THE EVALUATION OF ENVIRONMENTAL QUALITY: A METHOD OF PREDICTING THE ENVIRONMENTAL EFFECTS OF URBAN TRAFFIC

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SUMMARY

The work is concerned with the measurement and prediction of the environmental effects of traffic in urban situations,with a view to contributing to the development of theory and the provision of techniques in transportation planning which will allow such effects to be taken into account explicitly in the evaluation of transport proposals and projects. Its main emphasis has been on the problems of streets typical of urban areas as opposed to urban motorways on which most research has heretofore concentrated. The study has focused attention on the environmental effects measurable at the kerbside and involved the review and development of traffic and built form related models of traffic noise, pedestrian delay and atmospheric pollution. The issues of vibration, pedestrian risk and visual appearance have also been examined. The work has not only been concerned with 'objective' measures of environmental impact but also with 'subjective response' and the results of testing a series of hypotheses based psychometric approaches to stimulus/response issues are reported.

The research methodology for the development of the 'objective' models was based on the regression of observed variables on simultaneously measured independent variables. The 'subjective' aspects of the study were based on a survey of pedestrian response at the kerbside. Two direct methods of measuring pedestrian annoyance were used - cross modality matching and magnitude estimation.

The results of the 'objective' model development work produced a traffic noise model in terms of L10 for non free flow conditions with a standard error of 1.4dB(A) which is approximately half that found in models to date. Extremely good fits for pedestrian delay were

found with models based on the adaptation of models for 'free flow' conditions.

Less progress has been made in the prediction of pedestrian response. While, in some cases, very highly significant correlations were observed, the wide range of responses relative to the range of the traffic variables on the road network made it impossible to define the correct form of the relationship between the responses and the traffic. However, in the cases where the relationships were highly significant, a log/log relationship was the closest.

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C O N T E N T S

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND TO THE PROBLEM

The last decade has been marked by increasing concern with the quality of the environment, by the general public, politicians and planners. One of the chief causes of concern has been the rising volume of road traffic[1] and highway proposals which have been made for coping with it. This is demonstrated by the unprecedented scale of public campaigns against the building and urban motorways in London, Birmingham and many other cities[2] and by recent legislation on the amelioration of the environmental effects of road traffic. It is probable that the saliency of the problem of the environmental effects of traffic will continue to increase as people become more environmentally concerned in a context of increasing environmental decay.

The degree to which people's consciousness of the different ways in which road traffic affects the environment varies considerably, and this may affect public policy. Legislative response to the environmental effects of traffic has varied in different countries, partly because of variations in cultural awareness and partly because of different physical conditions. In Britain the greatest concern in legislation and planning seems to be with traffic noise. In the USA the emphasis is probably on the air pollution caused by traffic. While in France accident prevention

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1. Between 1964 and 1974 the passenger mileage by private cars rose by 70% (Advisory Council on Energy Conservation, 1976) in the same period the number of heavy commercial vehicles, over 8 tons (unladen weight), rose by 375% (DOE, 1975a).

2. See Community Action, (1972-1975).

3. The DOE forecasts that the number of cars and taxis will increase by 36% between 1976 and 1986 and that the number of heavy goods vehicles (over 1525 kg. unladen weight) will increase by 16% in the same period (DOE 1975b).

appears to be the main issue. Many other undesirable effects of traffic have been listed in official and semi-official documents. The Buchanan Report (1963) was an early and indeed seminal example of such a document in the United Kingdom. In it four main ways in which the quality of the environment is affected by road traffic are listed:

(i) Pedestrian/vehicle conflict

(a) Safety

(b) Constraints on the freedom of movement

(ii) Noise

(iii) Fumes and smell

(iv) Visual intrusion.

These four types of environmental impact are listed in all authoritive publications on the subject.[1] At this level of generality there is little disagreement on the list of impacts. However, many problems arise when more precise specifications are attempted. This is partly because of the reason mentioned above, i.e. the variation in cultural awareness, but it is also because of the sheer conceptual complexity of identifying both the "environment" and "environmental effects". Perhaps it is with a tinge of conceptual desperation that some economists refer to environmental externalities as "imponderables", (Gwilliam, 1970). The most common approach to such specification has been to define such impacts largely in terms of factors which are measurable and predictable.

One of the prerequisites for controlling the effects of the environmental "imponderables" from road traffic in a balanced and systematic way is the development of the ability to measure environmental quality and to predict and evaluate it at the planning stage (Waller, 1970). It is the

1. See for example the Report of the Urban Motorways Project Team (1973) or publications of the DOE (Watkins 1971, or Lassiere, 1974). Similar lists have been compiled by academics, e.g. Foster (1970) and Appleyard and Lintell (1972). Some of these include other less intrusive impacts such as vibration, loss of privacy.

remit of the present work to contribute towards this requirement of making environmental "intangibles" tangible.

1.2 LEGISLATIVE CONTEXT

Since the Buchanan Report debate on the means of controlling the ever increasing environmental effects of road traffic has been gathering momentum. This has resulted in a series of Acts requiring and enabling local authorities to tackle different aspects of the problem. The 1968 and 1971 Town and Country Planning Acts provided local authorities with powers to restrict the movement of vehicles in streets on environmental grounds. These powers have been used in implementing numerous pedestrianization schemes in shopping areas (Hills, 1975).

The Heavy Commercial Vehicles (Controls and Regulations) Act 1973[1] requires local authorities to define routes for heavy goods vehicles on environmental grounds. The Land Compensation Act 1973 requires local authorities to consider the environmental consequences of new or improved roads. It provides for the payment of compensation for the loss of value of residential property caused by the environmental disamenity of such schemes, as well as for the payment of grants for sound insulation. Previously owners were limited to seeking rate reductions. These Acts were supplemented by the revision of earlier environmental legislation imposing standards at a national level for the specification of new vehicles and for the use and repair of vehicles.

Common to the implementation of each of these four Acts is the requirement that local authorities be aware of the environmental costs and benefits of schemes and to compare them with the other costs and benefits. In the past such comparisons tended to be made by planners using their professional judgements to trade-off the costs and benefits.

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1. Frequently called the "Dykes Act".

However, as Pearce (1975) has shown, this led to unsystematic planning. Rational planning, on the other hand, requires that the environmental goals are translated into operational criteria so that the environmental effects of schemes may be examined and evaluated (Rothblatt, 1971). The need for defining these criteria will become more clear in the following section.

1.3 THE OPERATIONAL CONTEXT

Highway and traffic management planning are largely within the domain of local authority decision making. Research which is intended to contribute to the evaluation of the environmental consequences of such planning must, therefore, be oriented towards the practical problems faced by local authorities. This entails investigating the contexts in which they evaluate the environmental effects of traffic and in particular the bearing of urban motorways and the scale of plans on research design. There are four contexts in which the problems of the environmental evaluation of schemes arise for local authorities (J.U.R.U.E. 1972):-

(i) The Planning of new roads

(ii) The design of new roads

(iii) Improvements to existing roads

(iv) Traffic management of the existing road network.

In each of these decision-making situations comparisons may have to be made between alternative proposals, even if one of the alternatives is the "do nothing" situation. Each of the proposals may affect the users of the environment in different ways. Some may experience more noise in their homes, others less. Some may be subjected to greater pedestrian risk and others segregated from road traffic and so on.

An overall picture of the environmental consequences of a scheme can only be obtained by the systematic aggregation of the predicted changes to the quality of the environment which would be caused by the scheme. As well as the varying costs and benefits to the users of the environment, there are also costs and benefits to the users of the road network, and to the local authority, which have to be aggregated in the evaluation.

A qualitative distinction between urban motorways and other urban roads may be found in the aggregation of their environmental effects, as well as in their other costs and benefits. Urban motorways are primary links on the road network, where through traffic is segregated from local traffic and pedestrians, and which conform to certain design specifications.

Thus there is no risk to pedestrians, and their delay depends on access to subways or bridges. The inconvenience of finding crossing points often inhibits pedestrians, causing what some planners have called "severance". One of the ways in which the environmental effects of urban motorways are different from other roads is the extensive visual intrusion which they cause when they are elevated. There is also less variation in the noise levels on motorways because the traffic is free-flowing, on the other hand traffic noise is usually much louder because the flow is greater.

Public attitudes to the environmental effects of urban motorway traffic tend to be also affected by the relative suddeness of their appearance in comparison to the environmental effects from traffic on other roads which has usually built up over a long period of time. The public outcry at the building of a number of urban motorways in the late 1960's led the Department of the Environment to set up the Urban Motorways Committee, which made an extensive study of the environmental effects of urban motorways. Similar research has not been conducted on the environmental effects of traffic on the remainder of the urban road network, where the problem is arguably much more widespread.

The mileage of urban motorways built or planned in the United Kingdom is minute compared to the mileage of the remaining primary, secondary and local road networks. Apart from the imbalance of existing research and the greater extent of environmental problems on the non-motorway part of the network, there is another reason why research should be focused on the non-motorway network. This is because the increased cost of building new roads and the present restrictions on public expenditure[1] make it likely that little if any urban motorways will be built in the near future. Further, once motorways have been built, there is little that can be done about their environmental effects, except for some amelioration through design changes. On the other hand, there is a whole series of tools which planners can use to restrain traffic flows and thereby improve the quality of the environment on the rest of the road network. For these reasons the present study is directed towards the environmental problems of traffic on the non-motorway categories of urban road networks. However, it will also contribute indirectly to the evaluation of urban motorways, as one of the arguments used in their favour is the environmental improvement which they cause on adjacent secondary roads by attracting traffic off them.

Apart from the motorways/non-motorways dimension, the scale of highway and traffic management proposals may affect the methods of evaluation. For small scale proposals, such as the closing of the end of a road in a residential area, it may be possible to compare directly the benefits which would accrue to one group of individuals with the disbenefits which would accrue to another. It would be possible to consider at this

1. See White Paper on Public Expenditure (HMSO 1976).

scale the detailed characteristics of the land-use and estimates of exposure to the environmental effects of the traffic. With medium scale proposals, such as pedestrianizing a group of shopping streets, forming environmental areas or the delineation of lorry routes involving a number of streets, the degree of accuracy in the predicted traffic flows that could be achieved in the necessary "micro-assignments" would preclude the consideration of the same level of detail in evaluation as in small scale proposals. Similarly the degree of accuracy, which can be achieved in the assignments on design year networks defined in transportation studies allows even less detail of environmental effects to be considered in evaluation.

However, for each type of proposal, it may be noted that the sensitivity of the evaluation depends on the facility with which the various costs and benefits for each group of individuals may be identified, predicted and aggregated.

The relative importance of environmental improvement as an objective in the formulating of highway and traffic management proposals has tended to be related to the scale of the proposals. This is largely a reflection of the difficulty of translating the environmental goals into operational criteria for which the technical knowledge is available for measurement and prediction at the macro level. For example, it was stated explicitly in the West Midlands Transportation Study that environmental evaluation was not undertaken for precisely these reasons (West Midlands Transportation Study, 1974).

The awareness of the environmental problems of road traffic, which has developed since the Buchanan Report, has led to many research projects being sponsored by central and local government. These have contributed in many ways to the quantification of the quality of the environment which has enabled progress to be made in the systematic evaluation of the environmental benefits and disbenefits for all scales of highway and traffic management proposals. In fact research on the quantification of the quality of the environment has been an explicit objective in the generation of a number of these proposals. The Wandsworth[1] and Catford (Pearce and Stannard, 1973) studies are examples of these at the medium scale of proposal.

The environmental evaluation undertaken in the Coventry Transportation Study (1973) owed much to it having been selected by the D.O.E. for the development of methods of measuring, predicting and evaluating the environmental effects of transportation plans.

1.4 THE THEORETICAL CONTEXT

Even though the environmental effects of traffic on urban motorways are not included in this study, the methodological context for the evaluation methods by the Urban Motorways Project Team (1973) is of particular relevance to this work. They postulated three types of environmental evaluation:

1) The environmental Modelling Technique
2) The Environmental Evaluation Index
3) Cost-Benefit Analysis including "environmental cost".

The Environmental Modelling Technique does not go beyond the display, in tubular form, of the environmental effects by physical measures of the number of people affected and the degree to which they are affected. The results are based on the application of a set of predictive techniques to a set of design parameters. This technique, when used with orthodox cost

1. There have been a number of separate publications by the G.L.C. on different aspects of their research in the Wandsworth L.T.S. Traffic Zone 277. An outline of the project may be found in Eyles (1969).

benefit analysis, is similar to Lichfield's Planning Balance Sheet (Lichfield 1970), in that the results are not expressed in common units. It does, however, provide the relevant information in a systematic and comparable way and may prove useful in short listing options for a more comprehensive evaluation. The U.M.C. Project Team concludes that the viability of the technique still needs predictive equations to be more robust, and fabric descriptions (for exposure assessment) which are more successfully defined.

The Environmental Evaluation Index is a representation of the total environmental effects in one figure which can be considered alongside the other costs and benefits of the scheme. It is formed by the sum of the products for each environmental factor, of the intensity of response, the relative importance of the factor and the number of people affected. The U.M.C. Project Team concluded that this method would not be practicable until there was more knowledge on the basic processes of quantifying people's subjective responses, firmer conclusions on the thresholds of acceptability, the establishment of the relationships between impact and response, and more confident grounds for ranking the relative importance of the various environmental factors.

The remaining system of evaluation investigated by the Project Team was an adaptation of the orthodox costs benefit technique to include monetary values of the environmental externalities. Prest and Turvey (1966) in their classic review of the subject describe it as a technique which draws on welfare economics, public finance and resource economics to enumerate and evaluate all the relevant costs and benefits of projects. It has an established use in the evaluation of major road proposals. All the capital costs are included, plus the estimates of net savings in vehicle operating costs, imputed values of savings in leisure and work time and savings in the costs of accidents. No attempt has been made to solve the problem of ascribing values to the changes in the quality of the environment caused by the traffic over and above the payments required by the Land Compensation Act 1973. Clearly if this problem could be solved one of the major obstacles to rational environmental control would be eliminated.

The Project Team's consultants tried to tackle this question of putting a value on the environment by using a series of social surveys to monitor the behaviour of households in response to the bundle of environmental effects which goes with the traffic on urban motorways. They had only limited success in surmounting the research problems which they encountered but they were successful in showing the potential usefulness of cost-benefit analysis in this context.

These three types of evaluation which were investigated by the U.M.C. Project Team were outlined mainly to demonstrate and emphasize the elements of environmental evaluation in the context of transportation planning. These may be broken down into three categories:

(i) Identification

(ii) Prediction

(iii) Valuation

The first of these is the formulation of environmental goals and as stated earlier, the translation of these into operational criteria. This includes the identification of all the relevant physical variables and the development of the means of measuring them. The second may be divided into two sub-categories. On one hand there is the prediction of all the physical variables affected, and on the other hand there is the prediction of the number of people who are exposed and the length of time for which they are exposed to the various levels of the physical variables. In many cases the methods of prediction would have to be developed prior to the actual prediction itself. Lastly, there is the ascription of value to each of the environmental repercussions. Though these categories have been presented as an analytical chain they are in fact closely interrelated.

The identification of the environmental effects is particularly dependent on the value system adopted by the evaluator. The methodology of predicting the environmental effects of traffic also depends on the facilities which are available for valuation. In a study contributing to the methods of evaluating the environmental effects of traffic, the research design depends on the type of valuation being used. It is therefore necessary to outline the existing limitations in valuation methods and to specify the research objectives more precisely, before embarking on a critical review of present state of knowledge relevant to the research design.

CHAPTER 2: THE VALUATION OF ENVIRONMENTAL EFFECTS OF TRAFFIC

In each of the three types of evaluation studied by the U.M.C. Project Team, values have to be ascribed to the environmental effects of the traffic at some stage in the decision making process. In fact the different methods could be distinguished by the stage at which values are applied, as well as from whom the values are derived. For example in the Environmental Modelling Technique the planners and politicians implicitly put values on the different aspects of the environmental effects when they make decisions on the basis of the statement of environmental effects with which they are presented. This has been called the "authorities approach" by Walters (1975) and the "elitist approach" by Pearce (1975). At the other end of the spectrum there is what Walters called the "prices approach" and what Pearce called the "populist approach". The latter is where the population affected by a proposal vote on it on the basis of one man, one vote. This is not to say that the planners and, to a greater extent, the politicians would not be sensitive to the likely outcome of such a vote when using the "authorities approach". On the other hand, the "prices approach", of which cost benefit analysis is a prime example, may contain elements of elitism. It entails the ascription of values in monetary terms to the environmental disbenefits.

2.1 THE VALUATION OF THE ENVIRONMENT IN MONETARY TERMS

Monetary units have always been the meat of orthodox economists. There are, however, unresolved arguments, on their meaningfulness in contexts other than in exchange value, and money problems of incorporating distributional issues in methods of economic evaluation have, also yet to be resolved. On the other hand the development of a method for expressing environmental disutilities in monetary units would have tremendous heuristic value in the evaluation of highway and traffic management proposals, and unfortunately previous efforts in this direction have been at the best only partially successful.

Two broad approaches have been used in attempts to determine the monetary value of the environment. One is to observe the revealed behaviour of people in response to the environment, (i.e. the econometric approach). The other is by soliciting peoples' valuations (i.e. the questionnaire approach).

2.1.1. <u>The Econometric Approach</u>

Three main methods have been used in this approach. They are to observe:

(i) The change in the market price of a commodity because of exposure to environmental disbenefits, (e.g. house price differentials)

(ii) Costs incurred to avoid the greater cost of environmental disbenefits (e.g. the installation of sound insulation).

(iii) Other costs similarly incurred to which only shadow prices can be ascribed (e.g. diversion of journeys by pedestrians).

Much of the research on the effects of environmental disbenefits on prices has been in the context of the housing market largely because there is usually a degree of choice available to potential buyers of houses with a wide range of exposure to the environmental effects of road traffic. However, even under conditions close to and distant from urban motorways, the U.M.C. Project Team were not able to isolate what they called the "house price differential". This was partly because of multicollinearity between the determinants (e.g. between noise and access) and partly because the price differential was to some degree offset by some households being less susceptible to the environmental effects of traffic than others. But, a major research problem in this and the other approaches is the gap in the knowledge about the relationship between actual behaviour and underlying preference functions. As Johnson and Joyce (1975) state in this respect "a crucial vacuum exists regarding the nature and the relative importance of constraints that exist in different markets and among different socio-economic groups".

Starkie and Johnson (1975) were partially successful in determining the relationship between the acceptance of grants for sound insulation and noise levels from aircraft, although, ironically, one of the variables which they had problems in controlling for was noise from road traffic. Many of the same research problems arise when using this approach as in the prices approach. Where "shadow prices" have to be imputed for behaviour modification even greater problems arise.

However, even if the research problems in imputing monetary values to the environmental disbenefits of traffic were overcome the trenchant arguments of Self (1970 and 1975) on the validity of the results and their compatibility with other monetary values should not go unnoted.

Partly because of these arguments, but to a greater extent because of the apparent intractability of the research problems outlined above, it would not seem appropriate to attempt to put a value on the environmental disbenefits of road traffic on the non-motorway network by econometric methods. This point is substantiated by the lack of success by the U.M.C. Project Team in a more favourable research context. Some progress may be made in resolving the research problems particularly when psychologists and economists learn more about the relationship between market behaviour and preference functions.

2.1.2. The Questionnaire Approach

The last resort, in imputing monetary values to environmental disutility, has usually been to assume that elicited responses may be used.

One approach has been to ask respondents how much they would be willing to pay to avoid the environmental disutility. Another has been to ask how little they would be prepared to accept as compensation. Not only do the same problems of validity arise in this approach as in that of studying economic behaviour, but also there is the additional set of research problems associated with attitude measurement. In this context probably the most serious of these is the propensity of respondents to overstate their case in the hope in influencing policy. Ambiguous results were obtained from this method by the Roskill Commission (1971) and by the Urban Motorways Project Team. For example the Project Team found that almost 60% of their respondents stated that they would prefer the removal of all the environmental problems to any amount of compensation. Similarly, a significant proportion said that no amount of money would induce them to move. Unless some correspondence can be found between this approach and the econometric approach, in a favourable research environment where there is one major environmental stimulus, there is little point in using the approach in relation to more complex environmental states which are caused by road traffic. (Joyce and Johnson, 1975).

2.2. ENVIRONMENTAL INDICES

It has been shown that the valuation of the environmental effects of road traffic is not made explicit when environmental impact statements (e.g. the environmental modelling technique) are used. This leads to inconsistent and unsystematic valuations being made. It has also been shown above that the problems of attaining monetary values are relatively intractable. This leaves the intermediate type of valuation, which is the representation of all the environmental effects of the traffic in one index. This overall index of the quality of the environment may be formulated by comparing people's solicited responses with traffic variables.

However, there are many reasons, both theoretical and practical, why an overall index of environmental quality should best be derived from the combination of responses to the separate environmental variables affected by the traffic. The main theoretical reason is that the analysis of the relationship between subjective responses and individual environmental stimuli enables the testing of hypotheses based on psychological theory. One of the practical reasons is that the already existing body of knowledge on the identification and prediction of the environmental variables would not be used. There is also the point that present planning practice is oriented towards the use of environmental variables.

The development of an environmental index from people's subjective responses leaves three problems unresolved. The first is at the stage of overall evaluation, where the planners or politicians still have to use their "authority" to evaluate the environmental index which is not in monetary units along with the other costs and benefits which are. The second problem arises in the research design. It springs from the difficulty of isolating individuals' subjective responses to the environment which they perceive, from both their beliefs about harmful the unperceptible aspects of the environment and their feelings about other people's exposure to environmental states. Though useful information on these points may be elicited from respondents they should not be incorporated in an index of the quality of the environment. Logically, if health issues were to be included, the subjective responses of those affected should be included in the index, but it would be much more practicable to follow the current practice of applying standards as a preventative measure, and to include the predicted losses to public health as a separate category to be evaluated. People's views on the equitable distribution of environmental exposure are an important issue which raises many thorny questions in ethics and political theory. However, distribution issues can only be discussed in the most general terms until significant progress has been made in measuring the quality of the environment. The third problem relates to the validity of comparing the overall response elicited from one individual to that of another even when every effort has been made to have them on a common ratio scale. There seems no way round this problem and all conclusions would have to be circumscribed by this caveat on commensurability.

2.3 ACTIVITY CONTEXT OF RESPONSE

The change in the utility experienced by an individual due to a change in the flow of traffic may be caused by a number of the different types of changes in the quality of the environment which have been listed above, e.g. noise, air pollution, etc. Each of these may affect people along the same route in different ways depending largely on their activities within the existing land uses, e.g., people in hospitals and libraries would be more concerned about noise than pedestrian delay, while people working in noisy environments may not notice a change in the noise on the street. The number of people affected depends mainly on the land-use and the time of day, and the same people may be affected in different ways at different times, e.g., school children being affected by noise at one time and pedestrian risk at another.

It was decided to concentrate research on one activity context, that of pedestrians. This was done for a number of reasons apart from the obvious constraints of time and resources. Firstly, interviewing on the kerbside, where there was a close proximity between the respondents and specific obsevable environmental status, afforded the empirical testing of hypotheses on the relationship between people's responses and a number of different aspects of the environment which are not directly perceptible in other contexts. For example, the attitudes of people sitting in their home, towards pedestrian delay or risk in crossing the road, would be general in nature and would be more difficult to relate to particular traffic flows.

The concentration on pedestrians responses thus allows the greater facility for formulating the rules for predicting overall responses from a number of separate responses. Unless we can determine the methods for combining responses in one user context, it would not be possible to combine people's overall responses in that context with their overall responses in other contexts.

Apart from the kerbside context being more suitable for testing these hypotheses, its study of the quality of the environment also contributes to the study of environmental quality in other contexts, in that the prediction of noise at the kerbside is an input to prediction models for noise at points away from the road. Further, many of the methodological problems which have had to be solved in this user context are common to others.

A further restriction was a decision to limit the research to people's direct and personal responses to the environmental effects of traffic. This, insofar as it was successful, ruled out the responses being affected by more general attitudes on environmental control and attitudes about the effects on other people.

2.4 RESEARCH DEFINITIONS

2.4.1. Environment

Restricting the study to the relationship between the direct effects of road traffic and people's affects with the environment leads to a

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very specific definition of the word "environment". It excludes that part of people's surroundings which is affected when they are using a vehicle. It also excludes that part of their environment which is affected indirectly by the use of roads, such as benefits gained as a consequence of people or goods heaving been moved. As will be seen, the study is further restricted to the environment of individuals in one specific land-use, which is in this capacity as pedestrians, although many of the conclusions may be extrapolated to other land-use environments.

2.4.2. Annoyance

So far in this introduction, a number of words have been used to describe the relative value which people put on the environment as affected by traffic. These include "consciousness with disamenity", "social cost", "subjective responses", "affects" and "disutility". None of these lend themselves to being operationalised in the context of kerbside interviewing. Because of the constraints of kerbside interviewing, the respondents attention was focused on one concept which it was hoped would represent all of the relevant subjective responses of the respondents. A similar decision was made in the designing of the home interview questionnaire used in the National Environmental Survey where there were fewer time constraints on the interviews. They used the concept of "being bothered by", which was taken "to cover such connotations as annoy, irritate, worry, trouble, or 'to be concerned about'", (Sando and Batty, 1974).

The concept of annoyance was used in a corresponding survey of the Urban Motorways Project Team (1974). It was also used as the central concept in the present study, because it is a word of everyday meaning which refers to affects of a fairly transitory nature which could be related to specific environmental conditions. Alternative words such as "attitude" or "opinion" refer to more long term affects or beliefs which would not fit this criterion. "Impression" could be taken to refer to sensations as well as affects. "Being bothered" was not used because its meaning was considered to be less direct than that of "annoyance".

2.4.3. Indices and Variables

One of the purposes of the research could be viewed as attempting to define and calibrate the psychological scale of annoyance. In a survey context respondents can only represent their annoyance along objective scales. Inferring the psychological scale from such objective measurements is one of the critical problems in the research design. But though it may be represented in terms of the scales in which it was originally encoded, it is usually more helpful in the context of environmental planning to represent it as an environmental index. An environmental index is defined here as a numerical representation of one or more environmental effects of road or air traffic which is proportionate to the annoyance caused. It may be expressed as a transformation of one or more environmental variables (e.g. L_{10}), or a combination of both (e.g. the Noise and Number Index).

An environmental variable is a physical variable affected by traffic, but defined independently of the environmental context and arbitrarily selected on the implicit assumption that a transformation of it would contribute wholly or partly to the composition of an environmental index. The environmental variables and those indices which are not based solely on traffic variables are purely of heuristic value.

CHAPTER 3: A CRITICAL REVIEW OF THE PRESENT STATE OF KNOWLEDGE

This work finds its focus within the broad body of theory and practice forming transportation planning and management. As such the criteria used both to select and review the relevant literature stem from this orientation and from the specific objective of contributing to the assessment and evaluation of transport proposals against the criteria which have been defined above. This chapter, therefore, places its emphasis on attempts to model and predict traffic-related environmental indices.

3.1 MODEL EVALUATION

The criteria by which the models are judged range from general assessments of the environmental indices, to more specific tests of their reliability. Each of the six environmental effects of road traffic which have been listed in chapter 1, noise, pedestrian delay, air pollution, risk in crossing the road, vibration and visual intrusion will be discussed in the following section. The validity of the dependent variables in the light of existing evidence will be reviewed first. This will be followed by a description of the available models and an assessment of their reliability. Where possible their reliability will be judged according to their accuracy, robustness and simplicity. The accuracy of the models will be determined from their residual errors and multiple correlations, in the cases where these are published. The models' robustness will be assessed from their construct validity. Simplicity in the specification of models is a merit when it comes to application, and it also contributes to their robustness where there is a possibility of error in the data (Alonso, 1968). As well as these criteria, there is a more immediate concern with relevance as the specific interest focusses on the kerbside environment for the reasons discussed above. The final section looks at models for predicting overall and relative responses to the environmental effect of road traffic. The space devoted to each of the environmental factors is a reflection of the extent of the relevant knowledge in these areas, and should not be taken as an indication of their relative importance.

3.2. TRAFFIC NOISE

3.2.1. Indices Developed

Indices of noise have usually been based on transformations of sound levels. The standard units for measuring these have now become "A weighted" decibels (dB(A)) which are a function of sound pressures weighted in accord with the response pattern of the human ear.[1] As decibels only refer to instantaneous sound some measure has to be developed to express sound levels over a period of time which may also act as an environmental index. Many such indices have been developed, but notwithstanding the strong cases which have been made for a number of indices, (Griffiths and Langdon, 1968 and Robinson, 1969 and 1975), since the publication of the Wilson Report (1963) the L_{10} has become the index of traffic noise which is almost universally used in the U.K. The L_{10} is the sound level which is exceeded ten percent of the time.[2] As the sound levels from free flowing traffic and to a lesser extent, non-free flowing traffic,[3] are

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1. Glossaries of the technical terms applicable to the measurement of sound may be found in many sources, e.g. British Standards Institute (1963) Lassier (1974) or Architectural Journal (1969).

2. The L_{10} is usually discussed in terms of hourly periods. The 18 hour L_{10} is the arithmetic mean of the hourly L_{10} between 6.00 a.m. and mid-night.

3. Free flowing traffic is defined as where the distance between vehicles is randomly distributed, such as occurs on motorways which are not over loaded. Such conditions do not occur where traffic lights etc., tend to platoon the traffic, or where the inability to overtake causes the headways to tend towards uniformity.

approximately normally distributed, the L_{10} approximates to:

$$L_{10} = L_{50} + 0.5\ (L_{10} - L_{10}) \qquad (3.1)$$
$$= L_{50} + 1.28\ \sigma$$

Where σ is the standard deviation of the distribution and L_{50} and L_{90} are the sound levels exceeded 50% and 90% of the time. The mean energy level (L_{eq}) is widely used in some European countries to measure traffic noise and is strongly advocated for use in the U.K. by Robinson (1975) on the grounds of simplicity and, to introduce a new criteria, standardisation. It is calculated as follows:

$$L_{eq} = K \log \frac{1}{100} \quad f_i - 10^{L_i/K} \qquad (3.2)$$

Where K is a constant,

f_i is the percentage time that a sound level is in the i th interval,

L_i is a median sound level of the 5 dB(A) interval i

The same author (1969) had previously developed the Noise Pollution Level (L_{NP}) which takes the form:

$$L_{NP} = L_{50} + (L_{10} - L_{90}) + 0.0175\ (L_{10} - L_{90})^2 \qquad (3.3)$$

The Traffic Noise Index (T.N.I.) which was developed by Griffiths and Langdon (1968) places much greater emphasis on the variation in the noise levels:

$$T.N.I. = L_{90} + 4\ (L_{10} - L_{90}) - 30 \qquad (3.4)$$

In each of these four indices there is a different emphasis placed on the variation in the sound levels. The greater the emphasis, the more likely the index is to decrease as traffic flow increases. It has been shown that the L_{NP} begins to decrease for free flowing traffic after 1000 vehicles per hour (Waller, 1973).

There is no evidence from social surveys which definitely attests to the validity of one of these rather than another. Some of the difficulties in designing such a survey may be noted from the fact that the same data which was used to develop the TNI was also used to justify the L_{NP} and the 18 hour L_{10}, (Scholes and Sargent, 1971). There is also social survey evidence to support the L_{eq}, which gives the variation of sound a zero weighting, (National Swedish Institute, 1968).[1]

One of the main research problems, which has not yet been overcome, is that of defining the psychological continuum on which subjective responses may be measured. A high correlation between a measure of annoyance and an environmental variable (as for example in the National Swedish Institute's survey) is no proof that the variable should be regarded as an index of environmental quality unless there is also evidence that the measure of annoyance is a linear function of the actual annoyance experienced.

3.2.2. Existing Noise Models

Fortunately, almost all of the models which have been developed for predicting noise from traffic are relevant to kerbside predictions. This is because models for predicting noise levels at facades are best developed in two stages, (Delany, 1974), the first predicting the noise levels at a reference point close to the road, and the second the rate of attenuation.

Three approaches have been used in the development of prediction

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1. Quoted from OECD (1971) and Build International (1968).

models for road traffic noise, (Nelson, 1973). The most frequently used is the simultaneous measurement of sound levels and the characteristics of the traffic flows which are believed to influence the sound levels. The relationships are then determined by multiple regression. The other approaches are to develop theoretical models or to use scale model techniques. The latter method has been little used and though it may have potential in developing attenuation models, (Delany, Rennie and Collins, 1972); a method has not yet been developed for simulating the accoustics of road traffic (Nelson, 1973).

A number of workers have developed theoretical models for predicting noise from free flowing traffic e.g. Galloway (1962), Kurze (1971), Nelson (1973) and Delany (Vass, 1972), but more have been developed for non-free flowing traffic, and the complexity of these models and the large computer space required makes it unlikely that such theoretical models will be developed for non-free flowing traffic.

Field work measurements, as Nelson (1973) has stated, provide the closest contact with reality, though as a basis for model development the researcher has little control over the parameters affecting the noise level, and interactions between the various parameters cannot be readily separated. However, for non-free flowing traffic, it appears at the moment to be the only practicable approach, and it does not rule out the recalibration of the whole or parts of models designed for free-flowing traffic.

By far the most important variable in predicting L_{10} is the number of vehicles passing the measurement point. This is usually expressed in vehicles per hour. The sound pressure emitted by vehicles is approximately proportionate to the rate of flow and without exception it figures in logarithmic form in regression models where the dependent variable is in decibels. The specification of the composition of the traffic raises more of a problem. Johnson and Saunders (1968) used a relatively simple specification, which consisted of the percentage of heavy vehicles. They were responsible for one of the first systematic attempts to develop a noise prediction model from field measurements. In a reanalysis of their data Delany (1972) recalibrated the regression equations for estimating the L_{10}, L_{50} and L_{90}. In each case the models were in the form:

$$L = a + b \log V + C \log Q + dP \qquad (3.5)$$

Where V = mean speed of the vehicles

Q = total flow in vehicles per hour, (v.p.h.)

p = percentage of heavy vehicles.

This model has the merit of simplicity. Its accuracy is difficult to assess, though the multiple correlation in the case of L_{10} was 0.92. However, these models were based on data from free flowing traffic and the range of variables was outside that found in most non-free flowing traffic situations. The minimum speed was higher than the 30 m.p.h. limit on most urban roads, and the minimum flow was 780 v.p.h. These models would, therefore, at least need to be recalibrated from measurements of non-free flowing traffic.

Gilbert and Crompton (Crompton, 1971; Gilbert 1973) have developed a number of models for predicting the kerbside noise from non-free flowing traffic, using methods similar to Johnson and Saunders. The following regression equation is a typical result:[1]

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1. This model was developed for low flow streets. The equation quoted by Wigan (1975) where the constant was 58.58 had been corrected, as above (Gilbert, 1973).

$$L_{10} = 57.3 + 9.2 \log Q\,(1+0.09p) - 4.2 \log Vy + 2.3T \qquad (3.6)$$

Where y is the distance between kerbs in metres and

T is an index of the degree of platooning of the traffic.[1]

Common to all of their models is the specification of the flow-composition element. It could also have been written: "9.2 log (L + 10H)", where "L" and "H" are the flows per hour of light and heavy vehicles respectively. It is submitted that the constant relative weight, which they postulate for heavy vehicles compared to light vehicles, contains a theoretical weakness. This may be seen from a look at level recorder traces. As individual vehicles pass a microphone, dB(A) traces are described which approximate in shape to isosceles triangles. For similar speeds the angle at the points of these triangles remains fairly constant for both heavy and light vehicles, though the heavy vehicles tend to be 4 or 5 dB(A) louder than the light vehicles. It will be noticed that if a line is drawn through the triangles, corresponding to some L_{10}, the ratio of the length of the line within a triangle described by a heavy vehicle to that described by a light vehicle depends upon the level of the L_{10}, and of course the L_{10} depends upon the flow and the proportion of heavy vehicles. The greater the flow or the higher the proportion of heavy vehicles, the greater is the relative effect of heavy vehicles on the L_{10} compared to that of light vehicles. This also holds true when the sounds of the vehicles coincide with each other.

Equation 3.7 shows how this flow/composition element may be expressed in another way.

1. This index of platooning (or dispersion) was arrived at by counting the number of vehicles in successive ten second intervals, and dividing the variance of the numbers by their mean.

$$9.2 \log Q (1 + 0.09P) = 9.2 \log Q + 9.2 \log (P + 11.1) - 9.6 \quad (3.7)$$

This would add another degree of freedom in the calibration, which could improve the goodness of fit. The finagle tail of 11.1 has the effect of moving the values of the element further along the logarithmic curve to where it is straighter and more similar to equation 2.5. However, it does suggest another specification which could be tested, which is the logarithm of the percentage of heavy vehicles. Another specification which deserves testing for goodness of fit on the grounds of its simplicity is one in which the regression set contains the logarithm of the number of light vehicles and the logarithm of the number of heavies.

The residual error of regression equation 3.6 also causes concern. It was 2.7 dB(A). The 95% confidence bands round the estimated L_{10} are therefore approximately equivalent to multiplying or dividing the traffic flow by four. This range of errors, which makes its application in planning terms questionable, is the result of the logarithmic format of the specification. It is not possible to say from Gilbert and Crompton's publications whether the size of the residual error is significantly affected by the specification.

