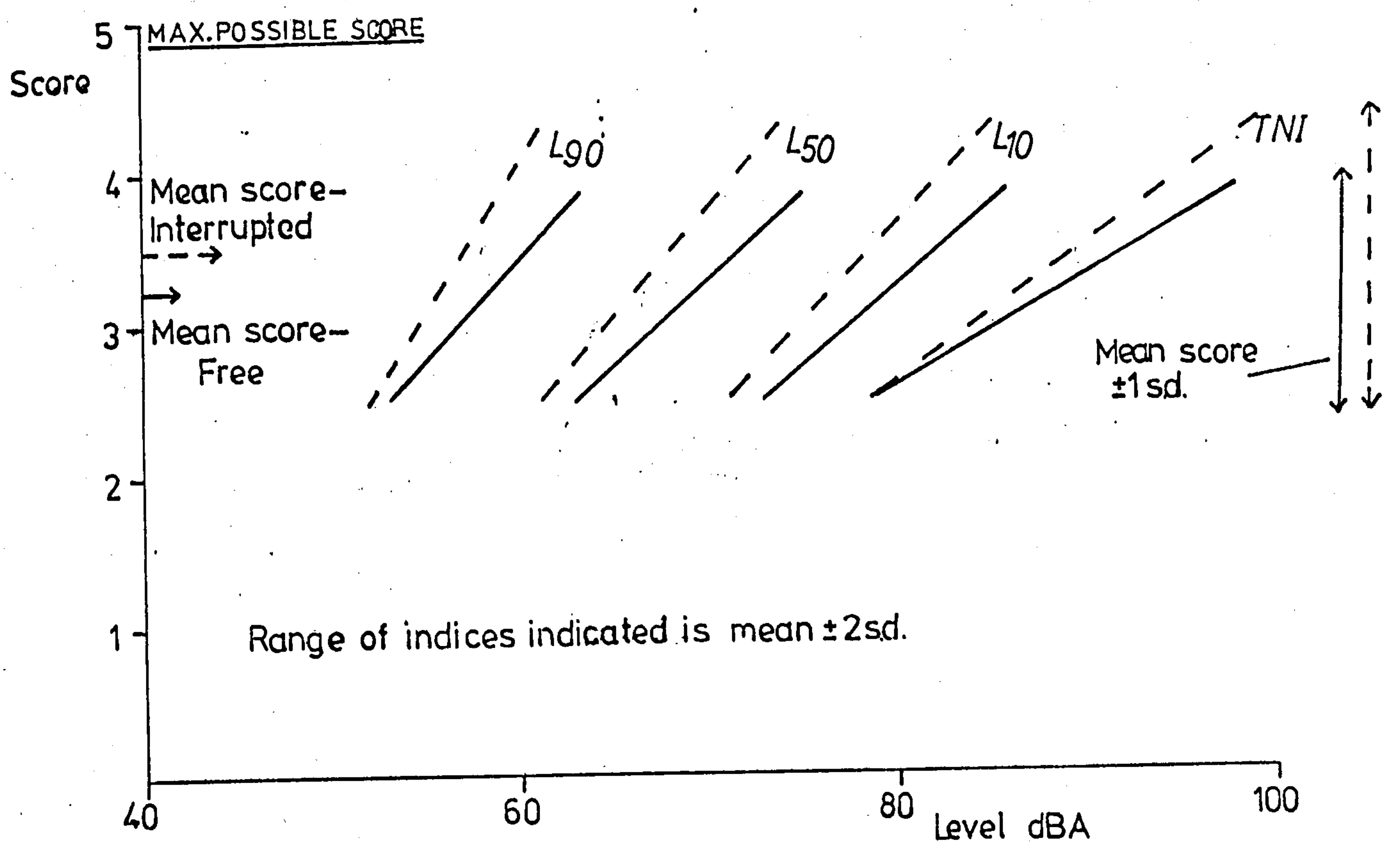
Significance level of .01 at correlation coefficient of .23

Table 11 Regression coefficients and constants from regression analysis between annoyance scores and noise indices (values of m, b, in equation y = mx + b)

Interrupted flow

Dependent variable	L_{10}		L_{50}		L_{90}		TNI	
	m	b	m	b	m	b	m	b
Q3. Traffic noise	.08	-.92	.06	-.81	.04	2.33	.02	2.44
Q4. Radio/T.V.	.19	-10.41	.12	-4.64	.08	-1.61	.07	-2.89
Q5. Going to sleep	.14	-7.21	.11	-4.19	.07	-1.25	.04	-.74
Q6. Waking at night	.10	-4.71	.06	1.47	.03	.51	.05	-1.55
Q7. Waking morning	.16	-7.63	.10	-3.22	.07	-.69	.04	-.50
Q8. Vibration	.24	-12.94	.17	-6.81	.12	-2.98	.06	-2.08
Q9. Accidents	.03	1.02	.03	1.31	.02	1.72	0	3.28
Q10. Fumes	.19	-10.74	.13	-6.02	.09	-2.96	.05	-2.04
Q11. Vis. intrusion	.14	-6.01	.09	-1.71	.05	.62	.04	-.09
Sleep total	.40	-19.55	.28	-8.88	.18	-1.42	.13	-2.78
Total	1.27	-59.55	.87	-25.93	.58	-4.31	.37	-4.17
Total with av, sleep	1.0	-46.52	.69	-20.01	.47	-3.36	.28	-2.31
Noise total	.91	-43.82	.63	-19.51	.41	-3.69	.28	-5.31
Total less vis. intrusion	1.13	-53.54	.79	-24.22	.53	-4.93	.32	-4.07
Q12. Preferred level	.17	-8.56	.10	-3.08	.06	-.16	.07	-2.47
Q13. Overall satisfaction	.18	-8.82	.11	-3.39	.08	-.83	.06	-1.26

Figs 9 to 18 .Regression analysis results.
Questionnaire responses plotted against
noise indices:- KEY



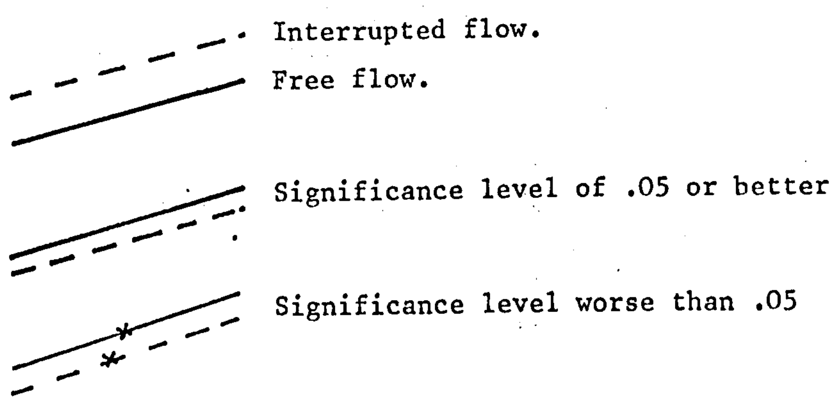


FIG 9 "Do you hear noise from passing traffic?"

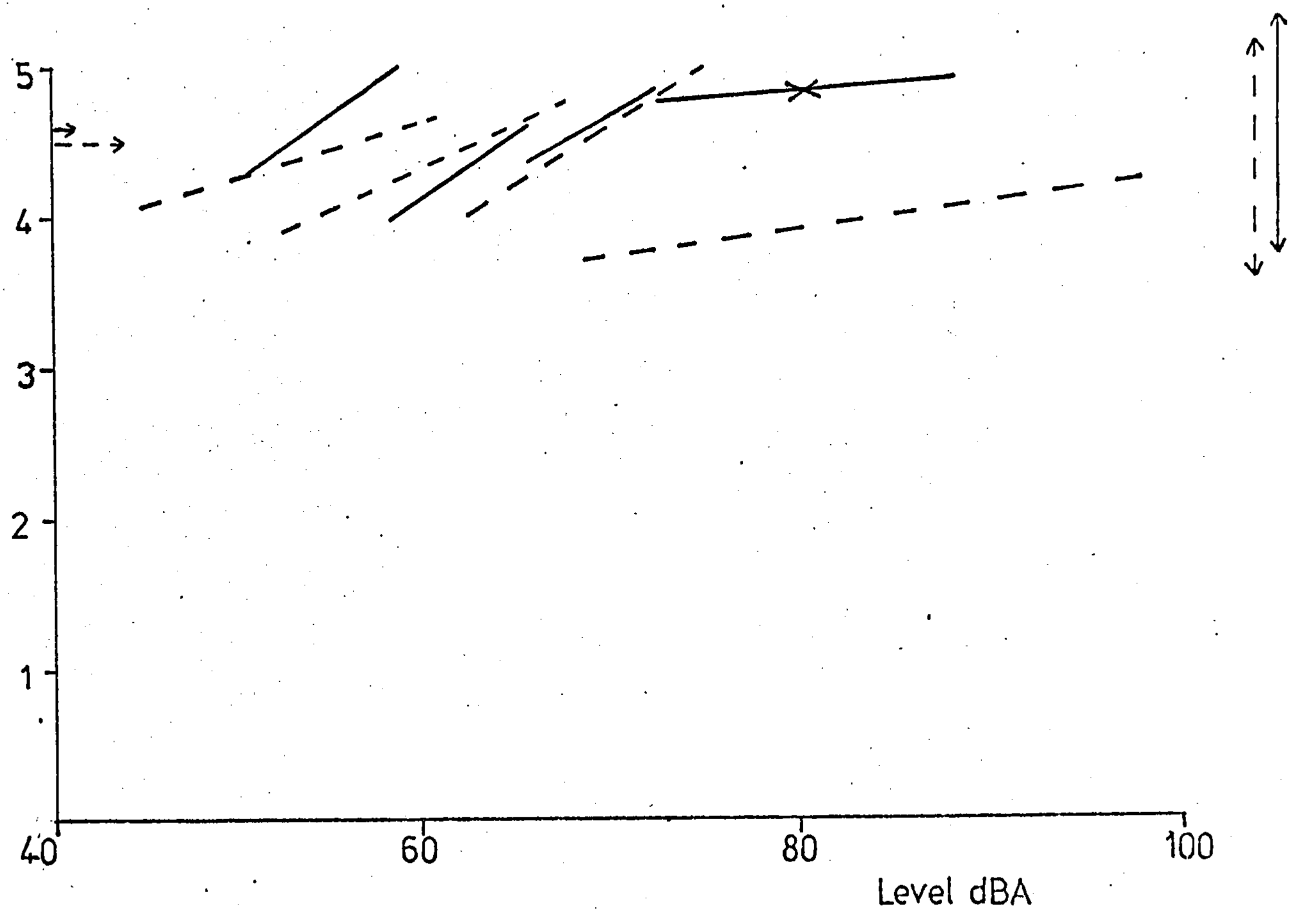


FIG 10 "Does traffic noise make listening to radio or T.V. difficult?"

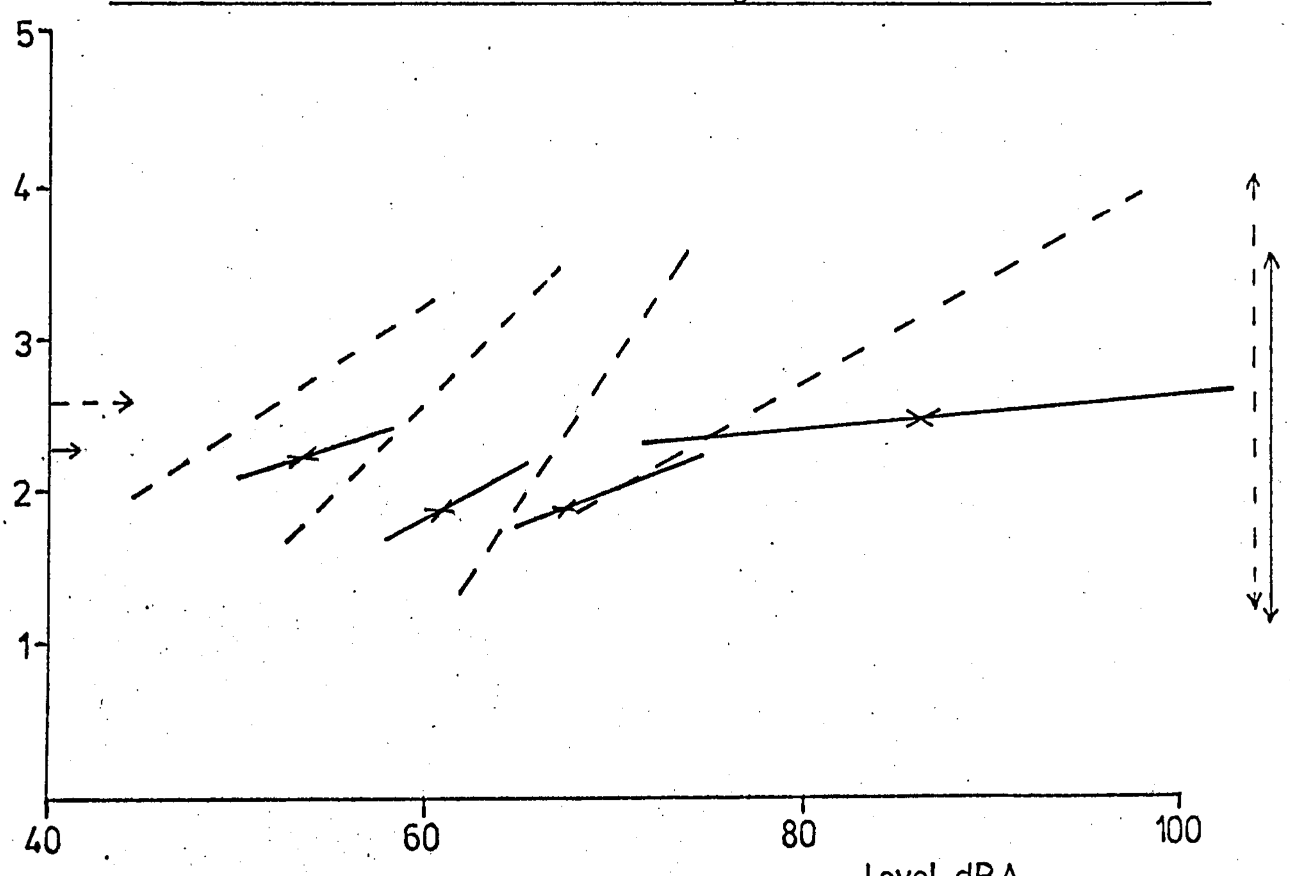


FIG 11 "Does traffic noise prevent you from getting to sleep at night?"

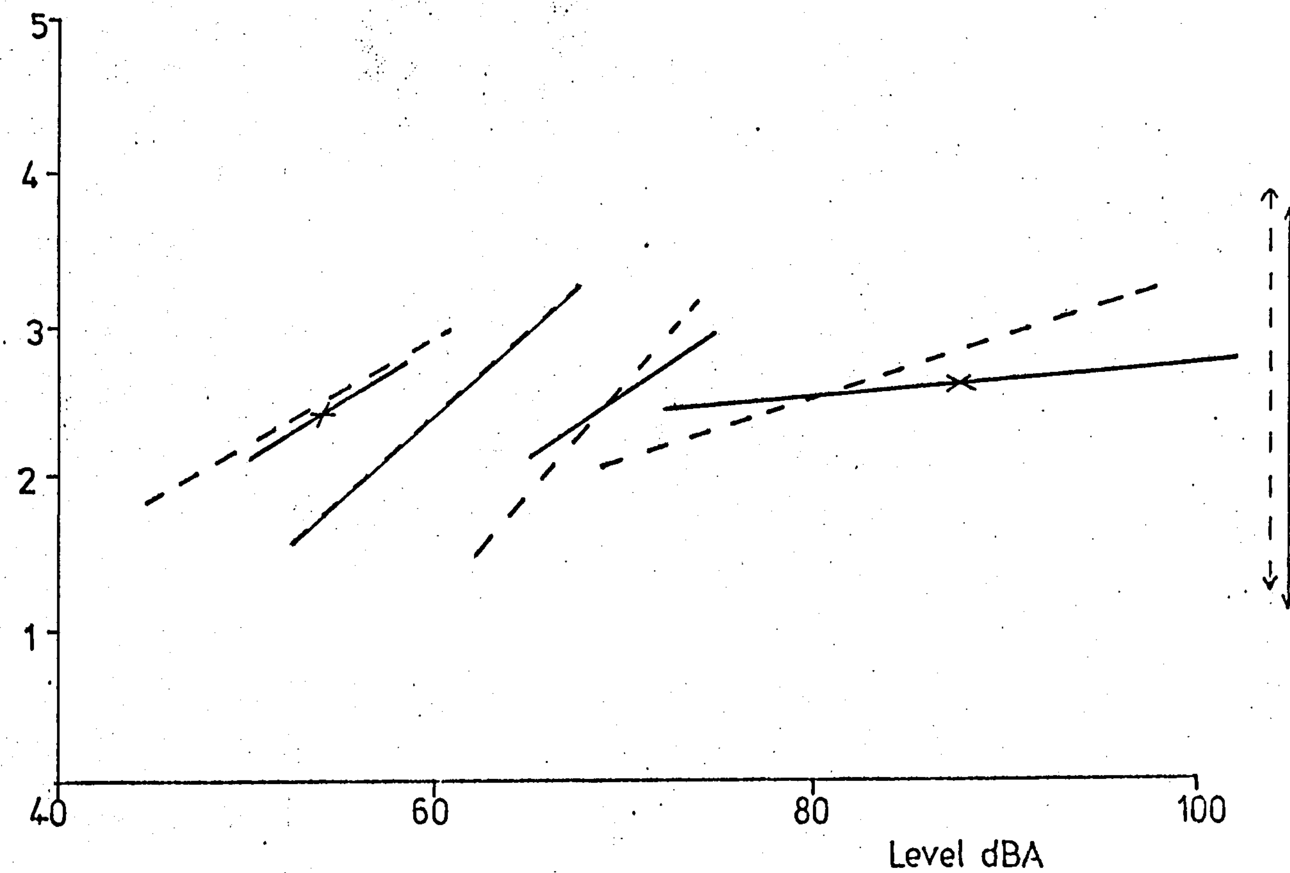


FIG 12 "Does traffic noise wake you up during the night?"

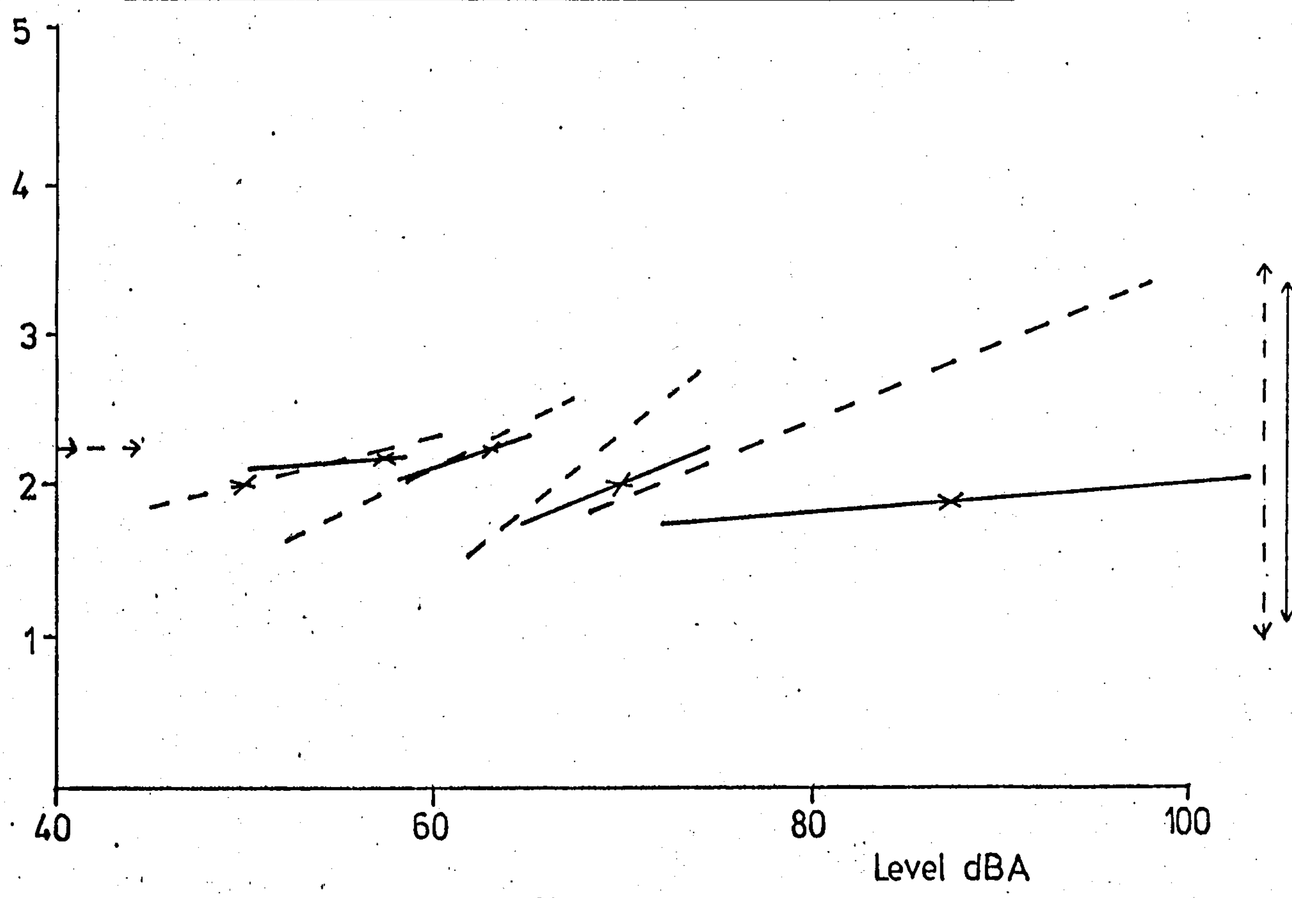


FIG 13 "Does traffic noise wake you up in the morning?"