In a reanalysis of a limited number of measurements published by Crompton (1971), it was found that the equation 3.5 type of specification and a theoretically based formula developed for free flowing traffic by Delany (Vass, 1972), both gave as good results as Gilbert and Crompton's own specification, (Hodgins, 1972). The multiple correlations were approximately 0.93 and the residual errors were 2.2 dB(A). Delany's model was based on the distribution of individual vehicles' sound patterns in drive-past recordings. Negative exponential distributions were used to describe the random pattern of headways between vehicles in each lane. An increase of 9 dB(A) in the peak noise levels of cars was taken as given for each doubling of speed and 4 dB(A) for heavy vehicles. Variation from the mean speed was allowed for, both with and between lanes. A close correlation was found between estimates using this model with a propogation element and the observed L_{10} at up to 160 metres from a range of traffic conditions, (r = 0.984 and R.E. = 1.32 dB(A)). Equation 3.8, which was quoted by Vass, is a simplified version of the original model developed by Delany:

$$L_{10} = a + b \log V + c \log Q \tag{3.8}$$

Where $a = 11 + 43 \ (i-e^{-p/25})$

$b = 5.5 + 16.5e^{-p/6}$

$c = 7 + pe^{-p/12}$

P = the percentage of heavy vehicles

V = the mean speed of vehicles in k.p.h.

Q = the traffic flow in vehicles per hour.

The Department of the Environment (1975b) has published another model for predicting the L_{10} from non-free flowing traffic. Its chief feature is the specification of the interaction element involving the speed variable:

$$L_{10} = 10 \log Q + 33 \log \left(V + 40 + \frac{500}{V}\right) + 10 \log \left(1 + \frac{5P}{V}\right) - 26.7 \tag{3.9}$$

Nothing is stated about the degree of accuracy that might be expected from it, or about how it was developed. However, it can be shown by the manipulation of the elements that the specification of the traffic and composition variables have similarities to Gilbert and Crompton's specification.

$$10 \log Q + 10 \log \left(1 + \frac{5P}{v}\right) = 10 \left(\log Q + \log 1 + \frac{5P}{v}\right) \qquad (3.10)$$

$$= 10 \log Q\left(1 + \frac{5P}{v}\right)$$

3.2.3 <u>The Effect of Vehicle Speed on Noise</u>

There are a number of ways in which the sound emitted by moving vehicles is affected by the speed at which they are travelling (R.R.L. 1972). This is probably reflected in the various specifications of the speed element in models described above. Waters (1974) has shown that engine speed is the most important single parameter in determining the noise of a modern deisel-engine commercial vehicle. The extent to which noise varies with speed depends on the vehicle load (Olson 1972). The rattling noise which some vehicle loads make may vary with the road speed of the vehicle. At high speeds, tyre noise and aerodynamic noise become more significant (Rucher and Glück, 1965). The variation in speed also affects the noise emitted (Harland, 1970).

There is evidence that indices of noise are related to the logarithm of the speed of the traffic flows, which is based on the observation of individual vehicles. Pried (1967) reported that for various sized stationery engines running between 500 and 3000 revolutions per minute there was a fairly consistent linear relationship between sound pressure and revolutions per minute when plotted on log/log axes, for each engine size. Lewis (1973) in a study of peak noise values of individual commercial vehicles driving under freely flowing traffic conditions, found that the peak decibel level was linearly related to the logarithm of their speed. The maximum speed in his study was 50 k.p.h. Waters (1974) found similar results at slower speeds under test conditions.

Harland (1970) found the same type of relationship in tests done with an 1100 cc motor car driven under experimental conditions. He also found, however, that particularly in first gear there was little relationship between speed and sound when the vehicle was accelerating. Similar results were found with a sample of six lorries over eight tons gross weight. From this he assumed that under 32 k.p.h. there is no relationship between speed and sound emitted. Implicit in this assumption is that vehicles are always accelerating under 32 k.p.h. which is not necessarily the case in non-free flowing traffic.

However, there is no direct connection between using a logarithmic function for describing this relationship and for describing the relationship between an index of noise over a period of time and the mean speed of vehicles in a traffic flow. Johnson and Saunders (1968) found that the relationship held good between the L_{10} and the speed of free flowing traffic, but there is conflicting evidence on whether it does for non-free flowing traffic. In some studies of non-free flowing traffic, Gilbert and Crompton found no significant relationship between L_{10} and speed. For example this was the case in their analysis of 200 observations taken in Edinburgh (Crompton, 1971). In fact they found a slight negative correlation between the L_{50} and the logarithm of the mean speed when the traffic flow was controlled. On the other hand they found a significant interaction between the logarithm of speed and the width of the road as shown in equation 3.6. They also postulated yet another type of interaction between speed and an independent variable, this time with the traffic flow. They stated that, for a given flow, the higher the speed the greater would be the spacing, with a consequent reduction in the sound level.

Vulkan, (1970) in discussing the interaction between speed and the proportion of heavy vehicles also noted that the composition of traffic is less important as speed increases, because the difference in noise emission between lorries and cars becomes less. A similar effect is described by the " log V" element in Delany's model (equation 3.8). The D.o.E. model (equation 3.9) is a more complex specification involving speed. In figures in two elements. In the first (i.e. 33 log (V + 40 + 500/V)) the value of the element is "U"shaped with respect to the value of the mean speed. The noise descreases as speed increases up to between 20 and 25 k.p.h. when it begins to increase. The second element (i.e. + 10 log (1 + 5P/V),) involves an interaction with the percentage of heavy vehicles. It entails that for any given percentage of heavy vehicles the estimated L_{10} decreases as the speed increases. It will be necessary to test each of these specifications empirically, but, other things being equal, the Johnson-Saunders specification has a considerable advantage in simplicity.

3.3 PEDESTRIAN DELAY

Two pedestrian delay variables exist which may serve as indices. They are the mean time that a pedestrian is likely to be delayed and the proportion of times that he would be likely to be delayed. Not other indices have been developed, and no research has been conducted which has definitely discriminated between them. Measurement of pedestrian delay will pose a number of problems. These will be discussed in the following chapters on the research methodology.

3.3.1 The Development of Adam's Formulae

The models which have been formulated for predicting pedestrian delay from the characteristics of traffic flows are theoretically based. The seminal research was conducted by Adams (1937). He determined that, assuming the pattern of arrival of vehicles is random, and that the headways between them are exponentially distributed in time, then the mean delay of pedestrians crossing the road would be:

$$D = (e^{Qt} - Qt - 1) / Q \qquad (3.11)$$

Where D = the mean delay in time (seconds) that the pedestrians would be delayed, including those times when there would be no delay.

Q = the total flow in vehicles per second

t = the minimum gap in seconds between vehicles that the pedestrian would accept.

Adams showed that it also followed from these assumptions that the percentage of time delayed would be:

$$\%D = 100\,(1 - e^{-Qt}) \qquad (3.12)$$

Where %D = the percentage of people arriving continuously at the kerbside who would be delayed.

However, in practice, on many roads the pattern of arrival may be significantly non-random due to, for example, traffic lights, pedestrian crossings, and bus stops, which may cause vehicles to group. This, Adams stated, causes a greater proportion of very short and very long headways between the vehicles. Dowell (1967) attempted to test whether Adams' equations held true in such a context. He observed the headways between vehicles at a number of sites in central Oxford where the flow was affected by traffic lights. He compared the estimated mean delay calculated from Adams' formula with the mean delay calculated from the observed distribution of headways. Using various minimum acceptable headways between 2 and 10 seconds, he found that there was little difference between the estimates for the lowest flows (170 vehicles per hour), but that for flows between 300 and 800 v.p.h. the estimated mean delay, when the random flow assumption was made, was generally much lower, although, as he points out, his sample was small and the "non-randomness" of the flows varied from street to street. It is noted that the "non-random" delay was 80% greater than the "random" delay at a 4 second minimum acceptable headway (MAH), and that it declined relatively to being 10% greater at a 10 sec. MAH.

In a follow-up survey Dowell found that the median accepted headway by pedestrians was between 4 and 5 seconds. This he found was not greatly dissimilar to that found in previous research. The MAH varies from person to person depending on their mobility and their motivation etc., and indeed it varies for each person depending on numerous subjective and objective factors.

Ashworth (1971) notes that the observed MAH may vary according to the method of observation. For example, the low correlation found between pedestrian delay and traffic flows measured in the Coventry Transportation Study (1973) has been attributed to the difficulty of knowing when a pedestrian has decided to cross the road (Bowers, 1972). Where delay is measured by observing pedestrians, no delay would be measured on cases where the pedestrian watched the traffic while walking and only attempted to cross when a suitable opportunity arose. In such a situation the degree of delay would depend on where the pedestrian was going rather than the flow of traffic.

Ashworth also stated that if it was assumed that people's MAH's are normally distributed with a variance of S^2 and a mean of e, then the mean delay is:

$$D = (e^{Qt} + Q^2S^2/2 - Qt - 1) /Q \qquad (3.13)$$

Like Adams' model this assumes that each pedestrian behaves independently of each other. As Ashworth points out, this is not so. If two or more pedestrians are waiting to cross the road at the same time, those who have the longest MAH tend to cross the road with those who have shorter MAH. He used the results of a computer simulation model to describe how the increase in pedestrians decreases the mean delay for given traffic flows. The rate of decrease is positively related to the traffic flow and negatively to the number of pedestrians crossing. The estimated mean delay fell by 45% when the pedestrian flow was changed from zero to 500 per hour for 1500 v.p.l flows. Tanner (1951) also developed models incorporating the behaviour of groups of pedestrians. Neither however discussed the effect of pedestrians on the distribution of headways.

Thus, it has been shown how there are considerable grounds for expecting that the Adams' formulae or some modification of them should provide a relatively good description of the form of the relationship between pedestrian delay and the characteristics of the traffic flow when it is not free flowing.

Having said that, it is still germane, in a critical review of the models which have been developed for predicting pedestrian delay, to report a model which was not based on Adams' formula. In the data which was published by Crompton (1971) only statistics on the percentage of time delayed were given. As the number of observations was limited, only a simple additive model was tested in the reanalysis of this data (Hodgins, 1972). In fact, only the logarithm of the total flow was significant:

$$\%D = 58.5 \log Q - 113.5 \quad (3.14)$$

Where %D = Percentage of time delayed

Q = Traffic flow in vehicles per hour

Multiple Correlation = 0.81

Residual error = 5.9

Sample size = 36

While this specification gives a relatively good fit, its robustness still needs to be tested with a much larger sample, where its accuracy can be compared with that of the Adams specification. It still remains to be seen whether mean delay or percentage of time delayed has the greatest bearing on annoyance delay.

3.4 ATMOSPHERIC POLLUTION

The problem of developing an environmental index for air pollution are quite different from the case of noise or pedestrian delay. The fact that little progress has been made in this direction may be due to there being a large number of different pollutants emitted by vehicles, and that the degree to which they are emitted varies according to the type of the vehicle and the way in which it is driven (Sherwood and Bowers, 1970) thereby making it unwise to use one pollutant as an indicator of the general pollution, although CO is sometimes so used. The problem is further compounded by the fact that the pollutants may or may not be perceptible and they may or may not be injurious to health. Those which are perceptible may not in some cases be found to be unpleasant.

3.4.1 Air Pollution Models

The methods for formulating models for the prediction of the pollutants tend to be similar regardless of whether they are environmentally undesirable or not. Also there may be cases where measurement of an undesirable pollutant may be difficult and the measurements of another environmentally neutral pollutant may be used as a surrogate for it. Therefore, the existing knowledge on model development of the non-environmentally intrusive pollutants will be reviewed as well as that for intrusive ones.

A great number of chemical compounds are emitted from the exhausts of vehicles, but the most important ones are carbon monoxide, lead compounds, oxides of nitrogen and smoke (Urban Motorways Project Team, 1973). Road traffic also spreads dirt and dust. Carbon monoxide, which is emitted mainly by petrol engines, can be lethal in large quantities. There is some evidence that it may be harmful in the concentrations found on city pavements; for example the length of the time periods which policemen do on duty at one cross road in Vienna, is restricted because a number had been overcome by the effects of carbon monoxide poisoning (Ritter, 1964). Lead pollution from exhausts is caused by the addition of lead to petrol to increase its efficiency. It can be a health risk because of its tendency to accumulate in animal and vegetable tissue where exposure takes place over a period of time. Neither lead nor carbon monoxide are perceptible.

Smoke consists almost entirely of carbon particles emitted by diesel driven vehicles. It is not considered to be a health hazard (Sherwood and Bowers, 1970) but it may act as a nucleate in haze formation, (Buchan and Charlson, 1968) which may absorb other gaseous pollutants and cause bronchial trouble (Bowen, 1964). It is highly perceptible and probably the most objectionable pollutant, (Sherwood and Bowers, 1970). Nitrous oxides have little direct effect, but they tend under certain climatic conditions to react photo-chemically with other chemicals to cause smog and increased ozone levels. Aldehydes and hydrocarbons are less important emissions which are perceptible and sometimes cause discomfort. Dust and dirt dispersed by vehicles can effect the quality of the environment, particularly where the concentrations are high (e.g. Urban Motorways Project Team, 1973).

While a number of surveys have been made in Britain of the levels of concentration of these atmospheric pollutants which are caused by traffic, there have been few systematic measurements of the characteristics of the traffic flows at the same time as of the pollutants, which would enable the development of models for predicting the air pollution from the traffic flow. Those surveys which were systematic tended to include a large number of measurements taken at one site over a period of time. Colwill's (1973) study in Reading is an example of this kind. He regressed the observed values of carbon monoxide, nitric oxide, smoke and lead concentrate on the traffic flow,[1]. The accuracy of his models appeared to be fairly good; the correlations ranged from 0.73 to 0.92. However, his observations were taken within 5m of a set of traffic lights and were, therefore, not typical of urban roads. In a similar survey of carbon monoxide levels in Birmingham, Bayley and Dockerty (1972) were less specific about the relationship found between the dependent and independent variables.

Gilbert and Crompton (1970a and 1970b) included carbon monoxide in their series of simultaneous measurements of environmental variables and their determinants, but the results of their analysis were not available until they were reported by Wigan (1975). They found a multiple correlat-

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1. In the latter case the regression was only on the flow of petrol driven engines.

ion of approximately 0.8 between the observed CO and the independent variables. This was similar to that found (Hodgins, 1972) in the re-analysis of the data which they published (Crompton, 1971). Their prediction model was:

$$CO = 2.26 + 0.14R - 0.63A + Q/V(.03T + 2.37/W) \qquad (3.15)$$

Where R = ambient temperature in degrees centigrade

A = mean wind speed (m.p.h.)

Q = two-way traffic flow

V = mean speed in (m.p.h.)

T = traffic pattern of arrival index

W = road width in feet.

The reasons for including third order interaction elements, which add to its complexity, were not given. However, it did include some variables in the climatic conditions at the time of measurements, which are a necessary indicator of rate of dispersion. Though values for these variables would not be available for prediction purposes, they do add to the robustness of the model, and estimates of their mean values could be used in prediction.

The concentration on developing models for carbon monoxide implies that it may be taken as a surrogate for other variables. Apart from further research that may be needed to improve the model, e.g. by including an element on the composition of the traffic, it is also necessary to formulate a model for predicting the concentrations of smoke on the kerbside. The environmental index of air pollution from traffic also remains to be developed.

3.5 PEDESTRIAN RISK

It was found in the National Environmental Survey that danger to pedestrians was the factor which bothered the respondents most; (Sando and Batty, 1974) yet little research has been done on the development of models for predicting the number of accidents from the traffic variables for given flows of pedestrians. Research which has been carried out, has tended to concentrate on other determinants of accidents, e.g. the age, sex and exposure of vulnerable groups (Howarth, Routledge and Repetto-Wright, 1974); exposure and distance to zebra crossings (Jacobs and Wilson, 1967), and the installation of zebra crossings (Duff, 1968).

The only available model for predicting accidents from both pedestrian flow and traffic flow was developed by Bayliss (1967);[1]

$$N = 0.0012\, F_T F_P - 5.28 \qquad (3.16)$$

Where N = pedestrian accidents per annum

F_T = 24 hour traffic flow

F_P = 24 hour pedestrian flow

A characteristic which is unique to this model, amongst those reviewed, is that the environmental variable is partly dependent on the number of people exposed. However, the expectation of one person being involved in an accident may be estimated by rearranging the formula:

$$N_P = 10^{-5}\,(7.9Q - 1450) \qquad (3.17)$$

Where N_P = the probability of the pedestrian being involved in an accident

Q = the traffic flow in vehicles per hour.

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1. Quoted from Wigan (1975).

The model is irrespective of the length of road involved. The accuracy of the model was not given.

Pedestrian risk is a health matter, and we are therefore not directly concerned with it. We are however concerned with the subjective responses of the pedestrians. No research reports are available connecting risk with people's perception of it, or connecting their feelings of annoyance with risk to their perception of it.

3.6 VIBRATION

Little research has been done relating vibration to pedestrians responses or to the characteristic of road traffic. There are, therefore, no indices of vibration or prediction models for this environmental factor. The following is a brief outline of the subject.

Vibration from road traffic may travel through the ground or through the atmosphere, (Urban Motorways Project Team, 1973), Ground-borne vibration is caused by heavy vehicles passing over irregularities in road surfaces. Little is known about its transmission or attenuation, but it is a problem which ought not to arise on modern roads (Whiffen and Leonard, 1971).

Air-borne vibration or infra-sound, as it is sometimes called, is low frequency sound which is largely emitted by deisel engines. It attenuates and is absorbed at little more than half the rate of sound in the normal audible range.

3.7 VISUAL INTRUSION

Research commissioned for the Urban Motorways Project Team (1973) was based on the use of the solid angle subtended by motorways. Environmental indices which were developed from relatively large samples of interviews included the traffic flows and the solid angle subtended by the motorways, (Lassiere, 1974). The index built for situations on the existing road network did not include an element for the solid angle subtended by the road:

$$V_t = 3.42 + .16C - .0005Q - 0.013P \qquad (3.18)$$

Where V_t = visual satisfaction score, on a 1 to 7 scale.

C = context constant, which can take the values 1, 2 or 3 depending on the visual quality of the surrounding buildings.

Q = traffic flow in vehicles per hour.

P = percentage of heavy vehicles.

The equation is valid for flows between 300 and 4,500 v.p.h. and for percentages of heavy vehicles of up to 60%.

The methods used for eliciting the responses were not given. Neither is the accuracy which might be expected. However, the implication of the report is that the solid angle subtended by the traffic is not a necessary element in the model.

3.8 OVERALL AND RELATIVE INDICES

No research reports, known to the writer, either establish indices of the various environmental effects of road traffic, which are on a common ratio scale, or an overall index of environmental quality. A number of writers have submitted methods of weighting exposure levels for different activity contexts for different numbers of people, e.g. Lassieré, (1974), or Weiner and Deak, (1972). Where weightings have been suggested, they may have been based on the best available information, but the definitive research has still to be reported.

The results of the National Environmental Survey reported by Sando and Batty (1974), indicate, by the percentage of people "bothered" and "seriously bothered", the relative importance of the main environmental effects of traffic both indoor and outside. See Table 3.1.

	Percentage of respondents	
	Bothered at all	Seriously bothered
Overall traffic	64	21
Individual disturbances		
i. Pedestrian danger	69	27
ii. Noise at home	49	9
iii. Noise out	54	16
iv. Fumes at home	7	3
v. Fumes out	47	23
vi. Dust and dirt	36	15
vii. Vibration	27	8
viii. Parking	21	12
Any of these eight disturbances	88	
Any disturbance when outside the home (i. iii. and v. above)	82	
Any disturbance when in the home (ii. iv. vi. vii. viii above)	66	
Any noise or fumes (ii. v. above)	73	33

Table 3.1 Percentage of people "bothered" and "seriously bothered" with environmental effects of traffic (From Sando and Batty, 1974).

As may be seen pedestrian danger caused the greatest bother, this was followed by fumes outside and noise outside . Approximate linear relationships between the percentages and the logarithm of the traffic flows may be noted, for the various types and levels of disturbance for which they published graphs. In some survey results published by the Urban Motorways Project Team (1974) there was approximately linear relationship between the percentage of people annoyed and the distance from the motorway for the various environmental factors, though the relationship between the percentage of people annoyed with noise was also approximately linearly related to the dB(A).

Hills and Rees, (1976), found in their survey of spontaneously given impressions by pedestrians that 18.4% mentioned pedestrian delay and 12.8% mentioned danger. This was compared to 4.5% for noise and 2% for air pollution. All their interviews were on one street and they did not attempt to relate their responses to the traffic flows.

3.9 SUMMARY

In this review of the present state of knowledge on the prediction of the environmental effects of road traffic, it was found that there was little agreement on the definition of an index of noise annoyance. The L_{10} has become widely accepted in the U.K., but models for its prediction on the kerbside of streets with non-free flowing traffic were relatively inaccurate. The reanalysis of a limited number of fieldwork measurements made by Gilbert and Crompton indicated that the recalibration of models developed for free flowing traffic may provide the best results from the point of view of accuracy as well as construct validity. This however needed to be checked from a much larger sample. The difference between the existing noise indices could be largely defined in terms of the weight which is placed, in the index, on the variation in the index, on the variation in the sound levels. It is necessary to test whether the L_{10} could be improved upon as an index of noise.

In the case of pedestrian delay there are two environmental variables - the mean delay and the percentage of time delayed. While, in practice, these variables may be closely related, there is no evidence as to how an index of delay should be defined. Most of the research on the prediction of delay has concentrated on the development of Adams' theoretically based model for predicting delay caused by free flowing traffic. Dowell's limited work suggests that Adams' formulae are relevant to non-free flowing traffic. However, further research is needed to substantiate this and to determine the degree of accuracy which might be expected. It is also necessary to determine whether other traffic variables such as speed and composition have an effect on delay.

There is a problem in the prediction of annoyance from air pollution from road traffic in that there are a number of pollutants emitted by vehicles, and that their rate of emission varies differently according to the way the vehicle is driven, and the type of fuel that is used. Some pollutants are not perceptible, but are injurious to health. Carbon monoxide is sometimes regarded as an indicator of air pollution, but it is not perceptible. It has been submitted by some workers that smoke is probably the most offensive of the pollutants, but much more work requires to be done before an index can be defined or predicted.

No research reports were found connecting pedestrian risk with the perception of it, or connecting feelings of annoyance with risk with the perception of it. It has been shown that risk in crossing the road is one of the environmental factors which concerns people most about traffic. The one model which has been developed for predicting pedestrian accidents shows a linear relationship with the traffic flow.

No indices or prediction models for vibration have been developed. Air-borne vibration is emitted largely by devised engines and travels much further than noise. Little is known about the transmission and attenuation of ground-borne vibration.

An index of the visual intrusion of vehicles has been developed. It was found that satisfaction was linearly related to the traffic flow and the proportion of heavy vehicles. The relationship with the solid angle subtended by the traffic was tested but it was not included in the model.

The definitive research has still to be reported on the development of indices of the various environmental effects of traffic, which are on a common scale, or an overall index of environmental quality as affected by traffic. It was found from graphs published by Sando and Batty, and the Urban Motorways Project Team that the proportion of people annoyed or bothered tended to be linearly related to the logarithm of the independent variables.

CHAPTER 4: RESEARCH METHODOLOGY: ENVIRONMENTAL VARIABLES

4.1 INTRODUCTION

Environmental indices and environmental variables were defined in Chapter 2. The latter were objective measures of aspects of the environment and the former were specified functions of environmental variables and/or traffic variables which were believed to be proportionate to subjective response. Environmental indices may be expressed as a function of traffic variables, for example, the index of visual intrusion reported by Lassiere (equation 3.17). However, there are two reasons why attempts should be made to define the indices in terms of environmental variables, and to develop models for predicting the variables. The first is that the use of variables affords the opportunity of testing theoretically based hypotheses on the relationship between subjective responses and the environmental variables. Similarly, theories on the additivity of responses to determine the overall response could be tested. If such theories could be established the index models would be more robust. The second reason is that many of the existing indices which are used in planning, are expressed in terms of environmental variables. To ignore the indices would not only be flying in the teeth of planning practice, but would also be running the risk of submitting inferior models.

When it came to fieldwork design a problem arose. It was not feasible to collect at the same time, the data necessary for the development both of the models for predicting the physical environmental variables, and the responses of the pedestrians to the environment. This was partly due to the risk that the team of five observers and their equipment for measuring the physical environment would affect the responses of the pedestrians and partly that the interviewing might also interfere with the physical measurements. There was the further probability that at a number of sites the pavement would become obstructed, which could add to the inaccuracies of the data.

This left no alternative but to conduct two surveys, the first to make fieldwork measurements which would enable the development of models for predicting the physical variables and the second for predicting the pedestrians responses. In the second survey either the environmental variables or the traffic variables have to be measured. It was decided to measure the latter for four reasons. Firstly, it was not feasible to measure some of the environmental variables at the same time as the pedestrians' responses, (e.g. pedestrian risk, and vibration). Secondly, the measurement of environmental variables alone would preclude the development of indices based on traffic variables. Thirdly, there was still the risk that the equipment and observers would distract the respondent's attention and bias his responses. Lastly, the initial result of analysing the data from the first survey showed that relatively good estimates could be made of the environmental variables which were measured.

Within these practical constraints, this chapter outlines the methodology adopted for developing models for the prediction of the environmental variables. The methodology adopted for predicting the pedestrian responses is contained in Chapter 5.

4.2 THE ENVIRONMENTAL VARIABLES

4.2.1 Traffic Noise

As has been seen in Chapter 3, the characteristics of the variables which constitute the existing environmental indices vary considerably. In the case of noise, one of the main problems is that of converting a complex series of sounds over a period of time into a single index. The existing indices were shown to consist, in varying forms, of an element representing the central tendency of the sound distribution and one representing the dispersion (although the latter may be given a zero weighting). It was, therefore, decided to record the sound in "A" weighted form, in such a way that the indices of central tendency and dispersion, as well as the noise indices mentioned above, could be ascertained. However, because of the extent to which the L_{10} has become established as the index of traffic noise in the U.K., the emphasis in the analysis was put on formulating a model for its prediction.

4.2.2 Pedestrian Delay

Observations of pedestrians delay depend on how the delay is defined and measured. In this study we are concerned with the quality of the environment at specific points on the kerbside, and therefore a very specific definition of delay has been adopted. This is the time in seconds in which one or more trained observers decide that it would be possible to cross to the far side of the road, at a normal pace, without pausing. From this the mean delay and the percentage of time delayed by a continuous stream of pedestrians arriving at the kerbside could be calculated, assuming the pedestrians judgements to be similar to those of the observer.

An alternative to this method is to observe the delay caused to pedestrians. Apart from the obvious constraint which this method imposes, that of only being able to observe delay where there are pedestrians crossing the road, this method entails a different concept of delay. In the case of noise and the other environmental factors, the variables and indices have been defined and measured without respect to pedestrian exposure. The observation of the delay which pedestrians are exposed to while they are waiting to cross excludes the time that some pedestrians take in diverting their journey in order to use crossing facilities, and the loss which they experience if they decide not to cross the road because of the traffic. It records no delay where pedestrians can walk along the pavement while looking for the opportunity to cross. The point where this type of pedestrian behaviour might be considered is in the application of prediction models for delay to pedestrian trip desire lines. The observation of the modification of pedestrians' behaviour due to traffic flows may be considered as an indication of environmental cost to the pedestrian, but as stated in Chapter 3, there are many disadvantages in this approach.

Once pedestrian delay has been defined and measured in these terms the problem of choosing the index of delay might appear straight forward, as there are just two possible variables; the mean delay and the percentage of time delayed. Both could be measured and it could be left to the analysis of the subjective data to determine which, if not both, should be adapted to form the index of delay. However, it may be found that the relevant index would be a transformation of one of these variables which would be more appropriately predicted directly from the traffic variables.

4.2.3 Atmospheric Pollution

It was not practicable to measure the concentrations of all the air pollutions mentioned in Chapter 3 because of the cost of the equipment and the difficulties of transporting to a large number of sites and setting it up each time. It was decided to measure two pollutants, partly because, as stated earlier, it would be unwise to rely on one pollutant as an indicator of general pollution and partly because it would be desirable to test whether the error in one model was due to variation in dispersion or measurement and specification errors. Smoke was chosen because of its widely noted unpleasantness (e.g. Sherwood and Bowers, 1970). Carbon monoxide was chosen as the second pollutant, partly because of its ease of measurement, and partly because of two factors which would distinguish its readings from smoke. Firstly, it is a gas unlike smoke which is a particulate. And secondly, it is produced almost entirely from the petrol driven engines, smoke being produced mainly by diesels. It was also possible that the CO might be found to act as a surrogate for other perceptible and annoying pollutants.

4.2.4 Other Variables

For the remaining three environmental factors, pedestrian risk, vibration and visual intrusion, traffic variables rather than environmental variables will be used to form the environmental indices. This is largely because of the difficulty of measuring and predicting the variables associated with these environmental factors. In the case of risk, the development of a model for the prediction of pedestrian fatalities, serious injuries and slight injuries would need a separate survey requiring data over a long period of time. Rather than conduct such a survey it was decided to concentrate attention on other aspects of the problem. This was partly because the probability of accidents is a matter of public health and the relationship between risk in the objective sense and people's perception of it is not yet known. Secondly, the existing model for predicting risk shows that where pedestrian flows are constant, risk is proportionate to traffic flow, (Bayliss, 1967). The relationship between pedestrian risk and delay has been commented on (Burt, 1972 and Ganguli, 1974). It may be found that the index of pedestrian delay will be closely related to annoyance with pedestrian risk. There were technical problems of measuring ground and air borne vibrations. The use of noise indices as surrogates will be tested. Traffic variables were relied on for the prediction of annoyance with visual intrusion, as in equation 3.18. This was partly because the consultants who were employed by the Urban Motorways Project Team spent considerable effort defining variables in terms of solid angles subtended, without being able to relate these variables convincingly to subjective response, and partly because the visual intrusion of traffic was not found to be a major determinant of overall subjective response to the environmental effects of traffic.

4.3 RESEARCH DESIGN

The most appropriate way of empirically testing hypothetical relationships between the environmental variables and the characteristics of the traffic flow was to take simultaneous field work measurements of all the relevant variables and to assess the results of regression analyses.[1] The relevant independent variables cover a number of aspects of the built form and climatic conditions as well as various characteristics of the traffic flows which were believed could be relevant. The specification of many of these variables has been discussed in the literature review. Other variables which are hypothesised to be determinants of noise, pedestrian delay and air pollution, will be discussed in the following sections. The sample and fieldwork design are discussed in Chapter 6.

The criteria which were used in assessing alternative regression models were similar to those used in reviewing the existing models for predicting the environmental variables. These were essentially validity and reliability. The validity of the models depends on the specification of the elements. This includes whether the correct variables are used and whether they are transformed in the correct way. In many cases the

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1. An outline of the computer procedures used in the study may be found in Appendix 1.

specification of the independent variables could be ascertained deductively. In other cases they were found by induction, where the construct validity of elements making a significant contribution to the statistical explanation of the dependent variables could be tested.

The concept of robustness includes aspects of validity and reliability. It refers to the accuracy of predictions in circumstances other than those in which the data, on which the model was based, was collected. Thus it depends in part on the construct validity of the specification, the size of the sample and the accuracy of the data collected. Simplicity contributes to the robustness of models. It may be that the specifications which give the best fit are not necessarily the best according to this criterion. Another factor which contributes to the robustness of models is the validity of using regression analysis. One of the requirements for using regression analysis is that the residual errors should be normally distributed and that the variance of these distributions should be constant for all values of the dependent variable. Regression runs which did not pass this test were rejected, though in some instances they gave indications of what a more correct specification might be.

The accuracy of the models was measured by the residual errors and multiple correlations. It was assessed by standard Student's t and analysis of variance tests. Elements were excluded at the standard 5% level, unless there was some reason for not doing so. In the chapters on the analysis, the t statistics of each of the elements is given, so that the reader may note the significance of the regression coefficients. A stepwise regression procedure was used in a number of instances to assess the result of the inductive approach. This routine is described in Appendix 1 .

Observations, (i.e. sets of simultaneously taken measurements) which had a residual error more than three times the standard error, were omitted from the data set, when the specification of the model appeared to be correct. The probability of such a residual happening by chance would be less than 1 in 1,000 times. Attempts were made to see if these observations contained any measurement errors or if they provided any useful information on the circumstances which caused large residuals. These observations were omitted without measurements errors being found; the results of the regression analyses both before and after the omission are given. (c.f. Draper and Smith, 1966 and Anscombe, 1960).

Judgements have to be made in determining which specification to recommend as well as on which data base it should be used. Upshaw's (1971) comment in a similar circumstance is accepted "In the final analysis, however, the decision is likely to be based on ad hoc evidence, which the reader may or may not credit in the same way as the investigator". For these reasons, alternative models which the reader may deem more appropriate than the one recommended are reported where possible.

4.4. TRAFFIC NOISE

The main variables which contribute to the prediction of traffic noise on the kerbside have been listed in the review of existing prediction models. Where possible these, and others gleaned from a literature review of prediction research, were included in the fieldwork measurements.

A number of writers have listed the variables which contribute to the prediction of sound emission within the context of noise control, (e.g. Rucher and Gluck, 1965, R.R.L. 1970 and Priede, 1971). While these lists overlapped considerably, they did provide another source from which variables for measurement could be selected. The latter lists also provided, in some cases, indications of the form of the relationship between the variables and the noise. Apart from the criticisms expressed in Chapter 3, three main ways in which the models could be improved are postulated here.

4.4.2 Traffic Composition

The first postulate is that the specification of the composition of the traffic could be improved by a more detailed classification of vehicle types. Vulkan (1970) show how in a sample of 1400 vehicles, the mean noise level of cars, light commercial and heavy commercial vehicles was 71, 74 and 78 dB(A). It was calculated from the statistics which he published that there was a significant difference between these means. An extra category was therefore defined for light commercial vehicles up to a load carrying weight of 35 cwts. Buses and coaches were also counted separately from heavy commercial vehicles, and motor cycles separately from cars.

4.4.3 Width of Carriageway and Parking

Delany (1972) has shown that sound from traffic can be well approximated by a linear function of the logarithm of the distance to the traffic stream. The rate of attenuation depends partly on the type of ground that the sound travels over. Therefore, given that the specification of the relationship is correct, the regression coefficient would still need to be calibrated. There are two problems in determining the distance to the traffic streams from the kerbside. Firstly, the existence of parked vehicles close to the observation point would have the effect of moving the traffic flow away from the kerbside if they were on the near-side, and towards the kerb if they were on the far side. Secondly, what may be called the centre of gravity of the traffic flow is affected where there are two-way flows, by the proportion of the traffic which is travelling in each direction.

Apart from affecting the centre of gravity of the traffic flow, parked vehicles could be expected to affect the passage of sound from the traffic to the kerbside, by either acting as a barrier or by reflection. Formulating the relationship between the precise positions of the parked vehicles and the sound on the kerbside would require a more complicated specification than could be tested empirically from fieldwork measurements. It was, therefore, decided to represent the existence of parked vehicles within 20 metres of a line across the carriageway through the observation point, by a series of four dummy variables.[1] The dummy variables demonstrate whether there is parking on the nearside of the road to the observation point or the far side, and also whether the parking is to the left or the right of the observation point. In figure 4.1 two of the dummy variables equal 1 and the other two 0.

A number of different specifications of these parking variables, the distance to the centre of the road and the proportion of the traffic in the near and far side flows could be postulated. The simplest way would be to treat them as three separate elements in the regression set. (Another method would be to combine them into one index). A crude index of parking could be achieved by combining the four dummy variables:

$$\text{Index of parking (Pk)} = P_{NL} + P_{NR} - P_{FL} - P_{FR} \qquad (4.1)$$

The assumption in this index is that the sound is increased or decreased

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1. The term "dummy variable" is used throughout the text to mean discontinuous dichotomous variables with values of 0 or 1. In many instances independent variables were measured on nominal or ordinal scales. These were converted to series of dummy variables, to which the methods of analysis being used were applicable (Ghiselli, 1964).

by equal amounts by parking in the near and far quadrants respectively.

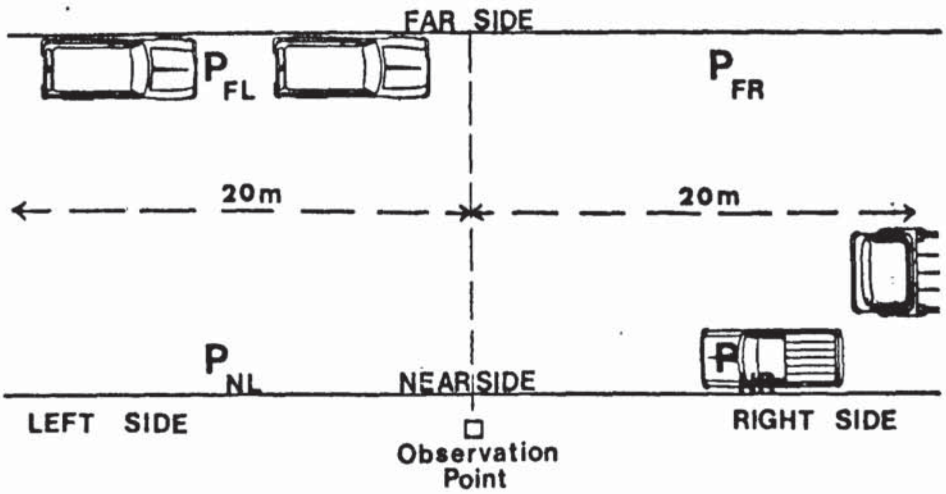

Figure 4.1: Definition of parking dummy variables (P). Subscripts N and F refer to the near and far sides, and L and R to left and right sides respectively.