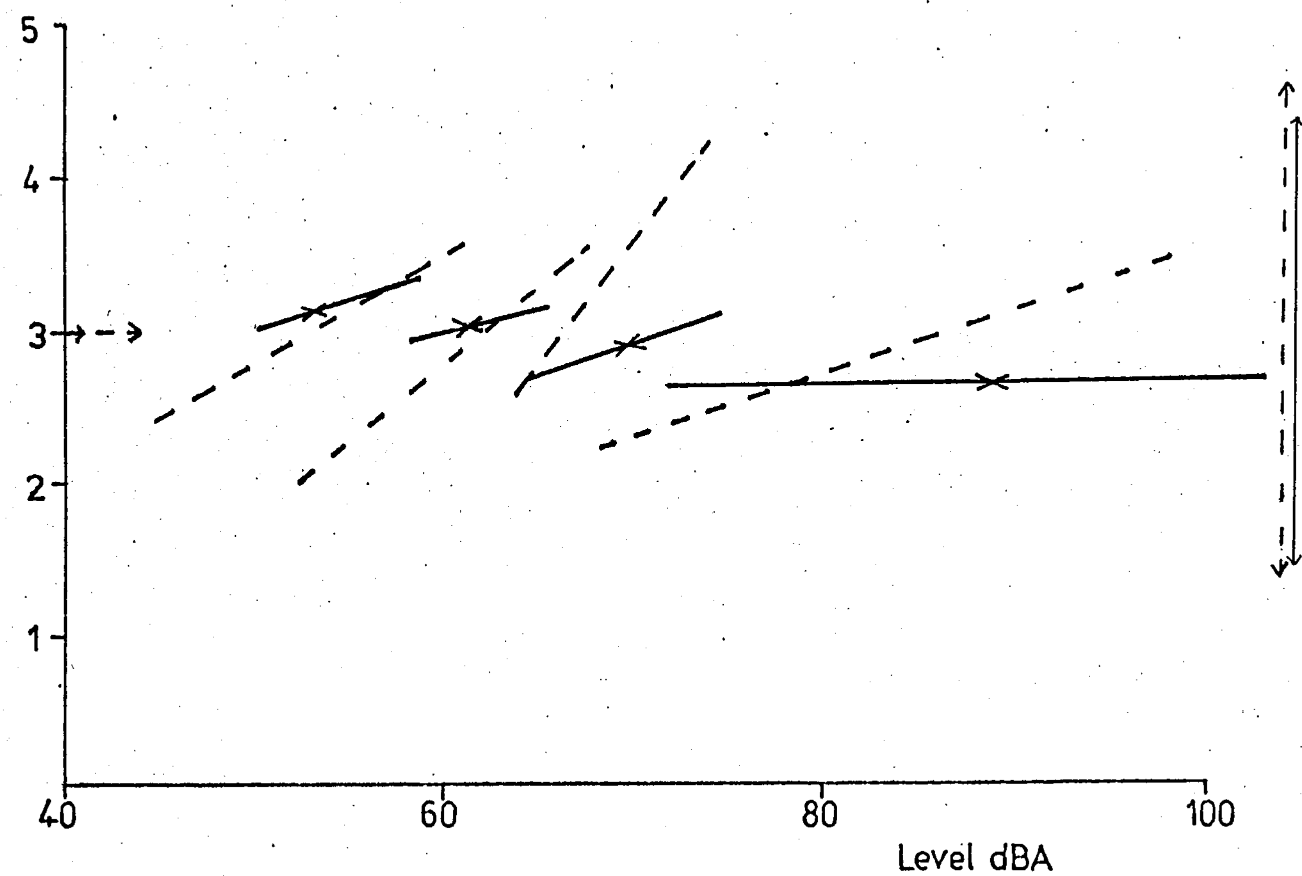


FIG 14 Total sleep disturbance score.

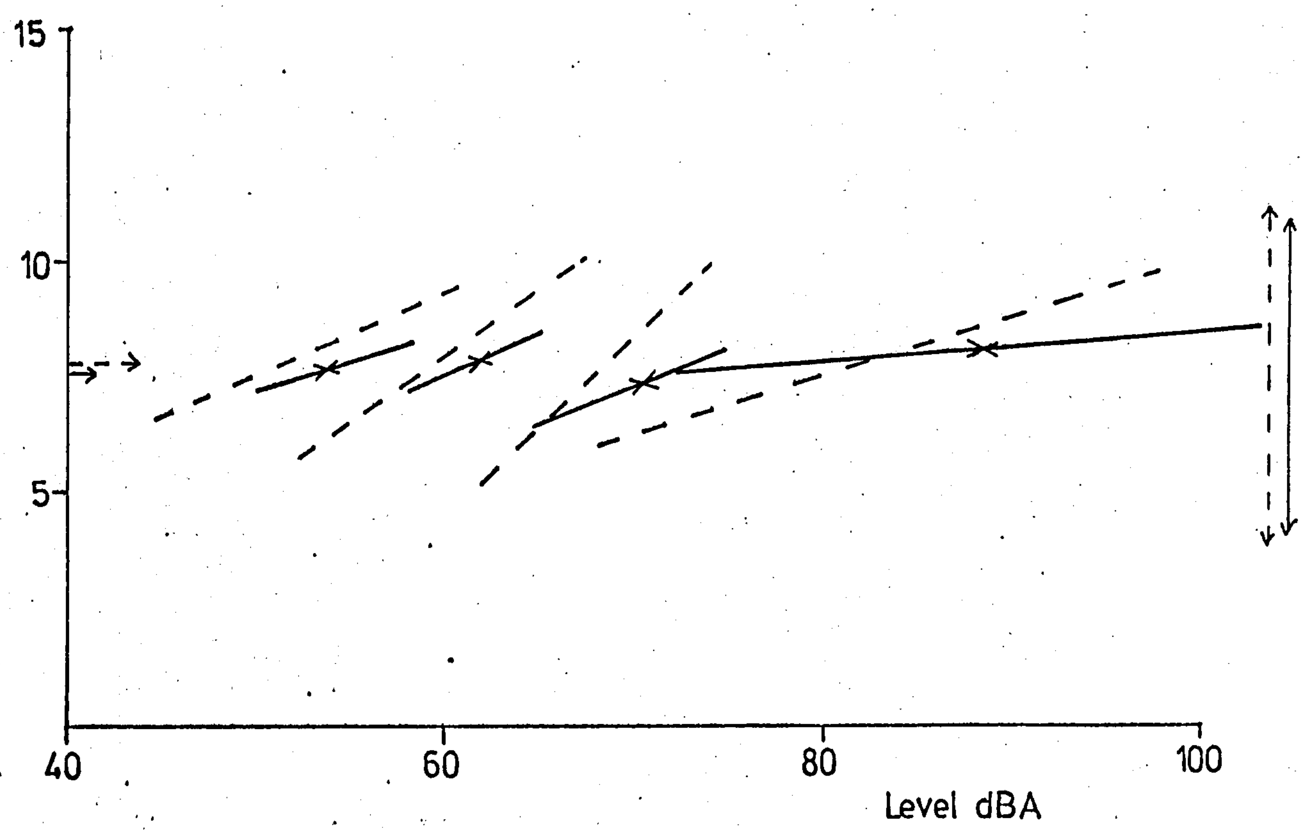


FIG 15 "Does traffic make your house vibrate?"

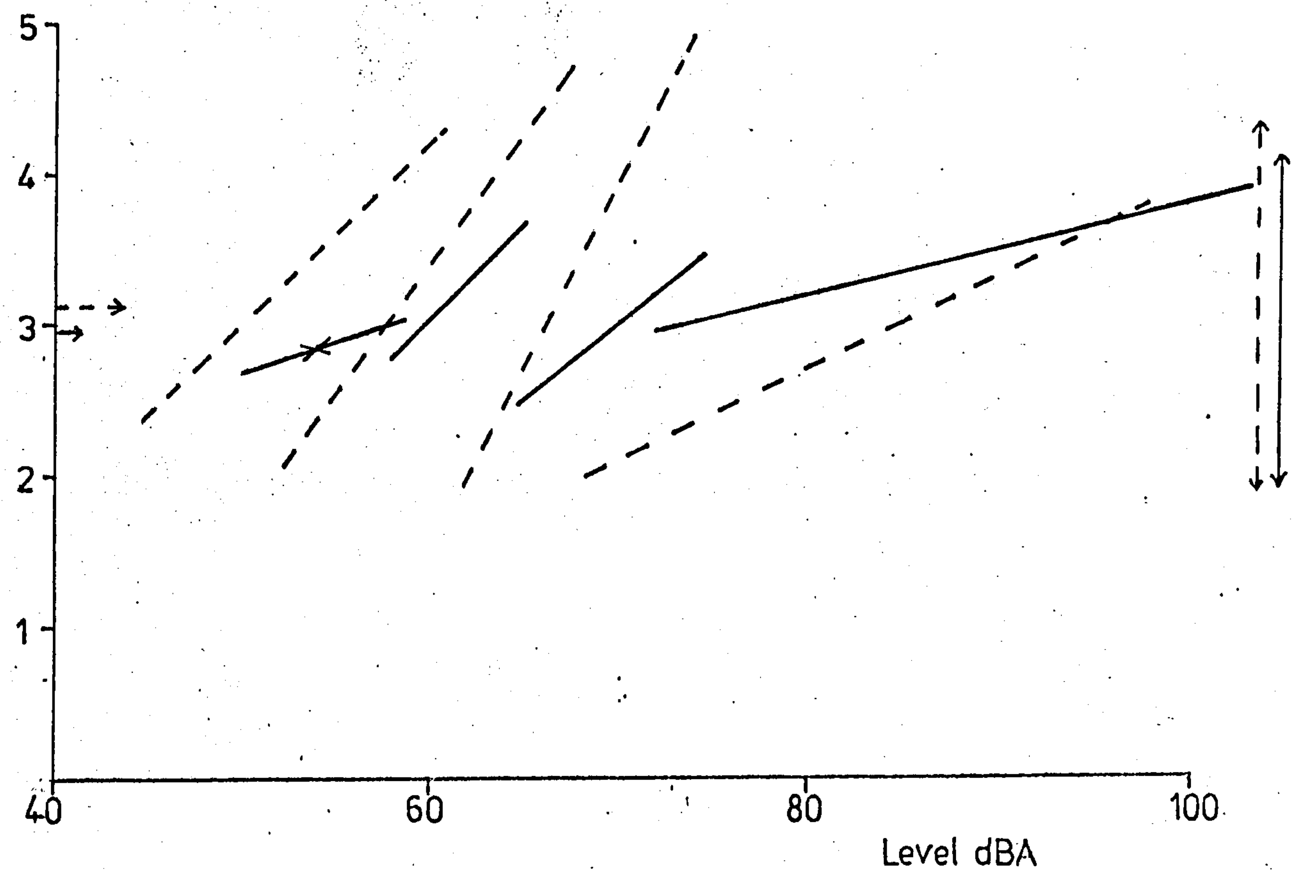


FIG 16 "Can you smell traffic exhaust fumes in the house?"

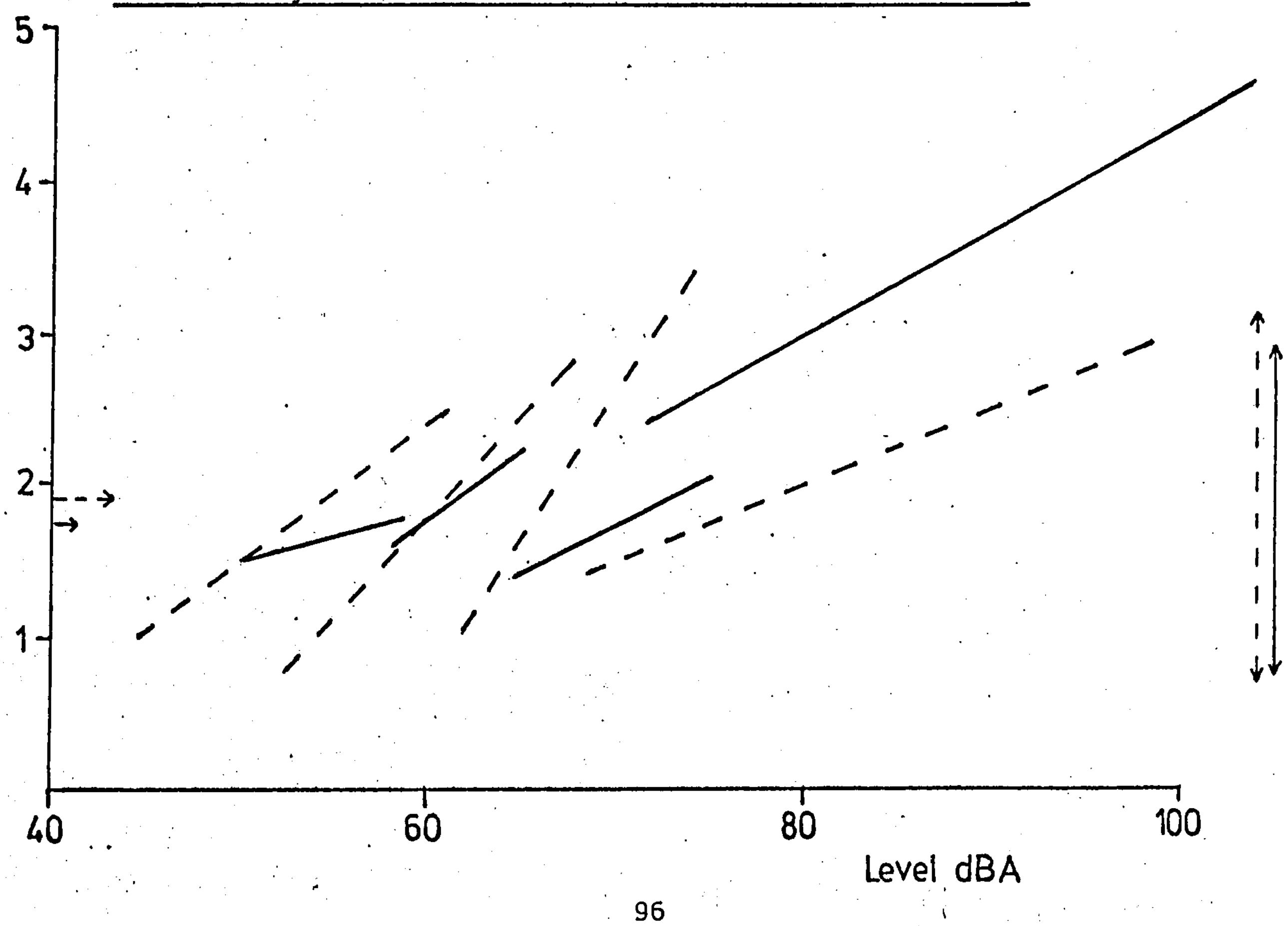


FIG 17 "Do you feel that the volume of traffic on the roads near to your home reduces the visual attractiveness of the area?"

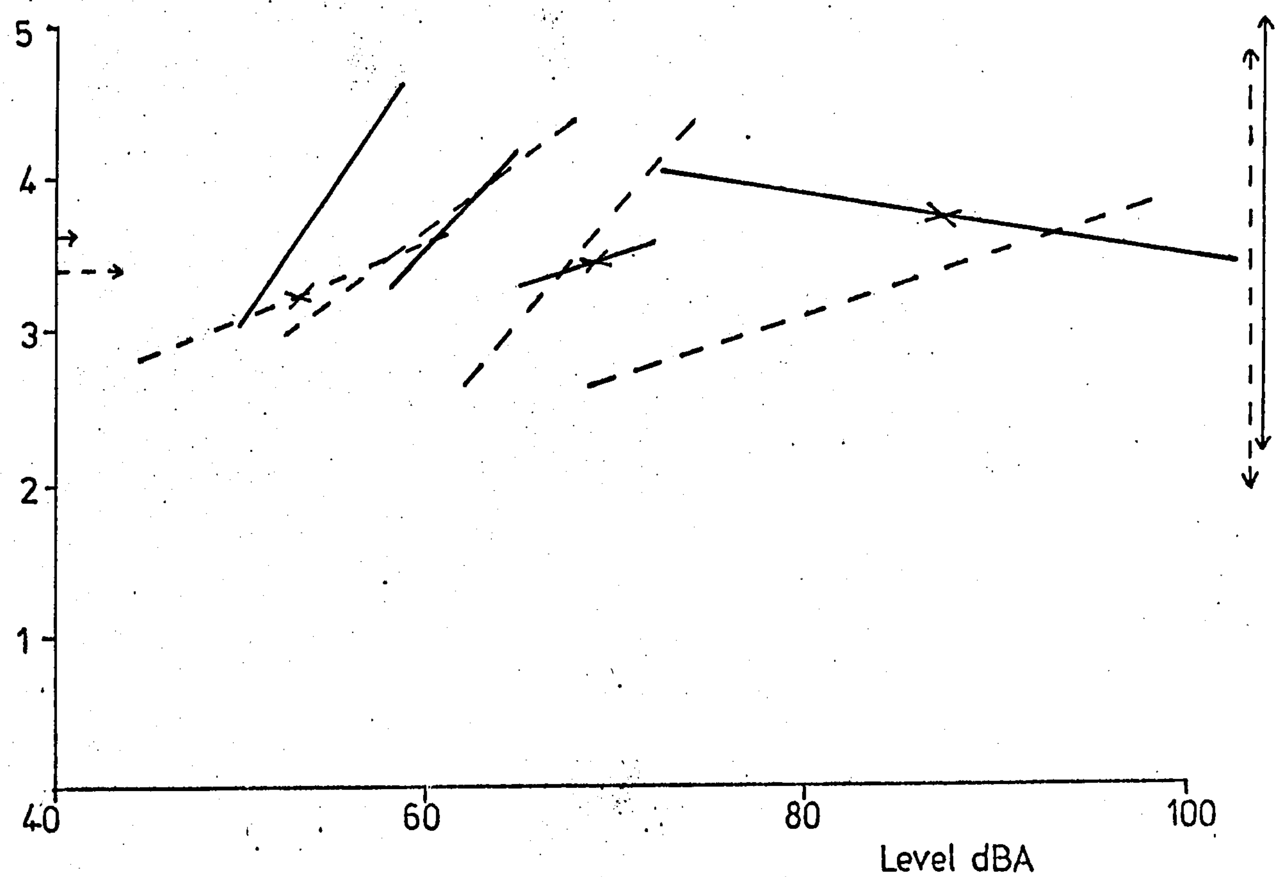
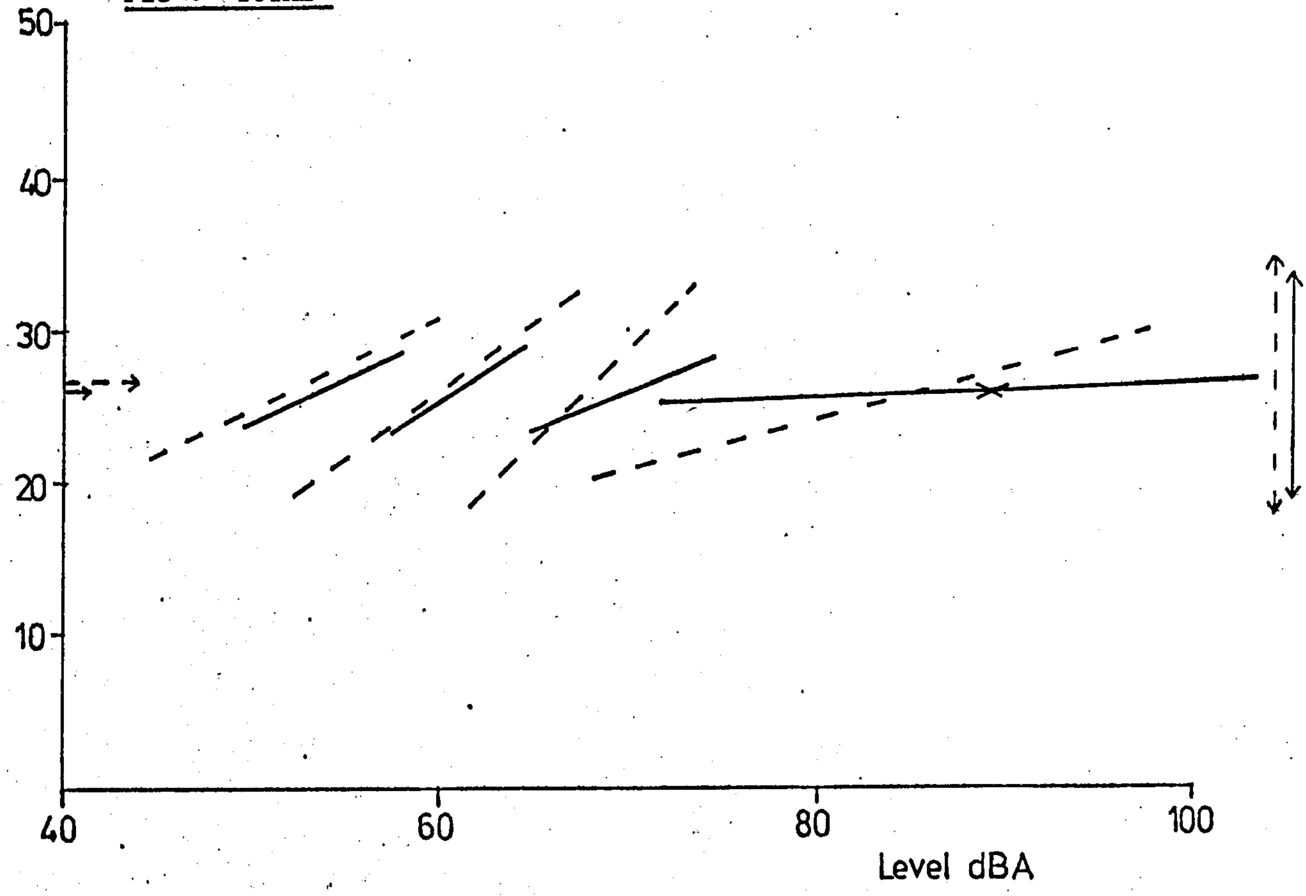


FIG 18 "TOTAL"



which remain fairly constant for individual vehicles, protrude less above the general noise level, lessening the rate of increase of annoyance, whereas in the free flow situation, an increase in L_{90} indicates a general increase in levels, including L_{10} levels. Rate of change of annoyance with L_{50} and L_{90} shows similar behaviour in both flow situations.

Question 4. Does traffic noise make listening to radio or T.V. difficult? (Fig.10)

In both flow situations the L_{10} levels correlate best, together with L_{50} in the free flow case, with the disturbance score. This shows that it is the magnitude of noise events, as characterised by L_{10}, that determines the difficulty experienced in hearing radio or television. It would be expected that response to this question would be largely due to the masking effect of noise peaks, with little psychological contribution. However it is possible that a person with a high general dissatisfaction with noise could bias his response to this question towards a greater dissatisfaction.

Interpretation of the graph is not attempted due to the low correlation coefficients in the free flow case.

Question 5. Does traffic noise prevent you from getting to sleep at night? (Fig.11)

In both flow situations L_{10} and L_{50} give the best correlation coefficients, showing that prevention of sleep tends to be caused by a combination of mean and peak levels. The graphs show no great differences in change of disturbance with level between the two situations.

Question 6. Does traffic noise wake you up during the night? (Fig.12)

The responses to this question would seem to indicate that peaks and fluctuation of level are important factors in determining whether a person is woken during the night. The best correlation in the interrupted flow case is with TN1 and L_{10}, while in the free flow case the TN1 correlation coefficient is higher than for the other sleep questions, although L_{10} gives the highest correlation coefficient.

Low correlation coefficients in the free flow case prevent meaningful interpretation of the graph.

Question 7. Does traffic noise wake you up in the morning? (Fig.13)

Question scores correlate best with L_{10} in the interrupted flow situation, showing that magnitude of peaks influences waking in the morning. Correlations are very low in the free flow situation. Generally, mean scores are higher than for the other sleep questions, showing this to be the time when noise affects sleep most.