Another method of specifying these variables would be to combine them into one index of the distance from the kerb to the centre of gravity of the traffic flows, as follows:

$$D_{cg} = P_{NL} + P_{NR} + (W - P)(Q_n + Q_f)/4Q \qquad (4.2)$$

Where D_{cg} = Distance to centre of gravity of traffic flow in metres.

W = Width of carriageway in metres.

EP = The sum of the four parking dummy variables (P_{NL}, P_{NR}, P_{FL} and P_{FR}).

Q = Traffic flow (subscripts N and F refer to the near side and far side flows respectively, e.g. Q = Q_N and Q_F).

The assumption in this formula is that the existence of parked vehicles within 20 m of a line across the road through the observation point would cause the traffic flow to be a metre closer to the centre of the road.

4.4.4 Propogation of noise

The propogation of traffic noise is affected by climatic conditions and the surrounding physical design. Of the climatic conditions, by far the most important is the speed and direction of the wind. Temperature and humidity have some effect, but it is too slight to have a significant effect on kerbside noise levels (R.R.L. 1970).

Buildings adjacent to the road may reflect sound from the traffic back to the kerbside. This may have a cumulative effect if there are buildings also on the far side of the road (Dickinson, 1971). The extent to which the sound is reflected depends on the distance of the buildings from the kerbside, and in the case of the buildings on the opposite side of the road, on the width of the carriageway. Reflection also depends on the size and form of the buildings and the accoustically absorbent quality of their exterior. As in the case of parked vehicles, it would be impracticable to measure and specify, and to test the significance, of all the relevant variables in a field work study. It was therefore decided, in the first instance, to measure the distance of buildings from the kerb, up to a maximum of 100 metres, and to take a crude measure of their height in storeys, for each side of the road. Their distance from the kerbside affects the degree to which the noise is reflected both through the inverse law of sound attenuation and the angle subtended by the buildings. A crude index of these variables would, therefore, be formulated by dividing the number of storeys by the logarithm of the distance of the buildings to the observation point.

4.4.5 Other Independent Variables

A number of other built form and traffic condition variables which have been postulated by other writers to affect traffic noise to some degree need to be measured so that this significance could be determined. These include the type and quality of the road surface and whether it is wet, (R.R.L. 1970). There is conflicting evidence on the significance of the effect of the gradient of the road, (Johnson and Saunders, 1968 and Blitz, 1974). Whether the road is a one-way street and whether the traffic becomes congested are further variables which should be tested. Gilbert and Crompton's (see Crompton, 1971) index of the pattern of arrival also deserves measurement. While the results would be biased by taking measurements where there was a noticeable noise coming from some other source, it might still be found that the land use of the area adjacent to the observation point would affect the measurements.

4.5 PEDESTRIAN DELAY

Much of the methodology of predicting pedestrian delay has already been discussed in the context of reviewing the application of Adams' formula. In testing the reliability of the models in non-free flowing traffic, the observed mean delay will be compared with the estimated delay from Adams' formula, (see equation 3.11), and the observed percentage of time delayed with the estimate using equation 3.12. It may be found that the observed delay where the pattern of arrival of traffic is non-random may be significantly different from the estimated delays where it is assumed that the pattern of arrival is random. It may be inferred from the diagrams in Dowell's (1967) paper, that it may be possible to develop a model for the estimated observed delay from non-random flows by either calibrating the minimum acceptance time in Adams' formula to give the best fit, or that the coefficient for the Adams' specification or the constant in the regression analysis are greater than unpublished research. Goldschmidt (1976) also found that mean delay increased accordingly as vehicles become grouped, but that the percentage of people delayed decreased in the same circumstances. It may be found in the regression analysis that the proportion of heavy vehicles and the speed of the traffic flow would make a significant contribution to the statistical explanation of the unexplained variance of the dependent variables.

There are statistical reasons why it is inappropriate to regress the percentage of time delayed on the independent variables. For certain values of the independent variables the predicted percentage could be outside the range of possible values, from 0 - 100. One way round this problem is to take the logistic transformation[1] of the percentage of time delayed as the dependent variable. This may be regressed on a corresponding transformation of Adams' formula:

$$\log \frac{\%D}{100 - \%D} = \log \frac{100(1 - e^{-Qt})}{100 - 100(1-e^{-Qt})} \tag{4.3}$$

$$= \log (e^{Qt} - 1)$$

4.6 ATMOSPHERIC POLLUTION

The methodological problems which may arise in developing models for predicting the concentrations of air pollutants are more inaccurate than for the other environmental variables. As has been seen in Chapter 3 the proportion of the variance of air pollution variables which has been satisfactorily explained by independent variables in existing empirical research has been much less than in the case of noise and pedestrian delay. The reasons are partly in the considerable variation in the emission of pollutants by vehicles because of the variation in the way which they are driven (Sherwood and Bowers, 1970) and partly because of the relative

1. This transformation is described in greater detail on pages 77 and 78.

difficulty of modelling the micro climate which affects the dispersion of the pollutants.

The principle determinant of the dispersion of the gases and particulates from the exhausts of vehicles is the movement of air; the effects of the humidity and temperature are secondary. The movement of the air may be caused by the balance from the speed of the vehicles or by wind. The direction and speed of the wind were, therefore, measured. The speed of the vehicles and all of the other relevant independent variables measured for the prediction of noise and delay were tested in the regression analysis.

4.7 SOURCES OF ERROR

The error in the prediction models falls largely into two categories, that which springs from the methodology, as has been discussed in this chapter, and that which is caused by random sampling and fieldwork design, the subject of Chapter 6. There is, however, one aspect of the sampling design which required a major methodological decision. This involves the concept of what is "typical" of the environmental conditions on the kerbside. There are many variables which affect the environment which are typical of urban streets, but which are not typical to a particular point on any one street. These include such things as building works, road works or refuse collection lorries. These variables could not be included in prediction models because of the difficulty. They were, therefore, controlled for by not taking observations where there was reason to expect that they would bias the results.

There is another category of variables affecting the environment which are related to traffic and are predictable. These include traffic on other roads, bus stops and pedestrian crossings. Because their effects are largely specific to particular points on the streets and typical of all parts of streets, it was decided not to take observations within 25 metres of a node defined on the Hammersmith Transportation Study road network, a bus stop on the near side of the road, or a pedestrian crossing.

Even though the environmental conditions on the kerbside which were measured were selected as being representative in this way, it was postulated that some of the residual error particularly in the model could be caused by factors peculiar to the site. For example, built form variables which might not be measured, such as the reflective quality of adjacent buildings, could uniquely affect the noise measured, also the location and phasing of traffic lights could uniquely affect the traffic flows and in turn the physical environmental variables. In an attempt to isolate the part of the residual error unique to the site, a second set of observations was taken at a number of the sites. The residual errors from these observations could then be compared with those of the first set and the correlation between them would give a measure of the error which was caused by the independent variables which are constant for both sets of measurements.

4.8 SUMMARY

It has been shown in this chapter that it was necessary to conduct the research in two stages; the first consisting of the development of models for predicting the physical environmental variables, and the second, of the development of models for predicting pedestrian annoyance. The latter is discussed in the following chapter. In the case of the physical environmental variables a decision was made, for a number of reasons, to limit the measurements to noise, pedestrian delay and air pollution.

The methods of developing the models by regression of the measurements of environmental variables on simultaneously measured traffic and built form variables were discussed, as were the criteria which should be used in evaluating alternative models. However it was noted that in the final analysis the model which should be chosen is to some extent, a matter of judgement, and therefore, where possible, alternative models are presented.

Because of its status, as an index of traffic noise in current planning practice in Britain, it was decided to concentrate on the prediction of the L_{10}. A number of traffic and built form variables were added to the list of independent variables discussed in the literature review. These included a sub division of commercial vehicles into heavy and light vehicles, and indices of parking, of the "centre of gravity" of the traffic flow, and of the sound reflected from adjacent buildings.

It was decided that pedestrian delay would be measured by an observer recording when he deemed it possible to cross the road. From this the mean delay, and the percentage of time delayed, could be calculated. While it seemed clear that the bases of the prediction models would be Adams' formulae, it was also postulated that other variables such as the traffic flow and composition could have an effect on pedestrian delay.

In the case of air pollution, smoke and carbon monoxide were chosen as the dependent variables. No additional independent variables were postulated as being determinants of these two variables.

CHAPTER 5: THE METHODOLOGY OF RESPONSE MEASUREMENT

5.1 INTRODUCTION

The concept of pedestrians' annoyance with the environmental effects of traffic has been defined in chapter 2. It is taken to mean the negative subjective responses of the pedestrians to traffic induced or related environmental effects at the time of interviewing. A number of reasons have been discussed as to why it is desirable to measure such responses on a ratio scale. They are essentially that systematic environmental evaluation requires that individuals' responses to the separate environmental effects of traffic be predicted and aggregated to form their overall response; and that these overall responses can then be aggregated for all the individuals affected. At the moment, the relationship between people's annoyances and the physical environmental variables is not known. Responses to a given change in an environmental variable at one level cannot, at the moment, be compared with the same change at another level of that variable, let alone with a given change in another environmental variable.

No standard method has been developed for measuring the subjective responses to the environmental effects of traffic. Even in the more general field of measuring attitudes to the environment there are a great number of competing methods which have been developed (Cane, 1973). Many of the existing attitude scales have been developed with the use of sophisticated measuring techniques, and are, therefore, open to criticism by those who say that the researcher is imposing his own rules of inference on the aggregation of unique measures of the subjective properties of environmental states. "Measurement by fiat" was the epitaph ascribed by Cicourel (1964) to all such scales which are alien to the "structure of social reality". One of the prerequisites for avoiding this type of criticism is to use a means of encoding attitudes which are of everyday familiarity to respondents. Another important prerequisite is that the attitude scale should be based on a sound theoretical foundation. Many of the existing indices of subjective response have little theoretical basis.

It is therefore necessary, in determining the methodological implications of developing a model for predicting pedestrians' responses, to begin from scratch and to review critically, albeit briefly, the theoretical assumptions which previous writers have made about the form of the relationships between subjective responses and physical variables. Apart from indices of subjective responses which have been developed arbitrarily or empirically, psychophysical theories have been used as the basis for prediction. These refer to sensations or perceptions, and stimuli, and not to the relationships between stimuli and the effects which they engender, which is the interest of this research. On the other hand however, consistent results have been obtained in developing psychological scales using the methodology of psychophysics. A problem of some importance in this context is that there are two competing theories of psychophysics and two consequential schools of thought on how subjective responses should be measured. It is therefore necessary to make a critical analysis of the evidence which has been submitted in favour of each school, before deciding on which method of measurement should be adopted. But first it is helpful to review the competing laws of psychophysics, so that their methodological implications may be understood in the context of the measurement of people's annoyance.

5.2 THE STEVENS/FECHNER CONTROVERSY

In 1850, Fechner developed his famous law, which was based on the assumption that each time a just-noticeable difference is added to a stimulus, the sensation increases by jumps of a constant size (Stevens, 1972). This assumption, together with Weber's law, that just noticeable differences grow in direct proportion to the size of the stimulus, led him to the supposition that sensation was linearly related to the logarithm of the stimulus (Fechner, 1966):

$$R = C \log (S) \tag{5.1}$$

Where R and S represent response and stimulus respectively, and C is a constant depending on the units in which the response is measured, and the sensory mode.

The other "law" of psychophysics, which has tended to supercede that of Fechner's, was formulated by S.S. Stevens. Stevens made a major contribution to the theory of measurement of sensation, and, it is submitted, of attitudes. He observed in a large number of experiments, that equal stimulus ratios produce equal subjective ratios, i.e. that the logarithm of the response was linearly related to the logarithm of the stimulus. This relationship has come to be called the "Power Law of Psychophysics", because, according to it, response is linearly related to the stimulus raised to the power of some constant:[1]

$$R = CS^{\alpha} \tag{5.2}$$

Where C is a constant depending on the units in which the measurements are made, and alpha is a constant which varies according to the type of stimulus.

Stevens (1961) later found that the relationship only held true over an

1. Stevens discussed his "Power Law of Psychophysics" in greater depth in later papers, but the first clear formulation of it was in an abstract in Science (Stevens, 1953).

effective threshold of the stimulus, values below this being not perceptible. Thus his law in its complete form should be expressed:

$$R = C(S - T)^{\alpha} \qquad (5.3)$$

Where T is the threshold value

Psychologists have used both of these theories of sensory psychophysics as the bases of hypotheses on the relationship between attitudes and stimuli: Stevens (1972) has shown how both these theories had been postulated by mathematicians in the eighteenth century to explain the relationship between money and the subjective value which people place on it. The curve describing the relationship between utiles[1] and money may be similar under both theories in some circumstances, which may explain why they have coexisted for so long.

Thurstone assumed that the perception of a particular stimulus on any given presentation is distorted somewhat by random and independent factors (Upshaw, 1971). It follows that if a stimulus is presented an infinite number of times the responses will be normally distributed about the best estimate of the response. Stevens has shown how what he believed to be the mistaken theory of Fechner was used by Thurstone in developing his poikilitic (confusion) scales. We have seen how Fechner assumed that just noticeable differences (i.e. measures of sensitivity) could be regarded as measures of sensation. Thurstone, similarly, assumed that the dispersion of his, correctly conceived, normal distribution of the respondents confusion could be regarded as a measure of attitude. From this he proceeded to develop the "Law of Comparative Judgement",

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1. Units of utility.

(Thurstone, 1927). This depended on the following relationship between the distance between responses "on a psychological continuum corresponding to two stimuli and the variabilities of the subjective impressions produced by the stimuli":

$$R_1 - R_2 = Z_{12} \sqrt{\sigma_1^2 + \sigma_2^2 - 2\, r\, \sigma_1 \sigma_2} \qquad (5.4)$$

Where R_1 and R_2 are the means of the distributions of the responses produced by the two stimuli.

σ_1^2 and σ_2^2 are the variances of these distributions.

Z is the normal equivalent deviate corresponding to the proportion of times one stimulus is judged to rank higher than the other.

r is the correlation between the judgement for the two stimuli.

Z_{12} is, of course, the only empirically determinable element in this equation and in order to solve it, it is necessary to make a number of simplifying assumptions. Thurstone lists a number of "cases" where different assumptions are made. The most commonly used is "Case V" where he assumed that the variance of the responses to different stimuli were of equal distance on the psychological continuum. This is in theory the same type of mistake that Fechner made that all just noticeable differences (jnd) are subjectively equal. The units which describe the psychological distance between the responses to stimulus (1) and stimulus (2) are not the same as those which describe the difference caused by stimulus (2) and stimulus (3) because the sensitivity of the responses is related to the magnitude of the stimulus.

Torgerson (1958), amongst others, developed Thurstone's methods to cover cases where the variance of people's responses was found to be insufficient to evoke confusion when stimuli were presented from a relative long continuum. The gist of his idea was "that when an observer sorts stimuli into categories he will exhibit errors and confusions;

and, from assumptions designed to relate these confusions to dispersions on the underlying psychological continuum, distances are established along the subjective scale", (Stevens, 1961). He called this the "Law of Categorical Judgements", and it is, of course, subject to the same criticisms as the "Law of Comparative Judgement".

Stevens, (1968 and 1972) has reported how magnitude estimation has "been used to scale such variables as strength of expressed attitude, pleasantness of musical selections, seriousness of crimes, and other variables for which the stimulus can be measured (even if) only on a non-metric or nominal scale". Magnitude estimation is one of the means by which his subjects were required to directly encode their responses in the experiments which led to his conclusions. They were simply presented with a stimulus, asked to ascribe any number to it which seemed appropriate, and then to assign successive numbers to further stimuli in such a way as reflected their subjective impression compared to the first stimulus and its number. Another method of directly scaling subjective responses which is frequently used is ratio estimation. This involves observers stating their estimated ratio of response to stimuli in comparison to a prior stimulus.

Most of the early experiments using ratio or magnitude estimation of subjective response were designed to determine the relationship between such direct methods of scaling and the indirect methods of the Thurstonean style. In a wide range of studies it was found almost without exception that the indirect scale was a logarithmic function of the direct scale. Some minor exceptions have been attributed to the range of the stimuli presented to the subject being considerably outside the range of normal experience, (Engen and McBurney, 1964).

In one of the earliest experiments, Indow (1961) presented pictures and descriptions of wristwatches to 127 university students and asked them to say which of each pair of watches they preferred, and also to encode magnitude estimations of their desirability by marking positions on 8 cm lines. "The subjects, in effect, matched length of line to subjective value, a kind of cross-modality procedure. By comparing the ratio scale determined with the aid of the 8 cm line to the Thurstonian scale (case v) derived from the "noise" or confusions in the pair of comparisons, Indow was able to demonstrate an approximate logarithmic relation between the two kinds of scales." (Stevens, 1968).

Other researchers produced similar results which were based on widely different subject matters. These included occupational prestige (Perloe, 1963 and Kunnapas and Wikstrom, 1963), the seriousness of offences and delinquency, (Sellin and Wolfgang, 1964), and the aesthetic judgement of musical excerpts, (Kohl, 1965), but pride of place for research on this issue goes to Ekman and his collaborators. First Ekman established that variation in subjective response measured in psychological units is linearly related to psychological magnitude measured in the same units, (Ekman, 1956 and 1959). In a further series of experiments they demonstrated the invariance of the logarithmic relationship between the direct and indirect scales, using subject matters as diverse as the aesthetic values of handwriting samples and drawings of trees, (Ekman and Kunnapas, 1960, 1962A and 1962B), the political importance of Swedish kings (Ekman and Kunnapas, 1963a), the seriousness of offences (Ekman, 1962) and the masculinity of adjectives (Ekman and Kunnapas, 1963b).

Stevens (1968) showed how Thurstone's poikiltic scale is necessarily a logarithmic function of magnitude estimation scales, because it is based on the assumption that just noticeable differences are of constant size instead of being proportional to the magnitude of the stimulus. The results of this can be seen algebraically by recourse to equations 5.1 and 5.2:

$$R_p = C \log (S) \tag{5.1}$$

$$R_m = CS^{\alpha} \tag{5.2}$$

$$\therefore \log R_m = \alpha \log S + C$$

$$R_p = C \log R_m + C \tag{5.5}$$

Where R_p is the response on a poikilitic scale and R_m on a magnitude scale. The constants vary in the equations.

Stevens (1972) also verified this relationship empirically. He regarded its corresponding ubiquity in the experiments quoted above, coupled with what he called "Ekman's law", as a test of the validity of using magnitude estimation where the stimulus is not on a ratio scale and where subjective responses rather than sensation are being encoded.

Stevens (1957), showed that when subjects are asked to ascribe their responses to physical stimuli to prescribed equal-appearing categories such as very small, small, medium, large or very large, the scale obtained was somewhere between the scales obtained by magnitude estimation and by counting just noticeable differences, (see Figure 5.1). This occurred when the stimuli was on a prothetic scale.[1] When the stimuli are on a metathetic scale, the category scale is usually parallel to the magnitude estimation scale. Category scales are always some kind of compromise between the two other scales, depending on the methods used. The larger the number of categories used the closer the category scale is to the direct measurement scale. The fact that category scales

1. Prothetic scales are quantitive. Metathetic scales refer to qualitive states (e.g. the amount of one colour mixed with another). For further definitions see Stevens (1959).

in attitude measurement, such as developed by Torgerson, (1958), tend to be between magnitude estimation scales and poikilitic scales, is further evidence that the methodology of psychophysics is relevant to the measurement of subjective responses.

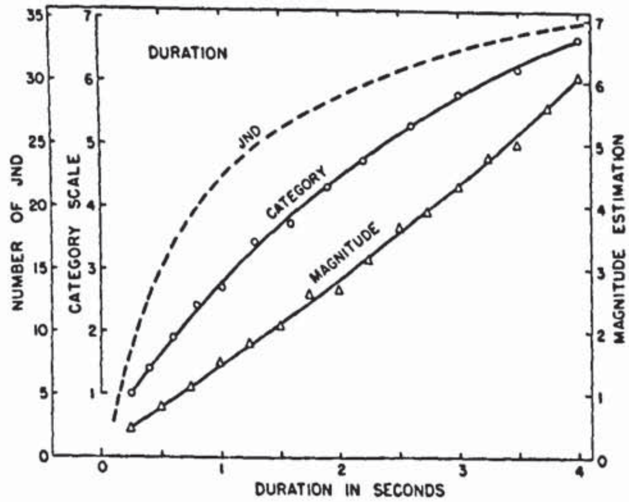

Figure 5.1: A typical example, in linear coordinates of the relationship between poikilitic scales, category scales and magnitude scales (From Stevens, 1957).

From the above arguments, it is concluded that not only is it valid to assume that direct measurements, such as by magnitude or ratio estimation, are linearly related to response, but also that is is valid to use magnitude or ratio estimation where subjective responses are being measured, even where the stimulus cannot be measured on a ratio scale. In a similar context, that of aircraft noise, Stevens (1970) himself suggested that people's subjective responses to noise was similar to their perception of its loudness, which he had shown to be linearly related to the value of the sound pressure raised to the power of 0.6. This can be shown to be the same as the generally accepted statement that addition of 10 dB(A) being equivalent to doubling the loudness, though the writer does not know of any reference to the equivalence of these statements, (the proof is given in Appendix 1). However, it does give added weight to the acceptance of the Power Law. The graphical expression of a power law relationship where the exponent is less than unity would show that, in the case of annoyance with noise, the disutility would increase at an ever decreasing rate as in Figure 5.2a. Or expressed in economic terms, the marginal disutility would decrease at an every decreasing rate.

However, Hart, (1973) in a discussion on aircraft noise, speculated that it is quietness which should be treated as a good. Therefore, given that its utility would increase at an every decreasing rate, the disutility of the noise would increase at an ever increasing rate, as in Figure 5.2b. This raises the question as to what the level of noise would be when there is no utility. In Fig. 5.2a it is simply at that point where the person becomes annoyed with the noise. However, in Fig. 5.2b it is when the sound pressure is at infinity, which is much less plausible conceptually. Should we conceive of utility when there is no noise (as distinct from sound) as being at the maximum for that person? If so it could be argued that people, having different responses to each other, would have different utilities from the quietness when there was no noise.

It may be noted that the shape of the curve in Fig. 5.2b, defined by a maximum utility minus any noise value to the power of an exponent less than one, is different mathematically from a disutility defined by noise to the power of an exponent greater than one. If it could be described by an exponent greater than one it would not be compatible with the utility of quietness having a power law relationship with any sound variable. All indices of noise are, in fact, the same as for sound in that they increase rather than decrease with disutility.

A third hypothesis is submitted here which has some of the characteristics of both Figs. 5.2a and 5.2b. It is that there is a limited range to any one person's annoyance and that annoyance approximates to zero at infinitely low values of the environmental index. It then increases at an ever increasing rate, until the annoyance is half way between zero and the maximum when it increases at an ever decreasing rate, approximating to maximum annoyance of infinitely high values of the environmental index. A further reason for testing this hypothesis is that it assumes a symetrical relationship between the response and the environmental variable, which entails that the progress along the psychological continuum of responses is by a process of substitution rather than addition, that is by a metathetic rather than a prothetic process (Stevens, 1959). Testing this hypothesis determines whether the environmental variable is on a quantitive or qualitive scale. Whether or not the relationship between responses and a metathetic scale should be described by a cumulative normal distribution curve as in Figure 5.2c, (and there are many precedents in psychology for using the normal distribution) it is more than likely that the curve should give a good description of the annoyance.

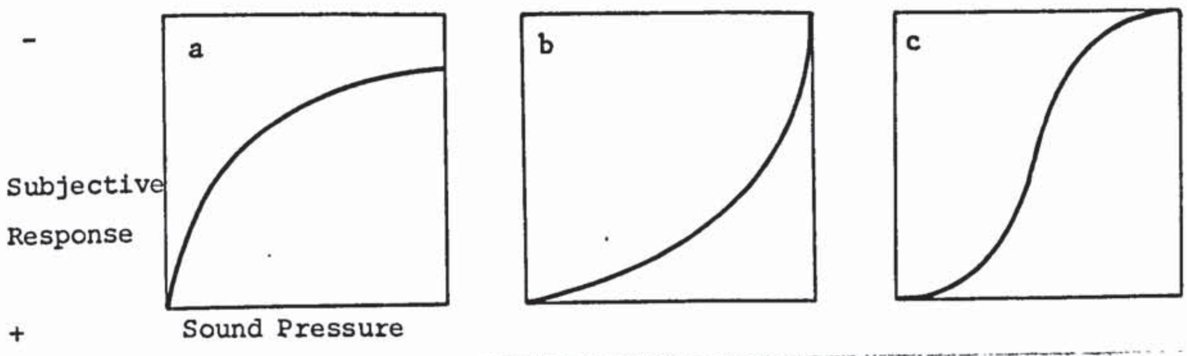

Figure 5.2: Hypothetical relationships between subjective response and sound.

No evidence has been submitted in favour of the latter two models which suggests their superiority over the Stevens type form. The hypothesis chosen to be tested is therefore that annoyance with sound from traffic is linearly related to the sound pressure raised to some power. In the analysis, though, a brief look will be taken at the strength of the relationship between annoyance and sound using the other two specifications.

All this presupposes that there is just one dimension to annoyance or at least that the one environmental impact, such as noise, induces annoyances which can be aggregated on a single scale. It is however, quite conceivable that this is an unwarranted assumption. Take, for example, the case of a housewife. She may be annoyed with the noise from the traffic outside because:-

1. She cannot hear what the children are saying.
2. She is tired and can't relax because of the noise.
3. Some of the traffic is articulated lorries, which she believes should be on some other route.
4. She knows from the amount of traffic that it is getting late in the day and that she still has a lot to do.

It is unlikely that her annoyance with each of these would be linearly related to each of the others for all values of the noise level, and that when aggregated they would only approximate to the one of the models whichever was the correct one.

5.3 THE USE OF BINARY RESPONSES

The validity of assuming the commensurability of unique measures of subjective responses to environmental conditions has been referred to above. One of the ways mentioned for resolving this problem is to allow respondents to use everyday methods of expressing their subjective feelings. One of the most obvious of such methods is to elicit binary responses by asking such questions as "Are you annoyed or not annoyed with ..?". While this greatly reduces the response criteria differentials, it certainly does not eliminate the variation and as has been seen, according to the Fechnerians, it is in fact the differences in people's responses which can be used to define the attitude scale.

The theoretical discussion which follows is set in the context of attempting to develop a ratio scale of annoyance, and to establish that the corresponding index of the quality of the environment is an environmental variable raised to some power, from survey data on the proportions of people annoyed with different environments.

Little research has been published on the subject of estimating the proportion of people annoyed with given environments, or to put it more precisely on the distribution of the thresholds at which people become annoyed. That which exists points to the thresholds being relatively widely distributed. For example, researchers in the Audiology Group in Salford University report that a fifth of the population are sensitive to noise (perturbables) and a third are not bothered at all (imperturbables), (Bryan and Tempest, 1973). Alexandre (1974) concluded that there was a linear relationship between the proportions of people annoyed and existing aircraft noise indices in his review of surveys of annoyance with aircraft noise. Yet, in a diagram (reproduced below) where he combines the results of five airport surveys there is an implication that the relationship is in fact sigmoidal, suggesting that people's annoyance thresholds are normally distributed about the indices of aircraft noise.

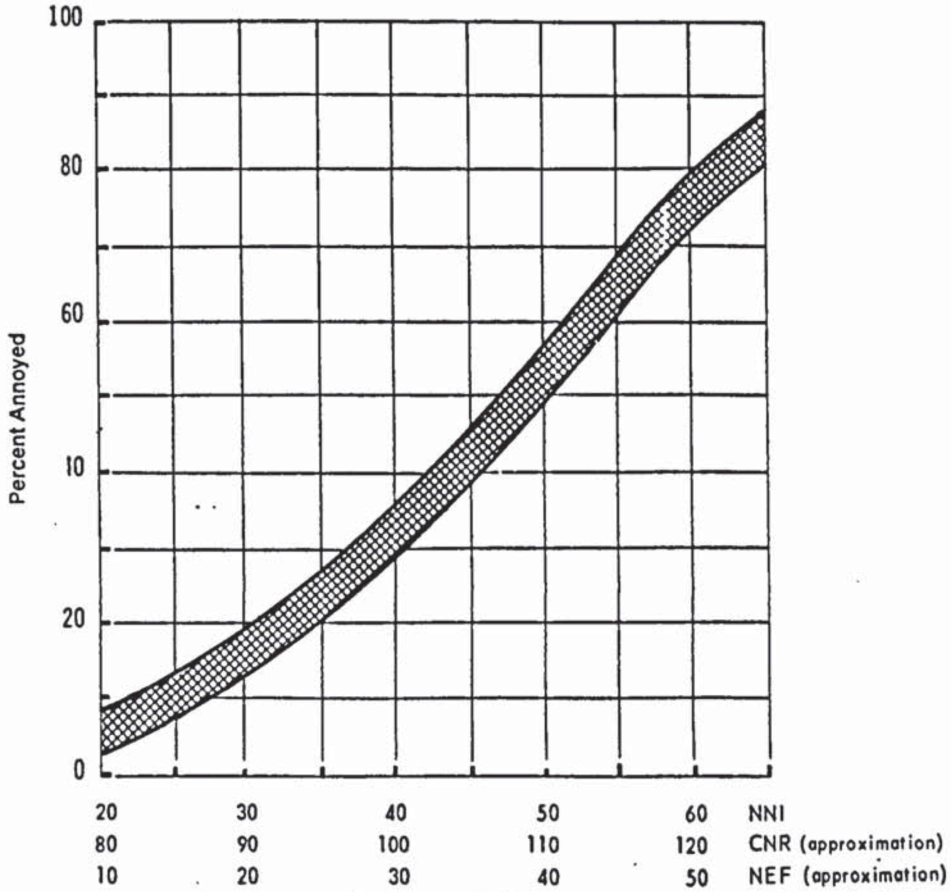

Figure 5.3: Graph showing the relationship between the proportion of people annoyed and three indices of aircraft noise (from Alexandre, 1974).

5.3.2 The Logistic Transformation

To test the hypothesis that there is a sigmoidal relationship between the proportion of people annoyed and an environmental index, it is necessary to transform the proportions into normal equivalent deviates (or "probits") (Finney, 1947), and to see if they are linearly related to the independent variable. This type of transformation, which expresses the equivalent proportion of the area under a normal curve in terms of standard deviations from the mean, is a complicated process requiring the integration of the normal distribution equation. Researchers usually follow the work of Cox (1970) and use the much simpler logistic transformation. Cox defined the logistic response curve as:

$$P = \text{Prob}(Y = 1) = \frac{e^{\alpha + \beta x}}{1 + e^{\alpha + \beta x}} \qquad (5.6)$$

$$\text{so that } \log \frac{P}{1-P} = \alpha + \beta x \qquad (5.7)$$

In order to see whether this transformation was dissimilar to normal deviates, the coordinates of points on a cumulative normal distribution curve were taken and the values on each axis were graphically related to the logistic transformation of the values on the other axis. The effect of the transformation in linearizing the normal ogee may be seen in Figure 5.4. It very slightly over compensates for the curves of the normal ogee. The logistic transformation of proportions and percentages is therefore used a number of times in the following chapters. It is of particular relevance to the following section where a critical review is made of an attempt to draw inferences from the relationship between the logistic transformation of the percentage of people annoyed and the Noise and Number Index.

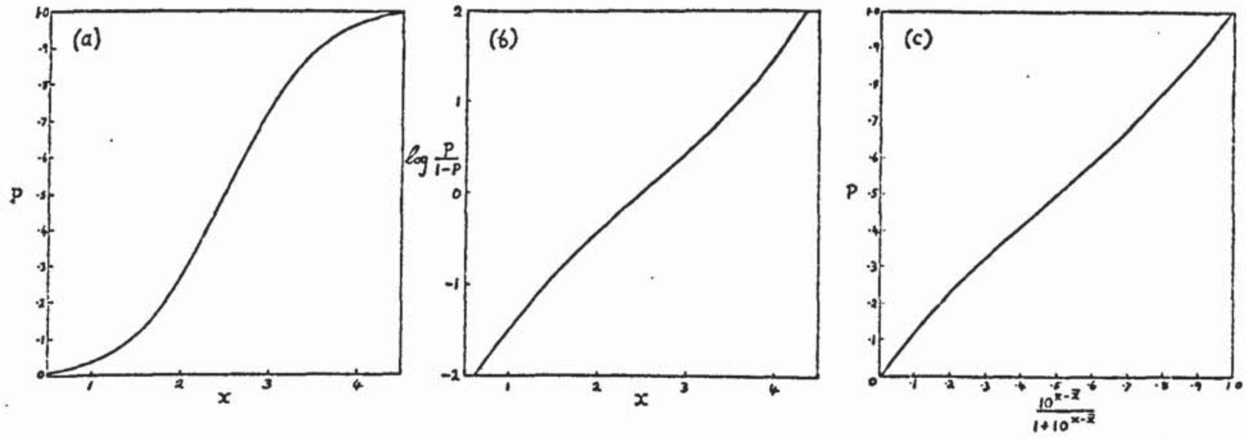

Figure 5.4: The normal distribution and the effects of the logistic transformation of its axes.

5.3.3 A Review of a Paper by Waller

Few contributions to the study of the relevance of Stevens' Power Law to environmental planning have been made to date. But there is one stimulating paper (Waller, 1969) which deserves critical attention. In it he tried to show the relationship between Power Law and a "real life" situation, which was the proportion of people annoyed with aircraft noise as measured on the Noise and Number Index (NNI).

He implicitly equated the anti-log of the logistic transformation of the proportion of people annoyed with aircraft noise $P/(1-P)$ with aggregate annoyance. He showed, graphically, a relationship found between the proportion of people annoyed and the N.N.I. which they experienced. The proportions are plotted on a normal probability scale and a linear relationship is apparent. Later, he describes this relationship algebraically:[1]

$$\frac{A}{1-A} \simeq \frac{1}{12.5} \text{ antilog}_{10}\ 0.026\ (\text{N.N.I.}) \qquad (5.8)$$

Where A = the proportion of people annoyed.
Thus the logistic transformation of the proportions is linearly related to the N.N.I. which itself is a logarithmic scale:

$$\log \frac{A}{1-A} \simeq 0.026\ (\text{N.N.I.}) - 1.1 \qquad (5.9)$$

Waller implies that the expression of equation 5.8 as a power relationship demonstrates the existence of Steven's Power Law in the form:

$$C_j \frac{A_j}{1-A_j} = R_j = a_j\, S_J^{\alpha_j} \qquad (5.10)$$

---

1. Two assumed typing errors in Waller's published equation have been corrected.

Where R = response and S = the level of the stimulus, c = constant, j = the type of the stimulus. When Equation 5.8 is expressed in power law form it becomes:

$$\frac{A}{1-A} = \left[\left(\frac{1}{12.5} \right)^{\frac{1}{0.026}} \left(10^{N.N.I.} \right) \right]^{0.026} \qquad (5.11)$$

This can be expressed more simply by dividing N.N.I. by 20 (as one does with dB(A) and rearranging:

$$\frac{A}{1-A} = .072(S)^{.52} \qquad (5.12)$$

Where $S = 10^{(N.N.I.)}$.

It is of interest to note that, according to this equation, if the N.N.I. is on a ratio scale and applies to the annoyance of an average person, then the constant in its formula should be 122 and not 80.[1]

1. The annoyance threshold of the median man is the mean of the normal distribution described by equation 5.9 type regressions. It may be, calculated by solving for A = 0.5. In this case the mean is approx. 42 N.N.I. The standard deviation may be found by dividing any value of A (except 0.5) both by the regression co-efficient and the number of standard deviations that it is known that the given proportion is away from the mean in a normal distribution. Here it is approx 25 N.N.I.

   We know that the N.N.I. is

   $$N.N.I. = \overline{PNdB}_{max} + 15 \log N - 80$$

   Where N is the number of aircraft passing per hour. As 42 N.N.I. is the best estimate of zero annoyance for the average person (the median person), it follows that if the N.N.I. is on a ratio scale as was the intention (Wilson, 1963), then it is 42 units too high. In other words, the constant should read 122, when it applies to the average man.

Unfortunately, Waller did not dwell on the theoretical implications of the novel ideas which he floated. It is therefore necessary to take a critical look at his findings and to examine the relationship between the normal distribution of people's thresholds and the existing theories of perception and attitude measurement which we have reviewed above. The fact that it was implicit in Waller's argument that a theory could be established from the observed responses of a number of people does not make solving the problem methodologically different from the development of a Thurstone type scale which is based on a number of responses from one individual, in circumstances where it may be assumed that responses are distorted by random and independent factors.