The fact that people are probably sleeping lightly at this time will account for this to a certain extent. This result should be investigated further as emphasis has previously been placed on disturbance when going to sleep.

Total sleep score (Fig.14)

Overall sleep disturbance would seem to be explained best by L_{10} in the interrupted flow case, and possibly by L_{10} in the free flow case, although correlation coefficient is low (.13). The graph shows that a given L_{10} will produce a higher disturbance score for interrupted flow especially at higher levels. The fact that the same L_{10} in the two flow situations can be produced by different patterns of noise goes some way to explain this (see discussion of final annoyance score below).

Question 8. Does traffic make your house vibrate? (Fig.15)

Question scores correlate highly with L_{10} in both flow situations. This indicates a strong link between incidence of vibration and the magnitude of peak noise levels. Therefore vibration can be considered an extension of noise, and presence of vibration can be taken as indication of high peak levels. At higher levels, the increase of reported presence of vibration for a given L_{10} in the interrupted flow case, could be explained by the differences in characteristics of noise in the two flow situations, as mentioned in the previous paragraph, and discussed later.

Question 9. Does the possibility of accidents caused by vehicles near to your house worry you?

Although it was thought that as levels increased people would become more aware of the presence of traffic, and hence the dangers associated with it, very low correlation coefficients for all indices do not bear this out. Accident fear would seem to be linked more to family structure (e.g. young children), or to the previous occurrence of accidents, than to noise. No graph was drawn as correlations were too low.

Question 10. Can you smell traffic exhaust fumes in the house? (Fig.16)

Similarly to Question 3, this question was considered to be not only an indicator of presence of fumes. It was thought from experience gained when applying the pilot questionnaire, that a person generally dissatisfied with the traffic would be more sensitive to the presence of fumes and either be immediately aware of a slight smell, or exaggerate his answer.

The best correlation is with L_{10} in the interrupted flow case, and with L_{50} in the free flow case. In interrupted flows, high L_{10}s indicate the presence of lorries, and hence a large amount of diesel fumes. In free flows, high levels of L_{10} do not necessarily indicate the presence of lorries.

The only pair of lines on the graph which are both comparatively significant are those for L_{50}. They show very little variation between the two flow situations.

Question 11. Do you feel that the volume of traffic on the roads near to your home reduces the visual attractiveness of the area? (Fig.17)

Response to this question appears to be similar to that for Question 3, with the best correlation in the interrupted flow case being with L_{10}, and with L_{90} in the free flow case. The only pair of lines on the graph which are both significant are those for L_{50}, and these show little variation of change of response with level between the two flow situations.

It would seem, as in Question 3, that the response to this question can be taken as some indication of noise annoyance, as the higher the level becomes, the person is more aware of the presence of traffic and its intrusion on the environment.

Total Scores.

Total scores obtained from various combinations of the scores from the above questions behave similarly to one another. The main difference is in the degree of correlation with the noise indices.

"Total":- sum of Questions 3,4,5,6,7,8,9,10,11. (Fig.18)

In the free flow case L_{50} correlates best with annoyance score, while for interrupted flow the best correlation is with L_{10}. Annoyance shows similar behaviour between the two flow situations as L_{50} and L_{90} increase, while annoyance is greater for interrupted flows at high L_{10} levels.

"Total with average sleep":- sum of Questions 3,4,8,9,10,11, + ((5,6,7) ÷ 3). (Fig.19)

By weighting the total sleep disturbance score so that its contribution is the same as the other individual questions, response patterns do not change greatly, but correlations with L_{10}, L_{50}, and L_{90} increase.

"Total less visual intrusion":- sum of Questions 3,4,5,6,7, 8,9,10. (Fig.20)

This total was included as it was thought that the visual intrusion question was possibly less noise linked than any other question, but behaviour of the scores, and correlation coefficients do not vary significantly from those of the "Total" score.

"Noise and vibration total":- sum of Questions 3,4,5,6,7,8. (Fig.21)

Behaviour of the graphs was again similar to that shown for the above totals, although the highest correlation coefficient is between scores and L_{10} in both cases. This could be due to pure noise and vibration annoyance being caused by the peaks in level. The majority of correlation coefficients are smaller for this total than for the total with average sleep score.

Question 12. "How much quieter would you prefer the traffic noise?" (Fig.22)

This question is taken as being an indicator of general dissatisfaction. There is no opportunity for the respondent to express satisfaction as a score of 1 indicates a response of "no quieter" which can be thought of as a neutral position.

In the free flow situation scores correlate best with L_{90}, while for interrupted flows scores correlate best with L_{10}.

Question 13. "How satisfied are you overall with the traffic noise around here?" (Fig.23)

A neutral central point is provided in this question, allowing respondents to express degree of satisfaction or dissatisfaction. Correlations between scores and levels are similar to those in the previous question, as is behaviour of the graph, with the L_{10} line for free flow not significant. The L_{50} line shows that rate of increase of annoyance with level is similar in both flow situations but annoyance is

FIG 19 "TOTAL WITH AVERAGED SLEEP SCORE"

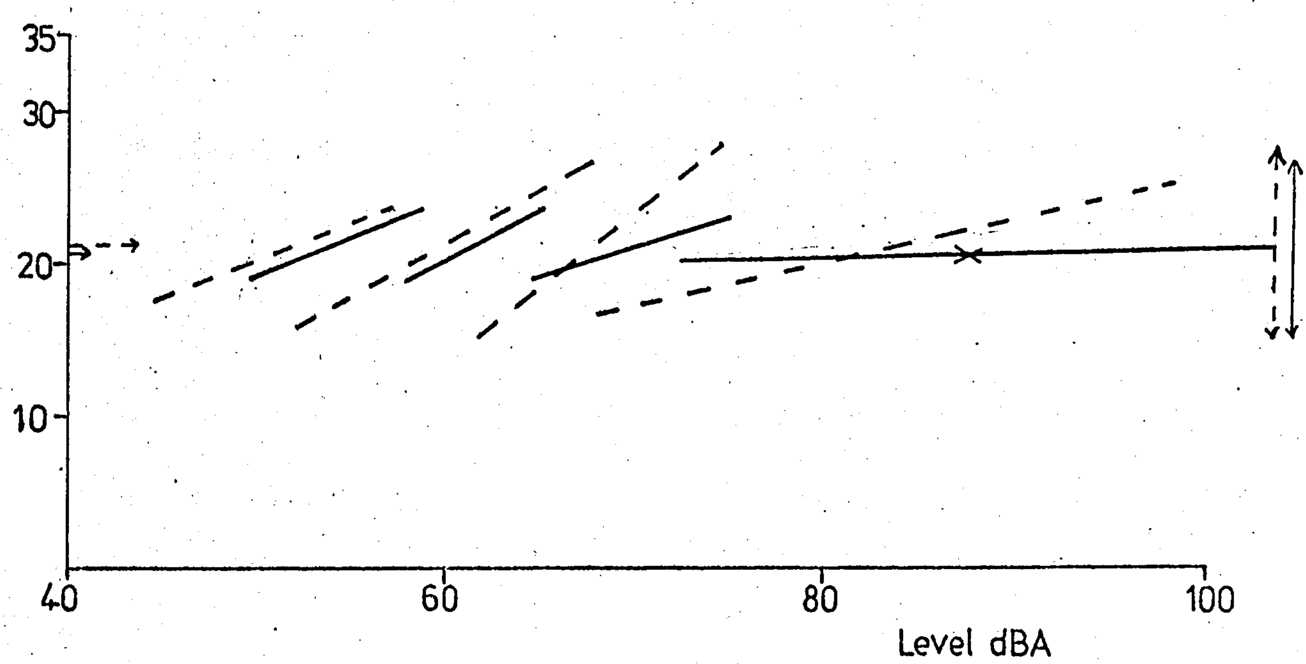


FIG 20 "TOTAL LESS VISUAL INTRUSION QUESTION"

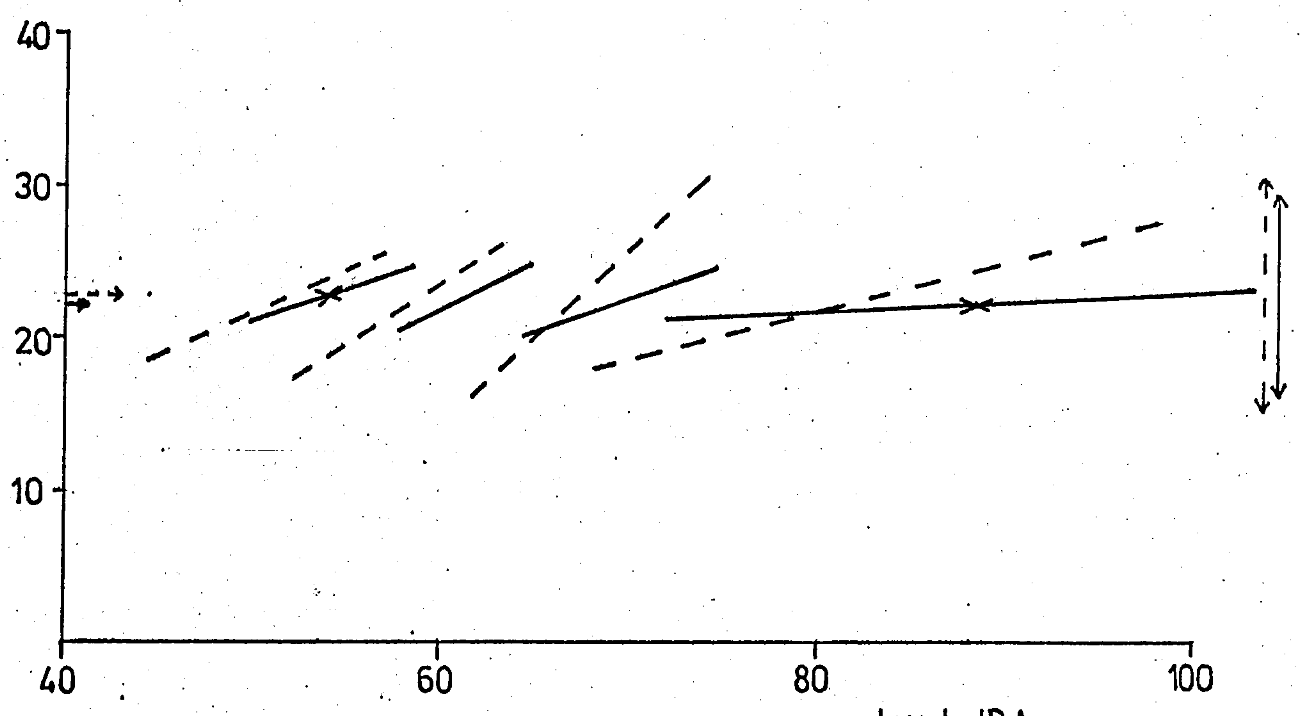


FIG 21 Total of questions involving noise and vibration only.

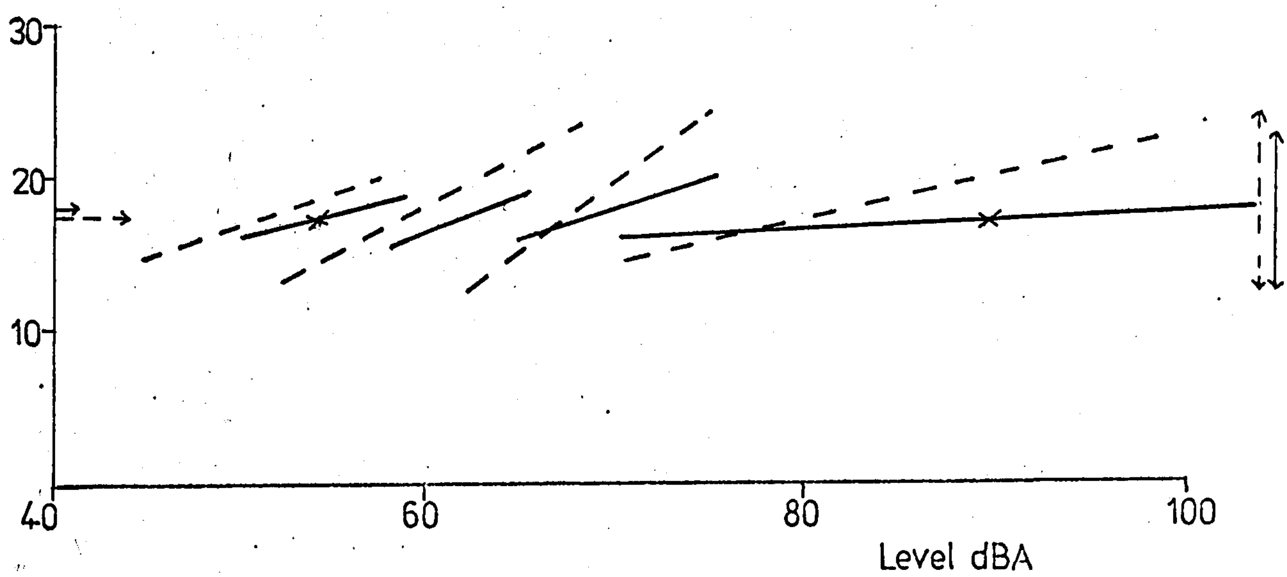


FIG 22 "How much quieter would you prefer the traffic noise?"

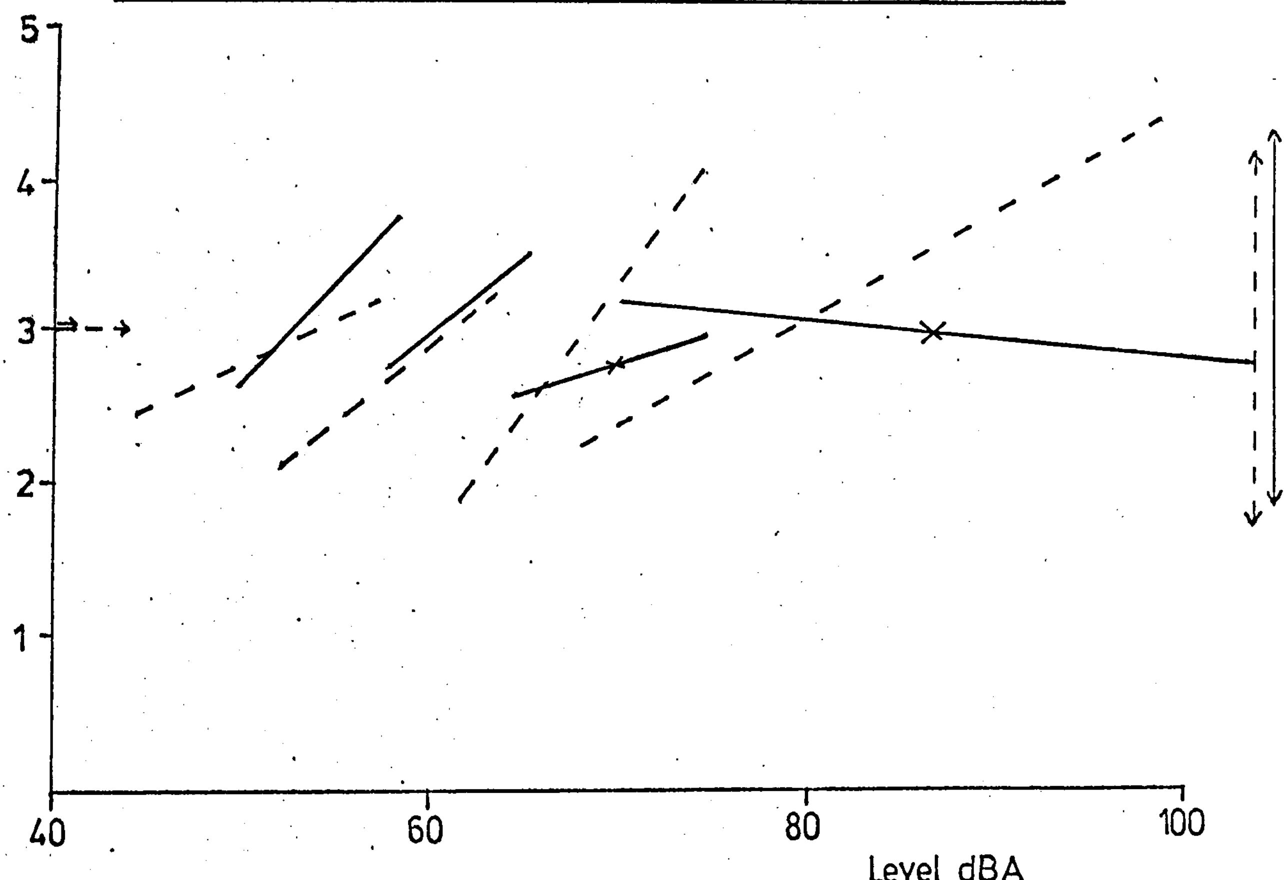


FIG 23 "How satisfied are you overall with the traffic noise around here?"

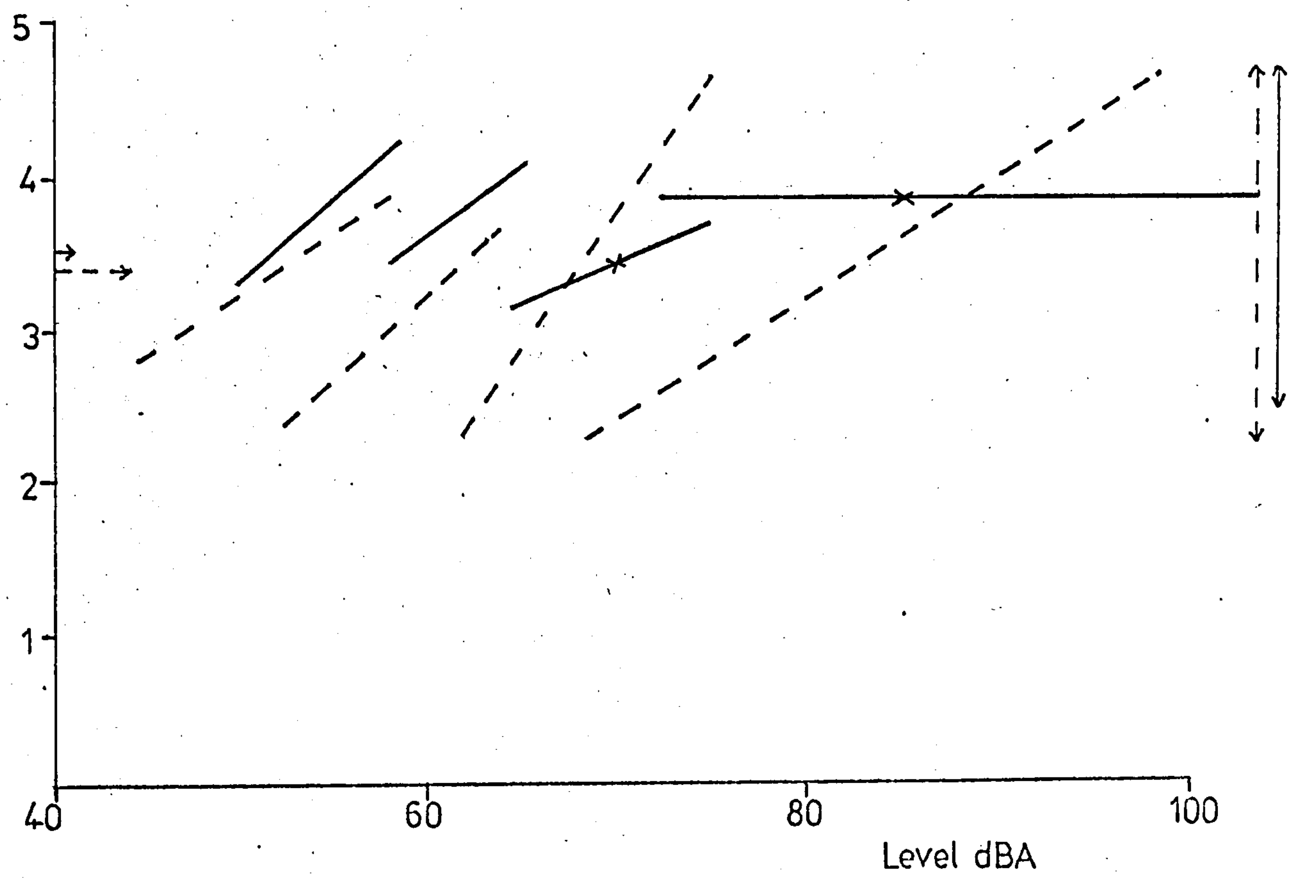


FIG 24 "TOTAL WITH AVERAGED SLEEP LESS ACCIDENT FEAR QUESTION"

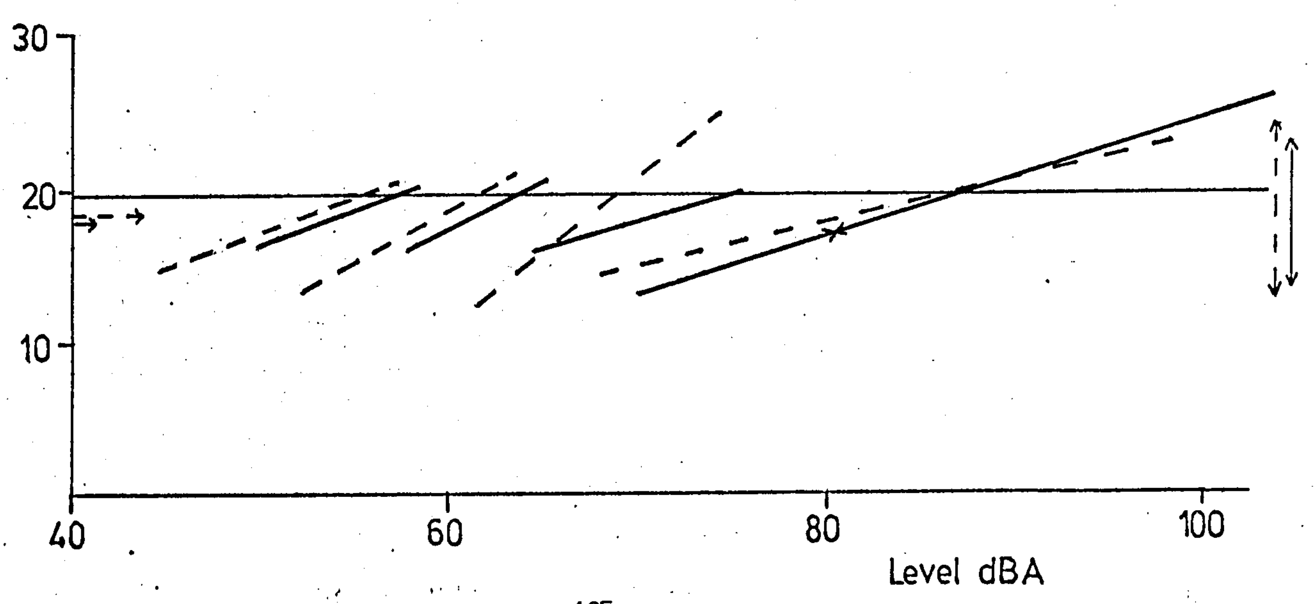


FIG 25 "TOTAL LESS ACCIDENT FEAR QUESTION"