Where Waller went wrong was in uncritically accepting that the, presumably, significant correlation from equation 5.8 demonstrated the validity of the N.N.I. as the correct environmental index. It may be that other indices formed from very different transformations of the sound measurements would give more significant results. In fact, the logarithmic structure of the N.N.I. has Fechnerian connotations. It is not valid to take an equation describing the relationship between observed responses and stimuli, transform it to a power relationship, and then to say that it is evidence of the operation of Stevens Power Law and that the other side of the equation describes the attitude scale. There is no apparent justification in the implication of Waller's assumption that the proportion of people annoyed divided by the proportion of those not annoyed is proportionate to aggregate annoyance. Nor, indeed does he offer any arguments in its defence.

From the point of view of the methodology of the present study, the critical issue arising out of this review of Waller's paper is whether or not is is possible to define an attitude scale from observed binary responses. The following argument shows that it may not be possible, unless assumptions can be made about the degree to which peoples's sensitivity changes over the range of stimuli with which we are concerned.

If it was given that effectual responses are normally distributed for any given stimulus, then for any given point on the attitude scale, such as the most likely annoyance threshold for the median person, there is a corresponding point on the environmental index scale and the normal distribution of responses which the given stimulus evokes could be conceived of as a corresponding normal distribution on the environmental index scale. This is because the environmental index is by definition linearly related to the magnitude of annoyance, and therefore a probability density curve on one axis is of the same form when mapped on to the other. However it was worng to believe that, when the environmental index was defined as being linearly related to annoyance, there was a heteroscedestic relationship between the two scales and that any point on our conceptualised normal distribution on the environmental index scale would evoke proportions of people annoyed which would have normal equivalent deviates corresponding to the normal distributionson the annoyance scale. The figure 5.5 shows in exaggerated form how significant heteroscedasticity would bias the results. The X and Y axes represent the environmental index and the annoyance scale respectively, and the diagonal line is the linear relationship between them. S_o represents the point on the environmental index which evokes a mean response R_o which is the annoyance threshold of the median man. Stimuli S_1 and S_2 evoke mean responses R_1 and R_2. These are equal distances from S_o and R_o respectively. The distributions of the responses from the three stimuli are also shown. The normal curves are drawn such that the area under each of them is the same and that their related standard deviations increase as their means increase.

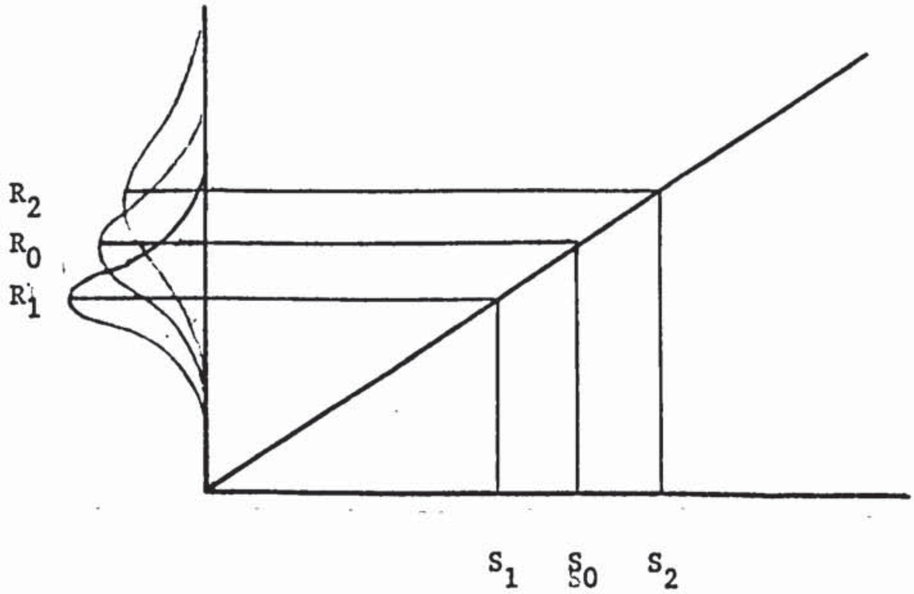

Figure 5.5: Diagrammatic example of heteroscedasticity bias.

The point of the diagram is to demonstrate graphically how equal distances on the Y axis (which may be expressed in normal deviates) may bisect the normal distributions into differing proportions of areas. To be able to identify the best environmental index through goodness of fit with observed normal deviates would require that the normal distribution of responses evoked by any stimulus would be bisected into the same proportions by the mean of any other response as its mean would bisect the normal distribution of the other response. If this was the case, the standard deviations of the distributions in the diagram would be the same and, as $R_1R_0 = R_0R_2$, the area of the distribution round R_1 which is above R_0 line on the Y axis would be the same as that of R_2 below the R_0 line, (these are the shaded areas in the diagram).

We have seen from Ekman's Law that the variation in responses is linearly related to the value of the environmental index. It may be possible to determine the degree of heteroscadesticity empirically. It may transpire that in the current survey that may not be a significant factor. Attempts will therefore be made to verify the conclusions drawn from the ratio scale survey data by an analysis of the binary responses.

5.4 THE COMBINATION OF ATTITUDES

So far in this chapter we have been discussing the relationship between annoyance with environmental variables and the values of the environmental variable. It has been argued how the hypothesis should be that individuals annoyance with the environment are related to the relevant objective measures of the environment in the same way as sensations are related to stimuli in Stevens' Power Law of Psychophysics. In order to be able to predict pedestrians overall annoyance with the quality of the environment as effected by the road traffic it is necessary to have some theoretical model of intra-individual additivity of subjective responses. The results of empirical verification of two hypothetical models of this type using Power Law relationships have been reported. The first of these is a multiplicative model. Shinn (1969) asked 25 subjects to make magnitude estimations of the power of a number of ficticious nations based on various given combinations of three national attributes: population (Pop), gross national product per capita (GNP) and the percentage of GNP devoted to its military establishment (Mil). He found the following equation gave the best fit:

$$\text{National Power} = k_1(\text{Pop})^{.41} \times k_2(\text{GNP})^{.62} \times k_3(\text{Mil})^{.28} \qquad (5.13)$$

Where k is a constant depending on the units employed.

The generalised form of this model may be expressed in the context of the present study:

$$R = \prod k_i S_i^{\alpha_i} \qquad (5.14)$$

Where R = overall index of subjective response

S_i = each stimulus

α_i = the constant to which S_i is raised.

Shin also tested a simple additive model, but found that it gave nowhere near as good a fit. In discussing this research Stevens said simply "The multiplicative model proved far superior, as it turned out", without offering any theoretical reasons as to why one should be better than the other, (Stevens, 1972).

Ewing (1973), however, found that the additive model gave the best results in his research on the prediction of choice of travel modes, this form may be expressed:

$$R = \sum k_i S_i^{\alpha_i} \qquad (5.15)$$

He quoted Edwards and Tversky (1967): "One idea so completely dominates the literature on riskless choice that it has no competitors. It is the additive composition notion. It asserts that the utility of a multi-dimensional alternative, such as a commodity bundle or a job offer, equals the sum of the utilities of its components".

It is submitted here, however, that while it is true that the model should be additive, it is the variables which cause the utilities which should be added and not the utilities themselves. This is obvious in the simple case where three gifts of money are received, the total utility is $(A + B + C)^{\alpha}$ and not $A^{\alpha} + B^{\alpha} + C^{\alpha}$. The same would apply where the gifts utilities are based on different power functions when the gifts are converted to common units. This may be done by calculating the utility of each gift by raising it to the power of its constant exponent (α_i) and then taking the (α_0)th root of the utility, where (α_0) is the exponent for calculating the utility from the stimulus in the units of which the gifts are being expressed. The total utility is then the sum of these common units raised to the power of α_0:

$$R = \left(\sum k_i S_i^{\alpha_i/\alpha_0} \right)^{\alpha_0} \qquad (5.16)$$

While this model may be the soundest theoretically and is certainly the simplest conceptually, its statistical complexity, may require more sensitive measurements of subjective response than it is possible to conduct in the context of kerbside interviews.

For the record, there is a fourth type of model which has been used extensively partly because of its simplicity and partly because it can be calibrated by multiple regression:

$$R = \sum k_i S_i \qquad (5.17)$$

This model, which was postulated by the economist Marshall has been used to the satisfaction of a number of researchers developing indices of the quality of the environment, e.g. Troy (1971 and 1972), Peterson (1967), and Church (1973). In the unique case where the exponents of the stimuli are all equal to one, it gives the same results as equations 5.15 and 5.16.

5.5 THE SURVEY DESIGN

Having developed the theoretical arguments leading up to the design of the survey it now remains to present the practical arguments for chosing the survey methods which we described in detail in the next Chapter. The reasons for not measuring the environmental stimuli at the same time as the pedestrians were encoding their responses and the reasons for developing models for predicting the environmental variables have been discussed already. It was decided that the pedestrians responses should be related to estimates of environmental variables based on measurements of the characteristics of the traffic flow taken before and after the interviewing. The measurements were quite straight forward and the relevant details are reported in the next chapter.

There were essentially three different criteria for designing the pedestrian interviewing procedures. The first was that the interviews should be sufficiently brief to hold the respondents attention until completed. Bearing in mind the responses during the pilot survey and the fact that a proportion of the interviewing would be done during the morning rush hours it was decided that interviews should not last longer than 2½ or 3 minutes.

The second criterion was that the reliability of the responses should be maximised by having the pedestrians to encode their responses in as many different ways as was feasible. It was therefore decided to elicit magnitude estimations and ratio estimations from them. The methods and analysis methodology will be outlined in the following two sections. The third criterion was to gather as much control data as was feasible. These are described in Chapter 6.

5.5.2 The Magnitude Estimation Method

The choice of mode in which people on the kerbside could encode their responses was extremely limited. The method had to be relatively simple, thus not requiring much instruction, and had also to require as little equipment as possible. The method, used by Indow (1961), of asking respondents to express the degree of their feelings by the distance they place a mark along a line fulfilled both these requirements. It also had the very important advantage that the psychological magnitude of distance perception is known to be almost linearly related to distance, i.e. the exponent in the equation 5.3 formula is approximately unity, (Stevens and Guirao, 1963). It is therefore possible to test the possible relationships by the goodness of fit between logarithmic functions of the dependent and independent variables, and calibrate the exponent by regression.

5.5.3 <u>The Ratio Estimation Method</u>

One of the problems in attempting to elicit people's responses to the physical environment in the way which has been discussed, is that different people may use different distances along the line to represent the same degree of annoyance, and that the end of the lines, i.e. "extremely annoyed" means different things in different cases. If this was due to people using different units of distance to represent the degree of annoyance, it should be theoretically possible to control for this variation in the response criteria by taking the ratio of the distances marked for one physical environmental variable to those marked for another as the dependent variable. This can only be done where annoyances are encoded for both physical environmental variables.

1. Stevens and Guirao demonstrated this in a number of experiments using both cross modality matching with brightness and loudness, and magnitude estimation.

The original hypothesis may be re-expressed:

$$D_{ij}K_j = C_i(S_i - T_i)^{\alpha_i} \tag{5.18}$$

Where D_{ij} is the distance along the line which person (j) places his mark to represent his annoyance with the physical environmental variable (i) and U_i is the unit of annoyance that is being used by person (j). In this case our lack of knowledge of U_i may be surmounted by dividing the annoyance encoded for one physical environmental variable by that of another:

$$\frac{D_{1j}K_j}{D_{2j}K_j} = \frac{C_1(S_1 - T_1)^{\alpha_1}}{C_2(S_2T_2)^{\alpha_2}} \tag{5.19}$$

The unit of annoyance which the respondents use is therefore no longer relevant and given the original assumption, the exponents may be calibrated by regressing the logarithm of the ratio of the distances marked on the logarithms of the ratios of the physical environmental variables:

$$\text{Log}\,\frac{D_i}{D_2} = \alpha_1 \log(S_1 - T_1) - \alpha_2 \log(S_2 - T_2) + C \tag{5.20}$$

The thresholds may be calibrated iteratively as described above. The constant is the logarithm of the ratio of the constants in equation 5.19.

One problem with this method is that the calibration of an exponent may be affected by the choice of the other independent variable in the regression set. A significant difference between the calibrations would indicate that the method of analysis was not appropriate.

While this method of analysis has been described for convenience in the context of the "lines data", it was originally designed for the analysis of a different type of data, which was that of the "Environmental Assessment Recorder" (EAR). This data was collected in a similar way to that collected by the consultants (S.C.P.R.) to the Urban Motorways Project Team (1974). Respondents were shown a board with a card on it showing a list of predefined environmental variables, such as noise, pedestrian delay, etc. They were then asked to put pegs opposite the environmental variables in proportion to the amount of annoyance which they felt with respect to them. The point of departure from S.C.P.R.'s use of the technique is in the method of analysis and the inferences drawn from the results. The game bears only a superficial resemblance to the distribution of counter games used by S.C.P.R. (Hoinville, 1973) or Wilson (1968).

5.6 SUMMARY

In the discussion of the methodology which should be used in the development of models for predicting pedestrian annoyance on a ratio scale, it was argued that the annoyance should be linearly related to some function of the environmental variables based on the theories of perception. Two competing theories of psychophysics were reviewed. These were Fechner's Law, which postulates a logarithmic relationship (as in equation 5.1) and Steven's Law, which postulates a power relationship (as in equation 5.3). Both of these theories have been used extensively in attitude measurement, but it was argued on theoretical grounds that attitude scales, based upon Fechner's theory, are not linearly related to the psychological continuum on which affective responses are experienced. The central hypothesis to be tested was therefore that pedestrian annoyance has a power relationship with the physical environmental variables. However, it was also necessary to test that the power relationship was significantly stronger than either the logarithmic or linear relationships. A further hypothesis which required to be tested was that the environmental variables were on a prothetic rather than a metathetic scale.

The possibility that the annoyance scale (i.e. the environmental index) could be defined for discontinuous dichotomous responses was explored in depth. However it was concluded that this would not be possible without knowing the degree of heteroscedasticity which existed.

A new theory on the additivity of annoyances was developed (see equation 5.16). This required ascertaining the strength of the relationship between overall annoyance and the sum of the environmental variables, expressed in common units, and then raised to the power of the exponent relevant to the units used. The constraints caused by interviewing on the kerbside necessitated the use of simple methods for the encoding of the responses by the pedestrians. However, it was thought desireable to check the reliability of the results by using more than one method for the pedestrians to encode their responses. The respondents were therefore asked to use both a cross-modality and a ratio estimation technique. Distance along a line was the response mode used in the former method. As the perception of distance is linearly related to the distance perceived, (i.e. the exponent in the Power Law relationship is unity) the responses, as measured, were assumed to be linearly related to the subjective response. The use of these two methods, and the other measurement methods used in both surveys, will be described in the following Chapter. So, also, will be the sampling design.

CHAPTER 6: REPORT OF FIELDWORK

The purpose of this chapter is to report the way in which the theoretical and methodological issues discussed in Chapters 4 and 5 were translated into a viable set of measurement operations and how these operations were executed. The practical problems encountered will be discussed and their implications for the objectives of the study will be examined. Particular attention is therefore paid to the issues of sample and fieldwork design and the preparation of the data before analysis. The discussion is structured around separate descriptions of the physical environmental survey and the survey of the pedestrians subjective responses.

6.2 SAMPLE DESIGN

6.2.1 Physical Environmental Survey

Ideally, the sample should be selected with respect to all of the independent variables which were postulated to be determinants of the variables which it is wished to predict. This was not possible because of the large number of independent variables involved and because information was only available on the distribution of a few of them. Fortunately, those for which information was available included two of the principal determinants of the environmental variables: the flow and the composition of the traffic.

For any given specification of a regression model based on fieldwork measurements, increasing the size of the sample causes the accuracy of the predictions to approximate to that which would exist if the sample was infinite. Where there is one independent variable (x), the expected error in a prediction of y for a given value of x, where $y = a + b\bar{x}$, is

$$E(e_p) = (R.E.)\sqrt{1 + \frac{1}{N} + \frac{(X_o - \bar{X})^2}{(X_i - \bar{X})^2}} \qquad (6.1)$$

Where R.E. is the residual error, and N is the sample size. "C_p" is t distributed. (See Huang, 1964).

When the size of a sample is greater than 30 the shape of the t distribution becomes similar to the normal distribution. Thus 30-35 observations are considered adequate for constructing a linear regression model where there is only one independent variable. The addition of each new independent variable to the regression set reduces the degrees of freedom by one and this loss may be made up by increasing the sample size by one. Yeomans (1968) shows graphically how the confidence bands diverge from the point of the means on the diverge from the point of the means on the regression line. It may be seen how the $(x-\bar{x})^2$ term in equation 6.1 is the cause of this. The effect of this term may be reduced by increasing the range of the values of the independent variable in the sample, i.e. by increasing the denominator.

Bearing in mind the sampling theory, the large number of variables and the need to take more than one set of measurements at a number of sites, it was decided to play safe and draw a relatively large sample. A sample of fifty sites was drawn and two observations (sets of measurements) were taken at each of them. Half of this second set of observations were conducted under circumstances where the traffic conditions were as similar as possible to the first phase and the other half as different as possible, (i.e. during peak-hours, if the earlier measurements were in the off-peak and vice versa). A further 25 observations were taken at the request of the London Borough of Hammersmith in a specific area which appeared to them to be a potential "environmental area". These did not significantly distort the sample which had been drawn. In all there were 125 observations which could be used in the prediction of one or more of the environmental variables. In cases where the equipment failed in the measurement of a physical environmental variable or where unusual conditions developed during the time of the observation, affecting the value of the dependent variable, the data was rejected for the prediction of that variable but not for the others. Appendix 3 contains a full list of the sites, showing the completed observations classified by time of day and environmental variable measured. The right hand columns refer to the survey of pedestrians subjective responses. The Appendix also contains a map showing the location of the sites in the Borough.

In order to draw a random sample of sites it was necessary to have a list of the road links in the borough with records of main characteristics of the traffic flows which could be used as a sample frame. The listing of links was provided by the road network which was defined for "base year" assignments in the Hammersmith Transportation Study. This included all the roads in the Borough except those which were regarded by the transportation study team to be used for access only or were relatively insignificant in traffic terms. However, at the time of sampling, the base year (1968) a.m. peak assignment flows were the only data available on the characteristics of the traffic. In an analysis of the data collected in a cordon origin and destination survey, conducted as part of the Transportation Study, it was found that the proportion of heavy good vehicles was significantly lower in the a.m. and p.m. peak hours than during the day. The peak periods were defined using the Cordon Survey data as being from 8.00 a.m. to 9.30 a.m. and from 5.00 p.m. to 6.30 p.m. The off-peak periods were defined to be from 9.30 a.m. to 12.30 p.m. and from 2.00 p.m. to 5.00 p.m. The sample was therefore drawn from the a.m. peak assignment data and observations were taken from 8.00 a.m. to 6.30 p.m. to ensure a wide distribution of the proportion of heavy vehicles. In order to widen further the range, a small number of streets, which were noted during the survey to have relatively large proportions of heavy vehicles, were selected for observations.

It was found that the number of roads in each category of flow decreased as the flow increased, (see Figure 6.1). As the variance of the traffic flow in the sample would be increased by having approximately equal numbers of observations at each end of the range of values in the population, a stratified random sample was drawn from the roads on the network. A larger sample than was required was drawn, because a relatively large number of streets had to be rejected either because the traffic system had been changed since the network was defined, or because it was found that there was noise coming from other sources which could not be controlled for. This included noise from other roads. (No observation was taken within 25 metres from a junction with another link on the network). Roads adjacent to flyovers, railways or building construction were also rejected because of their extra noise, as were those undergoing repair. In order to minimise the correlation between the number of vehicles, efforts were made to take an equal proportion of observations in each category of flow during peak periods.

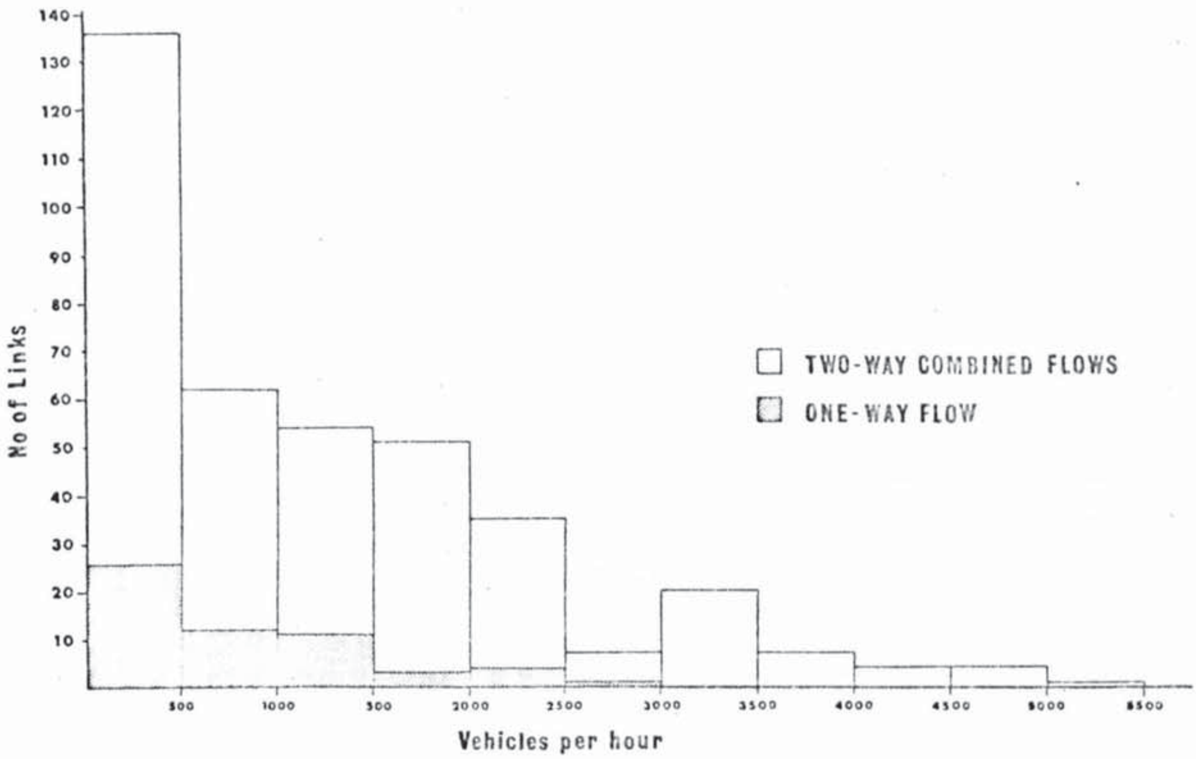

Figure 6.1: Diagram showing the number of links per category of traffic flow in the base year assignment in the Hammersmith Transportation Study, 1968.

A decision also had to be made regarding the length of time for which simultaneous recordings of the physical environmental variables and their postulated determinants should be made. Sampling error caused by random variation in the effects of the independent variables decreases as the sampling time is increased. On the other hand, biases may be introduced into the observed relationship between the variables if the values of the independent variables are changing over time. Therefore a balance has to be made between obtaining a representative measure of the variables and the risk of the values of the variables changing during the observation. Johnson and Saunders (1968) recommended a minimum measurement period of 15 minutes. Gilbert and Crompton (1971) made their recordings for periods as short as 10 minutes. However, in an attempt to minimise the sample error, measurements were taken for 20 minutes and care was taken to avoid recording during periods when the traffic flows and composition was likely to change, such as at the beginning and end of peak periods.

5.2.2 The Pedestrian Responses Survey

As the method of analysis of the data collected in the survey of pedestrian responses was similar to that of the physical environmental survey, the same arguments about the variance of the independent variables applied. It was not possible, however, for pedestrians to cross a number of primary roads because of physical barriers. This meant that data could not be collected about the respondents annoyance with the delay and risk in crossing the roads. As one of the main objectives in the study was the prediction of overall annoyance, interviews were not conducted at these sites because of the lack of compatibility of the data. This had the effect of considerably reducing the range of traffic flow at the sites visited. Similarly, as the analysis required sufficient observations where overall annoyance could be related to estimates of the physical environmental variables, interviews were not conducted on one-way streets, because models had not been developed for predicting delay on them. Altogether, it was only possible to interview at 30 out of the 75 sites where the physical environmental variables were measured. Interviews were not conducted at some sites because there were insufficient pedestrians or because the environmental conditions were significantly affected by sources other than road traffic.

As a wide range of responses was expected from the pedestrians for any given environmental conditions, the possibility was foreseen that it would not be possible to find significant relationships between the responses and the estimates of the physical environmental variables. A way of avoiding this was to take some measure of the central tendency, for each set of responses where the environmental conditions were constant, as the dependent variable. Because of this, more than one set of interviews was taken at 19 sites such that the number of interviewing periods was raised from 30 to 50. One set of interviews had subsequently to be rejected. The number of interviews to be taken during each interviewing period was also raised to reduce the sample error of the measure of control tendency finally adopted. In all a target of 500 interviews was set, in fact 522 productive interviews were achieved. This was an average of 10.7 interviews per interviewing period.

6.3 MEASUREMENT METHODS

The main features of the survey designs have already been outlined in discussion of the methodology of the study. In both surveys a set of dependent variables was measured simultaneously with a set of independent variables which were postulated to be causally related to them.

In the survey of the physical environment, noise, pedestrian delay and air pollution levels were recorded for 20 minute periods at the same time as recordings of the traffic flow characteristics, climatic conditions and built-form variables. The following two sections describe the methods of measurement used for the dependent and independent variables in this survey. The specifications of the equipment used may be found in Appendix 4. Examples of the record sheets used in this survey and in the survey of the pedestrian responses are contained in Appendix 5. The description of the methods used in the survey of the pedestrians responses follows that of physical environmental survey below.

6.3.2 Physical Environmental Survey: Dependent Variables

Sound

A microphone was placed 0.3m back from the kerb and at a height of 1.2m. The position of the other recording equipment and the observers is shown in Figure 6.2. The microphone may be seen on the right hand side of the photograph. It is connected to the recording equipment in the cabinet. The observer reading the radar meter (on the street) is seated on the pump which sucks the air through the filter to record the smoke levels. The two observers on the left of the photograph recorded the traffic flow on the near and far sides of the road. The observer in the centre, who is recording the wind speed, also recorded the pedestrian delay.

Figure 6.2: Photograph showing the relative position of the observers and the equipment.

The data was collected with reference to a line through the microphone and at right angles to the kerb. In the text 'near side' refers to the side of the road on which the recording equipment was placed and 'far side' refers to the opposite side.

The microphone was connected to a precision sound level meter which 'A weighted' the sound before it was recorded. A two track tape recorder was used and the second track was used to identify the recording and to record such commentary as was required during the observation.

Prior to recording, the tape recorder and the sound level meter were calibrated such that the expected range of traffic noise fell within the dynamic range of the tape recorder which was 50 dB(A). An accoustic calibrator was attached to the microphone and a constant sound of a known level was fed into the tape recorder via the sound level meter. In the laboratory the sound recordings were fed through a level recorder and the constant sound from the accoustic calibrator was used to calibrate the output. A pen recorder gave a graphical record of the'A' weighted sound levels, examples of which may be seen in Figure A5.1. The level recorder was attached to digital analyser which recorded the length of time that the sound level was within given 5 dB(A) ranges. This data was graphed and interpolated to find the L_{10}, L_{50} and the L_{90}. The distribution of sound levels was found to be approximately normally distributed and therefore by normal probability graph paper was used to increase the accuracy of the interpolation, (see Figure A5.2 in Appendix 5).

Pedestrian Delay

A standard cassette tape recorder and modified microphone was used to record pedestrian delay. The microphone was attached to a switchable battery operated accoustic generator. When the switch (a spring loaded bell-push type) was depressed a high-pitched sound signal was fed into the cassette recorder. The microphone was used for labelling the start and finish of the recording. During the twenty minute recording period the observer took into account the traffic flowing in both directions and when he felt it was safe to cross to the opposite side of the road he would press the switch on the accoustic generator and keep it pressed for as long as he felt it was safe to cross. Being safe to cross was defined as being able to cross at a reasonable speed without pausing in the centre of the road.

The cassettes were played back through a level recorder. The paper feed was set at 1mm per second and an example of the rectangular wave form of the 'bleep' on the chart is shown in Figure A5.3. Direct measurement of the troughs gave the delay times from which the percentage of time delayed and the mean delay time were calculated. The percentage of time delayed was simply the sum of the delay periods, multiplied by 100 and divided by the number of seconds in the observation period. The mean delay was calculated by dividing the sum of the squares of the length of the delay periods by twice the length of the observation period.

Smoke

The degree of stain on filter paper, through which the air was pumped, was used to determine the level of smoke in the atmosphere. A battery-powered pump was used to suck sample air through a special filter-paper at a known rate of flow. The degree of darkness of the smoke stains was later measured in the laboratory with a reflectometer. Reference was then made to the Warren Springs Smoke Concentration Tables to arrive at the smoke concentration in microgrammes per cubic meter, using the reflectometer reading and the known rate of air intake, the time period of the observation and the diameter of the stain on the filter paper. The smoke sampling equipment was placed on the opposite side of the portable trolley to the noise microphone to minimise its effect on the noise recorded.

Carbon Monoxide

The level of carbon monoxide was recorded by pumping a sample of the atmosphere through Drager tubes containing CO sensitive crystals. Three tubes were used consecutively during each observation period, and the mean of the readings was taken as the level of CO in parts per million (ppm) for that observation.

6.3.3 Physical Environmental Survey: Independent Variables

The pattern of arrival of the traffic was recorded by observers dictating codes into tape recorders as the vehicles passed the observation point. One observer was responsible for the traffic flow in each direction. The codes indicated types of vehicles which were passing (i.e. 'one' for cars and taxis, 'two' for light commercial vehicles, 'three' for medium and heavy commercial vehicles, 'four' for buses and coaches and 'five' for motorcycles). Sometimes arbitrary distinctions had to be made between the types, for example vans which were commercial models of cars, i.e. built on a car chassis, were given codes different to those of the cars, yet the difference which they might make to the environment could be minimal. Vans and lorries over 50 cwt. were regarded as being code 'three'.

The 20 minute recordings were afterwards played through a level recorder with the paper speed set at 1 mm per second. The voice sounds appeared as vertical lines on the chart, (see Figure A5.4 in Appendix 5). The recorded speech was also monitored and the operator placed marks on horizontal columns on the chart according to the code heard. Counts were then made of the marks in each of the columns which were grossed up to give the flow per hour for each of the types of vehicle.

The index of dispersion, as defined by Crompton and Gilbert (1971), was calculated from the means and variances of the numbers of vehicles counted in ten second periods, i.e. the number of marks counted in consecutive 10 mm distances on the charts. This was done for the flows in each direction and for the combined flows.

The speed of the vehicles in the far-side traffic flow was assumed not to have a significantly different effect on the environment than that of the near side flow. The speeds were recorded manually by an observer reading a radar meter. When the traffic flow was too high for the speed of every vehicle to be recorded, readings were taken at 15 second intervals. The mean of the readings was then taken.

While the equipment was being placed in position, a note was made on the fieldwork reference sheet of the existence of bus-stops within 50 m of the observation point. The same was done for parked vehicles within 25 m of the site. The presence of pedestrian crossings within 50 m of the site was also noted. A number of subjective observations were made about the road surface and the climatic conditions. See figure A5.5 in Appendix 5. A hand anemometer was used for measuring the wind speed, the mean was taken of three recordings taken before, during and after the observation period. The direction of the wind was also noted. Photographs were taken of the buildings on each side of the road.

The width of the highway between the kerbs and the distance from the kerbs to buildings (if any) on each side of the road, were measured from a 1:1250 map. An estimate of the gradient of the road at the observation point was made from the heights above sea level given on the map at each side of the site.

It was noted at the beginning of the survey that aircraft clearly had a major impact on the noise climate. It was essential, therefore, to identify their frequency and the parameters of their flight-path.

The study area was approximately 16 km. from Heathrow Airport and was crossed by the approach corridor. As aircraft may join the corridor at any point between 12 and 35 km from the airport, the path of individual aircraft is variable. Most of them fly close to the minimum height of 2000 ft. 16 km from the airport and they descend at a steady rate towards the end of the runway.[1] During the survey, aircraft which could be heard over the noise of the traffic were noted on a reference tape and subsequently during the analysis the duration of the noise was measured. This was approximately 5% of the recording time throughout the survey.

6.3.4 The Pedestrians Responses Survey: Dependent Variables

The theoretical reasons for the methods which were used to determine pedestrians' annoyances with the quality of the environment have been given in chapter 5. It was decided that they should be asked to place marks along lines, such that the distance from one end of the line represented the magnitude of their annoyance with aspects of the environment. The Environmental Assessment Recorder (EAR) has also been described and how it was to be used to ascertain the relative annoyance with the various aspects of the environment which the respondents felt. In this section we are concerned with the procedures followed and the description of the record sheets and the operation of the EAR.

Every effort was made to introduce the subject to the pedestrians and to ask the questions in as standard a way as possible. Throughout the interview the emphasis was placed on the fact that it was with the

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1. Private communication from the London Airport Authority, December, 1974.

environmental conditions as affected by the traffic at that moment on that street to which we wished them to respond. An example of an interview sheet is given in Figure A5.7 in Appendix 5. The interviewer introduced himself by saying "Good morning" (or "Good afternoon" as the case might be) "We are doing a survey of people's attitudes to the quality of the environment. We would be grateful if you would please put a mark along these lines which would represent the extent of your annoyance with the items listed here, as they are at this moment on this road." The top line was used as a demonstration, the respondents were told that if they were not annoyed to put the mark on the left end, if they were extremely annoyed to put the mark towards the other end, and if they were moderately annoyed to put the mark as far along the line as would represent the extent of their annoyance. As they were being told this, marks were being placed along the line.

The respondents were asked to express the magnitude of their annoyances with the six selected components first and then they were asked to mark the overall annoyance line. In an attempt to eliminate bias which might be caused by the order of the annoyances, two types of sheet were prepared and approximately every second respondent was given a different type of sheet.

'Not Annoyed' was printed over the left hand end of the line, and as may be seen in Figure A5.7 a noticeable stop was printed at the end to signify that the representations of annoyance began from that point. Slight calibrations were placed along the line at 7.5 mm intervals to help to indicate that the line was a measurement scale. 'Extremely annoyed' was printed close to the end of the line, but no noticeable mark was printed at this end of the scale.

The respondents were then asked to describe the traffic by putting an 'X' in what they thought was the appropriate box between 9 pairs of opposite adjectives, as in a semantic differential test. Finally they were asked to express the extent of their agreement or disagreement with three statements which might give an indication of their predisposition to be annoyed with the traffic. The clip board was then taken from the respondent and the purpose of this trip and whether their household had access to a car, as well as a number of demographic details, were coded on the interview sheet.

If the respondents had expressed any annoyance with any of the items on the lines they were asked to use the EAR. This consisted of two pieces of perspex bolted together with a piece of cardboard between them, on which the environmental items and the instructions were stencilled. A photograph of the EAR is shown in figure A5.8 in Appendix 5. It measured 38 cm by 28 cm. The list of annoying items could be slid out and turned round so that the list would be in a different order. This was done approximately half way through each interviewing period.

Verbal statements took precedence over the distance along the line on which the marks had been made, in determining whether the EAR should be used. Eight pegs were placed opposite the environmental factor with which they had expressed the greatest annoyance; the respondents were then asked "If you used eight pegs to represent your annoyance with ..... as it is at the moment on this road, how many pegs would you use to express your annoyance with .....?" As the respondent answered, the interviewer would go through the list of items in the order they were on the EAR. When this was done they were asked to look at the distribution of pegs and to say if they would like to change them in any way. The distribution of pegs was then recorded on the interview sheet and the variable which was given eight pegs initially was noted.

In the early stages of the survey, for approximately the first hundred interviews, respondents were asked if there were any other ways in which the traffic affected their environment. There were many answers but none mentioned any items which could have been added to the list. All referred to aspects of accessibility.

6.3.5 The Pedestrians' Responses Survey: Independent Variables

In the earlier survey of the physical environmental variables, measurements were made of a wide range of independent variables which were postulated to have an effect on the environmental variables. The models which were eventually developed and used for estimating the values of the environmental variables, which were in turn to be used in determining the causes of variation in the pedestrians responses, may be found at the end of Chapter 7. Only traffic and built form variables which featured in these models were measured in the second survey.

It may be seen from the t statistics how the transformations of the traffic flow and the proportions of the types of vehicles of which it is comprised are by far the most important determinants of the environmental variables. The values of these variables were obtained in a similar way as in the survey of the physical environmental variables. Recordings were made of the arrivals of the vehicles (by type) for ten minutes before and after each interviewing period. When the interviewing appeared likely to exceed an hour, an extra recording of the traffic flow was made during the interviewing.

Neither the speed nor the index of dispersion of the traffic was measured. It was hoped that estimates of the values of these variables could be obtained from models developed from the data of the physical environmental survey. (See section 7.7) The built-form data was the same as collected in the earlier survey. The incidence of parking was noted as before.

6.4 CONCLUDING REMARKS

Only those aspects of the field work which bear directly on the analysis have been described here. The more detailed descriptions of the field work measurement and control are contained in the series of appendices. In all cases the best available equipment was used and regular checks were made of their functioning. The following three chapters report the analyses of the measurements.

CHAPTER 7: THE PHYSICAL ENVIRONMENT: PREDICTION MODELS

7.1 INTRODUCTION

The analysis of the data collected in the sample survey of the physical variables is reported in this chapter. The subject matter is, therefore, confined to the relationship between the three environmental factors, noise, pedestrian delay and air pollution, and the traffic and built form variables.

The problems of defining these physical environmental variables have been discussed above. In the case of noise, we are primarily concerned with the development of a model for predicting the sound level in dB(A) which is exceeded ten percent of the time (L_{10}). Models are also developed for predicting the L_{50} and the L_{90} so that estimates may be made of the indices of noise which include the variation of the sound as a parameter, such as the L_{NP} and the T.N.I. (see pages 22-24).

Two aspects of pedestrian delay have been defined, and prediction models will be developed for each of them so that the relative value in predicting subjective responses may be tested. They are the percentage of time that a person arriving randomly at the kerbside would be delayed, and the mean time for which that person would be delayed. As discussed in Chapter 4, the logarithm of the mean delay and the logistic transformation of the percentage of time delayed are also regressed on the independent variables. For air pollution, the dependent variables are the observed levels of carbon monoxide and smoke and their logarithms.

7.2 THE NOISE MODEL

In Chapter 3 it was hypothesised that the form of the relationships between the L_{10} and the traffic variables described for free-flowing traffic might provide the best basis for the development of models for predicting the noise from non-free-flowing traffic. In particular, it was submitted, on the basis of the reanalysis of other researchers' data, that specifications in the form of Delany's negative exponential model, (equation 3.8) and Johnson and Saunders simpler model, (equation 3.5) might provide the best fit. The Gilbert and Crompton type specification was also tested in spite of some theoretical reservations which have been made above. Separate sections of this chapter are accordingly devoted to reporting the results of regressing the observed L_{10} on each of these three ways of specifying the traffic flow and composition variables. These sections are followed by reports of regressions of the L_{50} and the L_{90} on the various specifications of the independent variables. First, however, it is necessary to look at the problem of how the noise from the aircraft should be controlled for in the regression analysis.

7.2.2 The Interaction of Aircraft and Traffic Noise

It was noted in the previous chapter that noise from aircraft appeared to the observers during the survey to have a major impact on the noise climate on the pavements. Recordings had, therefore, been made of the number of aircraft heard, the length of time for which they were heard and the distance of the survey point from the centre of the flight path.[1]

The challenge of isolating the effect of this unexpected determinant of variation in the L_{10} added a new dimension to the methodology of the analysis. During the survey, and looking at the paper trace of the

1. This was defined as the actual distance to the flight path, and not to a line beneath it; thus, the height of the aircraft also affects the value of the variable.

noise level recordings, it became clear that there was an interaction between the effects of the aircraft on the L_{10} and that of the traffic. Figure 7.1 shows typical examples of the effects of road traffic and aircraft on the dB(A) level recordings on low flow streets close to the flight path. In other cases, where there were high traffic flows, similar aircraft could barely be heard or identified on the dB(A) trace.

In early regression analyses, it was found that accurate estimates of the L_{10} from the two sources could not be derived from the energy sum of estimates of their separate contributions to the sound levels. It was therefore hypothesised that a linear interaction between the estimated contributions of the two sources would give a reliable description of the observed noise levels. Testing this would require two regression runs. First, an estimate of the sound of the traffic could be found by regressing the observed L_{10} on the traffic and built form variables, the aircraft noise being partially controlled for by including the logarithm of the distance[1] to the flight path and the ratio of aircraft[2] to vehicles as variables in the regression set. In the second run, the L_{10} would be regressed on the estimates calculated from the traffic and built form model, the logarithm of the distance to the flight path and the product of these two variables. Thus, the first regression equation would be of the form:

$$L_{10} = f(t_i) + C_1 - C_2 \log D + C_3 \text{ Ra} \qquad (7.1)$$

Where $f(t_i)$ = a function of the traffic and built form variables.

c = constants calibrated by regression. (C_1 includes a value

1. The propogation of sound follows an inverse square law and therefore dB(A) are linearly related to the logarithm of the distance to the source, see Delany (1972). The ratio of aircraft to vehicles is used to control for the interaction in this iteration.

2. The length of time that aircraft were heard was found to give similar results as the number heard.

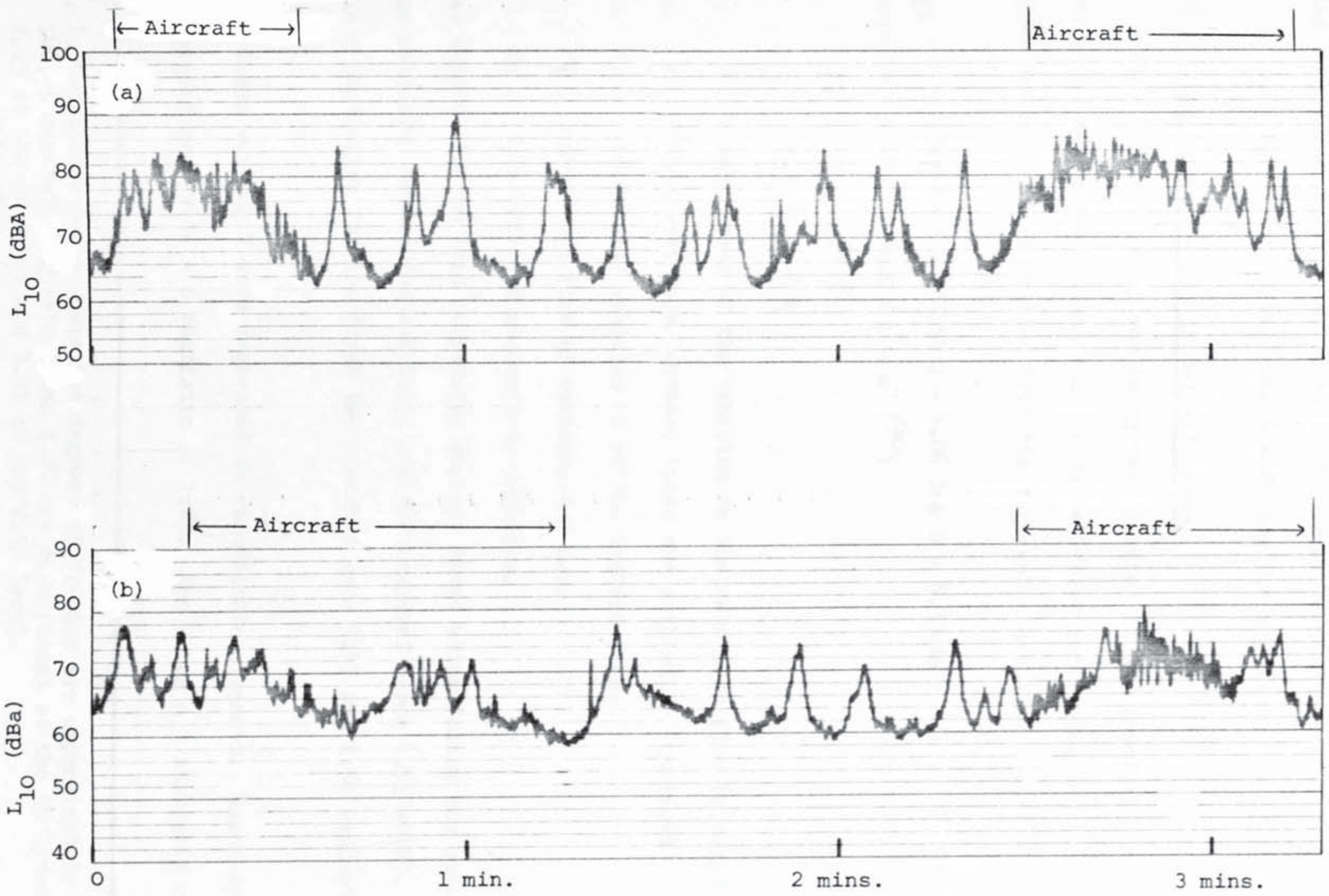

Figure 7.1 Typical recordings of sound of aircraft and traffic in low-flow streets close to the flight-path. (a) D = 0.8 km.; (b) D = 3.4 km.

representing the noise from the aircraft at source)

D = the distance to the flight path.

Ra = the ratio of aircraft to vehicles.

And the second equation would be in the form:

$$L_{10} = C_4 f(t_i) + C_5 f(t_i) \log D - C_6 \log D + C_7 \qquad (7.2)$$

7.2.3 The Recalibration of Delany's Model

When Delany's model was being recalibrated it was found that a number of other traffic and built form variables were significant.[2] When these variables were omitted from the regression set, the result was:

$$L_{10} = \alpha + \beta \log V + 0.2\gamma \log Q - 4.06 \log D + 8.35\, Ra \qquad (7.3)$$

Where $\alpha = 44.3 + 34.9\,(1 - e^{-P/40})$

$\beta = 10.6\ e^{-P/12}$

$\gamma = 47.9 + Pe^{-P/9}$

V = mean speed of the vehicles in the near side flow (k.p.h.)

P = the percentage lorries, buses and a third of the light commercial vehicles is of the traffic flow

Q = the total flow of vehicles per hour

Ra = the ratio of aircraft to vehicles.

The sample size in this regression and all those which follow was 110. The multiple oorrelation was 0.955 and the residual error 1.71 dB(A). The t statistics for the first two elements were 3.43 and 2.84 respectively.[1]

Gamma and log Q were regressed on as separate elements. Gamma was not significant with a t statistic of 1.02. Log Q had a t statistic of

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1. In two-tailed tests where the degrees of freedom are approximately 100, t statistics greater than 1.99 are significant at the 5% level, 2.63 at the 1% level and 3.41 at the 0.1% level.
2. See equation 7.4.

13.36. Log D was also very highly significant with a t statistic of 5.89, but Ra was not significant with a t statistic of 1.39.

The percentage of heavy vehicles specified in the negative exponentials of these models includes a third of the percentage of light commercial vehicles. This proportion was adopted from a regression of the L_{10} on the percentage of cars, the percentage of heavy vehicles and the other significant variables, where the regression coefficients of the first two variables were 10.1 and -5.7 respectively. The model, however, was relatively insensitive to variation in this sub-division of light commercial vehicles, though the calibration used gave a significantly better fit than the percentage of heavy vehicles on its own. On the face of it, this reversion to two categories of vehicles suggests that there was no advantage in the more detailed classification of vehicles used in the field work measurements. On the other hand, it may not have been possible to identify visually the light commercial vehicles which should have been included with the heavies. The sub-division of the light commercial vehicles may reflect the average proportions which are driven by petrol and diesel oil and thus accord with the work of Lewis (1973) who found that there were just two distinct classes of vehicle (petrol and diesel driven) from the point of view of noise emissions.

The calibrations[1] when the L_{10} was regressed on all the significant variables were:

$$L_{10} = \alpha + \beta \log V + \gamma \log Q + 0.34\ Pk + .47\ Rq - 8.1 \log W \qquad (7.4)$$
$$+ 0.15\ T - 2.71 \log D + 12.6\ Ra + 35.9$$

---

1. The exponents were calibrated iteratively.

Where $\alpha = 43.7\ (1 - e^{-P/40})$

$\beta = 13.2\ e^{-P/12}$

$\gamma = 0.44\ (24.5 + Pe^{-P/9})$

and Pk = Index of parking (see equation 4.1)

Rq = The ratio of the traffic flow on the near side to that on the far side.

W = The width of the street in metres between the kerbs.

T = The number of storeys in the near side facade divided by the logarithm of their distance to the kerbside (in metres) (see page 58).

The multiple correlation was 0.966 and the residual error 1.51 dB(A). The t statistics for the separate elements in equation (7.4) and for the other corresponding first stage regression equations are shown in Table 7.1. The calibrations of all these equations are displayed together in Table 7.3. In Delany's original equation (3.8) the beta element contained two constants such that the logarithm of the mean speed could be included in the regression set as a separate element. However, it was not significant in either regression equation 7.3 or 7.4.

The result of the second regression run, where equation 7.2 was calibrated, was:

$$L_{10} = 0.467\ f(t_i)\ \log D - 0.55\ f(t_i) - 24.4\ \log D + 114.21 \qquad (7.5)$$

Where $f(t_i) = 43.7e^{P/40} + \beta \log V + \gamma \log Q + .34\ Pk + .47\ Rq - 8.1 \log W + 0.15\ T$

as in equation 7.4.[1]

1. Note that the constant in alpha was not included, to avoid repetition in the constant and the "log D" element.

TABLE 7.1

Student t Statistics of Elements in "First Stage" Regression Equations

Element	Equation								
	7.4	7.7	7.9	7.13	7.14	7.10	7.11	7.12	7.18
log Q	14.14	4.51	4.61		4.50	4.50	4.52	4.55	4.82
	$e^{-P/40}$ 4,76			log(A+ 2L+3H) 8.90	Log(%A +2%L+ 4%H) 6.81				
	$e^{-P/12}$ logV 3.94	logV. logQ. 1.91	2.01	3.77	1.89	1.90	1.91	1.98	2.39
	$Pe^{-P/9}$ logQ 2,35		P logV 6.80						
Pk	1.90	2.08	2.10	2.41	2.15	2.09	2.08	2.18	2.30
Rq	2.14	2.29	2.18	2.38	2.39	2.28	2.22	2.21	2.55
logW	4.06	3.95	3.97	3.82	3.99	3.85	3.92	3.62	3.46
T	2.75	3.19	3.30	3.14	3.19	3.16	3.17	2.92	3.18
logV		2.22	2.12	4.32	2.20	2.21	2.23	2.28	2.71
P		6.99				A/Q 2.49 H/Q 2.28	$\log\frac{L1}{Q}$ 7.03	$\log\frac{A}{Q}$ 5.07 $\log\frac{L}{Q}$ 1.77	7.06
logD	3.93	4.22	4.23	4.37	4.23	4.20	4.21	4.39	5.42
Ra	2.24	1.95	1.92	1.70	1.96	1.78	1.95	0.96	

In this regression the multiple correlation improved to 0.970 and the residual error to 1.46 dB(A) after the degrees of freedom which had been lost in the first regression were allowed for.[1]

Figure 7.2 shows graphically the relationship between the percentage of heavy vehicles (P) for four selected traffic flows, based on equations (7.4) and (7.5). The distance from the flight path was set at 6.5 km, which was approximately the maximum recorded during the survey. Speed was set at 30 km.p.h. The other variables were set at the observed mean values, except for the width of the road based on the traffic flow.[2] Note how the four curved lines could be represented by four straight and parallel lines without any great loss of accuracy. This in fact occurs in the Johnson-Saunders type model.

7.2.4 <u>The Recalibration of Johnson-Saunders Model</u>

As with the previous model, it was found that when the L_{10} was regressed on the basic elements, a number of other independent variables, which were hypothesised as having an effect on the L_{10}, were in fact significant. Equations (7.6) and (7.7) show the results of these regressions without and with these extra variables:

$$L_{10} = 9.95 \log Q + 17.0P + 60.74 \qquad (7.6)$$

Multiple correlation (R) = 0.950

Residual error (R.E.) = 1.77 dB(A)

Log V was not significant with a t statistic of 1.62. The t statistic of Ra was 1.52.

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1. The individual statistics are difficult to interpret because of the multicolinearity of the elements due to the interaction. They were 4.87, 1.55 and 4.25 respectively

2. It was found that there was a significant relationship between the width of the road and traffic flow, and that the relationship could best be described by: $\log W = 0.16 \log Q + 0.55$.

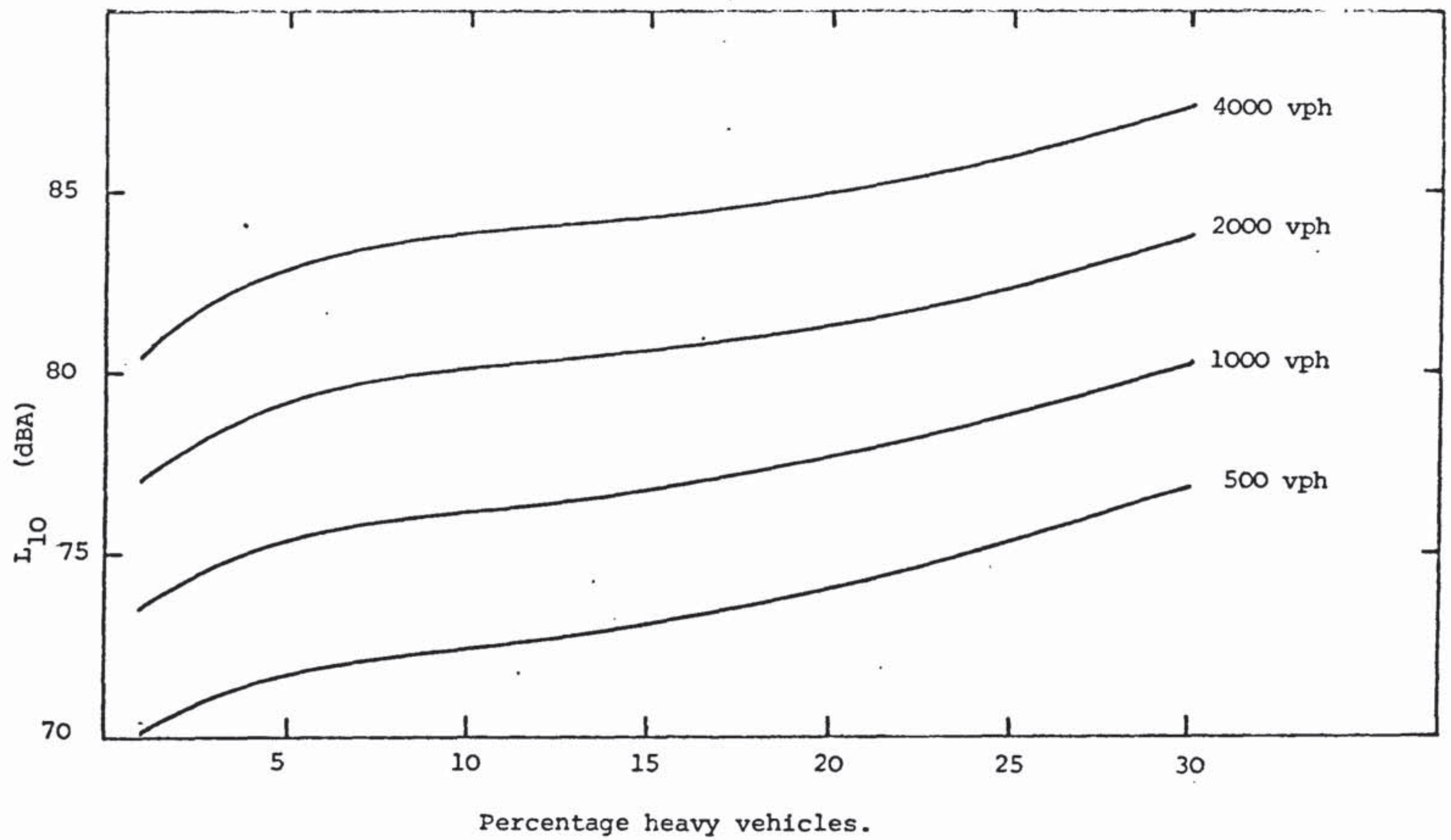

Figure 7.2 The relationship between L_{10} and the percentage heavy vehicles (P) for four values of Q. V = 30 km.p.h., D = 6.5 km (Based on equation 7.5 .)

$$L_{10} = 20.88 \log Q + .162P + 22.5 \log \; - 6.1 \log . \log Q \quad (7.7)$$
$$+ .38\,Pk + .49\,Rq - 8.1 \log W + .18T - 2.95 \log D$$
$$+ 11.25\,Ra + 20.58.$$

The multiple correlation was 0.966 and the residual error was 1.52 dB(A). Note that an almost significant interaction element between the logarithm of the total flow and the logarithm of the speed was included in equation 7.7; its t statistic was 1.91.[1]

In the second stage regression, (i.e. where $f(t_i)$ is based on equation 7.7) the multiple correlation improved to 0.969 and the residual error to 1.46 dB(A):

$$L_{10} = 0.43\, f(t_i) \log D - 0.48\, f(t_i) - 30.36 \log D + 119.2 \quad (7.8)$$

The reasons for expecting an interaction between the effects of speed and the percentage of heavy good vehicles were discussed earlier. When such an interaction element was included, based on the existing elements in the regression set, the t statistic of the proportion of heavy vehicles (i.e. P) on its own drops to 1.88. The t statistic of the interaction element is, however, 6.8:

$$L_{10} = 21.47 \log Q + 21.7 \log \; - 6.47 \log \; \log Q + 0.38\,Pk \quad (7.9)$$
$$+ 0.47\,Rq - 8.2 \log W + 0.19T + 10.96P \log \; - 2.97 \log$$
$$D + 11.14\,Ra + 24.88.$$

The multiple correlation was 0.965 and the residual error 1.53 dB(A). In the second regression these improved to 0.968 and 1.48 dB(A). This

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1. Some statisticians claim that, where a sign of a regression element is hypothesised, a one-tailed test may be used, in which case the interaction element would be significant. However, this claim is not generally accepted, see Lieberman (1971).

specification gives a marginally less good fit, but their relative merit is more a matter of judgement, based on their construct validity. A summary of the coefficients in all of the first stage regression equations is presented in Table 7.3. Some of the equations are described only in this Table. The coefficients from the second stage regression runs may be found in Table 7.2.

No. of 1st Stage Equations	$f(t_i)$ log D	$f(t_i)$	log D	Constant
5.4	0.46	-0.55	-24.4	114.2
5.7	0.43	-0.48	-30.36	119.2
5.9	0.42	-0.46	-29.58	117.3
5.13	0.40	-0.40	-30.57	115.5
5.14	0.48	-0.68	-34.12	132.7
5.10	0.42	-0.47	-27.91	115.7
5.11	0.43	-0.49	-30.59	119.4
5.12	0.38	-0.31	-29.21	109.4

Table 7.2: Regression Coefficients and Constants in "2nd Stage" Equations.

The multiple correlation and residual errors for both stages of all the specifications are shown in Table 7.4. The degrees of freedom and the error sum of squares are also included for the second stage regressions.

First Stage Regression			Second Stage Regression				
Equation	Multiple Correl-ation	Resid-ual Error	Equation	Multiple Correl-ation	Resid-ual Error	degrees of freedom	Error Sum of Squares
7.11	0.966	1.51		0.969	1.45	98	205.92
7.7	0.966	1.52	7.8	0.969	1.45	98	207.16
7.4	0.966	1.51	7.5	0.970	1.46	95	203.32
7.10	0.966	1.52		0.969	1.46	97	207.93
7.12	0.965	1.54		0.968	1.47	97	210.89
7.9	0.965	1.53		0.968	1.47	98	212.14
7.13	0.965	1.52		0.968	1.48	97	212.43
7.14	0.965	1.53		0.967	1.52	96	220.75

Table 7.4: Summary of the goodness of fit L_{10} prediction models tested.

Equation No.	Unique Elements	Common Elements: $\frac{\log V}{\log Q}$	Ph	Rq	logW	T	logV	logD	Ra	Contrast
7.4	43.7 + 13.2 + 0.44		+.34	+0.47	-8.1	+0.15		-2.71	+12.6	35.9
7.7	20.88 logQ + 0.162P	-6.1	+.38	+0.49	-8.1	+0.18	+22.5	-2.95	+11.25	20.58
7.9	21.47 logQ +10.96P logV	-6.47	+.38	+0.47	-8.2	+0.19	+21.7	-2.97	+11.14	24.88
7.13	21.9 log (A+2L+3H)	-6.79	+.42	+0.51	-7.8	+0.18	+24.7	-3.02	+9.83	20.02
7.14	20.99 logQ + 18 log(%C+2%L+4%H)	-6.08	+.39	+0.51	-8.2	+0.19	+22.5	-2.98	+11.40	23.02
7.10	$20.97 \log Q - 5.7\frac{A}{Q} + 10.15\frac{H}{Q}$	-6.1	+.38	+0.49	-8.0	+0.18	+22.6	-2.96	+10.92	26.00
7.11	$20.88 \log Q - 31.2 \log(\frac{L}{Q})$	-6.1	+.38	+0.47	-8.0	+0.18	+22.5	-2.93	+11.23	20.69
7.12	$21.33 \log Q - 22.6 \log\frac{A}{Q} - 2.6 \log\frac{L}{Q}$	-6.4	+.40	+0.48	-7.5	+0.17	+23.4	-3.09	+5.70	16.52
7.18	22.28 logQ + 0.165P	-7.5	+.42	+0.54	-6.7	+0.19	+27.0	-3.49		19.55

TABLE 7.3 "First Stage" Regression Equations

Three other regression equations were tested which incorporated modifications to the specification of the traffic/composition elements in equation 7.7. The insertion of the percentage of cars and the percentage of heavy vehicles (i.e. heavy commercial vehicles, and buses and coaches), instead of P, yielded only marginally different results than P, (see equation 7.10 in Tables 7.2, 7.3 and 7.4). Similar results were obtained by substituting the logarithm of P for P, but a slightly better fit was obtained by using the logarithm of (1 - P), i.e. the proportion of cars and two thirds of the proportion of light commercial vehicles (see equation 7.11). A marginally lower multiple correlation was found by using the logarithms of the separate percentages. In this case the logarithm of the percentage of lorries and buses was not significant, (see equation 7.12).

7.2.5 The Use of Gilbert and Crompton's Specification

The theoretical weakness of the specification of the classified vehicle counts in Gilbert and Crompton's model has been discussed in Chapter 3. Even so, the similarities between their survey design and that of the current research, and it being one of the few attempts which had previously been made to predict the kerbside L_{10} from non-free flowing traffic, make it incumbent to test its robustness.

In spite of a large amount of field work, the researchers have not made a definitive report to their findings.[1] Because of this, and as none of their models makes allowance for the effect of aircraft noise,

1. In fairness, of course, this may be because they also may have reservations about the theoretical validity of their specification.

the most favourable test was made of their model. This was to recalibrate their specification of the classified counts and to add all the significant variables as in the previous cases. The result gave a multiple correlation of 0.965 and a residual error of 1.52 dB(A). This was virtually identical with the statistical explanation given by the other models described above. However, it was found that the best fitting calibration showed a relatively low weighting for heavy vehicles compared to their original models, though as in the case of the definition of "P" the model was insensitive to variations in the calibration. The following was the result of regressing L_{10} on the independent variables including the Gilbert and Crompton specification.

$$L_{10} = 21.9 \log (A + 2L + 3H) + 24.7 \log V - 6.79 \quad (7.13)$$

$$\log V \log Q + 0.42Pk + 0.51Rq - 7.8 \log W +$$

$$0.18T - 3.02 \log D + 9.83\, Ra + 20.02$$

Where A = the number of car and motorcycles passing per hour.

L = the number of light commercial vehicles per hour.

H = the number of heavy vehicles per hour.

It was hypothesised that a better fit could be obtained by having an extra degree of freedom in the regression set through expressing Gilbert and Crompton's specification of the classified counts as $C_1 \log Q + C_2 \log (\%A + C_3\%L + C_4\%H) - 2$, where the percentages are the classified counts of the total flow. The hypothesis transpired, in fact, to be false, the residual error being 1.53 dB(A) and the multiple correlation 0.965 (see equation 7.14). In the second stage regression these came to 1.51 dB(A) and 0.967.

7.2.6 <u>The D.o.E. Model</u>

The D.o.E. model was the least successful in predicting the variation of L_{10}. When the L_{10} was regressed on the elements in equation 3 and the two aircraft noise control variables, it was found that the "log (V + 40 + 500/V)" element was not near being significant. (t statistic was 0.46.) Neither was the R_a element significant:

$$L_{10} = 10.43 \log Q + 67.92 \ (1 + 5H/V) - 4.54 \log D + 61.53 \qquad (7.15)$$

The t statistics were 23.4, 2.8 and 5.8 respectively. The multiple correlation was 0.931 and the residual error 2.06 dB(A). However, the logarithm of the mean speed would have had a t statistic of 5.4 if it was added to the regression set and "P" would have had a t statistic of 6.2. These would have riased the multiple correlation to 0.946 and 0.950 respectively if they were added separately. Even when these variables and the other significant variables in equation 7.7 were added to the regression set, the "log (V + 40 + 500/V)" still did not become significant, though its t statistic rose to 1.7. The interaction element was significant (t statistic = 2.4), though the "P log V" element, as in equation 7.9 had a significant partial correlation outside the regression set. In a stepwise regression run "P log V" replaced "log (1 + 5P/V)" in the regression set. Thus, the indications are that neither of the D.o.E. elements containing the mean speed variable contributes to the prediction of L_{10} over and above the specifications which were tested above. No empirical justification was found for the "log (V + 40 + 500/V)" element whatsoever, and neither has it been shown that the second element has merit over "P log V" or indeed over "P".

7.3 DISCUSSION OF NOISE MODELS

A surprising result of the above regressions is the similarity of the multiple correlation, both between the models and between the two regression stages. However, the higher the multiple correlation, the greater is a marginal increase as a proportion of the unexplained variance. There was an average difference of 0.03 between the multiple correlations in the two regression stages. This represents a statistical explanation of almost 10% of the unexplained variance. The significance of this, and the other differences between the correlations, depends not only on the extent of the differences but also on the relative number of degrees of freedom lost in the equations. The number of degrees of freedom lost in the regression analyses is the number of elements in the equation (including the constant). However, the degrees of freedom are not the sample size less the sum of the degrees of freedom lost in the two stages because this would involve the double counting of the logarithm of the distance to the flight path, the function of the traffic and built form variables and constant. Whether or not the "Ra" variable should be counted in the degrees of freedom is debatable as it does not appear in the final model. The conservative alternative was chosen, and there was therefore one less degree of freedom in the final models than in the first stage regression equations. Given this, the 0.03 difference between the two stages of the regression is highly significant, it being equivalent to a partial correlation of 0.3.

In order to compare the goodness of fit of the models, two additional statistics have been appended to Table 7.4: the sum of the squares of the residual errors, and the degrees of freedom. The degrees of freedom lost are counted from the elements in the regression set plus the constants which were calculated iteratively. This places Delany's theoretical model at a relative disadvantage when comparing the goodness of fit. The equations in Table 7.4 are written in descending order of goodness of fit according to the residual errors given the diverse forms of the equations, there is no one statistical test of the significance of the difference of goodness of fit between them. However, a difference of means test between the "Z" scores of 0.970 and 0.967 yielded a t statistic of 1.71. Thus, there are no grounds for selecting or rejecting any of the models on the grounds of goodness of fit. The exception to this is the D.o.E. model where its characteristic elements were found not to have empirical merit. It was found by using chi-squared tests that the residuals were not significantly differently distributed from a normal distribution in any of the regressions. The highest single residual was approximately 2.8 standard errors. The discussion proceeds to an inspection of the construct validity and significance of the separate elements in each of the models.

7.3.2 The Effect of Aircraft Noise

The logarithm of the distance to the flight path of the aircraft approaching London Airport was generally the most significant element in the first stage regressions apart from the specifications of the traffic flow and composition. This element was also found to be very highly significant[1] on its own and as an interaction element in the second stage regressions. It is submitted, therefore, that this form of controlling for the noise of aircraft is acceptable on the grounds of construct validity, conceptual simplicity and statistional significance.

1. The standard notation of significance is used: Significant = P 0.05; highly significant = P 0.01; and very highly significant = P .001.

The relationship between the L_{10} and the distance from the flight path is shown graphically, in Figure 7.3, for four selected values of traffic flow. The percent of heavy vehicles (i.e. "P") is set at 15% and the other variables as in Figure 7.2. It may be noted how aircraft do not affect the L_{10} when the traffic flow is as high as 4000 vehicles per hour (v.p.h.). Their effect increases as the traffic flow decreases. When the flow is 500 v.p.h., being close to the flight-path increases the L_{10} by an average of 4 dB(A).

Even though the specification of the "log D" element has been shown to be acceptable, some doubt may be expressed on the inclusion of the other aircraft noise variable (i.e. the ratio of aircraft heard to the traffic flow: "Ra"). It was originally included to control for the interaction between the aircraft noise and the traffic noise. It transpired in the analyses to be marginally non-significant (see Table 7.1). One of the reasons for the similarity between the models may be due to the multicolinearity of the variables in the regression set. There was in fact a correlation of almost 0.6 between "Ra" and the logarithm of the total flow. A third demerit of the element was the subjective nature of the measurement of the number of aircraft heard, the observations being affected amongst other things by the loudness of the traffic noise. This feature would also make its prediction impossible when assessing design year noise levels. Equation 7.16 shows the result of omitting the "Ra" element from the Johnson-Saunders type model (i.e. equation 7.7):

$$L_{10} = 22.28 \log Q + .42Pk + .54\ Rq - 6.7 \log W + 27.9 \log V + 16.6P - 3.49 \log D + .19T - 175 \log Q \log V + 19.55. \quad (7.16)$$

R = 0.965

R.E. = 1.53 dB(A)

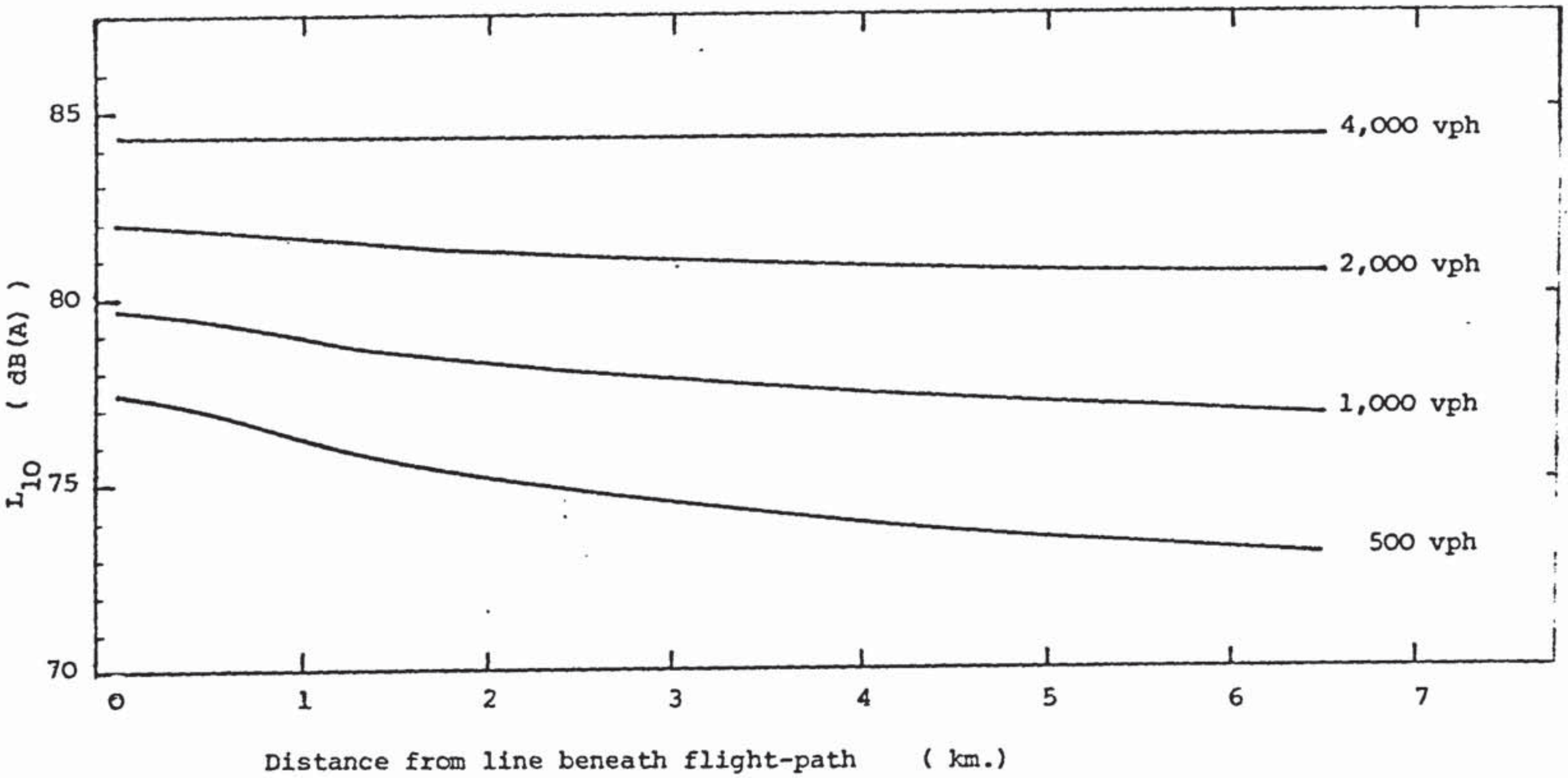

Figure 7.3. The relationship between L_{10} and the distance from the line beneath the flight-path for four values of Q. P = 15% and V = 30 km.p.h. (Based on equation 7.5)

The "$f(t_i)$" variable in the second regressions was always non-significant on its own. For example, when it is omitted from equation (7.8) the multiple correlation drops a point to 0.968 and the residual error rises to 1.47 dB(A). The t statistics of the remaining elements soar from between 4 and 5 to over 30. Equation (7.17) shows the calibrations of equation (7.16) when this variable is omitted from it:

$$L_{10} = 0.30\ f(t_i)\ \log D - 24.0\ \log D + 88.88 \qquad (7.17)$$

In this case the multiple correlation is 0.969 and the residual error 1.39 dB(A).