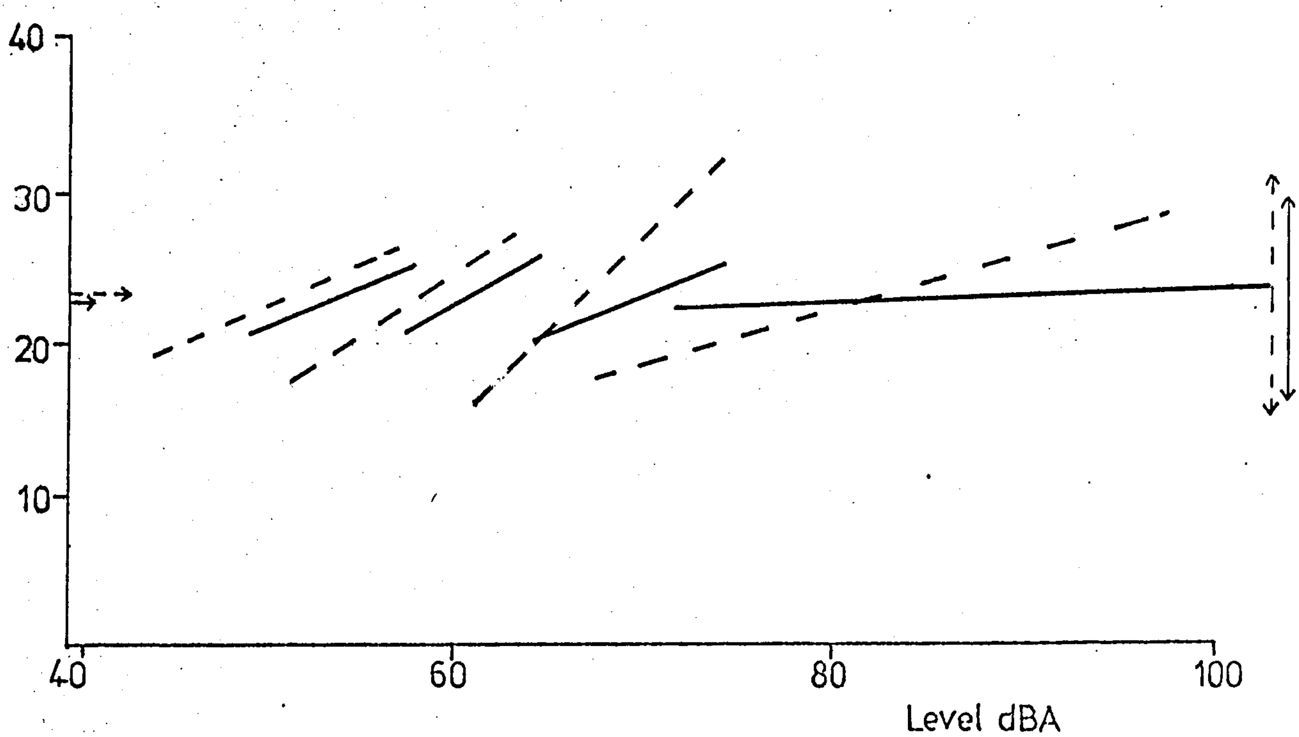
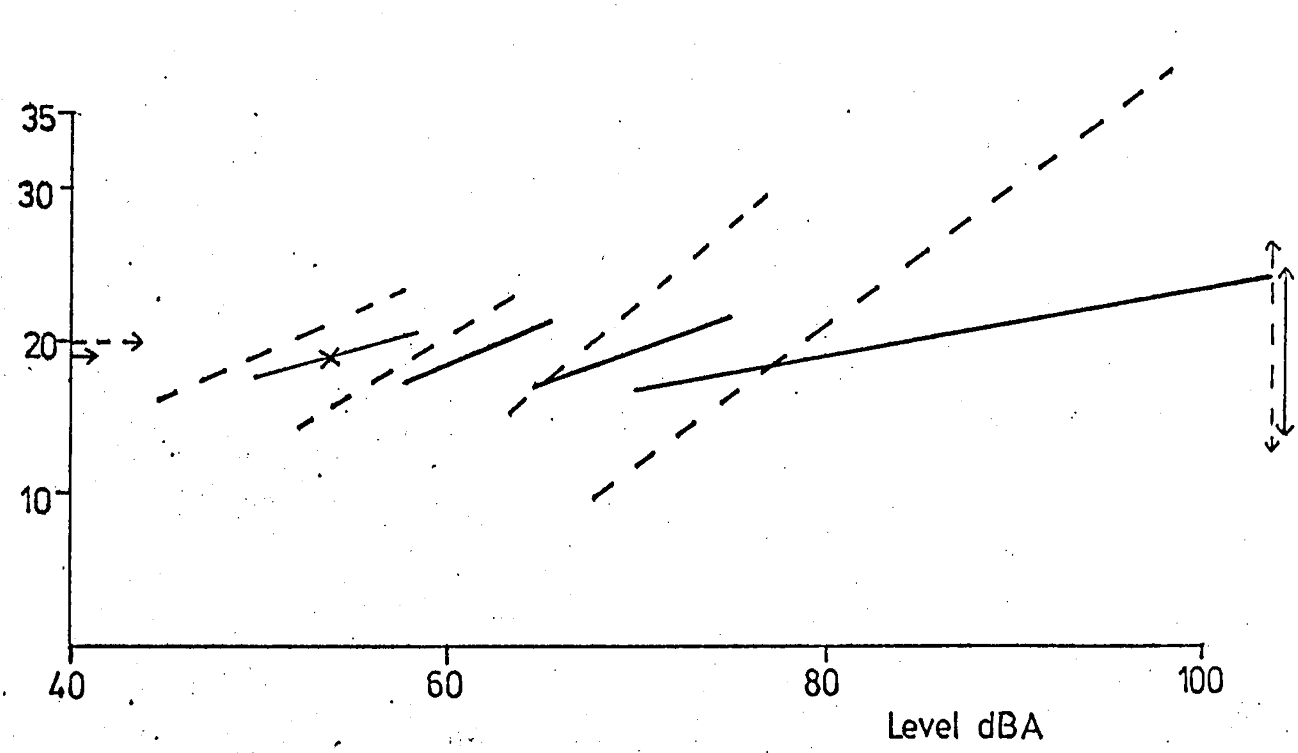


FIG 26 "TOTAL LESS VISUAL INTRUSION AND ACCIDENT FEAR QUESTIONS"



greater for a given L_{50} in the free flow situation. The L_{90} line shows a slightly greater increase of annoyance with level for free flows. This is likely to be due to the difference in noise characteristics as outlined in the discussion of Question 3 above.

Mean scores are between 3 and 4 for both flow situations, showing a general tendency towards dissatisfaction at the kind of noise levels which are being considered here.

<u>Question 15. "How long have you lived in your present house?"</u>

No significant relationship was found between scores for this question and the two general satisfaction questions (13 and 14).

<u>Question 14 and "Comments".</u>

Table 12 indicates the percentage of respondents in each flow situation who mentioned certain noise generating factors:-

TABLE 12

	Free Flow	Interrupted Flow
Continuous noise or drone	10	6
Heavy vehicles only	11	8
Heavy vehicle noise	8	8
Heavy vehicle vibration	10	18
Speed	13	5
Bumps caused by road surface	6	1
Acceleration or gear changing (up or down)	1	10
Braking	3	27
Motor cycles	3	11

It would be expected that a free flow would produce more continuous noise, more noise due to high speed and hence more noise from uneven surfaces.

Heavy vehicles seem to be major contributors to annoyance in both flow situations, with vibration dominant in interrupted flows. Braking, acceleration and gear changing are also important noise sources in interrupted flows.

The high noise output from motor cycles when accelerating also seems to be a contributor to annoyance at intersections.

10.3 Relationship between Traffic Noise Index and annoyance.

In general, annoyance scores and TNI correlate satisfactorarily in the interrupted flow situation. However, correlations tend to be very low for free flows, for which the index was originally designed.

TNI's in the present study are calculated from 18 hr. values of L_{10} and L_{90}, whereas they were calculated from 24 hr. values in the original study (8). This could affect correlations, because as the number of vehicles flowing per hour increases, TNI tends to increase to a maximum between 500 and 1000 v/h, and then decrease. If the number of vehicles per hour in the period between 2400 hrs. and 0600 hrs. is in the 500 to 1000 range, then by missing out this period average TNI can be considerably distorted.

A paper by Rice (44) quotes the results of a traffic noise study in which a complex set of varying traffic situation noises were aligned at equal background levels, and then judged subjectively. He states that a good noise measurement unit should have maximum flexibility and sensitivity of physical measurement (a large value of standard deviation of measured range when aligned at equal background levels, σp), and minimum subjective scatter (a small value of standard deviation of measured range at equality levels, σs). The factor, Goodness Factor, is defined as $\sigma s/\sigma p$. The smaller G.F. is, the better the unit.

TNI has a G.F. of .88 whereas G.F.'s for L_{10}, peak, and L_{EQ} are .30, .30, and .50 respectively, indicating the relatively poor performance of the Index, and its unsuitability as an indicator of annoyance. This is reflected in the present survey by the low correlations between TNI and annoyance, although account must be taken of the possible distortion of TNI due to 18 hr. measurements being used.

The original TNI survey used median annoyance scores at each of 14 sites. Annoyance score was obtained from a 7 point question similar to Question 13 of the present survey. Reference to the regression result for Question 13 indicates an extremely low correlation between annoyance and values of TNI in the free flow situation. Rice's findings that individual subjective scatter is high for TNI at equality levels are confirmed in the present survey where 139 points have been considered, as opposed to the 14 points of the original survey which probably tended to smooth out individual scatter to a great extent.

10.4 Choice of final annoyance score.

Due to the poor performance of the accident fear question it was decided to remove it from the three total scores "Total with averaged sleep", "Total", and "Total less visual intrusion" and carry out a regression analysis between these new totals and the noise indices. The results are shown in Tables 13 & 14.

The graphs for these results, Figures 24 to 26 , indicate the same type of behaviour of scores with level, as found with the previous total scores.

The "Total with averaged sleep less accident fear question" gives the best correlations with percentile levels compared with all the other totals, for both flow situations, and therefore is taken as the final annoyance score.

This total correlates best with L_{10} in the interrupted flow case, and with L_{50} in the free flow case. The graph (Fig. 24) shows that the greatest difference in change of annoyance with level between the two flow situations occurs at high L_{10} levels, whereas L_{90} and L_{50} lines behave similarly to each other in both situations. At the top end of the L_{10} range, annoyance score of 19 occurs at a free flow L_{10} of 76 dB(A) and at an interrupted flow L_{10} of 68.5dB(A).

L_{10} cannot be used as a predictor of annoyance if free flow and interrupted flow sites are to be compared, because of this discrepency.

Table 13 Correlation coefficients between new totals and noise indices

Interrupted flow 129 cases

Mean	S.D.	Dependent variable	L_{10}	L_{50}	L_{90}	TNI
18.15	5.36	Total with av. sleep less accident	.56	.48	.33	.40
23.31	7.42	Total less accident	.51	.44	.30	.38
19.88	6.60	Total less vis. intrusion and accident	.51	.44	.31	.55

Free flow 139 cases

17.80	4.46	Total with av. sleep less accident	.22	.25	.21	.07
22.86	6.25	Total less accident	.20	.21	.18	.08
19.22	5.51	Total less vis. intrusion and accident	.21	.20	.13	.18

Table 14 Regression coefficients and constants from regression analysis between new totals and noise indices

Interrupted flow

Dependent variable	L_{10}		L_{50}		L_{90}		TNI	
	m	b	m	b	m	b	m	b
Total with av. sleep less accident	.97	-47.54	.66	-21.32	.44	-5.08	.29	-5.59
Total less accident	1.24	-60.57	.85	-27.24	.56	-6.03	.37	-7.45
Total less vis. intrusion and accident	1.10	-54.57	.76	-25.53	.51	-6.65	.87	-48.74

Free flow

Total with av. sleep less accident	.38	-8.98	.57	-17.24	.43	-5.14	.39	14.37
Total less accident	.50	-12.02	.69	-19.39	.51	-4.69	.06	17.94
Total less vis. intrusion and accident	.46	-12.69	.56	-15.16	.33	1.21	.22	1.38

It would seem that L_{10} does not measure some characteristic of the noise which is a major contributor to annoyance. A given L_{10} can indicate either intermittent short duration but high peaks in a free flow situation, or long duration and flatter peaks in interrupted flows, as vehicles accelerate. The latter characteristic is likely to cause more annoyance than the former so explaining the difference in percentile levels which give the same level of annoyance.

Although the L_{50} and L_{90} lines indicate the same type of behaviour as that found with L_{10}, the tendency to diverge at high levels is much less marked. The difference in L_{50}'s at an annoyance score of 19 is in the order of 2dB(A), and the difference in L_{90}'s is 1.6dB(A). As prediction methods have an accuracy in the order of $\pm$ 2dB(A), these lines can be treated as being the same when used in conjunction with such a method.

L_{50} and annoyance score correlate best in the free flow case, indicating that mean levels are more important than peaks in causing annoyance in this situation. Although the peaks, as indicated by L_{10}, are the most important factors in determining annoyance in interrupted flows, L_{50} also correlates highly with annoyance. L_{50} could then possibly be used as a more consistent predictor of annoyance for both types of flow situation.

TN1 does not correlate significantly with annoyance in the free flow case so interpretation of the behaviour of the TN1 lines on the graph is not attempted.

10.5 Reliability of the questionnaire.

A split half reliability test was carried out on the questionnaire by dividing the final annoyance score into two halves. Thus the sum of Questions 4, 8, and 11 was correlated with the sum of Questions 3, 10 and the average sleep score, for each flow situation.

Correlation coefficient for free flow was .61, which gave a "stepped up" reliability of .76.

Correlation coefficient for interrupted flow was .73, which gave a "stepped up" reliability of .84.

Both these levels of reliability indicate that the questionnaire can be expected to give reasonable repeatability in responses.

10.6 Internal correlations between questionnaire items.

A correlation analysis was carried out for all the questionnaires, between the individual items. The results are shown in Table15.

Generally correlations are high enough to produce a high level of significance with 268 cases, although length of residence shows no relationship with other items, and the accident question shows a trend towards low correlations with other items. Apart from these two exceptions the reasonable internal correlations indicate that all the other questions are noise related to a fairly high degree.

10.7 Unidimensionality of individual items.

High levels of correlation between individual items and total scores obtained by summing these go some way towards indicating unidimensionality of the items. Therefore a correlation analysis was carried out for all the questionnaires between item scores and final annoyance score (Table16). With 268 cases, a correlation coefficient of .6 indicates a high degree of interrelationship, and as no items show a smaller correlation than this, a degree of unidimensionality can be assumed.

10.8 Calculation of final score which indicates dissatisfaction.

In order to determine what point on the "total with averaged sleep less accident" scale indicated dissatisfaction, a regression analysis was carried out between Question 13, the overall satisfaction question, and the total. Correlation coefficient for all subjects was .76, indicating that the total chosen as a final annoyance score was a good indicator of overall satisfaction. The reason for not just using

Table 15. Correlation coefficients between individual items in questionnaire 268 cases

	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q15
Q3. Traffic noise	.41	.38	.35	.39	.40	.27	.26	.36	.51	.52	0
Q4. Radio/T.V.		.49	.39	.36	.41	.27	.41	.30	.39	.48	-.02
Q5. Going to sleep			.71	.66	.43	.42	.48	.40	.49	.56	-.03
Q6. Waking at night				.59	.33	.32	.45	.32	.41	.52	.03
Q7. Waking morning					.31	.32	.38	.30	.39	.49	.07
Q8. Vibration						.27	.46	.37	.39	.49	.09
Q9. Accidents							.27	.37	.29	.37	.01
Q10. Fumes								.31	.34	.44	.06
Q11. Visual intrusion									.62	.64	.03
Q12. Preferred level										.76	-1.0
Q13. Overall satisfaction											-0.6
Q15. Length of residence											

Question 13 as a final annoyance score was that the use of several items reduces individual question bias and increases reliability.

Regression coefficients obtained from the analysis were (Fig 27):-

m = 3.56	b = 5.89 for interrupted flow	(r = 0.78)
m = 3.09	b = 7.00 for free flow	(r = 0.73)
m = 3.34	b = 6.39 for all subjects	(r = 0.76)

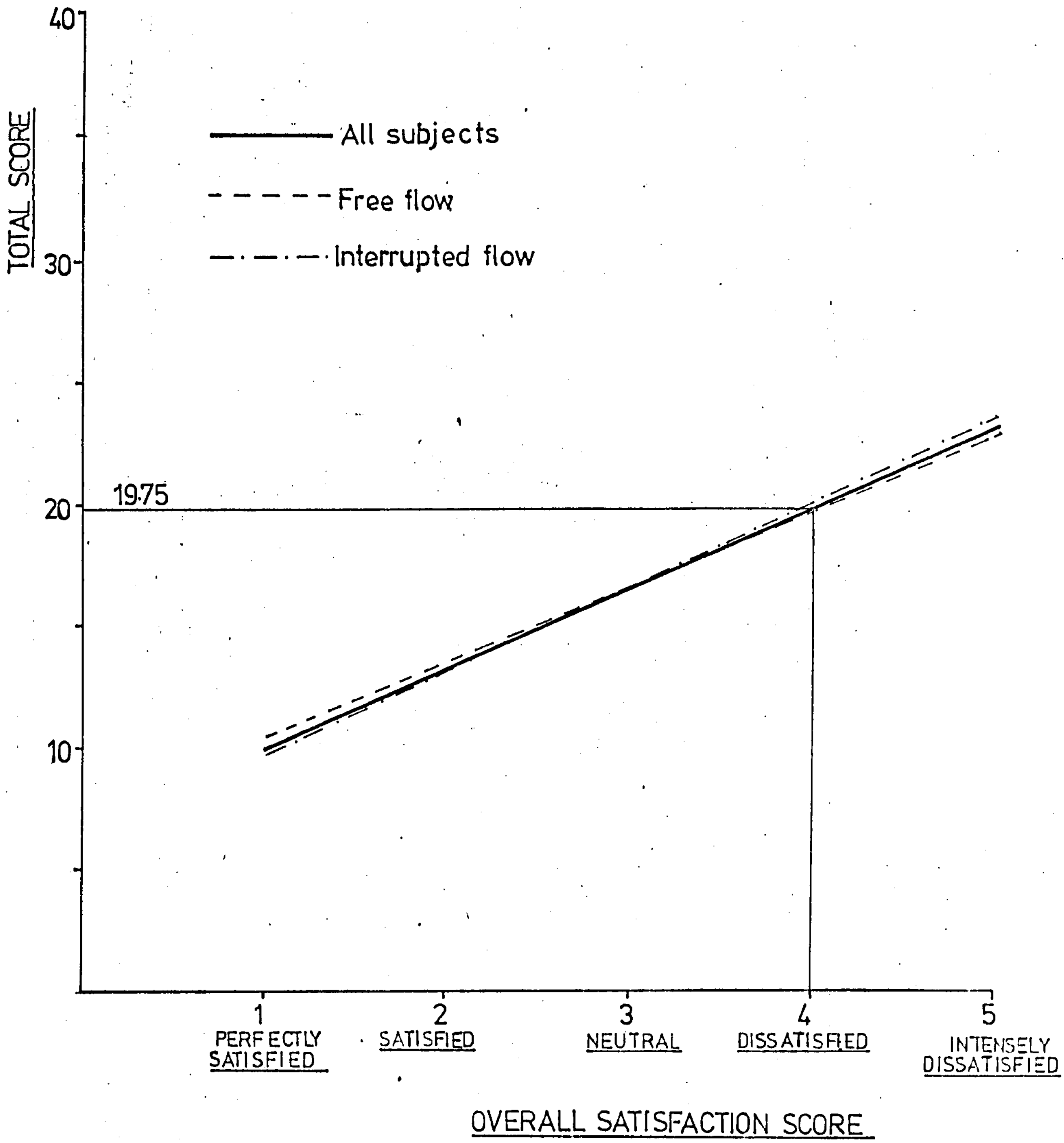
A "dissatisfied" response to Question 13 is indicated by a score of 4. For interrupted flow this is equivalent to a total score of 20.13, for a free flow it is equivalent to 19.36, and for "all subjects" it is equivalent to 19.75. It was decided to use the "all subjects" value of 19.75 as the indicator of dissatisfaction, as values for free and interrupted flows taken separately did not differ significantly from it (a maximum score difference of 0.39 in a potential score of 30).

Table 16. Correlation analysis between items making up final score, and final score (Total with averaged sleep less accident question.)

	Item	Correlation coefficient between item and total
Q.3.	Traffic noise	0.63
Q.4.	Radio/T.V.	0.72
Q.5	Going to sleep	0.73
Q.6.	Waking at night	0.64
Q.7.	Waking in morning	0.61
Q.8.	Vibration	0.72
Q.10.	Fumes	0.70
Q.11.	Visual intrusion	0.68

This closeness in regression coefficients between the two flow situations shows that the questionnaire final score is equally applicable in gauging

Fig 27 Regression line of "Total with average sleep less accident" against overall satisfaction score.



annoyance where flow is either free or interrupted.

Referring back to Fig.24 and Table 14 , the implications of the dissatisfaction level when it is applied to the two flow situations can be observed. The L_{10} level at which dissatisfaction can be expected to occur is 75.6dB(A) for a free flow and 69.2dB(A) for an interrupted flow. The L_{50} levels which produce dissatisfaction are 64.7 dB(A) for a free flow, and 62.3dB(A) for an interrupted flow, while the L_{90} levels are 58.0dB(A) for a free flow and 56.5dB(A) for an interrupted flow. The TN1 level required to give a score representing dissatisfaction is 87.4 for an interrupted flow, but correlation coefficient in the free flow situation is too low for meaningful interpretation of the graph.

11. Discussion of Survey.

11. Discussion of survey.

During processing of survey results some shortcomings within the questionnaire came to light. Although these were not serious, further studies of this type would be improved by taking them into account. These shortcomings involved double glazing, use to which the rooms closest to the road were put, and shift workers' sleeping habits, all of which would affect received noise levels and characteristics.

Several respondents mentioned that they had had double glazing installed, and that this had greatly reduced levels within the home. Others mentioned that noise sensitive activities were confined to rooms away from the road, so lessening the effect of noise, and lowering annoyance scores. Some shift workers who slept during the day indicated confusion over whether their day time sleep period should be considered as "night" for the purposes of the survey.

As respondents had been selected only because they lived at the particular sites which had been chosen as suitable for the survey, a full spectrum of social class could not be guaranteed. In fact, as the sites were all subjected to fairly high noise levels, it is likely that the upper classes were underrepresented, as they would be in a better financial position to choose the location of their homes. However, it can be argued that this increased ability to move will always be the case, and so inclusion of the reactions of the higher social classes are irrelevant.

Age had not been included in the questionnaire, in order to increase the chances of obtaining a response. Sex of the respondents had been noted during choice of the sample, but had eventually not been included in the analyses as previous studies have shown little relation between sex and response.

The fact that the points indicating actual difference between noise levels and prediction in Figs. 3 to 8 do not coincide with the lines of gradient obtained from the physical study shows that it is unwise to apply the general result to specific situations. However, it should be noted that the noise measurements for the survey were based on a maximum of 180 minutes of measurement, as opposed to the 798 minutes of measurement which produced the results of the physical study, and so scatter would have a greater effect on the survey measurements. This tentative application of the results of the physical study to the survey was felt to be adequate, and an improvement over such surveys as the London Noise Survey (3), where noise measurements were taken at one position only per site, and assumed invarient. If time is available, further studies would be improved by taking 18 hour measurements at each house under consideration, although individual scatter of responses could minimise any advantages obtained through increased accuracy.

Although extrapolation of the physical results beyond the furthest measurement point was warned against, it was felt that use of the gradients obtained from that study, combined with the actual measurements taken for the survey, would produce useable results in this particular situation.

It is unlikely that the poor correlations shown between annoyance levels and the various indices in the free flow case were due to the questionnaire being biased in its content towards the factors causing annoyance in interrupted flows. This is shown by the fact that internal behaviour of the questionnaire, as indicated by internal correlations, was very similar in the two flow situations. It is possible, as annoyance levels tend to be generally higher in interrupted flow situations, that people living at these sites will have their attitudes more firmly fixed in their minds. At the lower annoyance free flow situations, people will not be constantly aware of the noise, and therefore will be more vague about their attitudes, leading to lower correlation.

Although TNI performed badly for free flow situations, its worth should not be devalued on the basis of the results of the present survey, as it could possibly have been seriously affected by using 18 hour average levels to calculate it. Instead, its relatively good performance for interrupted flows could perhaps be taken as an indication of its suitability as an indicator of annoyance at interrupted flows. This can be explained by the fact that TNI includes a measure of level fluctuations, which will tend to be greater for interrupted flows as vehicles halt and then accelerate. However, behaviour of annoyance with TNI would not appear to be the same in the two situations, so that a certain TNI level will not indicate the same annoyance level for a free flow as it does for an interrupted flow.

It would seem that responses to the three sleep questions indicate that the greatest annoyance occurs early in the morning, as traffic flows build up. People will be sleeping lightly during this period and are more easily woken, although a person may wake naturally, hear the noise, and assume that it was that which woke him. However, this new result could be used as the basis for futher work, as sleep disturbance is an important factor in overall annoyance.

The behaviour of the final annoyance score, "Total with averaged sleep less accident" with the indices under consideration is shown in Fig. 24. The relative closeness between the pairs of regression lines for L_{50} and L_{90} shows that if annoyance caused by a certain noise distribution is to be comparable between the two flow situations, then it would be wise to use L_{50} or L_{90} to characterize the distribution, as opposed to L_{10} or TNI. The L_{10} lines diverge at the high end of the noise range, and the TNI lines are not comparable due to poor correlations in the free flow case. Section 6.2.4 above notes that the C.S.T.B. in France (32) prefers the use of L_{50} as an annoyance indicator in urban situations (where interrupted flows are prevalent). The fact that the final annoyance score correlates best with L_{50} for free flows, and that it correlates well with L_{50} for interrupted flows, as well as the closeness of the L_{50} regression lines, would appear to confirm the usefulness of L_{50} as a general indicator of annoyance.

Although the final annoyance score correlates best with L_{10} for interrupted flows, and satisfactorarily with L_{10} for free flows, the divergence of the regression lines at the top of the noise level range means that L_{10} does not characterize the noise distribution well enough in in terms of the annoyance it produces. This argument assumes that there are no great psychological differences which cause different annoyance reactions between the two flow situations. A certain L_{10} level may be produced by intermittent peaks followed by short quiet periods, as in a free flow situation, or by long noise events caused by an individual vehicle or a group of them followed by long periods of quiet, as in an interrupted flow situation. This latter characteristic would appear to be an important contributor to annoyance at interrupted flows, as it will interfere with communication more than the intermittent and short peaks of a low concentration free flow. At high concentrations, such as during rush hours, free flow noise will become more continuous, but this only occurs for a relatively small part of the 18 hour day.

A useful continuation to this study would be an investigation of the way in which the L_{10} regression line for interrupted flows diverges from the line for free flows at different distances from the intersection. The interrupted flow line will tend to rotate away from the free flow line as the intersection is approached, but it is not known whether the two lines would always intersect at the same point. For the present study, people living within 320m. of the intersection (approximately where the physical study indi tes that L_{90} and L_{10} revert to free flow levels) are grouped together as the "interrupted flow" sample, and assumed to all be within the area of influence of the intersection.

The range of levels encountered during the survey was unfortunately rather limited. Table 17 compares this range of levels, as indicated by mean level $\pm$ 2 s.d., with the range of levels which occurred during the TNI survey (8), and the C.S.T.B. survey (32).

Table 17. Range of levels for present survey, TNI survey and C.S.T.B. survey.

	Present survey (free flow)	Present survey (interrupted flow)	TNI	C.S.T.B.
L_{10}	64.9 - 74.9dB(A)	61.4 - 73.8dB(A)	62 - 76dB(A)	-
L_{50}	57.3 - 64.9dB(A)	51.9 - 67.5dB(A)	54 - 61dB(A)	53 - 75dB(A)
L_{90}	49.3 - 58.1dB(A)	44.4 - 60.4dB(A)	48 - 54dB(A)	-

It can be seen from the table that the ranges used for the development of TNI are as limited as those of the present survey, and so results of the present survey should not be invalidated on the basis of limited data, if TNI data is acceptable. The levels for the present survey are in the region where annoyance is most likely to occur, lower levels being likely to produce a less structured response pattern to the questionnaire.

It would be unwise to extrapolate the regression lines beyond the ranges indicated in Table 17, as it is unlikely that reaction to lower or higher noise levels will follow the pattern set over the given ranges.

12. Conclusions.

12. Conclusions

12.1 The Physical Study.

Actual values of L_{10}, L_{50}, and L_{90} close to an intersection controlled by traffic lights tend to show an increase over free flow prediction of approximately 3dB(A), 5dB(A), and 9dB(A) respectively.

The increase over prediction tends to fall off linearly with distance from the intersection at a rate of 1dB(A)/100m, 3dB(A)/100m, and 3dB(A)/100m for L_{10}, L_{50}, and L_{90} respectively.

Factors affecting noise generation by traffic at intersections are many and complex, leading to a considerable amount of scatter of individual results. Also, results for three major road sites with different traffic flow characteristics and estimated velocities were combined. Therefore the above conclusions should only be taken as an indication of general tendencies, and not applied to a specific situation if anything more than a general feel for the noise characteristics is required. It is hoped that this study provides the basis for further analysis of the intersection situation, with a fuller consideration of the variables involved.

12.2 The Survey.

18 hour averaged L_{50} shows reasonably consistent behaviour as an indicator of annoyance between free and interrupted flow situations, and is recommended if a comparison of annoyance caused by traffic noise in both situations is required.

18 hour averaged L_{10} correlates well with annoyance scores in both flow situations, but does not indicate level of annoyance consistently between the two situations.

TNI based on 18 hour averaged values of L_{10} and L_{90} correlates poorly with annoyance scores for free flow sites, although the Index's emphasis on fluctuation in level appears to have led to satisfactory correlations with annoyance at the interrupted flow sites, where fluctuation is an important annoyance producing factor.

The combination of items from the questionnaire which performed best as an indicator of annoyance included questions on awareness of noise, communication interference, sleep interference of three types, vibration, fumes, and visual intrusion.

18 hour L_{10} levels and annoyance, as measured by the questionnaire responses, correlate well for both flow situations. Linear regression lines between annoyance score and L_{10} show that annoyance level is the same for both flow situations for an L_{10} in the region of 66dB(A), but as L_{10} increases, annoyance at a given L_{10} becomes greater for interrupted flows compared with free flows. This means that L_{10} does not describe fully the factors in a noise distribution which cause annoyance, and makes it unsuitable as a general indicator of annoyance for varied traffic flow situations.

The results of the survey show that dissatisfaction, as indicated by a score of 4 on a 5 point scale ranging from "perfectly satisfied" (1) to "intensely dissatisfied" (5), with the central point (3) representing neutral, is the mean reaction at an external 18 hour L_{10} level of 75.6dB(A) when free flows are involved, and 69.2dB(A) for interrupted flows. This result shows that the upper limit of 68dB(A) for 18 hour L_{10} measured 1m from the exposed facade (and hence increased by approximately 3dB(A) because of reflection), quoted in the Noise Insulation Regulations(20), is likely to be satisfactory for most traffic flow situations.

The regression lines for L_{50} show some divergence,but at a much lesser rate than that exhibited by the L_{10} lines. A mean response of "dissatisfied" occurs at an 18 hr. L_{50} of 64.7dB(A) for a free flow and 62.3dB(A) for an interrupted flow. Correlation between annoyance and L_{50} in both flow situations is satisfactory.

The poor performance of TNI for free flows could have been due to distortion of the Index due to the use of 18 hour averages instead of the 24 hour averages which are supposed to be used.

The survey results show that not only is there a need for a unified system of noise measurement for comparison of noise levels from different sources such as cars, aeroplanes and industry, but also a unified system is required for comparisons between noise levels produced by the same source (traffic) in different flow situations.

It is hoped that if either L_{EQ} or L_{NP} is introduced as the basis of a unified system, that it will provide comparability between commonly encountered traffic flow situations, and further research into this aspect of the problem is recommended.

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Appendix A. Statistical methods used during the study.

Appendix A. Statistical methods used during the study.

a) Frequency distributions applied to noise levels.

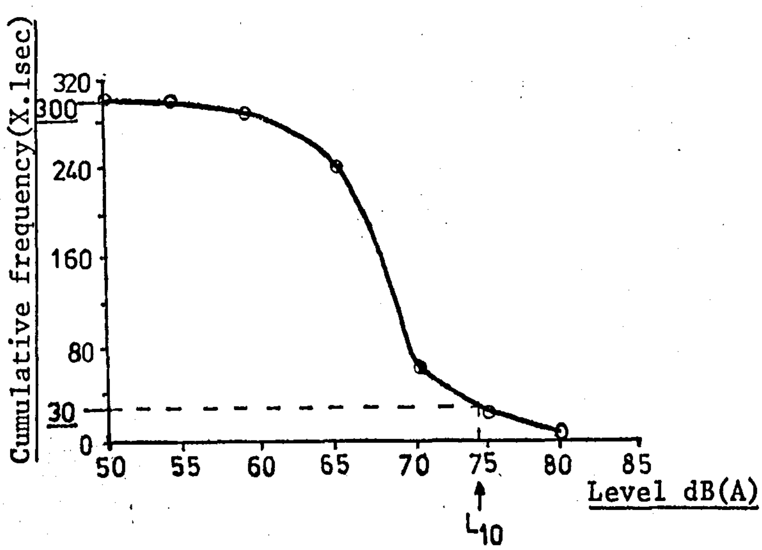
A variable classified according to its magnitude or size can be arranged in a frequency distribution.

When applied to the statistical distribution of noise level with time, the type of distribution considered is as shown in Table A.1.

TABLE A.1

Noise level class interval (dBA)	Frequency (Time spent in each interval in multiples of .1 second)
50 - 54	5
55 - 59	10
60 - 64	50
65 - 69	170
70 - 74	40
75 - 79	20
80 - 84	5

Fig A.1 Example of a cumulative frequency plot



In order to calculate the percentile level L_X, the level exceeded for X% of the time, a cumulative frequency distribution must be calculated. Statistical distribution analysers operate on a "more than" cumulative distribution, which follows from the distribution shown in Table A.1 in the manner shown in Table A.2.

TABLE A.2

Noise level class interval (dBA)	"More than" cumulative frequency (X.1 sec)
50 - 54	300
55 - 59	295
60 - 64	285
65 - 69	235
70 - 74	65
75 - 79	25
80 - 84	5

The cumulative distribution may then be plotted as cumulative frequency against noise level (Fig.A.1.). The normal practice in the U.K. is to plot the frequency point at the left hand extremity of the relevant class interval and join the points in a smooth curve. L_X may then be determined graphically by drawing a horizontal line from the point on the vertical axis representing X% of the total time involved, (in the above case, 300 X .1 sec.), to the curve, and drawing a vertical line from where the horizontal line meets the curve to the horizontal axis. The point where this line meets the horizontal axis gives the value of L_X.

b) Correlation and Regression Analysis.

In order to establish whether a relationship exists between two variables, correlation analysis may be utilised. If sample data can be assumed to be derived from normal populations, and any association between variables is assumed linear, then the product-moment, or Pearson method may be used. This gives the correlation coefficient as :-

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

where (x_i,y_i) is one of n data points, y being the dependent variable, x being the independent variable. $\bar{x}$ and $\bar{y}$ are the mean values of x and y.

r can vary from -1 to +1, with a value of 0 representing no correlation, and a value of +1 or -1 representing complete correlation. If the sign of r is +, then correlation is positive, and as one variable changes, so the other changes in the same direction. If the sign of r is -, then correlation is negative, with one variable increasing as the other decreases, and vice versa.

Degree of correlation is not simply assessed from the magnitude of r, as the size of the sample of the population which is being analysed is important. If the size of the sample relative to the population is large, then a low value of r can still represent a good correlation. For example, a significance level of .01 (probability of .01 of accepting linear hypothesis when it should be rejected) requires a value of r=.87 for a sample of 7, but a value of r=.25 for a sample of 100.

A desirable level of significance when accepting the linear hypothesis is .01, although .05 can be tentatively taken as satisfactory.

Even if correlation coefficient and sample size taken together indicate a high degree of correlation, a causal relationship need not exist between the two variables. Other reasons for high correlation may be that the variables are related by one or more common "causes", or possibly by pure chance. Therefore great care needs to be taken when interpreting the results of a correlation analysis.

The Pearson analysis extends to provide the equation y=mx+b which describes the line of best fit for the data.

The regression coefficient is given by :-

$$m = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

and the constant is given by :-

$$b = \bar{y} - m\bar{x}$$

The knowledge of the regression equation allows prediction of one variable to be carried out if the value of the other variable is known.

Appendix B. Individual results of the physical study.

Appendix B Individual Results of the Physical Study

Increase of actual level over predicted level for different values of distance d from the centre of intersecting flow

Southfields Park				Tamworth				Rothley			
d(M)	L_{10}	L_{50}	L_{90}	d(M)	L_{10}	L_{50}	L_{90}	d(M)	L_{10}	L_{50}	L_{90}
12	4.1	2.7	4.7	9	3.2	3.7	6.3	10	1.2	3.1	6.0
	4.7	4.4	5.4		2.6	4.7	8.6		2.0	6.4	10.7
	6.7	4.4	7.7		3.7	3.9	6.4		3.8	4.4	7.7
	4.1	3.3	8.0		5.5	5.8	9.3		1.0	3.4	8.1
	2.9	3.8	6.4		3.3	5.4	9.3		4.1	6.3	9.4
35	5.8	4.1	8.6	15	3.4	4.8	11.0	15	2.9	4.6	6.2
	0.7	-1.5	3.6		0.6	5.9	9.4		3.1	4.1	9.2
	4.0	3.5	8.2		2.5	5.5	8.9		1.6	2.6	8.5
	2.6	2.6	5.0		3.4	5.7	8.9		3.6	5.3	11.1
	9.7	8.9	13.6		4.7	6.5	11.0		4.1	6.6	9.5
55	4.8	3.5	9.7	20	0.1	3.9	9.9	20	2.8	3.0	8.9
	2.1	2.7	5.5		2.1	5.9	9.0		5.2	6.5	11.7
	-.4	2.5	6.1		0.5	4.1	7.6		1.0	2.7	8.3
	6.5	5.5	8.2		3.9	6.3	9.0		5.1	4.3	8.1
	7.9	8.2	11.8		4.1	5.5	10.0		4.0		
65	1.3	0.4	2.6	30	-1.0	10.6	5.3	30	2.1	3.7	6.6
	2.2	1.4	15.6		2.2	2.7	5.8		4.6	6.8	11.5
	3.3	2.4	3.6		-1.5	-3.0	0.6		2.1	1.9	6.3
	2.7	-1.2	9.6		3.1	4.6	8.6		5.7	8.1	13.2
	1.0				1.7	4.0	9.0		2.1	3.6	10.4
					4.3	6.5	10.4				
80	3.2	6.0	9.3		6.3	8.2	13.8	40	0.7	4.6	4.7
	3.0	5.4	8.7						2.0	6.4	10.4
	6.1	8.2	0.3	40	4.3	8.3	17.0		-.1	3.0	6.4
	0.2	3.1	4.8		3.7	11.5	17.6		-.2	4.1	7.0
	0.9	1.7	4.7		6.7	5.5	9.5		1.6	5.5	10.2
					2.8	4.5	7.8				

Southfields Park				Tamworth				Rothley			
d(M)	L_{10}	L_{50}	L_{90}	d(M)	L_{10}	L_{50}	L_{90}	d(M)	L_{10}	L_{50}	L_{90}
95	4.9	3.1	4.6		1.8	1.8	6.3	50	2.3	5.7	6.4
	2.8	1.1	2.7		5.8	6.1	11.6		0.6	2.1	8.9
	5.8	8.4	11.0						-.1	3.7	10.2
	5.1	5.2	8.6	50	4.4	6.1	13.2		1.6	5.1	8.7
					0.1	4.8	11.2		2.1	3.7	8.3
105	1.7	4.6	9.3		3.0	4.5	7.5				
	4.3	-2.7	5.9		1.0	2.2	6.9	60	-1.5	5.9	5.0
	0.3	2.4	7.1		1.5	2.7	8.5		4.2	8.3	10.7
	1.9	2.6	7.3	60	-3.0	-.5	5.7		1.5	6.0	8.6
					-0.8	-1.4	3.7		2.0	4.5	7.2
120	-.1	0.4	3.9		1.6	-1.3	4.2		0.1	4.6	9.9
	1.2	0.1	6.8		1.2	6.2	13.5				
	1.1	1.1	5.3		2.6	8.9	17.1	70	1.1	5.4	6.8
	4.2	5.6	9.8						1.7	4.4	6.5
	5.1	5.8	4.7	80	1.3	3.5	7.3		1.8	4.6	9.6
									2.6	6.4	9.2
				90	-1.3	-1.2	5.6		2.9	7.2	9.6
					0.4	-1.0	4.9				
								80	1.3	7.4	12.9
				95	3.1	4.0	6.2		0.6	3.6	5.4
					2.9	2.1	1.2				
								95	1.3	4.3	6.2
				115	5.3	4.1	9.3		0.6	3.6	4.3
					4.2	2.7	7.4				
								115	1.2	-1.8	4.5
				120	-1.6	-3.6	0.6		1.3	4.3	5.0
					0.1	-5.0	2.8				
				150	2.5	1.1	1.0				
					0	-2.8	1.7				

Appendix C. Pilot Questionnaire.

Loughborough University of Technology

Department of Transport Technology

TRAFFIC NOISE ANNOYANCE QUESTIONNAIRE

1) Subject Number:

2) Name:

3) Sex:

Male	Female
1	2

4) Age at last birthday:

Under 20	21-30	31-40	41-50	51-60	Over 60	No response
1	2	3	4	5	6	7

5) Length of residence in present house (years):

Under ½	½-1	1-2	2-5	5-10	Over 10
1	2	3	4	5	6

6) Occupation of head of household:

7) Family composition:

Adults Only (16+)	Adults + children of school age	Adults + children under school age	Adults + both
1	2	3	4

8) Could you name 2 or 3 things you like about living in this area*

Quiet	Little traffic noise	Little a/c noise	Little traffic	Few a/c	None of these	Nothing
1	2	3	4	5	6	7

9) Could you name 2 or 3 things you dislike about living in this area**

Noise	A/c Noise	Traffic noise	A/c + traffic noise	Traffic	A/c	None of these	Like everything
1	2	3	4	5	6	7	8

* If 1), 2),4), terminate interview.

** If 2), 4), 6) terminate interview.

ard (C) 10) Do you hear noise from passing traffic*

Almost Always	Frequently	Occasionally	Rarely	Almost Never
5	4	3	2	1

11) Could you say what it is about the character of the traffic noise that you find most disturbing:

12) What type of vehicle causes most annoyance:

ard (A)

Car	Sports Car	Motor Cycle	Heavy Goods	Buses	D/k
1	2	3	4	5	6

13) What time of day does traffic usually annoy you most:

ard (B)

Morning			Afternoon			Evening		
12-3	3-7	7-12	12-2	2-4.30	4.30-6.0	6-10	10-12	D/k
1	2	3	4	5	6	7	8	9

14) Does traffic noise make listening to radio or T.V. difficult:

ard (C)

No radio or T.V.	Almost Always	Frequently	Occasionally	Rarely	Almost Never
6	5	4	3	2	1

15) Does traffic interfere electrically by spoiling the sound or picture of the T.V. or the sound of the radio:

ard (C)

No radio or T.V.	Almost Always	Frequently	Occasionally	Rarely	Almost Never
6	5	4	3	2	1

16) Does traffic noise make telephone conversations difficult:

rd (C)

No Telephone	Almost Always	Frequently	Occasionally	Rarely	Almost Never
6	5	4	3	2	1

*If (1), terminate interview.

17) Does traffic noise make conversations within your home difficult:

Card (C)

Almost Always	Frequently	Occasionally	Rarely	Almost Never
5	4	3	2	1

18) Do you go to bed later than you would otherwise wish because of traffic noise:

Card (C)

Almost Always	Frequently	Occasionally	Rarely	Almost Never
5	4	3	2	1

19) Does traffic noise prevent you from getting to sleep at night:

Card (C)

Almost Always	Frequently	Occasionally	Rarely	Almost Never
5	4	3	2	1

20) Does traffic noise wake you up during the night:

Card (C)

Almost Always	Frequently	Occasionally	Rarely	Almost Never
5	4	3	2	1

21) Does traffic noise wake you up in the morning:

Card (C)

Almost Always	Frequently	Occasionally	Rarely	Almost Never
5	4	3	2	1

22) Has traffic noise affected the choice of room in which you sleep:

Card (D)

Greatly	Quite a Lot	A Little	Hardly at all	No
5	4	3	2	1

23) Does traffic make your house vibrate:

Card (E)

Almost Always	Frequently	Occasionally	Rarely	Almost Never
5	4	3	2	1

24) Does the possibility of pedestrians being knocked down near your house worry you:

Card (E)

Almost Always	Frequently	Occasionally	Rarely	Almost Never
5	4	3	2	1

25) Do you worry about collisions between cars occuring near to your house:

Card (E)

Almost Always	Frequently	Occasionally	Rarely	Almost Never
5	4	3	2	1

26) Can you smell exhaust fumes in the house from passing traffic:

Card (E)

Almost Always	Frequently	Occasionally	Rarely	Almost Never
5	4	3	2	1

27) How much quieter would you prefer the traffic noise:

Card (F)

Completely Quiet	Very much Quieter	Much Quieter	A Little Quieter	No Quieter
5	4	3	2	1

28) How much yearly compensation (e.g. a rate rebate) would you consider fair for putting up with the traffic noise:

£ / p

29) Taking into account all the noises you hear, what number on the scale best describes how satisfactory you find the noise conditions where you live:

Card (G)

Definitely Satisfactory 1	2	3	4	5 Definitely Unsatisfactory

End of interview

30) Address of house:

31) Distance of front of house from road:

32) Distance from middle of house front to intersection (if appropriate):

33) Type of road:

Major	Minor	Free flow	Traffic lights	Steep Gradient
1	2	3	4	5

34) Traffic flow:

Heavy	Medium	Light
1	2	3

35) Percentage Heavy Vehicles (approximately):

50%+	20%-50%	20%-
1	2	3

36) Any evidence of hearing deficiency:

Yes	No
1	2

37) Is house on bus route:

Yes	No
1	2

Appendix D. Main Questionnaire.