7.3.3 The Effect of Vehicle Speed

The logarithmic function of the mean speed variable has been included in the above equations in six forms. In all but equation 7.4 (i.e. the Delany type model) and equation 7.15 (i.e. the D.o.E. type model) it was included on its own and as an interaction element with the logarithm of the total flow. In every case it was significant on its own. In the Gilbert and Crompton type model it was very highly significant. The interaction element was of border line significance, except in the case of the Gilbert and Crompton type model where it was also highly significant. This is compatable with their view that other things being equal the L_{10} is lower when vehicles are evenly spaced. However, this is not clearly borne out in the other models, though this may be because of its greater multicolinearity with the "log Q" element.

There is little to choose between equations 7.7 which contains the element "P" and equation 7.9 which contains the interaction element consisting of the product of "P" and "log V" instead of "P". The latter has the merit of construct validity while the former is simpler. This is particularly a virtue where there may be a large degree of inaccuracy in design year estimates of speed. The interaction element involving speed and the proportion of heavy vehicles in the Delany type model (i.e. "$e^{-P/12}$ log V") was also very highly significant. Figure 7.4 shows graphically the results of this specification for three selected values of "P", where the traffic flow is 2000 v.p.h. and the distance from the flight-path is 6.5 km. The other variables were set as in Figure 7.2.

7.3.4 The Propogation Variables

The logarithm of the width of the carriageway was very highly significant in each of the regression equations. The ratio of flow on the near side to that of the far side (i.e. Rq) and the index of parking ("Pk") were also significant, though the latter's t statistic in one model was below 2. The combination of these three variables into one element representing the distance to the "centre of gravity" of the traffic flow was discussed in Chapter 4 (see equation 4.2). When the logarithm of this variable was included in the regression set, it was found to be consistently very highly significant (t statistic $>$ 4) and provided almost as good a fit as the three variables taken separately. The following is the result of including this element in the Johnson-Saunders type model:

$$L_{10} = 21.4 \log Q + 0.18T + 25.1 \log V - 7.3 \log Cg + 15.9P - 6.9 (\log V)(\log Q) - 3.6 \log D + 21.57 \qquad (7.18)$$

Where Cg is the distance to the centre of gravity of the traffic flow as in equation 4.2, (its t statistic was 4.6). The multiple correlation was 0.963 and the residual error was 1.55 dB(A). In the second stage regression of this model:

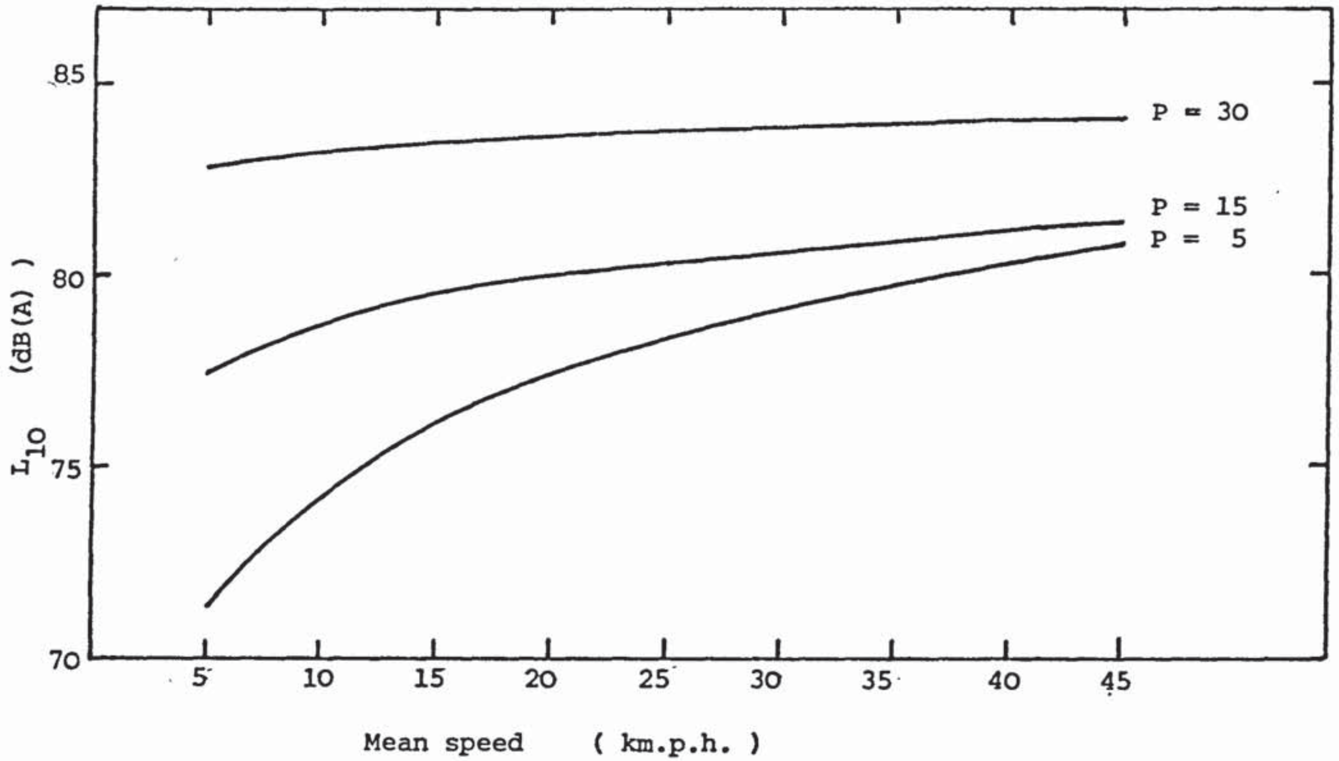

Figure 7.4. The relationship between L_{10} and the mean speed of vehicles for three values of P. Q = 2,000 v.p.h. and D = 6.5 km. (based on equation 7.5).

$$L_{10} = 0.297\, f(t_i) \log D - 23.67 \log D + 89.18 \qquad (7.19)$$

$R = 0.968$

R.E. = 1.46 dB(A)

This may be rewritten:

$$L_{10} = \log D\, (6.36 \log Q + 0.0053T + 6.39 \log V - 2.17 \log Cg + 4.72\, P - 2.05\, (\log V)\, (\log Q) - 7.03) + 89.18 \qquad (7.20)$$

The t statistic of "$f(t_i)$", which was excluded from the regression was 1.53, and that of the one-way streets dummy variable 1.52.

The remaining propogation element, which represented the reflection of sound from adjacent buildings was highly significant for the buildings on the near side of the road in each of the models. It was not significant for the far side of the road, and no interaction was found between the effect of buildings on each side of the road.

7.3.5 The Non-significant Variables

The remaining variables, which were hypothesised in Chapter 3 as effecting the L_{10}, were not found to make a significant contribution to the statistical explanatory power of the models. There was less noise in the residential streets, but not significantly so. The other land-use variables had even less effect on the L_{10}. None of the dummy variables representing the presence of nearby bus stops or pedestrian crossings, or any combinations of them which were tested, proved to be significant. Neither did the wind speed nor direction, time of the day, whether the road was dry, nor the index of queueing have a significant effect. Unlike in Gilbert and Crompton's findings, the index of the pattern of arrival did not make a significant contribution, neither did the individual indices for each side of the road.

The dummy variable representing whether or not the streets had a one-way traffic flow was not near being significant in any of the first stage regression equations (the maximum t statistic was 1.4). However, in the second stage regressions its t statistic rose to between 1.5 and 1.8. There was less noise on the one-way streets. The result of adding the one-way dummy variable (F_1) to equation (7.19) was:

$$L_{10} = 0.309\ f(t_i)\ \log D - 24.8 \log D - 0.74\ F_1 + 89.07 \qquad (7.21)$$

$R = 0.970$

$R.E. = 1.45$

The t statistic of F_1 was 1.78.

There was a slight, but not significant, relationship between the L_{10}, and the gradient of the road. This was in accord with the findings of Blitz (1973) who did not find positive results in a survey specially designed to determine the effect of the gradient on noise in non-experimental conditions. This may be due to the reduction in noise of vehicles going down hill on one side of the road largely balancing the increased noise on the other. It should be noted that the D.o.E. (1975) recommend the addition of "+ 0.3 G" in this model, where G is the gradient.

7.4 OTHER NOISE MODELS DEVELOPED

The emphasis in the analysis was on the development of models for predicting the L_{10}. This was because of the position of the index in current legislation and planning practice. The availability of the data, however, afforded the opportunity of regressing the L_{50} and the L_{90} on the independent traffic and built form variables which were used in developing the L_{10} models. This will enable the belief that the L_{10} is superior to the L_{50} or indices based on the three percentiles to be tested with the data collected in the survey of pedestrians responses. The standard deviation of the distribution of the normal levels (in dB(A)) were also regressed on the independent variables.

7.4.2 The L_{50} Model

The same model specifications were tested in regressing the L_{50} as in the case of the L_{10}, and similar results were found. There was little to choose between the models on the grounds of goodness of fit. The following models are submitted because of their simplicity.

$$L_{50} = 14.33 \log Q + 2.86 \log V + 9.61 P + 0.25T - 6.48 Cg - 0.95 L_R + 1.26F_1 - 3.15 \log D + 37.15 \quad (7.22)$$

$R = 0.969$

$R.E. = 1.67$

t statistic = 26.9, 2.5, 4.1, 3.9, 3.6, 2.4, 2.5, and 4.6 respectively.

Where L_R represents residential land use,[1] and F_1 one way streets. The other symbols are the same as used above. The result of the second stage regression was:

$$L_{50} = 0.30 f(t_i) \log D - 15.77 \log D + 79.71 \quad (7.23)$$

$R = 0.972$

$R.E. = 1.62$

t statistics = 23 and 42 respectively.

The multiple correlations were the same as for the L_{10} models, but the residual errors were higher, because of the greater variance in the

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1. L_R was defined as being equal to one when the land-use was residential or predominantly residential on each side of the road and within 50 metres of the observation point, and zero when it was not.

observed L_{50}. None of the interaction elements involving 'log Q', 'log V' or 'P' had significant partial correlations. On the other hand, dummy variables representing residential land use and one way streets were significant.

7.4.3 The L_{90} Model

When L_{90} was regressed on the independent variables it was found that the percentage of heavy vehicles (P) the Logarithm of the mean vehicle speed, and the logarithm of the distance to the 'centre of gravity' of the traffic flow (log Cg) were not significant as was the case in the L_{10} and L_{50} models. This was reflected in the relatively low multiple correlations, and high residual errors.

$$L_{90} = 11.83 \log Q + 0.26T - 1.30L_R + 1.65F_1 - 3.39 \log D + 40.7 \quad (7.24)$$

R = 0.909

R.E. = 2.54

t statistics = 19.9, 2.8, 2.2, 2.2 and 3.4 respectively.

If 'P' had been included, its t statistic would have been 1.90 and the result would have been:

$$L_{90} = 11.80 \log Q + 0.53P + 0.25T - 1.18L_R + 1.67F_1 - 3.59 \log D + 41.37 \quad (7.25)$$

R = 0.912

R.E. = 2.50

t statistics = 20.1, 1.9, 2.8, 2.0, 2.2 and 3.7 respectively.

$$L_{90} = 0.30\, f(t_i) \log D - 13.40 \log D + 74.35 \quad (7.26)$$

R = 0.912

R.E. = 2.50

t statistics = 13 and 23 respectively.

7.4.4 The Standard Deviation of the Noise Levels

The controversy about the weight which should be given to the variation in the sound levels, in a noise index, has been discussed in Chapter 3. It was therefore decided to test the relationship between the pedestrian responses and the estimated standard deviation of the noise levels. To this end the observed standard deviations of the sound levels (in dB(A)) were regressed on the traffic and built form variables, using the stepwise procedure:

$$S.D. = -3.63\ (10^{-4})\ Q + 2.4 \log (R_q) + 1.59 \log D_n + 4.67 \qquad (7.27)$$

$R = 0.657$

$R.E. = 0.70$ dB(A)

$N = 43$

t statistics = 3.5, 4.0 and 3.2 respectively.

Where D_n is the distance to buildings behind the observation point.

Less than half of the variance in the standard deviation was explained by the elements in the regression model, compared to over 90% in the noise models. As expected the standard deviation decreased as the traffic flow increased. The second element represents the greater variation in the sound levels when the flow on the near side of the road increases relative to the far side. The construct validity of the third element is less easy to confirm. It would appear that the reflection of the sound from buildings may be sufficiently distinct in time from the sound coming directly from the traffic to influence the variation significantly.

7.5 PEDESTRIAN DELAY MODELS

7.5.1 Introduction

The same method was used for developing the pedestrian delay models as was used for the noise models. The observed values were regressed on independent variables chosen by deduction, by a literature review, and in a few cases by induction. There were two basic dependent variables, the mean time delayed (D) and the percentage of time delayed (%D). The logarithm of the former and the logistic transformation of the latter were also regressed on the independent variables. It was found in all cases except the "log D" model that the Adams' formula gave a considerably better fit than simple transformations of the independent variables.

7.5.2 The Percentage Delay Model

The model for predicting the percentage of time that the observer judged that he would not be able to cross the road proved to be the most accurate in terms of multiple correlation. The minimum acceptable headway (MAH) which gave the best fit in the Adams' type specification was 3.5 seconds. For the 86 observations of two-way streets, there was a correlation of 0.970 between %D[1] and the Adams' formula (i.e. $100 - 100e^{-3.5Q}$, see equation 3.12). When % D was regressed on this specification, two other variables were found to be very highly significant. These were the variance of the number of vehicles passing in 10 second intervals on the near side flow (D_{nv}),[2] and the mean speed of vehicles in the near side flow (V). The calibrations were:

$$\%D = 116.3\ (1 - e^{-3.5Q}) - 0.026D_{nv} - 0.43\ V + 12.7 \qquad (7.28)$$

N = 86

R = 0.981

R.E. = 5.5% points

t statistics = 27.8, 4.0, and 5.6 respectively.

1. A measurement adjustment, which was made, is described in Appendix 8.

2. This is Gilbert and Crompton's index of dispersion for the near side multiplied by the traffic flow for 10 seconds.

where Q = the total flow of vehicles in vehicles for 10 seconds. The width of the street, the proportion of heavy vehicles, the ratio of the near side flow to the far side flow, the index of queueing or the pattern of arrival of the vehicles in the far side flow were not near being significant if added to the regression set.

It was found after the above regression that two observations had residual errors greater than three standard residual errors. A further regression analysis was accordingly made, for the reasons stated in Chapter 4, without these two observations. In this run the index of density which was described by Gilbert and Crompton (Crompton, 1971) was found to be significant. This variable was calculated by dividing the total traffic flow (v.p.h.) by the mean speed of the traffic in the near side flow.[1] The goodness of fit was much improved:

$$\%D = 115.7\,(1 - e^{-3.5Q}) - 0.017D_{nv} - 0.55V - 11.5Q/V + 16.8 \quad (7.29)$$

$N = 84$

$R = 0.989$

$R.E. = 4.29$

t statistics = 33.0, 3.0, 7.2 and 2.6 respectively.

It was postulated that other variables might more correctly affect the percentage delay through changing the MAH. This was tested in the case of D_{nv}. The higher its value the less became %D. Therefore, a function of D_{nv} was subtracted from the MAH (i.e. t) in the Adams' specification. D_{nv} was standardised to zero mean and unit variance. A fraction of this variable was then subtracted from the MAH in the Adams'

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1. The assumption was made here that for all practical purposes the speed on the far side was the same as on the near side.

element, to determine whether a marginal change in the MAH made a marginal improvement in the goodness of fit. This made the D_{nv} variable not significant, but even when it was included in the regression set, the multiple correlation was marginally less than in equation 7.32, which remains the recommended model.

7.5.3 The Logit Percentage Delay Model

As has been discussed above, models were developed for predicting the logistic transformation of the percentage of time delayed (logit %D) to enable the prediction of '%D' in such a way that the result would be constrained between 0 and 100. '%D' may be estimated by using the inverse of the logistic transformation:

$$\%D = 100 \frac{10^x}{1 + 10^x} \tag{7.30}$$

where x is the estimated 'logit %D'.

When 'logit %D' was regressed on the Adams' specification (equation 4.3) and the other independent variables which were hypothesised to be related to pedestrian delay, the result was:

$$\text{Logit}\ \%\ D = 1.41Q - 0.018D_{nv} - 0.0125V + 1.4D_{nv}\,(10^{-7}) + 1.99\,(1 - 3^{-3.5Q}) - 0.637 \tag{7.31}$$

$$N = 86$$

$$R = 0.970$$

$$R.E. = 0.171$$

When D_{dn} is a second order interaction variable comprised of the total flow speed and the combined index of dispersion of the two way flows:

$$D_{dn} = Q/VD_c \tag{7.32}$$

where 'D' is the combined index of dispersion for the flow on both sides of the road. This element was highly significant. The other variables were all very highly significant. However, as in the case of '%D' two observations were found to have unacceptably high residual errors. When these were omitted:

$$\text{Logit } \%D = 0.1Q - 6.7D_{nv}\ (10^{-4}) + 0.014V + 0.93 \log (e^{3.5Q} - 1) + 0.41 \qquad (7.33)$$

$N = 84$

$R = 0.984$

$R.E. = 0.12$

Each of the variables was very highly significant but 'D_{dn}' was no longer so.

There was a correlation of 0.9 between the estimate of percentage delay, which was calculated by applying equation 7.29 to equation 7.33 (%D), and the observed values.

7.5.4 The Mean Delay Model

The Adams' formula for estimating mean delay from traffic flows whose headways are poisson distributed was described in equation 3.11. In order to test how helpful it is in estimating the observed delay in the present context, the delay (D) may be regressed either on it in its entirety or on its separate elements. The latter was chosen as there would be an extra degree of freedom in the regression set. It transpired, however, that three observations had residual errors greater than 3 R.E. in the first run, two in the second and one in the third. These tended to have large values of D and it was noted that there was a very highly significant correlation (0.86) between the dependent variable and the residual. Thus there was a degree of heteroscledasticity which rendered regression analysis inappropriate with such a specification of the variables.

One way of reducing the correlation between D and D - D is to take log D as the regressand. There is another reason, which was noted in Chapter 5, why a model should be developed for predicting log D. It was because this specification of the delay variable would be the most appropriate to relate to the values of the subjective responses to the delay in order to test the hypothesis on the relevance of Stevens' Power Law of Psychophysics.

7.5.5 'The Log Delay' Model

When the logarithm of mean delay was taken, it was found that it had a remarkably high correlation ($r = 0.976$) with the percentage of time delayed. The correlation between D and %D was 0.697. The strength of the former relationship was due to the similarity between the logarithm of the sum of squares of the delay periods which was the basis of 'log D' and the sum of the delay periods which was used in calculating '%D'. It followed, therefore, that the specification of the "%D" model should prove a sound basis for the statistical explanation of the variation in 'log D'. This transpired to be correct. The '$(1 - e^{-3.5Q})$' element had a correlation of 0.94 with 'log D'. When other significant variables were included in the regression set the multiple correlation rose to 0.973. This was the same as was achieved with the logarithm of the Adams' formula for predicting mean delay. The regression equation containing the '$(1 - e^{-3.5Q})$' element contains two other variables which would themselves be difficult to predict. There were the logarithms of the distance to the centre of gravity of the traffic flow and the variance of numbers of vehicles passing in the 10 second intervals in the near-side flow. The additional significant variables when 'log D' was regressed on the deductively based element were the logarithm of the percent of heavy goods vehicles and the speed of the vehicles in the near side flow. The former became significant when two outlying observations were omitted. As the Adams specification allowed an extra degree of freedom, 'log D' was regressed on the two elements:

$$\log D = \log (e^{Qt} - 1 - Qt)/ Q \qquad (7.34)$$
$$= \log (e^{Qt} - 1 - Qt) - \log Q$$

However, the 'log Q' element was not significant in the regressions:

$$\log D = 0.718 \log (e^{3.5Q} - 1 - 3.5Q) - 0.020V + 0.15 \log P + 1.81 \qquad (7.35)$$

R = 0.973

R.E. = 0.17

N = 84

t statistics = 26.2, 8.0 and 2.8 respectively

where P = % of heavy vehicles + $\frac{1}{3}$ of the % of light commercials.

The corresponding regression equation when all the observations were including was:

$$\text{Log } D = 0.722 (\text{Log } (e^{3.5Q} - 1 - 3.5Q) - 0.019V + 1.62 \qquad (7.36)$$

R = 0.957

R.E. = 0.21

N = 86

t statistics = 24.1 and 6.2 respectively

The prediction of log D was the only context in which a specification other than that of Adams gave an equally good statistical explanation of the variance in the delay variable. This is because of the extremely close relationship between 'log Q' and 'log $(e^{3.5Q} - 1 - 3.5Q)$, the r = 0.999 $\log D = 1.66 \log Q - 0.021V + 0.16P - 3.19$ (7.37)

R = 0.971

R.E. ≐ 0.18

N = 84

t statistics 2 29.7, 8.6 and 2.8 respectively

Equation 7.37 is submitted as being the recommended model because of its simplicity. It should be noted, though that the correlation between 'log Q' and the Adams' specification tends to reduce as the values of the M.A.H. rise, and therefore equation 7.35 may be marginally more robust.

7.6 THE AIR POLLUTION MODELS

The models developed for predicting the degree of carbon monoxide and smoke in the atmosphere on the kerbside were much less accurate than those for predicting the L_{10} or the pedestrian delay. The proportion of the variance of the air pollution variables which could be statistically explained varied between 50% and 60%. This appeared to be largely due to not being able to control for the rate of dispersion of the pollutants. Unlike in the case of noise and pedestrian delay there is not the same background of empirical and theoretical research which would require checking and developing. The models are, therefore, based on induction to a greater extent than the other models. As many of the models which emerged using the stepwise procedure had similar multiple correlations, greater reliance was placed on construct validity and simplicity. As will be seen in the following chapter, the correlations between both carbon monoxide and smoke and the annoyance encoded for air pollution were relatively low; the model development, which was intractable anyway, did not require the same rigorous approach as did noise and pedestrian delay.

One observation, whose very high air pollution values were noted above, accounted for almost half of the unexplained variance when the carbon monoxide variable (CO) was regressed on the independent variables. This variable was also an outlier in the smoke (S) regression. When this observation was omitted other variables had residuals greater than 3 standard errors. These were not the same in each case.

As hypothesised the wind speed was very highly significant in all the regression analyses. The speed of the traffic in the near side land was also significant, very highly so in the case of CO. In the case of both CO and smoke, there was an increase with the traffic flow but at an ever increasing rate such that the logarithm of the traffic flows gave a similar degree of statistical explanation as the traffic flow itself. In both cases when the dependent variable was regressed on the numbers of cars (including motorcycles), light commercial vehicles and heavy vehicles, the numbers of light commercials was by far the most significant variable.

This was partly due to correlation which existed between the independent variables and had the consequence that the regression coefficients were difficult to interpret. It is submitted that the robustness of the model could be improved by avoiding using the number of light commercials as an independent variable.

7.6.2 The Carbon Monoxide Models

When CO was regressed on the independent variables, three observations were found to have residual errors greater than 3 standard errors. When these observations were omitted:

$$CO = 4.99 \log Q + 0.0022 D_{nv} - 18.2 \log V + 0.38 + 2.43 W_v \log V + 15.4 \qquad (7.38)$$

$N = 114$

$R = 0.790$

R.E. = 3.56

t statistics = 5.4, 2.4, 6.2, 2.2 and 2.7 respectively

However, the correlation between CO and the residuals for this equation was 0.22, which was significant. Because of this and the need in latter analyses for an estimate of the logarithm of the environmental variables, the following model was developed:

$$\text{Log CO} = 0.56 \log Q - 0.135W_v - .019VV + .026Pe^{-P/9} \log Q + .00024\ VW_v - .46 \qquad (7.39)$$

Where P = % of heavy vehicles plus a third of light commercials and Rq = ratio of nearside flow to that of the far side.

R = 0.801

R.E. = 0.259

t statistics = 9.5, 3.9, 4.9, 2.2, and 2.4 respectively.

N = 116

7.6.3 The Smoke Models

As in the case of CO, there was a significant correlation between the residual errors in the smoke model and observed levels of the dependent variable. The following is the recommended model for predicting the logarithm of the smoke levels. In this case there was no significant heteroscedasticity, but two observations were found to have unacceptably high residual errors.

$$\text{Log (Sm)} = 0.001\ v \log Qn - 0.036V + 0.188 \log Pn - 0.0275\ W_v + 0.64 \qquad (7.40)$$

R = 0.734

R.E. = 0.17

t statistics = 9.8, 9.7, 3.0 and 4.4 respectively

Where the subscripts "n" refer to the flows on the near side of the road, and W_v = wind speed. It should be noted that when Log (Sm) is regressed on the data for the combined flows the two very highly significant elements involving the speed of the traffic ceases to be significant:

$$\text{Log (Sm)} = 0.345 \log (Q) + 0.175 \log (P) - 0.031 W_v + 0.009 \qquad (7.41)$$

$$R = 0.714$$

$$R.E. = 0.179$$

t statistics = 9.3, 2.3 and 4.9 respectively

When smoke was being regressed on the independent variables, in the best specification none of the residuals were greater than three times the standard error, even though that was a significant degree of heteroscadasticity ($p = 0.04$). The model is therefore reported for reference:

$$Sm = 1.07\ (10^{-5}) VQ_n - 0.185V + 10.41Pn - 0.93Pk_n - 0.47W_v + 9.94 \qquad (7.42)$$

$$R = 0.687$$

$$R.E. = 3.26$$

t statistics = 6.5, 4.7, 2.5, 2.4 and 4.0 respectively

7.6.4 The Error in the Air Pollution Models

It is argued that a significant proportion of the error in the air pollution models is the result of the factors which affect the dispersion of air pollutants not being properly defined and specified in the regression models. While measuring the variables which affect dispersion may be an intractable problem, it is useful to have an indication of the proportion of the unexplained variance for which they are responsible. Such an indication may be had from the correlation between the residuals from the smoke and CO models. One of the reasons why CO was chosen for measurement was the fact that its emission was inversely related to that of smoke with respect to the proportion of diesel driven vehicles. Also, a wide range of independent variables had been placed in both potential regression sets prior to using the stepwise procedure. Therefore it is submitted that the residual error that is common to both models is caused by the mis-specification of determinants which are common to both the variables, and that it is unlikely that more than a small proportion of the common error is due to the mis-specification of the traffic and built form variables. In fact, as much as 99% of the unexplained variance in each model could be statistically explained by the residual error in the other. This statistic was calculated by applying the "logarithmic" models (equations 7.39 and 7.40) to all the observations, including the observation mentioned above where the pollution levels were very high. When this observation was omitted, the percentage fell to 98%. Thus if, for example, $\frac{3}{4}$ of this error could be accounted for, the multiple correlations of the air pollution models would be comparable to the noise and pedestrian delay models.

7.7 The Prediction of Vehicle Speed and Pattern of Arrival

Attempts were made to develop models for predicting the speed of vehicles and their pattern of arrival from the other traffic variables, so that estimates could be made of these variables, which could be used in predicting the environmental variables in circumstances where their values were not available. Unfortunately, little progress was made, for a number of reasons. Firstly, the multiple correlations tended to be relatively low. In the case of speed and its logarithm, none of the independent variables were found to be significantly related to it, except the index of queueing.[1] When queueing was controlled for, none of the other variables became significant, except some aspects of the pattern of arrival.

Only the total flow and its logarithm remained in the regression set when the index of dispersion was regressed using the stepwise procedure, using the 10% significance level.

$$(I.D.) = 0.19 \log Q + 8.3Q(10^{-5}) + 0.6 \qquad (7.43)$$

N = 110

R = 0.574

R.E. = 0.24

t statistics = 1.96 and 1.81 respectively

Where ID = the index of dispersion, (as defined by Gilbert and Crompton)

Q = the total flow in vehicles per hour

The goodness of fit was much better when the variance of the numbers of vehicles counted in the 10 second periods (D_v) was regressed on the independent variables:

$$D_v = 0.0029Q - 1.02 \log Q - 0.07W_e + 2.53 \qquad (7.44)$$

R = 0.947

R.E. = 0.80

t statistics = 17.3, 3.0 and 2.0 respectively

Where W_e = the effective width of the street (i.e. the width minus the of the parking dummy variables).

The corresponding statistic for the nearside flow (D_{vn}) figures in a number of the environmental variable prediction models. The results of

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1. This was the frequency of the times that the observer noted on the tape recorder that the speed of the traffic was zero.

its regression were similar to that above, except that the ratio of the flow on the nearside to that of the far side (R_q) replaced the effective width:

Dvn	$= 0.0026Q - 1.05 \log Q + 0.27R_q + 1.98$	(7.45)
R	$= 0.907$	
R.E.	$= 1.04$	

t statistics = 13.2, 2.4 and 2.0 respectively.

7.8 SUMMARY

7.8.1 The Noise Models

A feature of the L_{10} models which were developed was the close similarity between their standard errors. This places a large degree of responsibility on the judgement of researcher or the reader as to the relative weight which should be put on the other criteria for assessing the models, such as robustness and simplicity.

The logarithm of the distance to the flight path was found to be very highly significantly related to the L_{10}. It was submitted that there was an interaction between the noise from the aircraft and the noise from the traffic. Figure 7.3 shows how the aircraft have no effect on the L_{10} when the traffic is over 4,000 v.p.h., but increases the L_{10} by 4dB(A) when the flow is 500 v.p.h.

The three types of model which were tested, were identified according to the way in which the composition of the traffic was specified. Delany's type of model had the disadvantage of complexity and of the loss of a greater number of degrees of freedom. On the other hand, there was the unknown advantage it may have in robustness resulting from its theoretical basis. There was a query on the construct validity of Gilbert and Crompton's type of model though it had an error only slightly greater than the others tested. The Johnson and Saunders type of model was the simplest mathematically, and its goodness of fit was marginally better than those above. This model may therefore then be favoured for planning purposes. The goodness of fit of the DOE model either on its own or recalibrated appeared to have little empirical merit.

The logarithm of the mean speed of vehicles on the nearside made a significant contribution to the estimation of L_{10}, both on its own and interacting with either the logarithm of the total flow or with the percentage of heavy vehicles. The logarithm of the distance to the centre of the road, the ratio of traffic on the near side to that of the far side and the index of parking were all significant. Little accuracy was lost when these variables were combined into an index of the distance from kerbside to the "centre of gravity" of traffic flow (see equation 4.2). The index of noise reflection was consistently highly significant for the buildings on the near side of the road, but it was not significant for the far side.

Equally good results were obtained when the L_{50} was regressed on the independent variables using the Johnson-Saunders type of specification. However, when the L_{90} was regressed, a number of the independent variables became not significant. Less than half of the variance of the observed standard deviation could be statistically explained by the traffic and built form variables. Table 7.5 summarised the accuracy of the models for predicting the various dependent variables.

Dependent Variable	Equation	Multiple Correlation	Residual Error
L_{10}	7.8	0.969	1.45 dB(A)
L_{50}	7.23	0.972	1.62 dB(A)
L_{90}	7.25	0.912	2.50 dB(A)
(dB(A))	7.27	0.657	0.70 dB(A)

Table 7.5: The Accuracy of the Noise Models

7.8.2 The Pedestrian Delay Models

The highest multiple correlations of the study were found when the logarithm of mean delay and percentage delay were regressed on the independent variables. However, it was found that there was a wider range of error in the delay predictions than in the case of noise, and a number of outlying observations had to be omitted before the final regressions. Further, it was found that there was a significant degree of heteroscedasticity in the mean delay model, but this problem was resolved by taking its logarithm as the dependent variable. Table 7.6 summarises the accuracy of the models. The mean vehicle speed was highly significantly and inversely related to all of the dependent variables. The percentage of heavy vehicles, and indices of vehicle dispersion and density were significant in some of the models.

Dependent Variable	Equation	Multiple Correlation	Residual Error
%D	7.29	0.989	4.29% points
Logit % D	7.33	0.984	0.12
Log D	7.35	0.973	0.17

Table 7.6: The Accuracy of the Delay Models

7.8.3 The Air Pollution Models

The errors in both the CO and Smoke models were linearly related to the dependent variables to such an extent that it was not appropriate to use regression analysis. Taking the logarithm of the pollution levels as the dependent variables eliminated most of the heteroscedasticity, but it only marginally improved the multiple correlations and it did not eliminate outlying observations.

Table 7.6 shows the multiple correlations and the residual errors for each of the models. It is submitted that the relatively low multiple correlations are caused by the omission of variables which affect the rate of dispersion. The wind speed was highly significant in all of the models, but dummy variables representing the direction of the wind were not. There seems little scope for improving the accuracy of the models by changing the specification of the traffic and built form variables.

Dependent Variable	Equation	Multiple Correlation	Residual Error
CO	7.38	0.790	3.56 ppm
Log CO	7.39	0.801	0.26
Smoke	7.42	0.687	3.26 micro gr/m^3
Log (Sm)	7.40	0.734	0.17

Table 7.6: The Accuracy of the Air Pollution Models

7.8.4 The Speed and Traffic Dispersion Models

It was not found possible to develop models for predicting mean speed from the data collected. This appeared to be caused by the varying degrees of congestion on a number of the streets.

The index of dispersion of the traffic flow could only be described as a function of the traffic flow, and its multiple correlation was relatively low at 0.574. However, this was not the case for the variance of in the traffic flow where there was a multiple correlation of 0.947 with the significant traffic and built form variables.

7.9 MODELS USED IN RESPONSE SURVEY

Not all the independent variables which were in the models for predicting the environmental variables were measured during the pedestrian survey. Therefore, some of the models had to be simplified before using them in the second survey. Decision had also to be made about which model should be used, in cases where there were more than one to choose from.

In the case of noise, it was decided to use the Johnson-Saunders type model for both the L_{10} and L_{50}, both because of their simplicity and accuracy. However, the mean speed of the vehicles was one of the variables which was not available and the mean of the speeds for the 110 observations in the data set was substituted for it. Equation 7.46, which was based on equations 7.7 and 7.8, was the model used for estimating the L_{10}. Equation 7.47, which was based on equation 7.23 was used for estimating the L_{50}.

$$L_{10} = 0.302\ (\log D)\ (11.8 \log Q + 0.4\ Pk + 0.54\ Rq - 6.7 \log V + 0.165P + 0.19T - 76.1) + 88.8 \qquad (7.46)$$

$$L_{50} = 0.292\ (\log D)\ (14.3 \log Q + 0.096P - 0.95LU_r + 0.25T - 6.48 \log Cg - 49.0) + 79.7 \qquad (7.47)$$

Equations 7.48, 7.49 and 7.50 show the calibrations used in the response survey for %D, Logit %D and Log D respectively. These were based on equations 7.29, 7.33 and 7.35. The mean of the speed levels was substituted for V_s, and D_{nv} was estimated from equation 7.45. The antilogarithm of log D was used for estimating the mean delay.

$$\%D = 115.7\ (1 - e^{-3.5Q}) - 0.6Q + 15.1 \qquad (7.48)$$

$$\text{Logit}\ \%D = 01Q + 0.93\ \log\ (e^{3.5Q} - 1) + 0.66 \qquad (7.49)$$

$$\text{Log}\ D = 0.72\ \log\ (e^{3.5Q} - 3.5Q - 1) + 0.15\ \log\ P + 1.22 \qquad (7.50)$$

The same procedures were used in estimating the smoke and CO levels. In this case the most important missing variable was the wind speed. The models were based on equations 7.40 and 7.30.

$$\text{Log (Sm)} = 0.03Q_n + 0.19\ \log\ P_n - 0.3 \qquad (7.51)$$

$$\text{Log CO} = 0.518\ \log\ Q + 0.033\ Pe^{-P/9}\ \log\ Q + 0.295\ Rq - 1.07 \qquad (7.52)$$

CHAPTER 8: ANNOYANCE WITH THE ENVIRONMENTAL VARIABLES: PREDICTION MODELS

8.1 INTRODUCTION

Initial analyses of the returns of the questionnaire survey of pedestrian responses to the various environmental effects of the traffic confirmed that there was a very wide range of responses from different people to the same environment, which would make it difficult to draw inferences on the form of the relationship between subjective responses and the physical environment. Some respondents stated that they were not annoyed with noise when they could barely hear what was being said, others said they were extremely annoyed where the traffic flow was less than 100 vehicles per hour. Possible reasons for this will be discussed in Chapter 10.