Appendix D. Main Questionnaire.

14 **Could you say what it is about the character of the traffic noise that you find most disturbing. If nothing in particular comes to mind, write NOTHING....**

____

____

____

15 **How long have you lived in your present house**

Under 6 months	1
6 months – 1 year	2
1-2 years	3
2-5 years	4
5-10 years	5
over 10 years	6

Thank you very much indeed for helping us by answering these questions. Please send the forms back to us as soon as you possibly can.

If you would like to make any comments on the questions, we should be very glad to have them. Please write them on the next page.

Comments

____

Would you like to enter the £25 draw?

Yes	1
No	2

If you would, please put your name and address here

Name ____________________

Address ____________________

If you wish to make further enquiries, please contact Mr D M Waters at Loughborough University. (Telephone Loughborough 63171 extension 340).

Loughborough University

Department of Transport Technology

Dear Sir/Madam,

Traffic noise is a prominent feature of life today, especially, as in your case, near to major roads. We are involved in traffic noise research, and are anxious to find out more about its effects on different people. We hope that you can spare a few minutes to help us, by answering these questions.

When you have completed the questionnaire, please return the form to us, in the envelope provided, as soon as possible.

In compensation for your time and trouble, you can enter for a draw for £25. You will be eligible to enter the draw if you return the form by so it is important that you post the form today. If you wish to enter the draw, please make sure that your name and address are on the last page.

One more point – it is your own answers and opinions that we should like, so please do not consult with your friends or family.

Thanking you for your help.

Yours sincerely,

D J Johns

Professor D J Johns

Please answer each question by ticking the appropriate box

This is independent research, sponsored by the Science Research Council

1 Subject Number

2 Do you hear aircraft noise...

- frequently [1]
- occasionally [2]
- rarely [3]

3 Do you hear noise from passing traffic...

- almost always [5]
- frequently [4]
- occasionally [3]
- rarely [2]
- almost never [1]

4 Does traffic noise make listening to radio or T.V. difficult...

- almost never [1]
- rarely [2]
- occasionally [3]
- frequently [4]
- almost always [5]
- NO RADIO OR T.V. [6]

5 Does traffic noise prevent you from getting to sleep at night...

- almost always [5]
- frequently [4]
- occasionally [3]
- rarely [2]
- almost never [1]

6 Does traffic noise wake you up during the night...

- almost never [1]
- rarely [2]
- occasionally [3]
- frequently [4]
- almost always [5]

7 Does traffic noise wake you up in the morning (around 6 am – 7 am)...

- almost always [5]
- frequently [4]
- occasionally [3]
- rarely [2]
- almost never [1]

8 Does traffic make your house vibrate...

- almost never [1]
- rarely [2]
- occasionally [3]
- frequently [4]
- almost always [5]

9 Does the possibility of accidents caused by vehicles near to your house worry you...

- almost always [5]
- frequently [4]
- occasionally [3]
- rarely [2]
- almost never [1]

10 Can you smell traffic exhaust fumes in the house...

- almost never [1]
- rarely [2]
- occasionally [3]
- frequently [4]
- almost always [5]

11 Do you feel that the volume of traffic on the roads near to your home reduces the visual attractiveness of the area...

- greatly [5]
- quite a lot [4]
- a little [3]
- hardly at all [2]
- no [1]

12 How much quieter would you prefer the traffic noise...

- completely quiet [5]
- very much quieter [4]
- much quieter [3]
- a little quieter [2]
- no quieter [1]

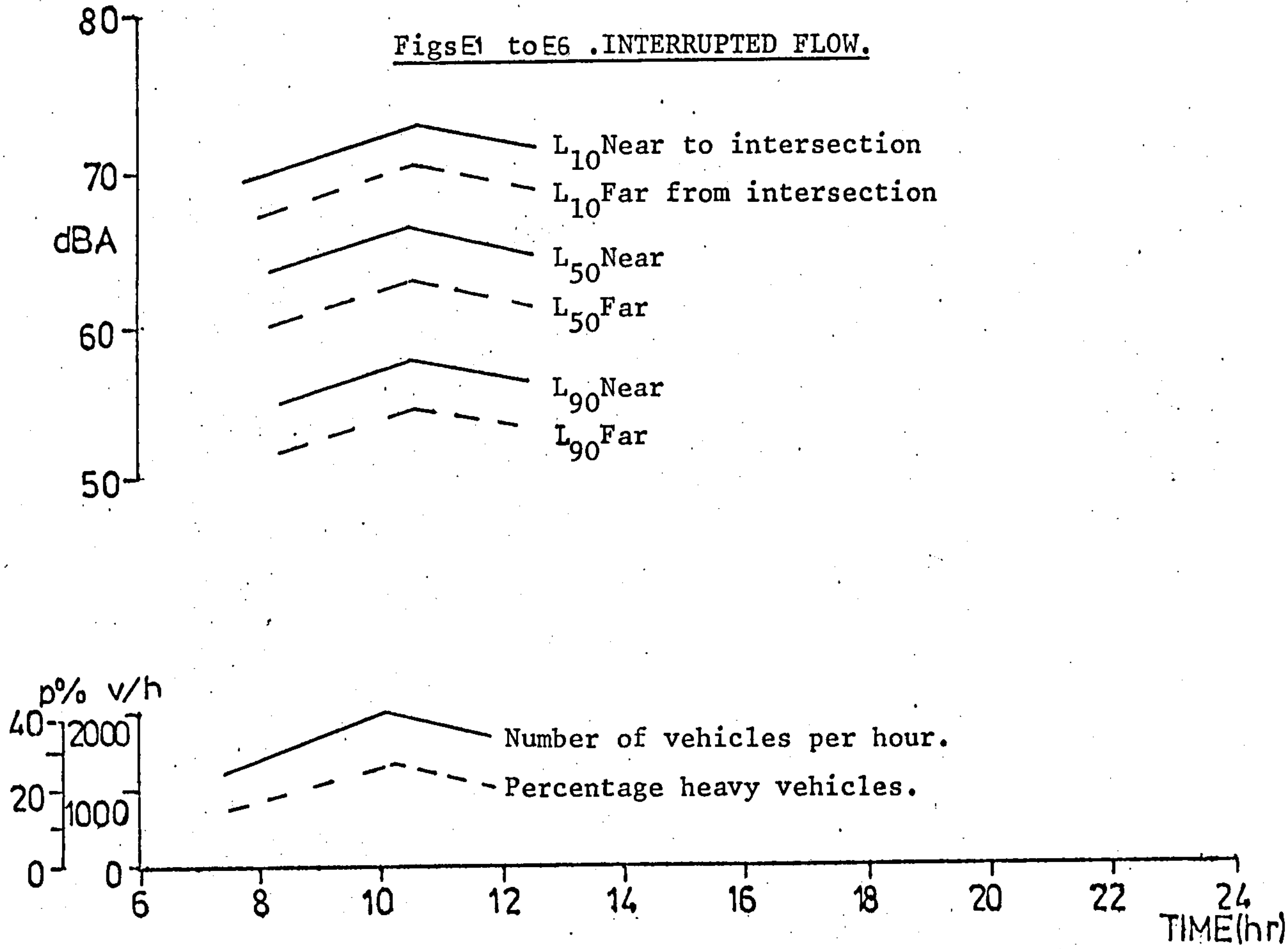
13 How satisfied are you overall with the traffic noise around here...

- perfectly satisfied [1]
- satisfied [2]
- neutral [3]
- dissatisfied [4]
- intensely dissatisfied [5]

Appendix E. 18 hour noise levels at survey sites.

18 HOUR NOISE LEVELS. KEY TO DIAGRAMS

Figs E1 to E6 .INTERRUPTED FLOW.



Figs E7 to E12 .FREE FLOW.

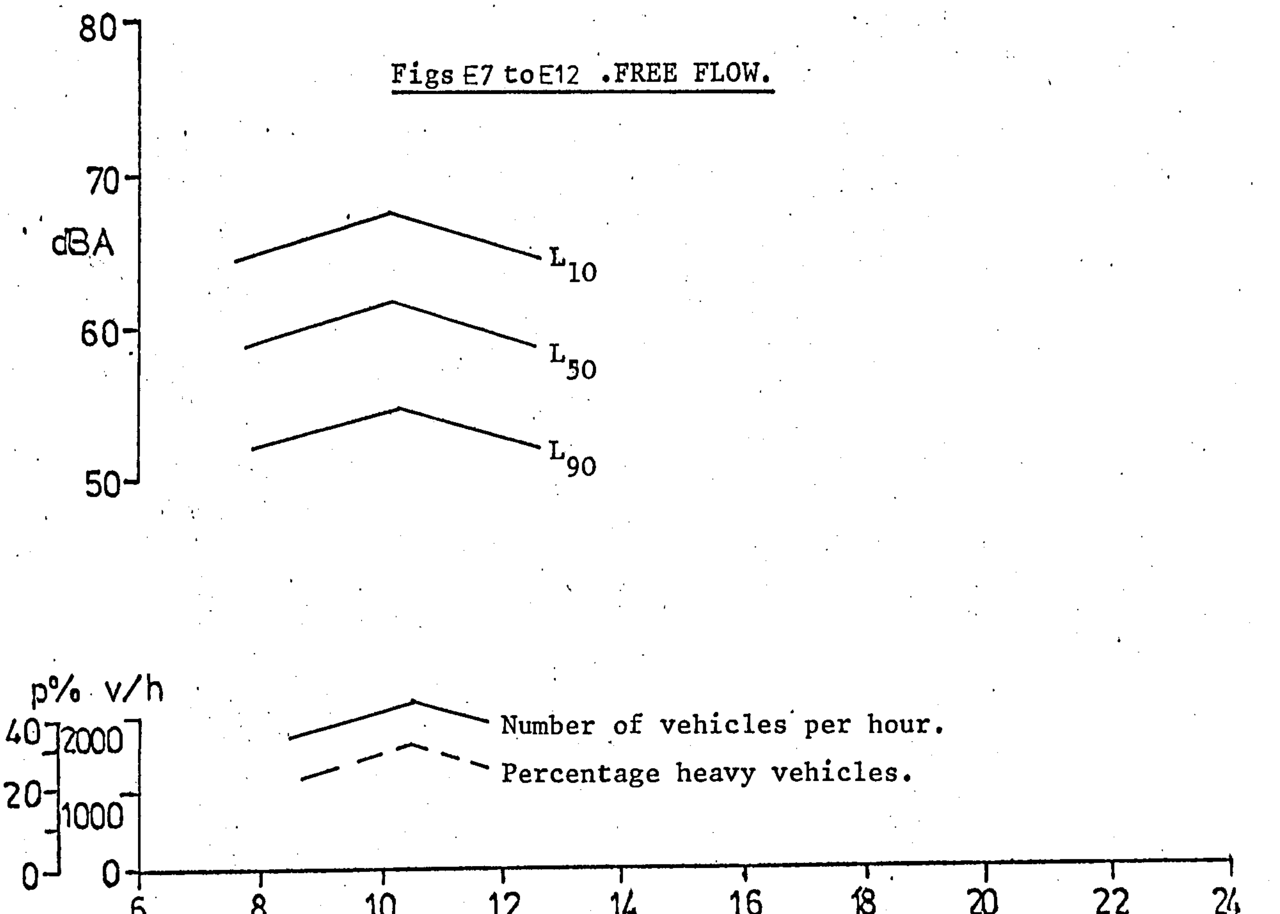


FIG E1 CORDEN AVENUE, DERBY (70m, 340m)

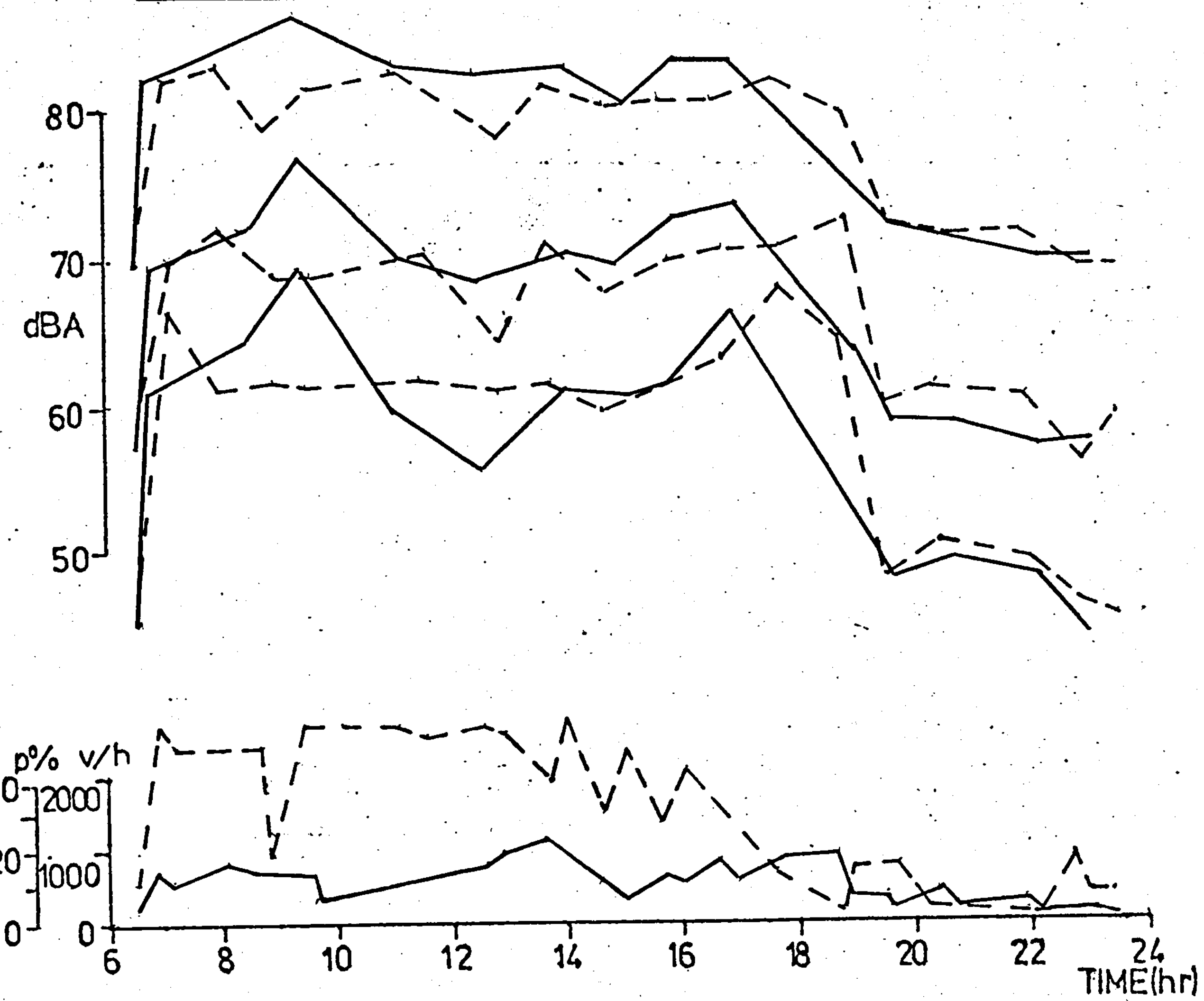


FIG E2 LOUGHBOROUGH RD, ROTHLEY (50m, 280m)

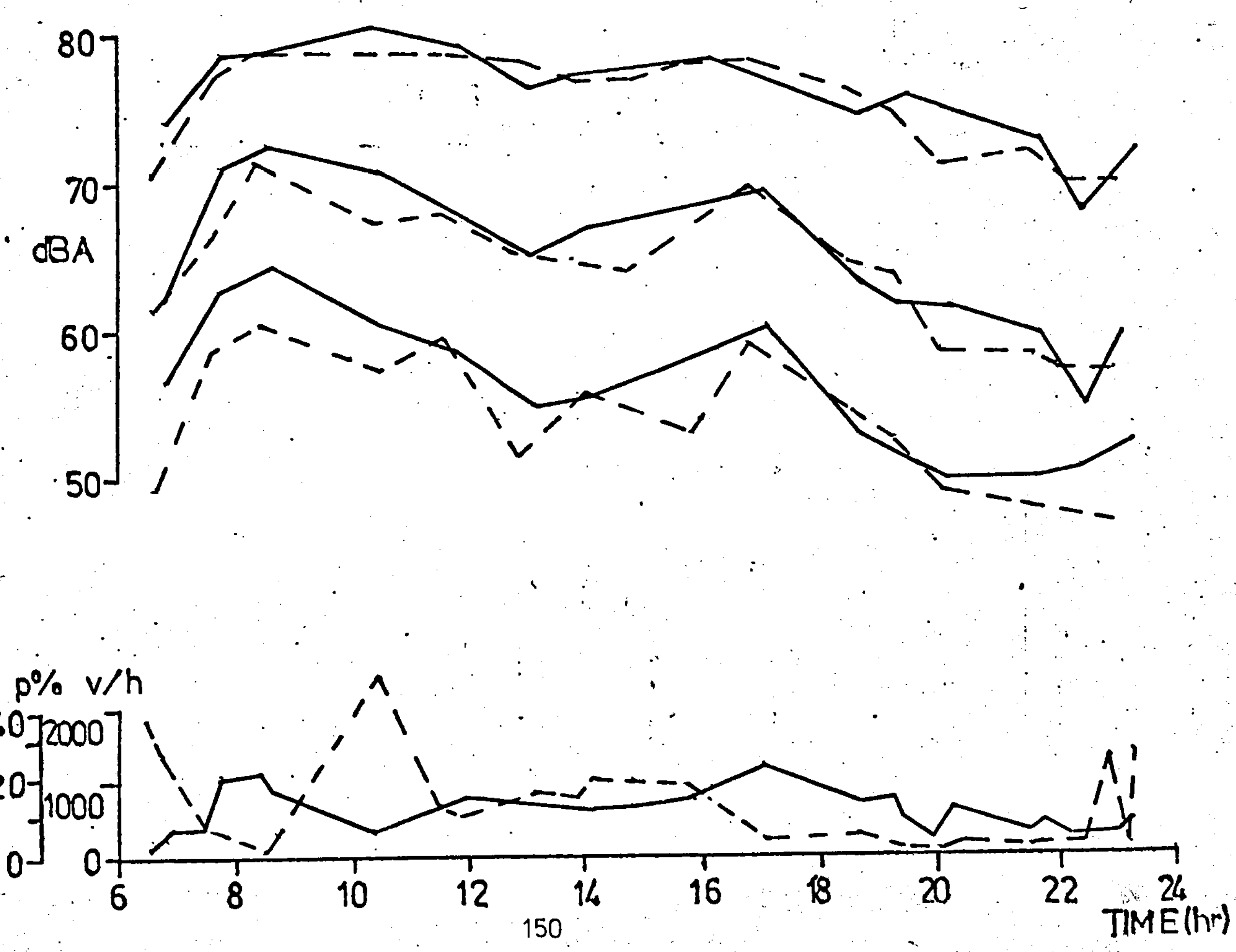


FIG E3 THE PORTWEY, LEICESTER (90m,215m)

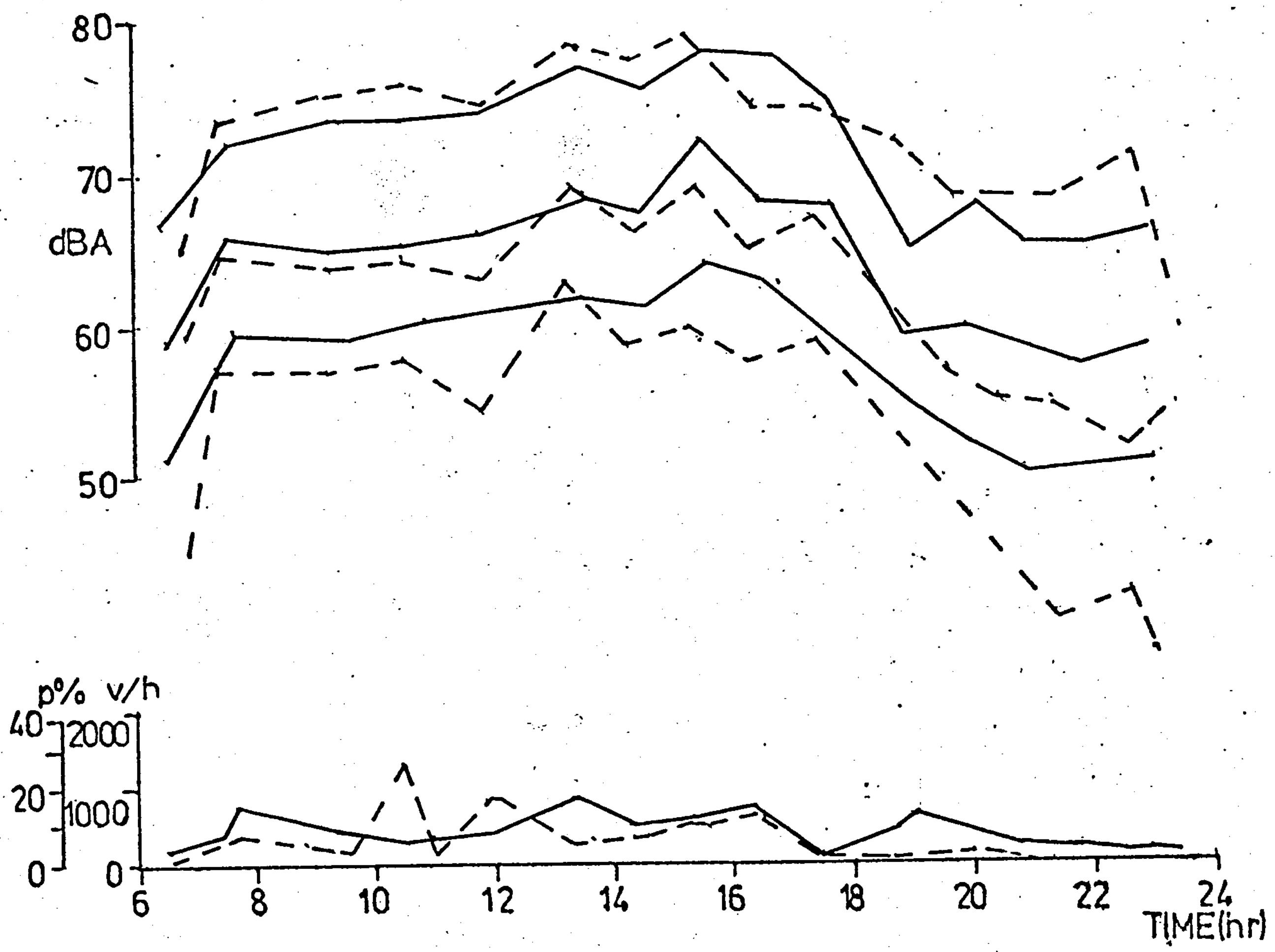


FIG E4 TAILBY AV, LEICESTER (50m,175m)

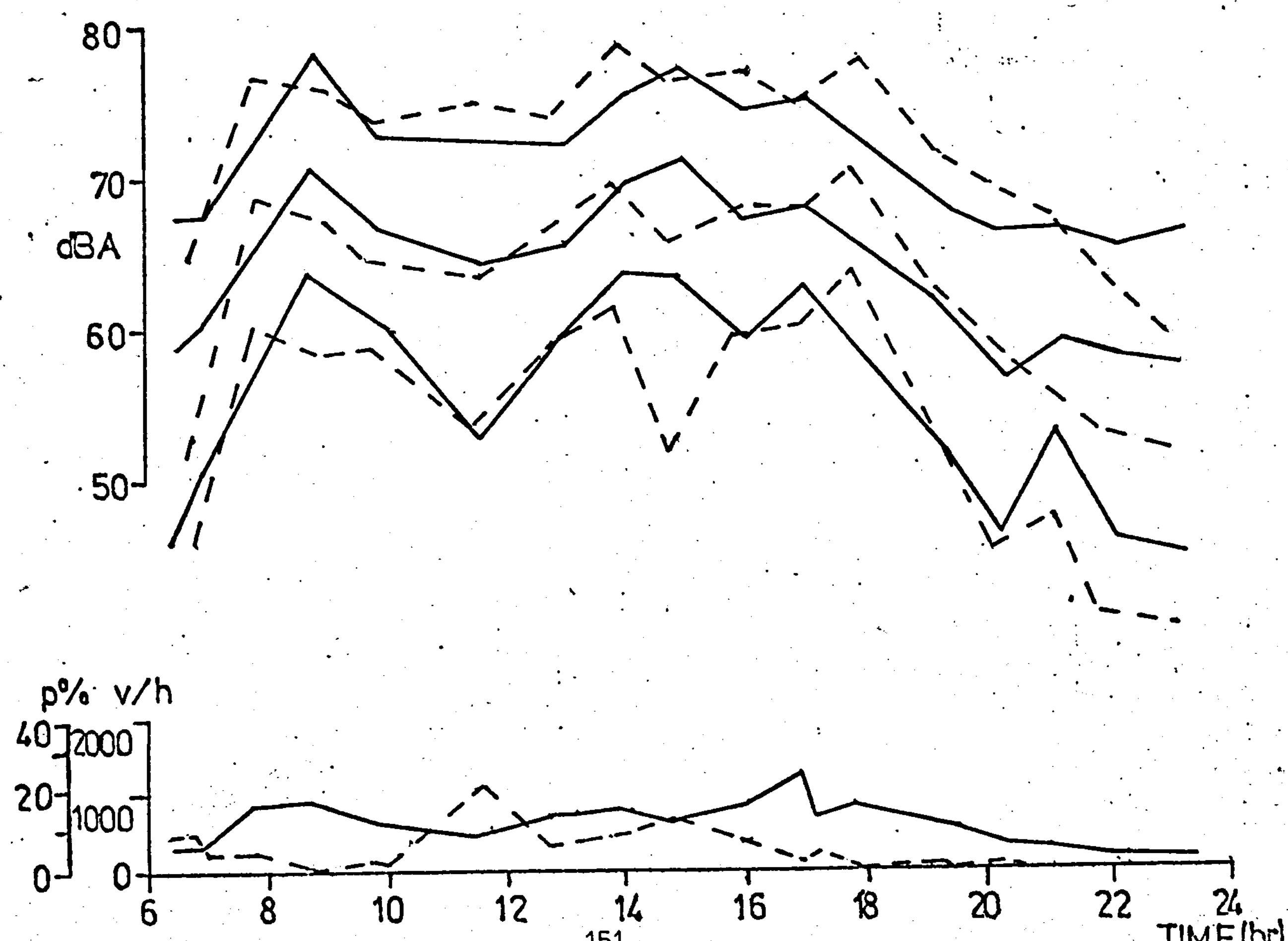


FIG E5 WESTERN BLVD. (100m, 220m)

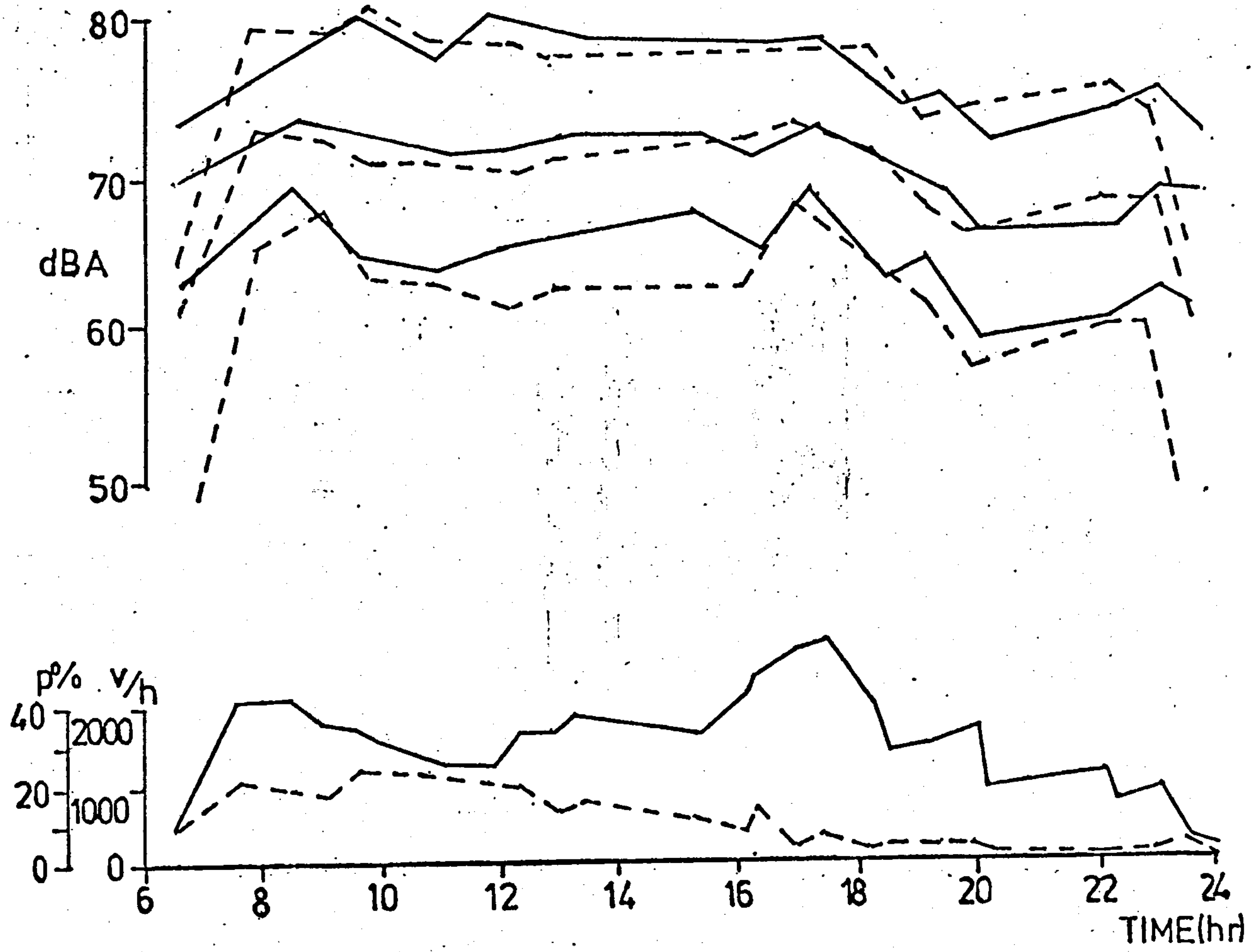


FIG E6 LOUGHBOROUGH RD. RUDDINGTON (45m, 340m)