As will be seen, one result of this was that it was not possible to use the method of analysis required to develop prediction models from the ratio of annoyance encoded. The sections discussing the relationships between individuals responses and the environmental variables will be followed by sections on relationship between the aggregated responses of individuals and the environmental variables. It was reported in Chapter 6 how the sample in the subjective responses survey was designed to meet the contingency of the variation in people's responses being so great as to make it very difficult to draw conclusions from them. This was done by taking a number of interviews (an average of 11) at each of the observation points under conditions where environmental effects of the traffic were constant for each set of interviews. This meant that possibly much of the variation in the responses could be cancelled out by taking some measure of central tendency of the responses encoded in each of the interviewing periods as the dependent variable. The chapter is concluded with an analysis of the relationship between the proportion of people annoyed or extremely annoyed and the environmental variables. Where relevant, the results of analysing the observer's own responses are referred to. A more detailed report may be found in Appendix 7.

The models which have been used for predicting the values of the environmental variables, which are compared with the subjective responses in this chapter, have been listed in the concluding section of Chapter 7. In some cases the results of using alternative noise models are compared.

The annoyance variables are represented by "A" followed by two subscripts. The first subscript represents the environmental impact which causes the annoyance, the second the means which was used to encode it. The following are the codes which were used:

a	Appearance	p	Air Pollution
v	Vibration	n	Noise
r	Risk in crossing the road	d	Pedestrian delay

E represents the data collected with the EAR and L data encoded on the lines. Thus A_{ne} is the number of "pegs" representing annoyance with noise using the EAR technique.

8.2 ANALYSIS OF THE "EAR" DATA

It was postulated that there was a power relationship between people's responses and the physical environmental variables and that this relationship could be demonstrated by regressing the logarithm of the ratio of the annoyance values encoded on the logarithm of the relevant physcial variables. For example if $A_n=S^a$ and $A_d=D^b$, then $A_n/A_d=S^a/D^b$ and

$$\text{Log } (A_n/A_d) = a \log S - b \log D \qquad (8.1)$$

In this case 'a' and 'b' could be calibrated by regression. It was found, however, in the analysis of the data, that where the logarithm of the ratio of the (number of pegs representing) annoyance with noise to the (number of pegs representing) annoyance with delay was regressed on the estimated L_{10} and the logarithm of the mean delay, that neither of the regression coefficients were significantly different from zero. In fact the multiple correlation was only 0.035. The corresponding multiple correlation for the "lines data" was similarly not significant at 0.05. None of the control variables made either of the physical variables near being significant nor were they significant themselves.

The reduction of the random variation in the responses by aggregating the data collected during each interviewing period is discussed below. While this marginally increased the multiple correlation, for both the EAR and the lines data, it did not make either of the regression coefficients significant.

There was a correlation of 0.51 between the logarithm of the ratios of the "EAR" data and that of the "lines" data. It might have been expected that the reduction of random error through the aggregation of the individuals responses for each of the interviewing periods would have increased the correlation significantly. In fact, it was only increased marginally to 0.065, from 0.05.

The logarithm of the ratio of the annoyance encoded for noise to that of delay was regressed on the physical environmental variables under the most favourable circumstances. The dependent variable was based on the means of the responses for the interviewing periods and was the mean of the logarithm of the ratio of the responses from both the EAR and the "lines" method. The independent variables were the logarithm of the estimated L_{10} sound pressure over 65 dB(A)[1] and the estimated logarithm of delay. This increased the multiple correlation but the independent variables were still not significant.

In the corresponding regression analysis, using the responses which the observers themselves encoded, the multiple correlation was 0.39 and the t statistics were 1.5 and 2.5 respectively.[2]

As stated, it is the variation in people's responses to given environments which is the cause of the lack of success in using this method of analysis. However, the results also show that the variation in individuals responses to one environmental variable is to a large degree independent of their responses to the other environmental variables. The "error" in the dependent variable is magnified by the division of one variable with an "error" by another with an "error".

The mean number of pegs placed opposite the environmental factors are displayed in Table 8.1. It is not legitimate to place too much emphasis on the relative means as the sum of the pegs used by respondents was not necessarily proportionate to their annoyance. As they stand, however, they are significantly different from each other in an analysis of variance test.

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1. The effect of aircraft noise is excluded in this estimate. This variable was the one which was found to have the highest correlation with the logarithm of the annoyance from noise which was encoded.

2. See Appendix 6.

	Means	Standard Deviations
Air Pollution	5.44	4.10
Risk	5.42	3.97
Noise	5.41	3.92
Delay	4.46	3.74
Vibration	3.57	3.75
Appearance	3.04	3.26

Table 8.1: Means and standard deviations of the EAR data.

The correlations between the annoyance variables from the EAR are shown in Table 8.2. Note that all the correlations are very highly significant. As had been expected, the highest correlations were between annoyance with risk and delay, and annoyance between noise and vibration.

Air Pollution		.436	.564	.417	.464	.436
Risk	.436		.487	.694	.415	.400
Noise	.564	.487		.485	.671	.489
Delay	.417	.694	.485		.418	.425
Vibration	.464	.415	.671	.418		.516
Appearance	.436	.400	.489	.425	.516	

Table 8.2: Correlations between EAR data.

8.3 ANALYSIS OF MAGNITUDE ESTIMATIONS

In the analysis of the distribution of the respondents' magnitude estimations which they encoded on the lines, a characteristic "W" shape was observed. For the seven lines roughly 30% of the respondents stated that they were not annoyed and another 12% stated that they were extremely annoyed. A further 10% of the "Xs" were placed approximately half way along the line. Even amongst the rest there was a slight tendency to place the x a quarter or three quarters of the way along the line. This suggests that the respondents were not using the lines as sensitively as had been expected, particularly in view of the results of the pilot survey. This inevitably placed some constraints on what can be inferred by treating the distance along the lines as being on a ratio scale.

The means and standard deviations of the distances along the lines for each of the annoyances are shown in Table 8.3. As in the case of the "EAR" data, an analysis of variance test showed that these were significantly different from each other. Table 8.4 shows the correlations between the annoyances. As feared the correlations between the responses and the estimates of the physical environmental variables were not significant. The highest correlation was between log A_d and Log D (r = 0.068, to be significant at the 5% level r would have to be at least 0.088). The correlations between annoyance with air pollution and smoke was negative.

Annoyance	Mean	Standard Deviation
Air Pollution	81.7	63.4
Risk	78.1	64.9
Noise	76.0	64.2
Delay	68.6	61.0
Vibration	50.3	59.1
Appearance	33.1	48.2

Table 8.3: Means and Standard Deviations of "Lines" Responses.

Annoyance	R	P	N	D	V	A	O
Risk		.35	.39	.54	.37	.35	.58
Air Pollution	.35		.49	.35	.43	.36	.56
Noise	.39	.49		.34	.60	.39	.68
Delay	.54	.35	.34		.31	.24	.54
Vibration	.37	.43	.60	.31		.42	.54
Appearance	.35	.36	.39	.24	.42		.50
Overall	.58	.56	.68	.54	.54	.50	

Table 8.4: Correlations between "Lines" Responses.

8.4 THE ANALYSIS OF THE AGGREGATED DATA

As referred to above, a possible method of controlling for the random variation in the responses is to take as the dependent variable a measure of the central tendency of the responses for each of the 49 interviewing periods. This would have the effect of greatly reducing the degrees of freedom in the analysis but it would also cause much of the variation in the responses to cancel out. There was a choice of using either the mean or the median as the measure of the control tendency of the responses. Whichever should be used would depend on whether possible inaccuracies due to treating values for the respondents who were not annoyed or extremely annoyed as being on a ratio scale is outweighed by the greater sensitivity of the mean to variations in the distributions of the responses. While this may be ascertained empirically, there may be a risk of selective argument in basing inferences on the most favourable results. The analysis is therefore reported for both sets of data.

8.4.1 Description of Annoyance Data

The number of interviews taken during each interviewing period varied; therefore, it was necessary to weight the means and the medians in the analysis accordingly. Table 8.5 shows the means and standard deviations of the weighted means and medians of the annoyances as encoded on the lines. The levels of the annoyances relative to each other are similar for both.

	Means		Standard Deviation	
Annoyance	Mean	Median	Mean	Median
Risk	81.7	80.5	18.6	37.5
Air Pollution	78.1	75.2	20.3	40.9
Noise	76.0	72.1	23.6	44.6
Delay	68.7	62.4	20.4	36.5
Vibration	50.3	28.0	18.8	28.2
Appearance	33.1	11.7	15.1	18.9

Table 8.5: The means and standard deviations of the mean and median annoyance encoded on the lines.

The means and median annoyances were similar except that the variation of the medians was much greater, both between the annoyance factors and for each annoyance factor. The correlations between the annoyances follow a similar pattern for both the means and the medians. These may be seen in Table 8.6. As expected, the correlations between noise "annoyance" and vibration " annoyance" were higher than any of the others. However, the relationship between risk "annoyance" and delay "annoyance" was only marginally above average. The correlations between the means tended to be higher than between the medians.

Annoyance	R	P	N	D	V	A	MEDIANS
Risk		.22	.43	.42	.39	.25	
Air Pollution	.24		.47	.49	.31	.42	
Noise	.34	.55		.46	.54	.15	
Delay	.36	.50	.47		.38	.13	
Vibration	.38	.35	.65	.35		.21	
Appearance	.28	.50	.33	.18	.36		
	MEANS						

Table 8.6: The Correlations between the aggregated annoyances encoded on the lines (N = 49). (The correlations between the medians are in the top left side of the table, and the remainder are the means).

As will be seen in the report of the analysis of the median and mean values for the interviewing periods, the correlations between the subjective and objective variable were significantly higher than when the individual responses were used. However, the percentage of the variation in the subjective variables which could be statistically explained was still relatively low, for example in the case of noise annoyance the maximum was roughly 25%. One of the reasons for this is the fact that the medians and means are subject to sample error. The average number of interviews during each period was 10.7 and the standard deviation of the responses (encoded on the lines) within the periods was roughly 50 mm. Therefore, assuming that the distribution of responses was normally distributed roughly 5% of the observed means would be more than 25 mm from the true mean.

8.4.2 The Prediction of Noise Annoyance

The strength of the relationship between the linear and logarithmic forms of the mean values of annoyance encoded on the lines, and various transformations of the estimated L_{10}, are shown in Table 8.8. Table 8.9 gives the corresponding statistics for the medians. The first column shows the correlations between the means and the estimated L_{10} sound pressure. The null hypothesis, that the correct relationship between responses and the physical environment was not in form of Stevens' Power Law, could not be proven if the correlations in this column were significantly greater than the others. The third column is the correlation between the median values of the responses and the logarithm of the physical variables. If Fechners' Law held true this column should contain the highest correlations. The last column contains the correlations between the logarithm of the median values, and the physical variable is just for the record. The rows refer to various transformations of the noise variables. The first is the L_{10} in dB(A). The next four contain the logarithm of the sound pressure over four arbitrarily chosen thresholds. The lowest estimated L_{10} was 71.0 dB(A).

Transformation of Physical Variable	Linear Relationship	Log/log Relationship	Linear/log Relationship	Log/Linear Relationship
L_{10}	.492	.509	.484	.496
Log(S.P)T=55dB(A)	.492	.510	.483	.496
Log(S.P)T=60dB(A)	.492	.512	.483	.496
Log(S.P)T=65dB(A)	-.492	.516	.481	.496
Log(S.P)T=67.5dB(A)	.492	.521	.480	.496
L_{10} exc.aircraft noise	.526	.566	.525	.537
L_{10} exc.aircraft noise T = 65 dB(A)	.526	.593	.527	.537

Table 8.8 (title on following page)

Table 8.8: Correlations between the Mean Noise Annoyance Encoded and Various transformations of the L_{10}. (N = 49) Where T = the postulated threshold and S.P. = L10 sound pressure.

Transformation of Physical Variable	Linear Relationship	Log/log Relationship	Linear/log Relationship	Log/Linear Relationship
L_{10}	.459	.404	.441	.396
Log(S.P)T=55dB(A)	.459	.405	.440	.396
Log(S.P)T=60dB(A)	.459	.407	.437	.396
Log(S.P)T=65dB(A)	.459	.409	.433	.396
Log(S.P)T=67.5dB(A)	.459	.413	.429	.396
L_{10} exc.aircraft noise	.475	.446	.458	.428
L_{10} exc.aircraft noise T = 65 dB(A)	.475	.463	.444	.428

Table 8.9: Correlations between the Median Noise Annoyances Encoded and Various Transformation of the L_{10}. (N = 49)

When a sample size is 49, correlations over 0.287 are significant at the 5% level, over 0.383 at the 1% level and over 0.5 at the 0.1% level. Thus all the correlations in Tables 8.10 and 8.11 are highly significant and a number are very highly significant. However, the differences between the correlations are not significant.

The correlations for the means were slightly higher than for the medians. For the means, the Stevens' type relationship was the strongest; but in the case of the medians, the linear relationship was the strongest. For the Stevens relationship there was a slight tendency for the correlation to rise as the threshold was raised. When the threshold was raised to 70dB(A), the correlation rose to 0.541 compared to 0.509 when the threshold was zero. However, the differences between the correlations are not sufficient to disprove any of the null hypotheses, and no firm conclusions can be drawn from these correlations alone.

It was noted during the analysis that there was evidence that the respondents may have been following their instructions more accurately than they were being given credit for. They had been asked to encode their annoyance with the noise from the traffic as it was at the time of the interview. Indications were noted in the analysis that perhaps it would have been less correct to relate their responses to the estimated L_{10} than to what the sound level would be if the noise from the aircraft did not exist. It is reasonable to suppose that people would say that they were not annoyed with the noise from the traffic in a road where the flow was low but where there was a lot of noise from aircraft. When the noise from the aircraft was controlled for by substituting 6.5 km for log D in the model, a closer relationship between the subjective and objective data was noted.

The estimated noise levels which were used in calculating these correlations were based on equation 7.46 which was developed from the Johnson-Saunders type of specification. It was decided to test whether the noise prediction model used would have any effect on the results. The model which was the most different from the Johnson-Saunders type was the one which was based on Delany's theoretically derived model (i.e. equation 7.5). Table 8.10 compares the main correlations using both models. The pattern of the correlations is virtually identical for the two models, except that they are slightly lower for the Delany type model.

	Linear Relationship		Log/log Relationship		Linear/Log Relationship	
MEANS DATA. Equation No.:	7.46	7.5	7.46	7.5	7.46	7.5
L_{10}	.492	.478	.509	.494	.484	.470
L_{10} T = 67.5 dB(A)	.492	.478	.521	.503	.480	.466
L_{10} exc.a/c noise	.526	.510	.566	.554	.525	.507
L_{10} exc.A/c noise T = 65 dB(A)	.526	.510	.593	.580	.527	.508
MEDIANS DATA						
L_{10}	.459	.445	.404	.390	.441	.428
L_{10} T = 67.5 dB(A)	.459	.445	.413	.398	.429	.418
L_{10} exc. a/c noise	.475	.461	.446	.435	.458	.449
L_{10} exc. a/c noise T = 65 dB(A)	.475	.461	.463	.457	.444	.438

Table 8.10: A comparison of the effect on the correlations between "annoyance" with noise and the estimated noise levels using different prediction models. ("Lines" data, N = 49)

Two further sub-hypotheses on the nature of the relationship between the encoded responses and the estimated L_{10} were tested. The first was that when respondents were placing their marks at the ends of the lines,

they were constrained by the ends, and that in some cases, at least, they would have placed the marks outside the bounds of the lines if they had been allowed. This was tested by seeing how the relationship with the noise was affected by placing the origins of the annoyance encoded marginally outside the beginning of the line and by assuming that values at the other end were also marginally outside. This was done by adding 30 mm to all the distances measured along the line except where zero annoyance was marked 1 and by adding 30 mm to the distance from the beginning of the lines for values indicating extreme annoyance. Table 8.11 shows the results for selected correlations. Again, the correlations were not significantly different. In fact they were marginally less, which suggests that the respondents were not constrained by the ends of the lines.

Transformation of Annoyance	Sound	Unadjusted	Adjusted for zero	Extreme Annoyance Adjusted	Both ends Adjusted
A	Sound Pr	.492	.490	.478	.479
Log A	L_{10}	.509	.502	.492	.497
Log A	L_{10} (T = 70 dB(A))	.541	.527	.509	.522
[illegible] A	A/C controlled S.P.	.526	.523	.510	.510
Log A	A/C controlled L_{10} (T = 65)	.593	.576	.560	.571

Table 8.11: The Effect of an Assumption on the Ends of the Lines on the "Means" Correlations.

The other hypothesis which was tested has been discussed in Chapter 5. It was that the relationship could be described by combining Stevens' and Hart's postulated forms of relationships, whereby there would be a limited range of people's possible annoyances and that their annoyance would converge on these values as the physical variables increased or decreased. This was tested by taking the logistic transformation of the proportion of the distance along the lines that the respondents made their marks and looking at the correlation between this variable and the L_{10} transformations. The correlations were only marginally different from those in the Table 8.8. See Table 8.12. As in the case of adjusting the values at the ends of the lines, the correlations were lower and the hypothesis was, therefore, regarded as being disproved and that there were no empirical grounds for believing that noise is on a metathetic scale.

Sound Pressure	Logit An
L_{10} Sound Pressure	.501
L_{10}	.499
L_{10} (T = 70 dB(A)	.508
S.P. A/C controlled	.535
L_{10} A/C controlled	.543
L_{10} A/C T = 65 dB(A)	.554

Table 8.12: The Correlations between the Logistic Transformation of the annoyance Encoded for Noise and Transformations of the L_{10} (Means Data).

8.4.3 Noise Annoyance and the L_{50}

Equally good correlations were found between the noise annoyance encoded and the L_{50} based variables as between the annoyance and the L_{10} variables. The L_{50} itself had a higher correlation than the L_{10}, but when the aircraft noise was controlled for and an effective threshold assumed, the L_{10} correlation was the higher. The difference between the L_{10} and the L_{50}, or the noise climate as it was called by Wilson (1963), was found to be closely related to the L_{50}. It was used as the measure of variation in the noise levels, rather than the standard deviation, for which estimates were found to be relatively inaccurate. Table 8.13 compares the L_{50} with the L_{10} correlations.

Type of Relationship	Threshold	L_{10}	L_{50}	$L_{10}-L_{90}$
Linear	0	.472	.485	
Logarithmic	0	.484	.487	.030
Log/log	0	.509	.515	.030
Linear (A/C controlled)	0	.526	.498	
Logarithmic (A/C controlled)	0	.525	.515	
Log/log (A/C controlled)	0	.566	.554	
Logarithmic (A/C controlled	L_{10}=70dB(A) L_{50}=60.0dB(A)	.527	.547	
Log/log (A/C controlled)	L_{10}=65dB(A) L_{50}=57.5dB(A)	.593	.613	

Table 8.13: A comparison of the correlations of L_{10} and L_{50} with noise annoyance.

The exponents in the power relationship were slightly lower for the L_{50} than for the L_{10}: 0.4 compared to 0.5. When aircraft noise was controlled for and effective thresholds of 57.5 and 65 dB(A) were assumed, the exponents were 0.31 for L_{50} and 0.33 for L_{10}. When various transformations of the noise annoyance were regressed on the L_{50} transformations, the partial correlations with the noise climate (i.e. $L_{10} - L_{90}$) were not significant. Thus no empirical evidence was found to support those noise indices which included a weighted variation element, nor could it be shown that the L_{10} was significantly closer related to subjective responses than the L_{50}.

8.4.4 Noise Annoyance and the Traffic Variables

In order to test whether the noise environmental variable gave statistically better estimates of the annoyance encoded than the traffic and built form variables, "A_n" and "log A_n" were both regressed on all of the independent variables used in developing the L_{10} models. The results of using the stepwise procedure with a confidence level of 5% was:

$$A_n = 54.3 \log Q - 3.9Pe^{-P/9} \log Q - 57.3 \qquad (8.2)$$

N = 49

R = 0.559

R.E. = 20.0 mm

t statistics = 4.6 and 2.2 respectively

Where Q = total flow in vehicles per hour

P = % of heavy vehicles as in equation 5.3

$$\log A_n = 0.37 \log Q - 0.026Pe^{-P/9} \log Q + 0.94 \qquad (8.3)$$

R = 0.596

R.E. = 0.12

t statistics = 5.0 and 2.4 respectively

These multiple correlations were, in fact, as good as best correlations between "annoyance" and the estimated environmental variables using Fechner's and Stevens' forms of relationships. Table 8.14 shows the corresponding correlations, and those between "annoyance" and the traffic flow by itself. The logarithm of the total flow gives a better statistical explanation of the variation in "A_n" for both the Stevens' and Fechner types of relationship. Equation 8.3 gives an equal correlation with "log A_n" as does the best fitting transformation of L_{10}. Thus, it may be inferred that just as good results may be had from predicting annoyance, as encoded in this survey, from traffic variables, as may be had from estimates of the noise levels.

	Linear	Log/log	Linear/log
L_{10}	.492	.509	.484
L_{10} exc. aircraft noise (T = 65 dB(A)	.526	.593	.527
Equations 8.2 and 8.3		.592	.559
Total flow	.432	.525	.489

Table 8.14: The correlations between noise "annoyance" and sound and traffic variables.

8.4.5. Description of Relationships

The previous tables have shown the strength of the relationships between various transformations of both the subjective and objective variables. It is also necessary to describe the relationships, particularly the calibration of the power law form, to see if the observed exponent is similar to the 0.68 which describes the sensation of loudness. Table 8.15 shows the results of regressing the three transformations of annoyance with noise on a number of the forms of the estimated sound variable, for the means of the ten sets of interviews. In none of the regressions were any of the residuals greater than three standard errors.

Dependent Variable	Regression Coefficient	Independent Variable	Constant	R	R.E.
A	0.0041	S.P.(A)	38	.49	21
A	0.0049	S.P.	38	.53	20
A	3.72	L_{10}(A)	-217	.48	21
A	3.63	L_{10}	-204	.53	20
A	36.1	Log SP(T=70 (A))	-58	.48	21
A	46.3	Log SP(T=65)	-96	.53	20
Log A	.50	L_{10} (A)	-1.1	.51	.13
Log A	.50	L_{10}	-1.1	.57	.13
Log A	.26	Log SP (T=67.5) (A)	-0.1	.54	.13
Log A	.45	Log SP (T=55)	0.1	.57	.13
Log A	.33	Log SP(T=65)	-0.4	.59	.12
Log A	.31	Log SP(E_q5) (T=65)	-0.7	.59	.12
Log A	.32	Log Q_n	01.0	.58	.13

Table 8.15: Selected Regression equations showing various relationships between the observed annoyance with noise and the estimated sound. (A) = Aircraft noise not controlled for.

There were two notable features in the regression equations describing the power law relationships. The first is that the coefficients were considerably lower than the 0.6 which is the exponent which describes sensation. The second, is the way the parameters of the equations vary when the threshold is changed. Equations 8.4 and 8.5 show these differences when the regression equations are transformed to predict linear functions of "annoyance". In both these cases "S" represents the estimated sound pressure after the effect of aircraft noise has been excluded.

$$A = 0.079(S)^{.5} \qquad (8.4)$$

$$A = 0.4(S-10^{65/20})^{.33} \qquad (8.5)$$

It was noted in the analysis of the observers own responses that the exponent was 1.68 when the threshold was zero, and that it fell to 0.71 when the threshold was 65 dB(A). (See Appendix 7).

8.5 ANNOYANCE AND VIBRATION

Vibration was not one of the variables measured during the survey of the physical environment. However, the relationship between annoyance with vibration and the L_{10} is reported because of physical relationship between sound and vibration and the relative high correlation between the annoyances with vibration and noise. Table 8.16 shows the relevant correlations between transformations of the "annoyance" with vibration and transformations of the L_{10}. The correlations were much lower than for annoyance with noise, but all of them were significant at the 5% level and some were significant at the 1% level.

Transformations of the Sound Pressure	MEDIANS		MEANS	
	Av	Log Av	Av	Log Av
S.P. (A)	.330	.357	.345	.340
S.P.	.359	.383	.373	.359
Log S.P. (A)	.307	.331	.326	.365
Log S.P. T=55 dBA (A)	.305	.329	.325	.368
Log S.P. T=65 dBA (A)	.297	.320	.321	.380
Log S.P. T=67.5 dBA (A)	.290	.314	.319	.392
Log S.P. T=70 dBA (A)	.285	.310	.321	.437
Log S.P.	.331	.361	.363	.409
Log S.P. T=55 dBA	.330	.360	.362	.418
Log S.P. T=65 dBA	.324	.350	.363	.465
Log S.P. Eq. 5.4 (A)	.303	.320	.313	.348
Log S.P. Eq. 5.4	.327	.352	.354	.400
Log S.P. Eq. 5.4 (A). T=67.5 dBA	.294	.304	.305	.371

Table 8.16: Correlations between selected transformations of annoyance with vibrations and of the sound variable. (N=49)

The pattern of the correlations were similar to those of Table 8.9 and 8.10. There was no significant difference between any of the correlations. The correlations using the mean values were higher than those of the median values. The power relationships were stronger than the logarithmic relationships and the correlations were higher when the noise from the aircraft was excluded from the estimate.

In the case of annoyance with vibration from the traffic, as well as for the other annoyances from the environmental variables which were not observed during the survey of the physical variables, it is particularly important to be successful in developing a model for predicting their variations from the traffic and built-form variables. Because of the relationship between vibration and heavy vehicles, a large number of transformations of the numbers of heavy vehicles were tested in regression analyses, both as separate and interaction elements. However, in no case was this t statistic greater than 0.95. The following equations are the results of a stepwise regression using the 5% confidence limit:

$$A_V = 23.4 \log Q - 20.7 \qquad (8.6)$$

$N = 49$

$R = 0.349$

R.E. = 17.8 mm

The t statistic of log Q was 2.55.

$$\text{Log } A_V = 0.36 \log Q + 0.57 \qquad (8.7)$$

$R = 0.376$

R.E. = 0.249

t statistic = 2.78

The multiple correlations are lower than those between noise annoyance and the traffic variables. But the correlations with the traffic variables are higher than with the noise variables. This is not surprising as the noise variables were acting as a surrogate for the degree of vibration. What is surprising, though, is that the heavy vehicles variables did not have a more prominant position in the models.

Table 8.17 shows the regression equations for the more important forms of relationships. Note that the exponent in the lower relationship is noticeably less than in the case of noise annoyance. The aircraft noise was controlled for in each of the noise estimates.

Dependent Variable	Regression Coefficient	Independent Variable	Constant	R.
A_v	0.0025	S.P.	+30.5	.345
A_v	39.9	Log SP	-103.5	.363
A_v	25.4	Log SP T=65 dBA	-43.0	.363
Log A_v	0.64	Log SP	-0.80	.409
Log Av	0.46	Log SP T=65 dBA	-0.05	.465
Log A_v	0.50	Log SP (A) T = 67.5	-0.25	.392

Table 8.17: Selected regression equations describing various relationships between the mean observed annoyance with vibration and the estimated round (N=49).

8.6 ANNOYANCE WITH PEDESTRIAN DELAY AND RISK

The relationship between annoyance with pedestrian delay and both indicators of delay are analysed. The estimated mean delay is based on the model for predicting the logarithm of mean delay, (i.e. equation 7.50). The percentage of time delayed is estimated from equation 7.48. Annoyance is also compared to the estimated logistic transformation of the percentage of time delayed using equation 7.49.

The annoyance with the risk in crossing the road is also compared with the estimated values of these pedestrian delay variables, though greater attention is given to developing a model for predicting annoyance with risk from the traffic variables, than in the case of annoyance with delay, where there were already relatively accurate models for predicting the relevant physical environmental variable. As the lowest values of the estimated delay variables are close to zero it is not possible to test whether an assumed threshold of annoyance could give a better fit in the log/log regression.

	Annoyance Variables	Environmental Variable				Total Flow	
		D	Log D	%D	Logit D	Q	Log Q
M	A_d	.536	.567	.565	.578	.560	.573
E	Log A_d	.518	.592	.586	.596	.552	.598
A	A_r	.252	.260	.275	.253	.273	.248
N	Log A_r	.236	.242	.255	.235	.254	.229
S	$A(d+r)/2$	.486	.511	.518	.513	.513	.507
	Log $A(d+r)/2$	.462	.491	.495	.491	.488	.485
M	A_d	.579	.598	.592	.606	.601	.596
E	Log A_d	.532	.691	.668	.669	.587	.679
D	A_r	.267	.236	.248	.234	.275	.223
I A	Log A_r	.192	.163	.165	.158	.192	.147
N	$A(d+r)/2$	.501	.493	.497	.496	.519	.484
S	Log $A(d+r)/2$	.541	.454	.447	.446	.464	.433

Table 8.18: Correlations between "Annoyance" with pedestrian delay and risk, and the physical variables ($N = 49$). $A(d+r)/2 = (A_d + A_r)/2$.

For annoyance with delay, the correlations for the median values were higher than those of the means, which was not the case with noise and vibration. However, as before, the correlations were not significantly different from each other. The correlations for the Stevens type relationship (i.e. the log/log form) were higher than the others in the case of annoyance with delay, but not so for the correlations between annoyance with risk and the delay variables. The correlations for annoyance with risk were lower than those for annoyance with delay as would be expected dur to the delay variable being a surrogate for the corresponding physical environmental variable for risk. The high correlation between the "%D" and "log D" has already been noted. It was not surprising, therefore, that the correlations of the "annoyances" with "%D" were very similar to those with "log D" and that the partial correlations between the "annoyances" and "%D" were not significantly different from zero when "log D" was controlled for. The high correlation between the logarithm of the traffic flow and the "log D" has also been noted above. This has resulted in their correlations with the annoyance variables being very similar. The hypothesis that the correlations between the annoyance with delay variables and the delay variables themselves could be improved by increasing the minimum acceptable headway was tested. It was found that this made little difference. For "D" and "%D" the correlations were slightly less when MAH = 5 seconds, whereas they slightly increased for "log D" and "logit %D".

The result of calibrating the Stevens type relationship was:

$$\begin{aligned} \text{Log}\,(A_d) &= 0.54 \log D + 0.109 \\ t &= 2.56 \\ R &= 0.69 \\ \text{R.E.} &= 0.276 \end{aligned} \qquad (8.8)$$

When equation 8.8 is transformed to predict Ad:

$$Ad = 1.28D^{0.54} \qquad (8.9)$$

Equation 8.10 shows the effect of regressing A_d on the same traffic and built form variables which were used in the development of the models for predicting D and log D. In this, as in all other regressions of transformations on the traffic and built-form variables, the stepwise regression procedure was used. 5% significance level was used for including variables in the regression set. Equation 8.11 shows the results of the corresponding regression where the dependent variable is log A_d. Both A_d and log A_d are based on the mean values.

$$A_d = 41.61 \log Q + 89.9 \quad (8.10)$$

N = 49

R = 0.57

R.E. = 16.9

t statistic = 4.8

$$\text{Log } A_d = 0.29 \log Q + 1.97 \quad (8.11)$$

R = 0.60

R.E. = 0.11

t statistic = 5.1

Neither of the transformations of the annoyance encoded for risk were significantly related to any of the independent variables.

The observers' own responses exhibited similar features for annoyance with delay and risk as for the other annoyances. The log/log relationships were stronger than the linear/log relationships, which in turn were stronger than the linear ones. However, the total flow was more highly correlated with the annoyance than the delay variables, see Appendix 7.

8.7 ANNOYANCE FROM AIR POLLUTION FROM THE TRAFFIC

In this case we are looking at the relationships between the transformations of the means of one set of annoyances encoded and the transformations of the estimates of two physical environmental variables. As has been discussed in Chapter 4 both smoke and carbon monoxide were measured because of the relative ease of measurement. In each case the correlations will be given for each of them separately and the multiple correlation for both of them together. It should be remembered, of course, that carbon monoxide is not perceptible, unlike smoke, and that is only being used here as an aid to prediction, rather than tracing the cause of the annoyance.

Transformation of Physical Variable	Transformation of Annoyance Variable A_p	Log A_p
Smoke	.080	.034
Log Smoke	.065	.020
Log Smoke (T = 25)	.073	.045
CO	.259	.247
Log CO	.273	.256
Smoke and CO	.279	.245
Log Smoke and Log CO	.284	.277
Total flow	.281	.260
Log (Total Flow	.269	.245

Table 8.19: Correlations between annoyance with air pollution and the physical variables (N = 49).

Table 8.19 contains the correlations between the transformations of the annoyance with air pollution, and linear and logarithmic forms of the mean values of smoke and CO for the interviewing periods. The minimum value of smoke was sufficiently high to enable seeing the effect of an arbitrary threshold on the correlations.

Smoke is more closely related to annoyance than CO and CO does not make an additional significant contribution to the statistical explanation of the variation in annoyance. Again the Stevens type relationship is stronger than the linear, with the Fechner type in between. The relationship between Logit A_p and the logarithms of the physical variables is only marginally different from that of log A_p. Neither did the assumptions about the values at the ends of the lines affect the strength of the relationship very much. Raising the threshold to 20 mc.gr./m^3 in the case of smoke increased the correlations slightly. The means yielded slightly higher correlations than the medians, but there was no significant difference between any of the correlations.

It was found that the transformations of the annoyance variable could be predicted just as well from the traffic and built form variables as from the estimated values of the physical environmental variables. This is probably a reflection of the relative inaccuracy of the air pollution models compared to those of noise and delay.

The correlations between annoyance with air pollution were not significantly related to any of the traffic or built form variables.

The correlations between the observers responses and the estimates of the air pollution variables were also considerably less than the corresponding statistics for the other environmental factors. Nevertheless the log/log relationship was still much stronger than the others, though not significantly. (See Appendix 7.)

8.8 ANNOYANCE WITH THE APPEARANCE OF TRAFFIC

For this annoyance with the environmental effects of traffic there was neither an estimated environmental variable nor one which could reasonably be used as a surrogate. Therefore the development of a prediction model depended entirely on the analysis of the relationships between it and the traffic and built-form variables. Thus the means and medians of the annoyances encoded and the various transformations of them were regressed on all the traffic and built-form variables which were used in developing the models for predicting the physical environmental variables, except those which were not available or could logically be deemed not to have any effect on people's attitudes twoards the appearance of the traffic. The regressions were carried out in the usual manner using the stepwise method with both the 5% and 10% confidence levels for excluding the independent variables. Unfortunately, however, none of the independent variables were significantly related to either the mean or median annoyance encoded for appearance, or with their logarithms.

8.9 THE PREDICTION OF THE BINARY RESPONSES

The theory of the relationship between the proportion of people annoyed (or extremely annoyed) with physical environmental variables has been discussed in Chapter 5. The strengths of these relationships, which were calculated from the data of the survey of the pedestrians' responses, are reported in this section. The statistics refer to three types of binary response: (1) annoyed or not annoyed according to the lines methods, (2) annoyed or not annoyed according to the EAR game, and (3) extremely annoyed or not extremely annoyed according to the lines method. The proportions refer to the binary data collected during each of the 49 interviewing periods. Where relevant the data is weighted by the number of interviews taken during these periods.

The following table shows how the proportion of people annoyed with each of the environmental variables corresponds to the order of the distances marked along the lines and the numbers of pegs used in the EAR:

Annoyance	Not Annoyed (Lines)	Not Annoyed (EAR)	Extremely annoyed
Risk	.25	.19	.19
Air pollution	.30	.20	.17
Noise	.31	.21	.16
Delay	.28	.20	.15
Vibration	.44	.35	.09
Appearance	.53	.37	.04

Table 8.20. The relative proportions of people annoyed with the environmental variables.

Equation 7.46 was used for the estimation of the L_{10}. The same prediction models were also used for the estimation of the delay and air pollution variables as were used in the previous sections.

8.9.1 Noise Annoyance

The correlations in Table 8.21 show the strength of the relationship between various transformations of the estimated L_{10} and L_{50}, and the proportions for the three sets of binary responses. The correlations are also shown for the mean of the proportions of people annoyed according to "lines" and the EAR. As in the case of Table 8.16, some random error cancelled out. The logistic transformations were only marginally different from the proportions in the strength of their relationships with the noise variables. They were neither consistently better nor worse. Controlling the effect of the aircraft on the L_{10} by substituting maximum distance from the flight path in the prediction model had the greatest and most consistent effect in increasing the correlations. Raising the assumed effective threshold also had as consistent, though not as great, an effect in raising the correlation.

Transformation of L_{10}	Annoyed Lines	Annoyed EAR	Annoyed Mean	Extremely annoyed
L_{10} (S.P.)	.385	.206	.319	.299
L_{10}	.375	.228	.337	.300
L_{10} (S.P.) (A/c controlled)	.397	.277	.366	.319
L_{10} (A/c controlled)	.420	.295	.388	.318
L_{10} (T = 65) (A/c controlled)	.441	.306	.405	.319
L_{50} (S.P.)	–	–	.381	.320
L_{50}	–	–	.326	.277
L_{50} (T = 57.5) (A/c controlled)	–	–	.419	.338

Table 8.21. The correlations between the proportions of people annoyed and the noise variables.

One of the reasons for the correlations appearing to be lower than they really are may be because of the small range of proportions observed. Table 8.19 shows the mean of the proportions and the maximum proportion for each of the three types of response. This also had the effect of causing a high correlation between the proportions and their logistic transformations (see column 3 of Table 8.19). The narrow range of the proportions was in turn affected by the narrow range of the stimuli. The minimum, mean and maximum values of the estimated L_{10} were 71.0, 78.8 and 83.3 dB(A) respectively. This also had the effect of causing high correlations between the various transformations of the L_{10}. These ranged between 0.87 and 0.99 where aircraft noise was included.