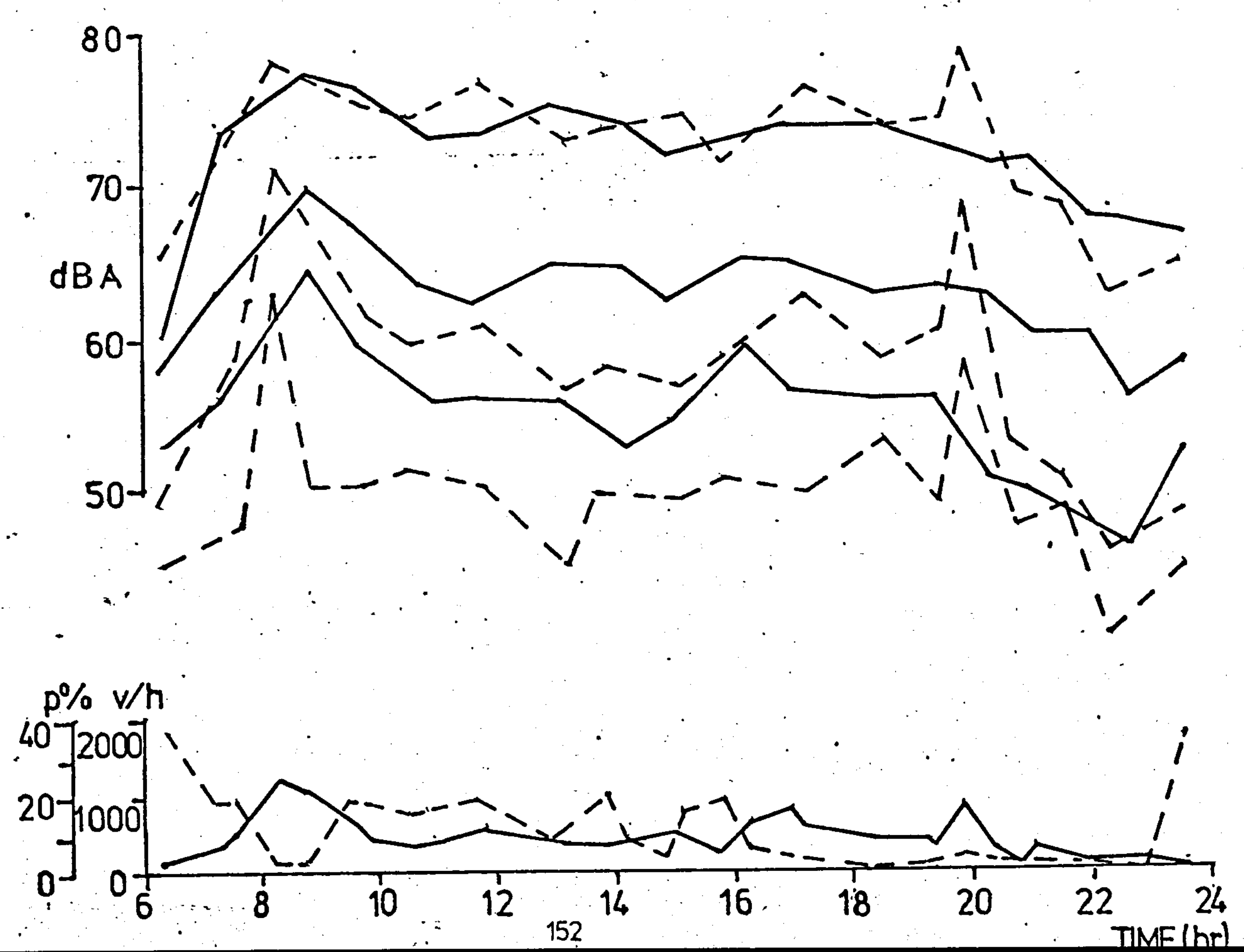


FIG E7 GROBY RD, GLENFIELD

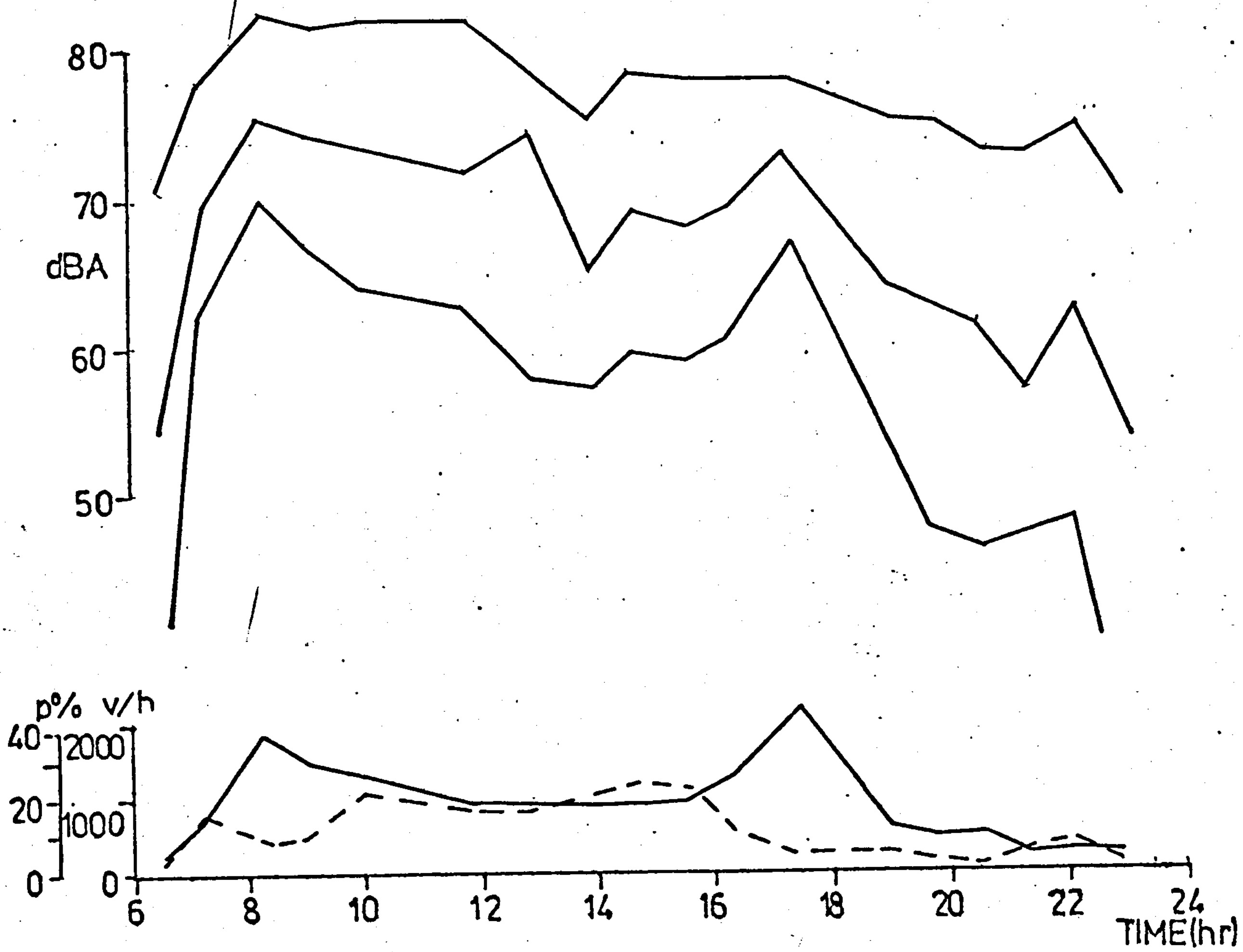


FIG E8 MARKFIELD RD, GROBY

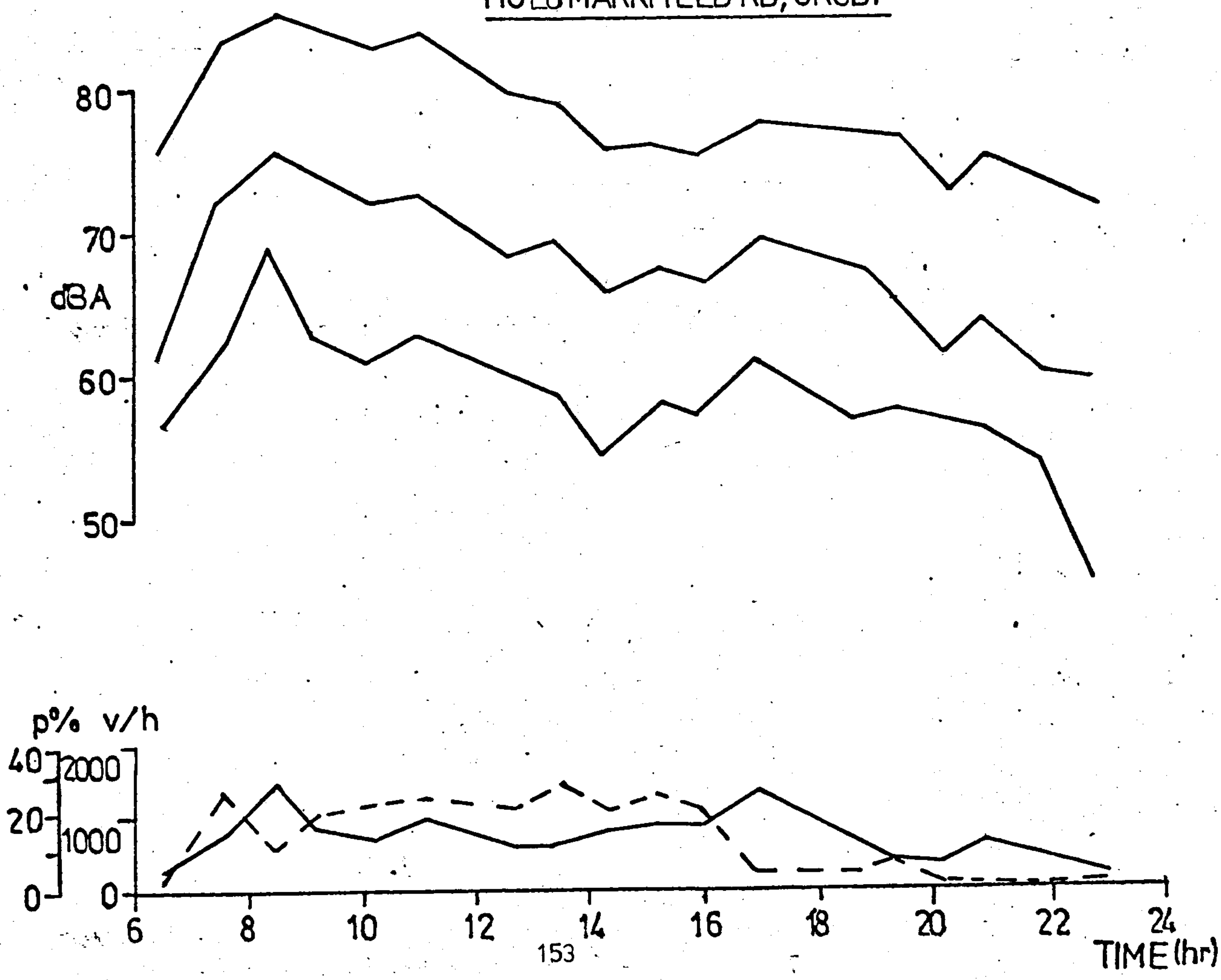


FIG E9 MELTON RD, TOLLERTON

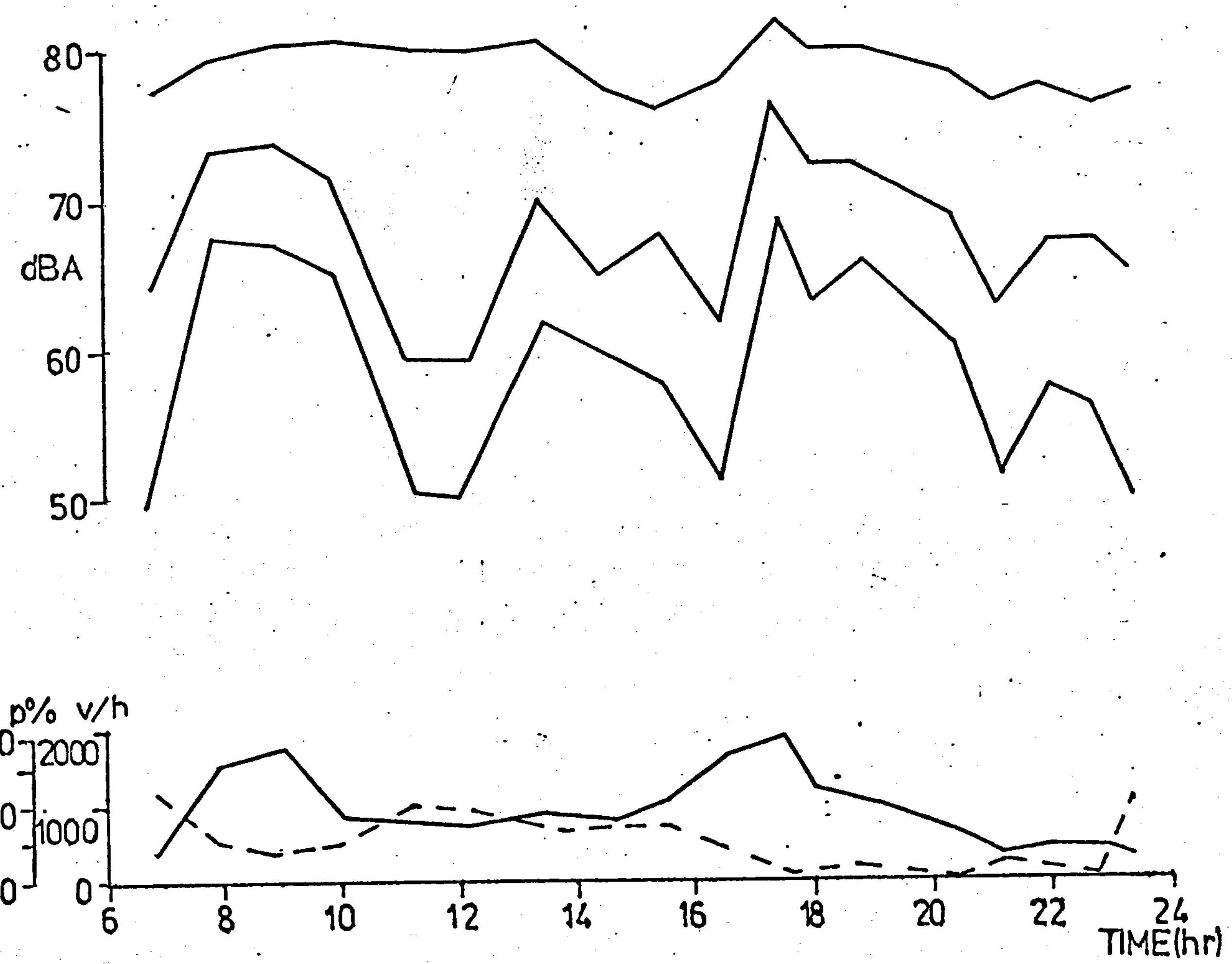


FIG E10 LEICESTER RD, MOUNTSORREL

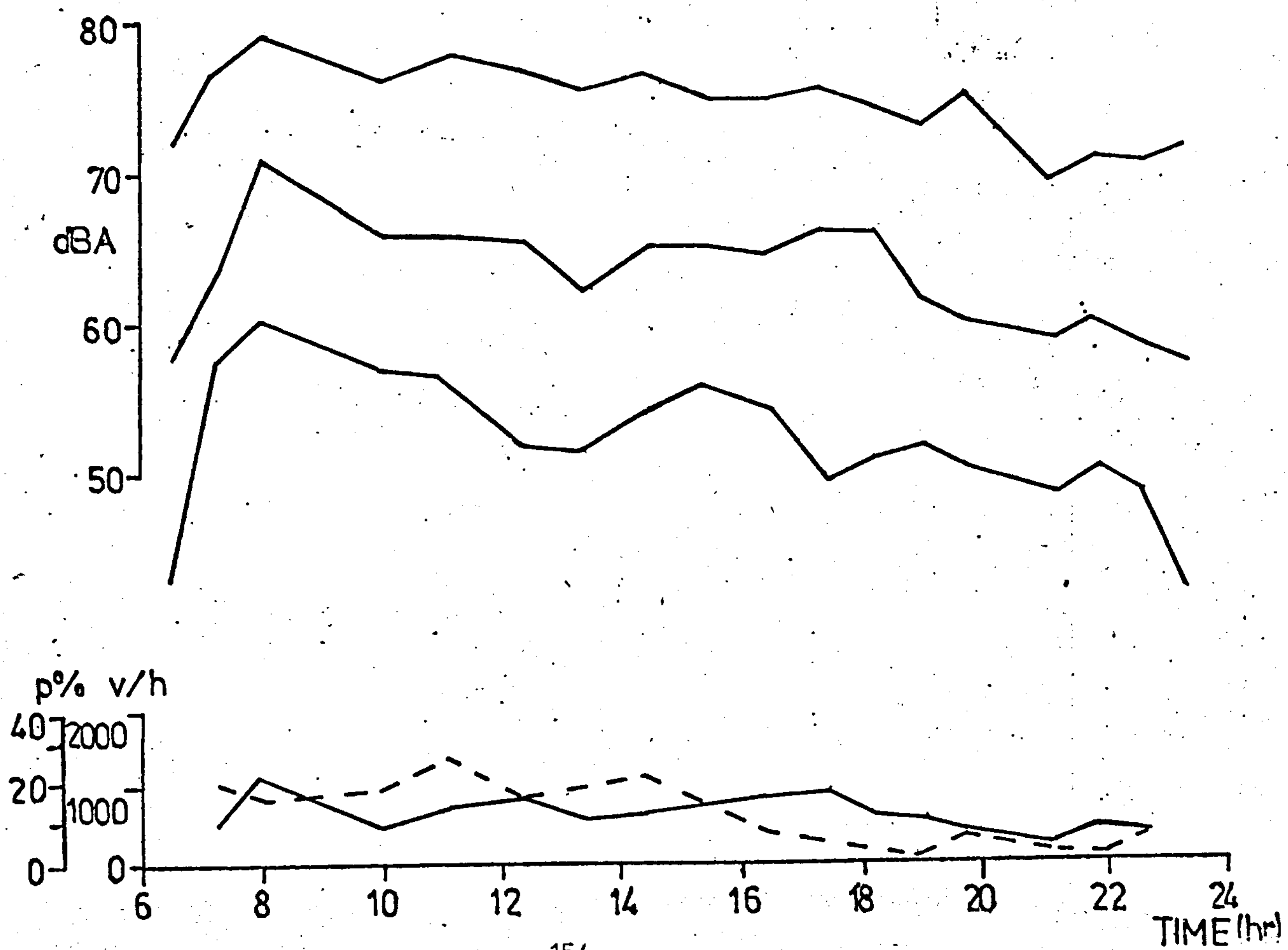


FIG E11 MIDDLETON BLVD, NOTTINGHAM.

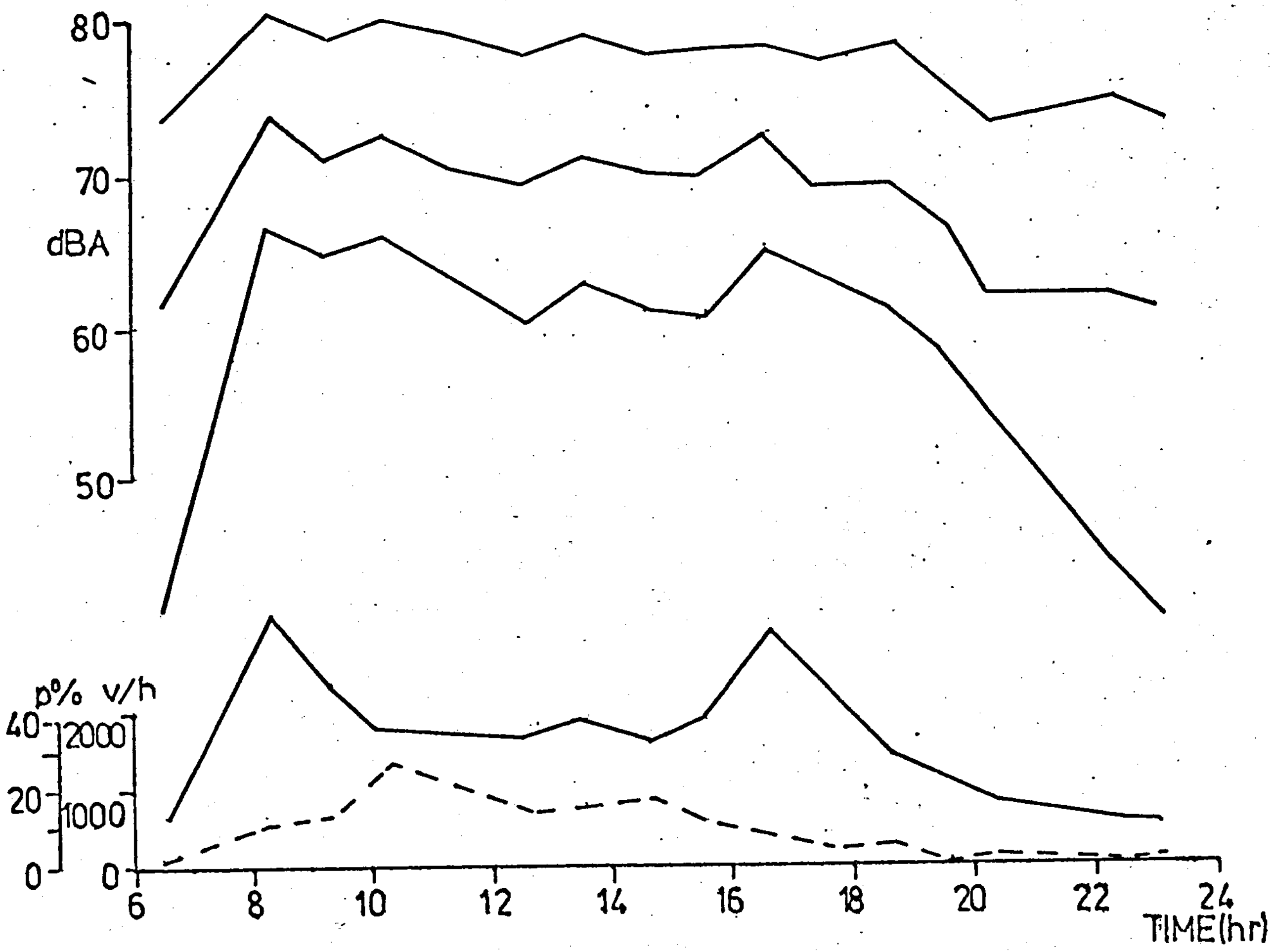
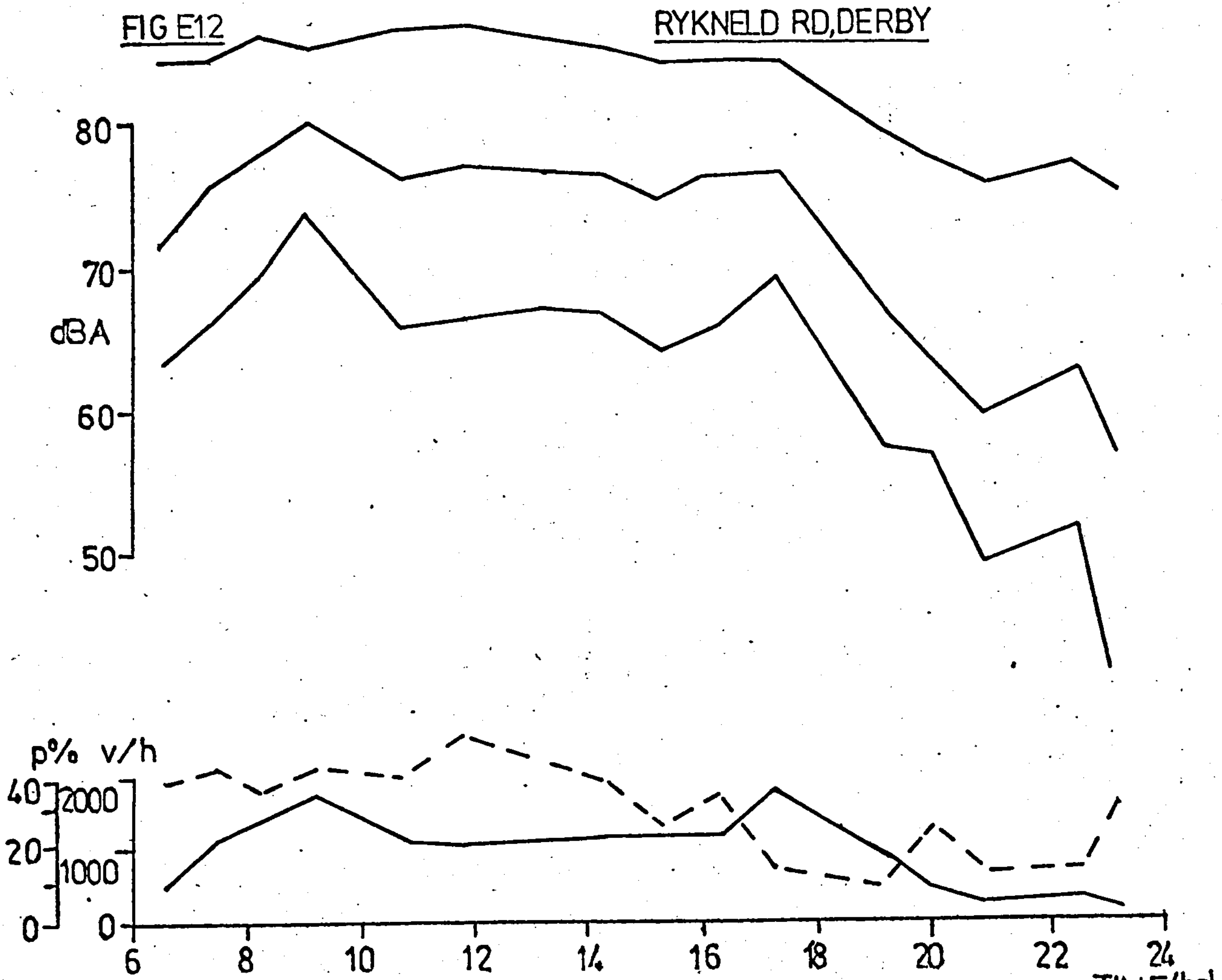


FIG E12 RYKNELD RD, DERBY



Appendix F. Data reduction examples.

Appendix F. Data reduction examples.

a) Physical study.

Rothley intersection at 10m from centre of cross flow, 7.5m from centre of main flow.

Vehicles per hour, $Q = 1130$ v/h entering intersection.

Percentage heavy vehicles, $p = 17.7\%$

Estimated velocity, $v = 60$ km/hr

Assume 1130/2 vehicles per hour for main flow and 1130/2 for cross flow.

Delany prediction :-

$$
\begin{aligned}
L_{10ref}(\text{main}) &= 17.56 + 16.361\log_{10}v + 8.971\log_{10}Q + .118p \\
&= 17.56 + 16,361\log_{10}60 + 8.971\log_{10} 1130/2 \\
&\quad + .118 \times 17.7 \\
&= 46.7 + 8.971\log_{10}565 + .118 \times 17.7 \\
&= \underline{73.5 \text{ dB(A)}}
\end{aligned}
$$

$$
\begin{aligned}
L_{10\ 10m}(\text{cross flow}) &= L_{10ref} - 14.8\text{x}\log_{10} 10/75 \text{ (Grassland)} \\
&=73.5 - 14.8 \times 0.123 \\
&=73.5 - 1.5 \text{ dB(A)}
\end{aligned}
$$

By decibel addition, if two levels 1.5dB(A) apart are added, then total is largest level plus 2.3dB(A).

Therefore, Total(main + cross flow) = $\underline{75.8\text{dB(A)}}$

$$
L_{10}(\text{actual}) = 77.0\text{dB(A)}
$$

$$
\begin{aligned}
\text{Therefore, } L_{10}(\text{actual}) - L_{10}(\text{predicted}) &= 77.0 - 75.8 \\
&= \underline{\underline{1.2\text{dB(A)}}}.
\end{aligned}
$$

b) Noise level calculation for the survey.

Levels required for house of subject 205, at 300m from centre of cross flow, and 25m from centre of main flow.

18 hour Delany predictions for house, calculated for combination of both flows as in (a) above :-

L_{10} = 61.5dB(A)
L_{50} = 52.5dB(A)
L_{90} = 43.0dB(A)

From Fig 4, additions due to intersection :-

L_{10} 0.7dB(A)
L_{50} 0dB(A)
L_{90} 0.2dB(A)

Therefore, 18 hour average levels are :-

L_{10} = 62.2dB(A)
L_{50} = 52.5dB(A)
L_{90} = 43.2dB(A)

Appendix G. Sample of S.P.S.S. set-up and output.

```
            RUN NAME         TRAFFIC NOISE SURVEY. R.R.K.JONES   JANUARY 1975
            FILE NAME        L2287RJ1
            VARIABLE LIST    VAR001,VAR003 TO VAR013,VAR015,L10,L50,L90,TNI,LEQ,LNP
            SUBFILE LIST     INTFLOW,FREEFLOW
            INPUT MEDIUM     CARD
            INPUT FORMAT     FIXED(F3.0,1X,12F1.0,6F5.1)

IGNORING INDEFINITE REPETITION. THE INPUT FORMAT PROVIDES FOR  19 VARIABLES.  19 WILL BE READ.
IT PROVIDES FOR  1 RECORDS ('CARDS') PER CASE.  A MAXIMUM OF   46 'COLUMNS' ARE USED ON A RECORD.

            # OF CASES       129,139
            COMPUTE          VAR020=VAR003+VAR004+VAR005+VAR006+VAR007+VAR008+VAR009+VAR010
                             +VAR011
            COMPUTE          VAR030=VAR005+VAR006+VAR007
            COMPUTE          VAR040=VAR003+VAR004+VAR008+VAR009+VAR010+VAR011+((VAR005+VAR006
                             +VAR007)/3)
            COMPUTE          VAR050=VAR003+VAR004+VAR005+VAR006+VAR007+VAR008
            COMPUTE          VAR060=VAR003+VAR004+VAR005+VAR006+VAR007+VAR008+VAR009+VAR010
            COMPUTE          VAR400=VAR040-VAR009
            COMPUTE          VAR200=VAR020-VAR009
            COMPUTE          VAR600=VAR060-VAR009
            COMPUTE          VAR700=VAR003+(VAR030/3)+VAR010
            COMPUTE          VAR800=VAR004+VAR008+VAR011
            VAR LABELS       VAR003,TRAFFIC NOISE/VAR004,RADIO OR TV/VAR005,GOING TO SLEEP/
                             VAR006,WAKING AT NIGHT/VAR007,WAKING EARLY MORNING/VAR008,
                             VIBRATION/VAR009,ACCIDENTS/VAR010,FUMES/VAR011,VIS INTRUSION/
                             VAR012,PREFERRED NOISE LEVEL/VAR013,OVERALL SATISFACTION/VAR015,
                             LENGTH OF RESIDENCE/VAR020,TOTAL/VAR030,SLEEP/VAR040,TOTAL WITH
                             AV SLEEP/VAR050,NOISE TOTAL/VAR060,TOTAL LESS VIS INTRUSION/
                             VAR200,TOTAL LESS ACCIDENT/VAR600,TOTAL LESS VIS INTR AND ACC/
                             VAR400,TOTAL WITH AV SLEEP LESS ACCIDENT
```

```
PROCESS SUBFILES EACH
REGRESSION      VARIABLES=VAR020,VAR003,VAR004,VAR012,VAR013,L10,L50,L90,
                TNI,LEQ,LNP
                REGRESSION=VAR020 WITH L10(2)/
                REGRESSION=VAR020 WITH L50(2)/
                REGRESSION=VAR020 WITH L90(2)/
                REGRESSION=VAR020 WITH TNI(2)/
                REGRESSION=VAR020 WITH LEQ(2)/
                REGRESSION=VAR020 WITH VAR012(2)/
                REGRESSION=VAR020 WITH VAR013(2)/
                REGRESSION=VAR020 WITH LNP(2)/
                REGRESSION=VAR003 WITH L10(2)/
                REGRESSION=VAR003 WITH L50(2)/
                REGRESSION=VAR003 WITH L90(2)/
                REGRESSION=VAR003 WITH TNI(2)/
                REGRESSION=VAR003 WITH LEQ(2)/
                REGRESSION=VAR003 WITH LNP(2)/
                REGRESSION=VAR003 WITH VAR012(2)/
                REGRESSION=VAR003 WITH VAR013(2)/
                REGRESSION=VAR004 WITH L10(2)/
                REGRESSION=VAR004 WITH L50(2)/
                REGRESSION=VAR004 WITH L90(2)/
                REGRESSION=VAR004 WITH TNI(2)/
                REGRESSION=VAR004 WITH LEQ(2)/
                REGRESSION=VAR004 WITH LNP(2)/
                REGRESSION=VAR004 WITH VAR012(2)/
                REGRESSION=VAR004 WITH VAR013(2)/
OPTIONS         6
STATISTICS      2
READ INPUT DATA
```

TRAFFIC NOISE SURVEY. P.R.K.JONES JANUARY 1975 10/06/75 PAGE

FILE L2287RJ1 (CREATION DATE = 10/06/75)
SUBFILE INTFLOW

VARIABLE	MEAN	STANDARD DEV	CASES
VAR020	26.2791	8.0642	129
VAR003	4.5194	0.7716	129
VAR004	2.5736	1.3737	129
VAR012	3.0078	1.2022	129
VAR013	3.4419	1.1720	129
L10	67.5659	3.0732	129
L50	59.6682	3.8600	129
L90	52.3527	3.9861	129
TNI	82.8488	7.5659	129

TRAFFIC NOISE SURVEY. P.R.K.JONES JANUARY 1975 10/06/75 PAGE

FILE L2287RJ1 (CREATION DATE = 10/06/75)
SUBFILE INTFLOW

* MULTIPLE REGRESSION *

DEPENDENT VARIABLE.. VAR020 TOTAL

SUMMARY TABLE

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B
L10	0.48412	0.23437	0.23437	0.48412	1.27032
(CONSTANT)					-59.55124

Appendix H. Regression analysis using two derived indices.

Appendix H. Regression analysis using two derived indices.

Although limited time did not allow L_{EQ} and L_{NP} for each house to be obtained during the survey, indices based on the Normal (Gaussian) Distribution approximations:-

$$L_{EQ} = L_{50} + (L_{10} - L_{90})^2 / 57$$
$$L_{NP} = L_{EQ} + (L_{10} - L_{90})$$

were calculated for each house using 18 hour average values of L_{10}, L_{50}, and L_{90}.

Althogh the resulting indices, which were named L_{EQ}(AV) and L_{NP}(AV) for the purposes of the survey, were not true ind - icators of equivalent energy level or noise pollution level, they were placed in a regression analysis with annoyance scores to assess their worth, if any, as noise indices. L_{EQ}(AV) represents average noise levels combined with a weighted measure of the fluctuation in levels, while L_{NP}(AV) adds to L_{EQ}(AV) a further measure of fluctuation. It was therefore a possibility, following on from the thought behind TNI, where background levels are combined with a weighted measure of fluctuation, that L_{EQ}(AV) and L_{NP}(AV) could correlate with annoyance.

In fact, when a regression analysis was carried out for L_{EQ}(AV) and L_{NP}(AV) with the final annoyance score "Total with averaged sleep less accident", the results shown in Tables H.1 and H.2 were obtained.

Table H.1 Correlation coefficients for final annoyance score with L_{EQ}(AV) and L_{NP}(AV)

	L_{EQ}(AV)	L_{NP}(AV)
Interrupted flow	0.57	0.59
Free flow	0.19	0.15

Table H.2 Regression coefficients and constants for final annoyance score with L_{EQ}(AV) and L_{NP}(AV)

	L_{EQ}(AV) Coefficient	L_{EQ}(AV) Constant	L_{NP}(AV) Coefficient	L_{NP}(AV) Constant
Interrupted flow	1.08	-45.92	0.98	-54.37
Free flow	0.33	-3.89	0.15	5.68

The correlation coefficients obtained between annoyance score and L_{EQ}(AV) or L_{NP}(AV) are higher than those between annoyance and L_{10}, L_{50}, L_{90} or TNI for the interrupted flow sites, and higher than the correlation coefficient between annoyance and TNI for the free flow sites. The improvement over TNI in the free flow case is not surprising as TNI performed so badly overall, but the general improvement over all the indices in the interrupted flow case is of interest.

It would seem that some measure of fluctuation in an index ensures good correlation with annoyance in interrupted flows, but that the weighting put on the fluctuation is critical. If an average noise distribution changes from L_{10}, L_{50}, and L_{90} levels of 70, 60, and 50 dB(A) respectively to 85, 70, and 55 dB(A), then TNI increases by 75% and L_{EQ}(AV) increases by 28%, showing TNI's large emphasis on fluctuation. L_{EQ}(AV), with its lesser emphasis on fluctuation correlates highly with annoyance, L_{NP}(AV), with its slightly greater emphasis on fluctuation shows improved correlation, but TNI, with the greatest emphasis, shows the lowest correlation. Hence, it is likely that optimum correlation between annoyance and a noise index can be achieved for interrupted flows by weighting fluctuations in level to an extent somewhere between that of L_{NP}(AV) and TNI.