	Mean Proportion	Maximum Proportion	Correlation with logistic trans.
Not Annoyed (Lines)	.31	.79	.936
Not Annoyed (EAR)	.21	.70	.883
Not Annoyed (Mean)	.26	.68	.921
Extremely Annoyed	.16	.59	.874

Table 8.22 Characteristics of observed proportions of people annoyed with noise.

8.9.2 The Effect of Further Aggregation

The wide range of sample error in the means of the lines data for the interviewing periods has been noted. This also happens in the case of the binary data (i.e. the percentage of people who are annoyed or not annoyed, etc.). It was found that roughly 20% of the respondents were not annoyed and that a similar percentage were extremely annoyed. Table 8.23 shows the sampling distribution in such a case where N=10. If 20% of the population was annoyed, there would only be a 30% chance of obtaining a sample of 2 people being annoyed out of 10 and another 50% chance of obtaining 1 or 3 people being annoyed in the sample.

X	Number of people annoyed in the sample	0	1	2	3	4	5	6+
P(X)	The probability of obtaining a sample of X people annoyed	.107	.269	.302	.214	.088	.026	.006

Table 8.23 The Binomial Distribution, where N=10 and P=0.2.

It has already been shown how the sampling error could be reduced by aggregating the responses encoded during the interviewing periods. It was hypothesized that the sampling error could be further reduced by increasing the sample size through aggregating the interviews taken at sites with similar environments. It was decided to test this hypothesis in the case of the proportions of people annoyed with noise.

Clearly the final results would depend to some degree on how the interviews were aggregated and one could not stand behind results which were selected out of a number of different types of aggregation according to how they fitted the case that one was arguing. Thus, clear rules were laid out beforehand, in some cases arbitrarily, and adhered to regardless of the results. It was decided to have 10 groups of observations with approximately 52 interviews in each. The procedure adopted to define these groups was to order the observations according to the estimated level of the L_{10}, and beginning at the observation with the lowest level, to group the observations in such a way that the decision on whether to add each observation to the group being formed or whether to regard it as being the first in the next group depended on which caused the number of interviews in the group to be closest to 52. The result was that there were 5 observations in each group up to the last which contained 4. The mean number of interviews in each group was 52.2 and the standard deviation was 4.2. The mean noise level was then calculated from the estimated L_{10}s for the interviewing periods by changing the decibels to sound pressure, prior to taking the weighted mean. The weighting was with respect to the number of interviews taken in the periods.

Table 8.24 shows the correlations between the proportions of people annoyed with noise both before and after this second aggregation of the data. The R^2 values are also shown. It may be seen how roughly 4 or 5 times as much variance is statistically explained in the combined data than in its original state[1]. The proportion explained is still, however, very much lower than the 95% noted in the London Airport Survey. To some extent this is still due to sampling error. The numbers of people in the London Airport Survey categories varied from 60 to 500, but the average was 250. The standard error of the sampling distribution is proportionate to the reciprocal of the square root of the sample size. Thus sample sizes of 10, 50 and 250 in a category have a relative effect on the standard error equivalent to multiplying it by .32, .14 and .06 respectively. If all of the unexplained variance was due to random sample error, and if it was reduced from 55% in the proportion of .06 over .14, through increasing the sample size from 50 to 250, it (the unexplained variance) would be reduced to 25%, i.e. if N = 250 then:

$$r = \sqrt{1 - \frac{(6)\ (.55)}{14}} = \sqrt{.75} = 0.85 \qquad (8.12)$$

So, if this reasoning is correct, and under the given circumstances, there could be a considerable improvement in the goodness of fit if the total sample was in the region of 2500.

		Not Annoyed (Lines)		Not Annoyed (EAR)		Extremely Annoyed	
	N	r	r^2	r	r^2	r	r^2
L_{10}(S.P.)	49	.39	.15	.21	.04	.30	.09
	10	.69	.48	.43	.18	.83	.69
L_{10}	49	.38	.14	.23	.05	.30	.09
	10	.69	.48	.45	.20	.82	.67
L_{10} {T=70 dB(A)}	49	.42	.18	.26	.07	.30	.09
	10	.69	.48	.47	.22	.82	.67

Table 8.24 The effect of aggregating the data on the relationships between the proportion of people annoyed and the noise levels.

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1 It should be noted that the confidence limits change also when the number of measurements is reduced. When N = 10, and needs to be 0.67 to be significant at the 5% level, compared to 0.29 when N = 49.

The further aggregation of the data had a much greater effect on improving the correlations for the proportion of people extremely annoyed, than for the proportion just annoyed. A feature of the correlations for the two sets of data was this uniformity for the various transformations of the noise levels. The proportions were also compared to L_{10} sound pressure raised to the power of 0.2, 0.5 and 0.7 with an effective threshold of zero and 70 dB(A), yet the correlations only varied marginally from those in Table 8.24.

8.9.3 The Proportion Annoyed with Vibration

The proportion of people annoyed with vibration was also correlated with the noise levels for both sets of data. The results are given in Table 8.25 for the L_{10} sound pressure and dB(A). The improvement in the correlations caused by aggregation to ten sets of data corresponded to that of noise annoyance.

Noise Transformation		Not Annoyed (Lines)		Not Annoyed (EAR)		Extremely Annoyed	
		r	r^2	r	r^2	r	r^2
L_{10} (S.P.)	N=10	.49	.24	.68	.46	.55	.30
	N=49	.24	.06	.31	.09	.26	.07
L_{10}(dB(A))	N=10	.47	.22	.65	.42	.47	.22
	N=49	.24	.06	.31	.10	.23	.05

Table 8.25 The correlations between the proportion of people annoyed with vibration and the noise levels.

8.9.4 Annoyance with Delay

The correlations between the proportion of people annoyed with delay were remarkable for two reasons. Firstly the correlations were considerably higher for the proportions than for the logistic transformations of the proportions. Secondly, the correlations between the proportions and mean delay were much lower than for the logarithm of mean delay. The correlations with the percentage of time delayed and its logistic transformation were similar to those of the logarithm of the mean delay, (see Table 8.26).

The Annoyance Transformation	The Delay Variable D	Log D	%D	Logit %D
$\%A_{dl}$	.399	.515	.507	.487
$\%A_{de}$	.350	.448	.422	.422
$\%A_{d}'$	.303	.325	.307	.334
Logit $\%A_{dl}$	.347	.432	.431	.410
Logit $\%A_{de}$	.231	.314	.298	.290
Logit $\%A_{d}'$	.222	.289	.251	.279

Table 8.26: The correlations between annoyance and the delay variables.

8.9.5 Annoyance with Risk

No significant conditions were found between the proportions of people annoyed or extremely annoyed with the risk in crossing the road and any of the delay variables.

8.9.6 Relationships with the Traffic Variables

The correlations between the proportion of people annoyed with each of the environmental factors and the total flow was only marginally less than with the relevant environmental variables (see Table 8.27). The partial correlation of no other traffic or build form variable was significant.

Annoyance variable	Total Flow (Q)	Log Q
$\%A_{nl}$	.31	.78
$\%A_{ne}$	.26	.29
$\%A_{n}'$	.30	.32
$\%A_{rl}$	.16	.18
$\%A_{re}$	.24	.26
$\%A_{r}'$	.21	.20
$\%A_{dl}$	.43	.50
$\%A_{de}$	.37	.43
$\%A_{d}'$	.32	.33
$\%A_{pl}$	.14	.17
$\%A_{pe}$	.23	.23
$\%A_{p}'$	.14	.11
$\%A_{vl}$	.17	.23
$\%A_{ve}$	.33	.36
$\%A_{v}'$	.31	.27
$\%A_{al}$	.01	.02
$\%A_{ae}$	.22	.21
$\%A_{a}'$	.13	.14

Table 8.27: Correlations between the proportions of people annoyed and the traffic flow.

8.10 SUMMARY

It was found that the wide range of responses of pedestrians to the same environment made it impracticable to draw conclusions from the individuals responses. However, when measures of central tendancy of the responses for the interviewing periods were related to the independent variables, significant correlations emerged. The means of the responses gave slightly better and more consistent results than the medians.

If similar response criteria were assumed, the most annoying environmental variable was the risk in crossing the road. Air pollution and noise were slightly less annoying in that order. There were followed by delay vibration and appearance of the traffic. The latter two were considerably less annoying than the others. There was a wide variation in the correlations between the annoyances. The highest correlation was between annoyance with noise and vibration.

The wide range of responses coupled with the relatively close correlation between the annoyance made it impossible to draw inference from the EAR data in the way that was intended. The correlations between the various transformations of dependent and independent variables tended to be similar. However, the Stevens type of relationship, which was expressed in the log/log form was the strongest in all but one of the three cases where the correlations were significant. (See Table 8.28). Similar results were also found in the analysis of the observers own responses.

Environmental Variable	Type of Relationship		
	Linear	Logarithmic	Log/Log
Risk	.252	.260	.242
Noise	.492	.484	.509
Delay	.536	.567	.592
Vibration	.345	.326	.365

Table 8.28: Comparison of the strength of three types of relationship with the environmental variables.

There was a consistent improvement in the correlations between noise and vibration annoyance, and the noise variables when the aircraft noise was controlled for. Raising the assumed effective threshold also tended to raise the correlation. The hypotheses that the responses were restricted by the ends of the lines and that the environmental variables were on a traffic metathetic scale were rejected. It was found that the correlation between the proportion of people annoyed with noise and vibration, on the one hand, the noise variables, on the other, were greatly increased when the interviews were aggregated into ten sets.

The logarithm of the total flow gave almost as good, and in some cases better, statistical explanations of the variance in the annoyance variables than did the environmental variables. In the next chapter, it will be seen whether or not the seperate environmental responses, or indeed, the environmental variables will be of assistance in predicting overall annoyance.

CHAPTER 9: THE PREDICTION OF OVERALL ANNOYANCE

9.1 INTRODUCTION

The importance of being able to define, measure and predict the overall annoyance of people with the environmental effects of traffic has been discussed at length in Chapters 1 and 2. While the development of models for predicting the physical environmental variables and the annoyance which they cause may be indispensible prerequisites to environmental planning and management, the prediction of overall annoyance is a prerequisite to the evaluation of environmental plans.

Reported in this Chapter is a systematic analysis of the relationships between the observed representations of overall annoyance and:

a) the representations of the annoyances with the six separate aspects of the environment,

b) the estimated physical environmental variables, and

c) the traffic and built form variables.

The report of the analysis is presented in two sections. The first deals with the development of prediction models for the magnitude of overall annoyance on a ratio scale, using the distances at which the respondents placed marks along the lines during the interview. The second section deals with the prediction of the proportion of people who were annoyed or extremely annoyed.

9.2 THE MAGNITUDE OF THE OVERALL ANNOYANCE

In Chapter 8, it was found that the means of the annoyances for the interviewing periods tended to be more closely related to the physical variables than were the medians. The means of the overall annoyances encoded were therefore taken as the variable from which the dependent variables were calculated.

9.2.1 The Relationship with Individual Annoyances

The very highly significant correlations between most of the annoyances with separate environmental factors has been noted in the previous Chapter. Similar correlations were observed between the overall annoyance and the individual annoyances encoded. (See Table 9.1). It follows from the multicollinearity between the variables that in the development of a prediction model of overall annoyance from the separate annoyances by regression that only a limited number of the separate annoyances would make a significant contribution to the statistical explanation of the variation in overall annoyance.

Equations 9.1 and 9.2 show the results of regressing the overall annoyance (A_o) on the individual annoyances both before and after aggregating the data for the interviewing periods, using the stepwise method.

Separate Annoyance	Linear Relationships			Log/log Relationships		
	N=522	N=49 Means	N=49 Medians	N=522	N=49 Means	N=49 Medians
Risk	.578	.539	.341	.625	.551	.450
Air Pollution	.556	.661	.671	.609	.681	.794
Noise	.683	.755	.560	.736	.718	.423
Delay	.538	.587	.487	.588	.587	.325
Vibration	.538	.551	.272	.566	.493	.376
Appearance	.504	.488	.435	.499	.414	.336

Table 9.1: Correlations between overall annoyance and the separate annoyances encoded.

$$A_o = 0.22A_a + 0.18A_r + 0.14A_p + 0.35A_n + 0.19A_d + 2.4 \quad (9.1)$$

$N = 522$

$R = 0.817$

R.E. = 33.2

t statistics = 6.4, 6.3, 5.3, 12.5 and 6.4 respectively

$$A_o = 0.27A_r + 0.27A_p + 0.34A_n + 5.28 \quad (9.2)$$

$N = 49$

$R = 0.86$

R.E. = 9.0

t statistics = 3.7, 3.5 and 5.0 respectively

Each of the physical environmental variables tended to be determined by the same traffic variables. Thus if the power law relationship held true between the annoyances and the physical environmental variables it might be expected that the logarithm of the annoyances would be more closely related to each other than to their linear forms and that the same would apply to the logarithm of overall annoyance. It may be seen from Table 9.1 that the logarithmic relationships did not tend to be much stronger. Equations 9.3 and 9.4 show the results of regressing the logarithm of the overall annoyance encoded on the logarithms of the individual annoyances:

$$\text{Log } A_o = 0.10 \log A_a + 0.20 \log A_r + 0.15 \log A_p + 0.39 \log A_n + 0.20 \log A_d + 0.06 \quad (9.3)$$

$N = 522$

$R = 0.847$

R.E. = 0.37

t statistics = 3.6, 6.8, 5,7, 14.6 and 7.2 respectively

$$\text{Log } A_o = 0.33 \log (A_r) + 0.32 \log (A_p) + 0.28 \log (A_n) + .12 \qquad (9.4)$$

N = 49

R = 0.86

R.E. = .053

t statistics = 4.4, 4.1 and 4.5 respectively

The fact that not more than three of the independent variables feature in these four regression equations at any one time is due to the degree of multicolinearity which exists. One way of resolving this problem is to develop new variables based on the sum or the weighted sums of separate annoyances. First, it was tested whether the sum of the annoyances or the sum of their logarithms was significantly less closely related to the overall annoyance than the relationships in equations 9.1 to 9.4 above. For the individuals responses the correlations were 0.806 and 0.822, compared to the multiple correlations of 0.817 and 0.847 for equations 9.1 and 9.3 respectively. The corresponding correlations for the mean responses for the interviewing periods were 0.86 and 0.84 compared to 0.86 and 0.86 respectively. These correlations were not significantly less. Secondly, a principal component analysis was conducted on the means of the annoyances for the 49 interviewing periods, the results of which are shown in Table 9.2.

ANNOYANCE	PRINCIPAL COMPONENT					
	1	2	3	4	5	6
Risk	.34	.40	.61	.52	.29	.03
Air Pollution	.44	-.35	-.43	.20	.47	.50
Noise	.48	.12	-.13	-.44	.38	-.63
Delay	.39	.39	-.50	.35	-.56	-.11
Vibration	.43	.15	.29	-.59	-.32	.51
Appearance	.35	-.73	.31	.18	-.37	-.28
% of variation	49.7	14.3	13.3	12.0	6.4	4.3
R^2 with A_o	.59	.06	.10	.02	.05	.37

Table 9.2: Results of Principal Components Analysis on the means of the annoyances. (N = 49)

The first principal component accounts for almost half of the variance and it clearly describes the common variation in the responses to separate environmental factors. The remaining components are more difficult to interpret, though the fourth reflects the relatively close relationship between annoyance with noise and vibration. The last row shows the proportion of variation of the overall annoyance encoded which is statistically explained by each of the components. The following equations shows the results of regressing overall annoyance on the principal components. Only components significant at the 5% level were included.

$$A_o = 0.92C_1 + 0.59C_5 - 0.62C_6 + 20.6 \quad (9.5)$$

R = 0.964

R.E. = 9.6

N = 49

t statistics = 6.9, 2.9 and 2.3 respectively

Where C_1, C_2, etc., are the components.

Discussed in Chapter 3 was the possibility that when some respondents were encoding their annoyance with the various annoying factors on the lines, they might estimate their annoyance from an environmental factor related to their susceptibility to annoyance from that environmental factor rather than their actual annoyance with the existing state of the environmental factor. For this reason it was postulated that a more accurate picture of the relative annoyance caused by each of the environmental factors during the survey may be had by comparing the mean responses encoded with the regression coefficients in equations 9.1 and 9.3. Table 9.3 shows the means, the regression coefficients and their products for both the individuals responses and their means for the interviewing periods. Columns 3 and 5 of the Table show conflicting results. However, there are grounds for arguing that noise is more annoying than the other environmental factors because of the correlations in Table 9.1 and the t statistics in equations 9.1 to 9.4.

Annoyance	Observed Means	N = 522 Reg. Coef.	N = 522 Product	N = 49 Reg. Coef	N = 49 Product
Risk	81.7	.18	14.7	.33	29.4
Air Pollution	77.9	.14	10.9	.32	24.9
Noise	76.2	.35	26.7	.28	21.3
Delay	68.7	.19	13.1	-	-
Vibration	50.3	-	-	-	-
Appearance	33.1	.22	7.3	-	-

Table 9.3: Statistics relevant to the relative importance of the environmental factors.

9.2.2 The Relationship with the Physical Environmental Variables

In this section the regression of the overall annoyance on the estimated physical environmental variables is reported. This is followed by an analysis of the relationship between the overall annoyance and the estimates of the separate annoyances based on the estimates of the physical environmental variables. This involves both the direct relationships and those between overall annoyance and various hypothesised combinations of the estimates of the annoyances.

Overall annoyance was regressed on the estimates of the four environmental variables, for which prediction models were developed, on the basis of linear, semi-logarithmic and logarithmic relationships. The data set used was the means for the interviewing periods. On no occasion did more than one independent variable have a partial correlation which was anywhere near being significant. Table 9.5 shows the correlations between the dependent and independent variables. The following equations are the results of the regressions when the stepwise procedure was used:

A_o = .0026S + 54.2 (9.7)

N = 49

R = 0.395

R.E. = 15.7

t statistic = 2.9

Where S is the estimated sound pressure L_{10} after aircraft noise has been controlled for.

A_o = 14.3 log D + 59.4 (9.8)

R = 0.408

R.E. = 15.6

t statistic = 3.1

Where D is the estimated delay in seconds.

$$\text{Log } A_0 = 0.082 \log D + 0.77 \quad (9.9)$$

R = 0.393

R.E. = 0.94

t statistic = 2.9

INDEPENDENT VARIABLES			TYPE OF RELATIONSHIP		
SOUND	Threshold (dBA)	Aircraft Noise Controlled	Linear	Logarithmic	Log/log
L_{10}	0	No	.393	.376	.363
	0	Yes	.395	.385	.375
	70	No	..393	.354	.347
	65	Yes	.395	.375	.370
L_{50}	0	No	.419	.404	.390
	0	Yes	.415	.410	.399
	60	No	.419	.388	.379
	57.5	Yes	.415	.390	.388
L_{90}	0	No	.422	.414	.397
	0	Yes	.413	.417	.402
	55	No	.422	.401	.388
	52.5	Yes	.413	.400	.392
DELAY					
Mean Delay			.364	.408	.393
% Delay			.420	.414	.397
AIR POLLUTION					
Smoke			.124	.128	.129
Smoke ($T = 20mc.p.m^3$)			.124	.131	.133

Table 9.4 (title on following page)

Table 9.4: Correlations between various transformations of overall annoyance and the environmental variables.

It may be seen from Table 9.4 that all the noise correlations are very similar. The L_{90} is slightly more closely related to overall annoyance than the L_{50} which is in turn slightly more closely related than L_{10}. Controlling for the noise from aircraft did not improve the correlation, as it did in the case of noise annoyance. The delay correlations were similar to those for the noise, but the air pollution variables were considerably less.

Equation 9.10 shows the effect of regressing overall annoyance on estimates of the separate annoyances, which could be made from the estimated levels of the physical environmental variables. These were based on the equations for estimating annoyance with noise and delay, which were described above. Equation 9.11 is the same except that the regressions were on the logarithms of the estimates of the annoyances. Equation 9.12 shows the result of regressing the logarithm of the overall annoyance on the estimates of the logarithms of the annoyances. The stepwise procedure was used with the 10% significance level criteria for inclusion in each case. The data base was the means of the values for the interviewing periods.

$$A_o = 2.53\,\hat{A}_d + 60.5 \qquad (9.10)$$

$N = 49$

$R = 0.398$

R.E. $= 15.7$

t statistics $= 3.0$

$$A_o = 26.5 \log \hat{A}_d + 56.5 \quad (9.11)$$

R = 0.408

R.E. = 15.6

t statistic = 3.1

$$\operatorname{Log} A_o = 0.15 \log \hat{A}_d \quad (9.12)$$

R = 0.393

R.E. = 0.76

t statistic = 2.9

In Chapter 5, the rules for adding annoyances were determined for circumstances where it had been established that annoyance was related to the physical environmental variables in the same way as responses and stimuli are in Stevens' Power Law of Psychophysics. It was submitted that if a value of one physical environmental variable (P_1), caused the same annoyance as some value of another (P_2), then the values of P_2 could be expressed in units of P_1 in terms of the annoyance which they both cause:

$$\frac{C_2}{C_1} P_2 = P_1^{\alpha_2/\alpha_1} \quad (9.13)$$

Where $A_1 = C_1 P_1^{\alpha_1}$

$A_2 = C_2 P_2^{\alpha_2}$

It was further submitted that the overall annoyance would be the sum of the physical environmental variables, expressed in the same units and raised to the power of the exponent calibrated for the variable whose units were used:

$$A_o = (P_1 + C_2 / C_1 \, P_2^{\alpha_2/\alpha_1} \quad \ldots \quad \frac{C_n}{C_1} P_n^{\alpha_3/\alpha_1})^{\alpha_1} \quad (9.14)$$

In verifying the validity of this equation in practice the correlation (0.395) between overall annoyance and its estimate based on equation 9.7 (i.e. $A_o = 10\ D\ (S - T)$) was compared with the correlation between the estimated noise and delay expressed in units of noise as in the form of equation 9.14. The latter correlation was found to be 0.391 which was less than the correlation using the simpler model. One of the reasons for this may be a degree of double counting in the additive process. For example, a proportion of the annoyance with delay may be a reflection of annoyance with noise and should not be regarded as annoyance due to delay alone. The correlation was 0.374 when log A_o was regressed on the logarithm of the sum of the two environmental variables expressed in units of sound pressure, compared to 0.370 when (SP - T) was the independent variable. However, this had the result of an anomalous change in the regression coefficient (i.e. the exponent when the equation is expressed in power law form). See equation 9.15:

$$\text{Log } A_o = 0.131\log(\text{noise units}) + 1.36 \qquad (9.15)$$

9.2.3 The Relationship with the Traffic Variables

The remaining set of variables from which estimates of the overall annoyance may be made is of the characteristics of the traffic and the built form. The overall annoyance was regressed, on all of the independent variables which had been used in the development of the models for predicting the physical environmental variables. The stepwise procedure was used with both the 5% and the 10% confidence levels as the criteria for including variables in the regression set. The results of both regressions are only given where there is a difference between them. The t statistics of variables which have been excluded are given where they are close to being significant at the 10% level.

A_o	$= 25.1 \log (Q) - 1.9$	(9.16)
N	= 49	
R	= 0.417	
R.E.	= 15.5 mm	
t statistics	= 3.1	

$\text{Log } A_o$	$= 0.145 \log (Q) + 1.42$	(9.17)
R	= 0.402	
R.E.	= 0.94	
t statistics	= 3.01	

Thus the only traffic or built form variable which was significantly related to overall annoyance was the traffic flow. The proportion of variation in the overall annoyance which was accounted for by the traffic flow was significantly less than that accounted for by the estimates of the physical environmental variables.

9.3 THE PROBABILITY OF OVERALL ANNOYANCE

In the above sections the relationship between overall annoyance and its various determinants was described. Overall annoyance was defined by the distance at which the respondents placed marks from the beginning of the lines when they were asked to estimate the magnitude of their overall annoyance. In the following sections the relationship between the percentage of people annoyed during the interviewing periods and the independent variables is looked at. Respondents were recorded as being not annoyed or extremely annoyed if they placed their marks within 3 mm. of either end of the lines. 75.6% of the respondents were recorded as being annoyed overall: 12.0% of them were extremely annoyed.

The percentages of people annoyed and the percentages of people extremely annoyed and their logistic transformations are regressed in turn on the percentages of people annoyed with the physical environmental factors, the estimates of the physical environmental variables with the traffic and built form variables.

9.3.1 The relationship with the separate annoyances

Table 9.5 shows the correlations between the percentage of respondents not annoyed overall and not annoyed with the separate factors are highly significantly greater than with the percentage of people extremely annoyed with the same factors, and vice versa for the percentage of respondents extremely annoyed overall. This is because of the relatively low correlations between the proportions of people annoyed and the proportions of people extremely annoyed. In fact, in the case of overall annoyance there was a slight negative correlation. The right hand side of the table refers to the logistic transformations of the percentages. These correlations are not noticeably higher than those for the straight percentages. The correlations are given for the means of the percentages of people annoyed as recorded on the "lines" and on the EAR, as well as for the separate percentages. These are represented by (M), (L) and (E) respectively. The proportion of the variance of the overall proportions which was explained by the means of the proportions was consistently higher than the means of the proportions of the variance explained by the separate proportions.

	Percentages		Logit Percentages	
	%A_o	%A'_o	%A_o	%A'_o
%A_r (L)	.59	.21	.34	.18
%A_r (E)	.56	.29	.32	.23
%A_r (M)	.62	.27	.36	.21
%A_r	.04	.61	.13	.51
%A_p (L)	.65	.06	.53	.12
%A_p (E)	.64	.13	.64	.10
%A_p (M)	.68	.09	.60	.12
%A_p'	-.03	.38	-.04	.23
%A_n (L)	.71	.12	.75	-.00
%A_n (E)	.59	.13	.47	-.02
%A_n (M)	.70	,13	.75	-.01
%A_n'	.19	.55	.19	.45
%A_d (L)	.52	.17	.39	.25
%A_d (E)	.52	.30	.34	.28
%A_d (M)	.56	.26	.43	.30
%A_d'	.07	.55	.08	.41
%A_v (L)	.62	.03	.62	-.02
%A_v (E)	.34	.25	.23	.23
%A_v (M)	.53	.16	.53	.10
%A_v'	.31	.46	.30	.37
%A_a (L)	.49	-.03	.41	-.02
%A_a (E)	.54	-.08	.61	-.09
%A_a (M)	.59	.03	.63	-.02
%A_a'	.04	.46	-.02	.36

Table 9.5: Correlations between the percentages of people annoyed overall with the separate percentages. (%A'=% extremely annoyed.)

9.3.2 Relationships with the Separate Annoyances

Whether or not a person is annoyed with the environmental effects of traffic may be related not just to whether they say they are annoyed with some of the components of the environment, but also whether they are extremely annoyed with the components. The dependent variables were, therefore, regressed on both the percentage of respondents annoyed and the percentage of those extremely annoyed with each of the six environmental factors. The 5% confidence level was used in the stepwise procedure. The percentage of people annoyed is represented by "%A", and an apostrophe is used to represent extremely annoyed (e.g. "$\%A_n'$") represent the percentage of people extremely annoyed with noise.[1] The mean of the percentages of people annoyed according to the lines and the EAR is used in the analysis.

$$\%A_o = 0.28(\%A_p) + 0.33(\%A_n) + 0.22(\%A_a) - .02 \qquad (9.18)$$

N = 49

R = 0.776

R.E. = .08

t statistics = 2.0, 2.6 and 2.2 respectively.

$$\%A_o' = 0.37(\%A_r') + 0.27(\%A_n') + 0.49(\%A_a') - .01 \qquad (9.19)$$

R = 0.770

R.E. = 0.072

t statistics = 4.1, 3.7 and 2.8 respectively.

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1. The proportion of people annoyed in these equations i the mean of the proportions observed when using the "lines" method and the environmental Assessment Recorder.

$$\text{Logit } \%A_o = 0.60 \text{ Logit } (\%A_n) + 0.34 \text{ logit } (\%A_a) + 0.234 \qquad (9.20)$$

R = 0.780

R.E. = 0.24

t statistics = 5.0 and 2.2 respectively

$$\text{Logit } \%A_o' = 0.54 \text{ Logit } (A_r') + 0.33 \text{ logit } (A_n') + 0.45 \qquad (9.21)$$

R = 0.583

R.E. = 0.56

t statistics = 3.1 and 2.4 respectively.

Because of the multicolinearity, not more than three of the independent variables featured in any of the regressions. A principal components analysis of the proportions showed similar weightings to that of the annoyances encoded on the lines. The results are shown in Table 9.6.

Annoyance	Principal Component No.: 1	2	3	4	5	6
Risk	.41	.37	.04	.61	.48	.31
Air Pollution	.42	.06	- .79	-.09	.05	-.43
Noise	.44	.08	-.08	-.55	-.16	.68
Delay	.42	.36	.35	.16	-.68	-.30
Vibration	.42	-.19	.50	-.39	.49	-.38
Appearance	.33	-.83	-.01	.37	-.21	.12
% Variation Explained	67.9	12.6	6.6	5.8	5.4	3.7

Table 9.6: Results of Principal Components of Percentage of Respondents Annoyed with the Environmental Factors.

9.3.2 Relationships with the Physical Environmental Variables

Similar results were obtained when the overall annoyance variables were regressed on the estimates of the physical environmental variables, as was found in the last section where the dependent variable was the mean of overall annoyances encoded on the lines method. Only one of the variables was significant and the correlations were relatively low. The logistic transformations of the percentage of respondents annoyed and the percentage extremely annoyed were regressed separately on three transformations of the estimated physical environmental variables. There were the linear form, its logarithm, and the linear variable raised to the power of the exponents calibrated in sections 8.4 and 8.6 above.

The estimates of the physical environmental variables used are the same as those used in the previous section. The t statistic of independent variables which would be significant at the 10% level if they were included in the regression set are also given.

However it was found that the logistic transformation of the proportion of people not annoyed was not significantly related to any of the three sets of independent variables. The highest correlation was 0.147 which was with the logarithm of the L_{50} sound pressure when aircraft noise was controlled for and the effective thresold assumed to be 57.5 dB(A).

The logistic transformation of the proportion of people extremly annoyed was significantly related to the independent variables in two cases:

Logit $\%A_o'$	$= 1.9\ (10^{-4}) L_{50} SP - 1.87$	(9.29)
R	= 0.406	
R.E.	= 0.63	
t statistic	= 3.1	

The t statistic of log D was 0.4

Logit $\%A_{\infty}'$	$= 0.6 \log D - 1.81$	(9.30)
R	= 0.427	
R.E.	= 0.62	
t statistic	= 3.2	

The t statistic of the logarithm of the L_{50} s.p. when the threshold was set at 57.5 and aircraft noise cotrolled was 1.5.

The air pollution variables were not near being significantly related in any of the regressions. There was a very low correlation between the two dependent variables (r = 0.075). The correlations could not be increased by regressions on the estimates of the principal components of the separate

/ annoyances ....

annoyances, as described in Table 9.2 . There was a correlation of 0.118 between the logistic transformation of the percentage of people annoyed and the aggregation of the physical environmental variables in units of noise as described in equation 9.15. In the case of the logistic transformation of the percentage of respondents extremely annoyed the correlation was 0.373

9.3.3 Relationships with the Traffic Variables

The same procedure was adopted with this section as in the section 9.2.4. The dependent variables were regressed on all traffic and built form variables which were used in the development of the physical environmental models and which could be calculated from the data collected during the survey. The results of the stepwise regression were:

$$\%A_o' = 0.14 \log (Q) - .31 \qquad (9.32)$$

$R = 0.362$

$R.E. = 0.10$

The t statistic of log (Q) was 2.7

$$\text{Logit } \%A_o' = 1.02 \log (Q) - 4.28 \qquad (9.33)$$

$R = 0.424$

$R.E. = 0.62$

The t statistic of log Q was 3.2

There was no significant relationship between the percentage of people annoyed overall and any of the traffic and built form variables.

9.4 SUMMARY

The correlations between overall annoyance and the separate annoyances encoded were very highly significant in most cases. When overall annoyance was regressed on the separate annoyances, multiple corrleations of between 0.81 and 0.86 were obtained, depending on the data set and the transformations of the variables used. In all the cases the regression coefficient of noise annoyance and its significance were the highest.

A principal components analysis of the annoyance showed that almost half of this variance could be accounted for by one component which described the common variance between them. There was a correlation of 0.77 between this component and overall annoyance. The weightings of the other components which were significant in a step-wise regression were difficult to interpret. Highly significant correlations were found between overall annoyance and the noise and delay variables, but in multiple regression not more than one of the environmental variables was significant. No progress could be made in improving these correlations by using the estimates of the separate annoyances. Equally good results could be obtained by using the logarithm of the total flow.

Similar results were found in the analysis of the proportions of people annoyed, except that they tended to be more erratic. No progress was reported in the analysis of the heteroscedasticity and the definition of the psychological scale by this method.

CHAPTER 10: CONCLUDING DISCUSSION

Throughout the thesis there have been two strands to the research: the prediction of the physical environmental variables on the kerbside which are affected by road traffic; and the prediction of the pedestrians subjective responses to the environmental effects of the traffic. The progress which has been made on both these fronts is summarised in the following sections and compared with the existing state of knowledge, in the light of the criteria which have been outlined in Chapter 3. The Chapter concludes with a discussion of the applicability of the results to the evaluations of the effects of highway and traffic management proposals on the quality of the environment of people on the kerbside, and in wider behavioural contexts.

10.1 THE ENVIRONMENTAL VARIABLES

10.1.1 The Noise Models

The most important finding in the analysis of the field work measurements was that L_{10} prediction models, which had been developed for freely flowing traffic, provide equally good, if not better, predictions of the noise from non-free flowing traffic than models which had heretofore been developed for that purpose. The multiple correlations of 0.97 and the residual errors of 1.46 dB(A) which were achieved are considerably better than the multiple correlation of 0.82 and the residual error of 2.7 dB(A) which was found with equation 3.6. It is to be expected that the results would not be as good as from models for predicting the L_{10} from freely flowing traffic, such as equation 3.8 where the multiple correlation was 0.98 and the residual error 1.32. The 95% confidence bands described by 1.96 residual errors of 2.7 are approximately equivalent to the result of multiplying or dividing the traffic flow by 4.

The corresponding effect of a residual error of 1.46 is multiplying or dividing the traffic flow by 2.

The construct validity of the specification of the distance from the flight path has already been discussed. The second stage regressions make a small, but significant, contribution to the statistical explanation of the variance in the observed L_{10}. No such clear recommendation was made on the specification of the traffic flow and composition variables. The Delany type specification would have considerable advantage over the other models if it could be shown that its goodness of fit was due to the headways between the vehicles not being sufficiently differently distributed from a random distribution to affect the results, rather than that the goodness of fit was purely fortuitous. This could not be determined without a great deal of further research. The Gilbert-Crompton type model provided a relatively good fit, though without the theoretical basis. In theory, the varying of the weight given to heavy vehicles according to the flow and speed of traffic should give better results. However, no empirical merit was found in the method used by the D.o.E in their model. This leaves the Johnson-Saunders type model which also both provided an equally good fit and did not have any theoretical basis. However, it does have the merit of simplicity, and therefore it was the model which was used in the estimation of the L_{10} for the analysis of the pedestrians responses. Estimates of the L_{10} based on other models were also related to the subjective data. The Johnson-Saunders type model gave a marginally better fit than the others.

The other variable with a problematical relationship with the L_{10} was speed. There were strong reasons for expecting that there would be a significant interaction between speed and the proportion of heavy vehicles. There was in fact, but it did not give any better fit than the logarithm of speed and the proportion of heavy vehicles on their own. On the other hand the interaction element between the logarithm of speed and the logarithm of the total flow was significant in some cases and almost so in the others. Its theoretical merit lies in the submission of Crompton's that at higher speeds, vehicles tend to be spaced more with a consequent reduction in noise levels. The D.o.E. specification "log (V + 40 + 500/V)" appeared to have empirical merit. The other elements in the regression equations were specified deductively and were all significant. However, the index of parking, the distance to the "centre of gravity" of the traffic and the sound reflection index all had a degree of crudity in their specification. On the other hand the correct specification would not be practicable and the submitted specifications have considerable merit in simplicity.

10.1.2 Source of Error in the Noise Models

A method was described, at the end of Chapter 4, of determining the proportion of the unexplained variance of the observed L10 which was caused by the unique characteristics of the sites at which the measurements were taken. These characteristics would include such things as the accoustically reflective qualities of the built form environment and the effects on the traffic flow of traffic lights. By taking a second set of observations at a number of sites it was possible to calculate the correlation between the residual errors for each site where more than one observation was made. The square of this correlation tells the proportion of the residual errors which is common to the sites. As stated, this is caused by characteristics of the sites which were not measured, but it is also caused by characteristics of the sites which may have been mis-specified in the models. This includes the noise from aircraft.

These correlations were calculated for each of the second stage regressions described in Chapter 2. In each case they were very similar. The minimum value was: $r = 0.40$, which was highly significant. It has been noted that a dummy variable, representing whether streets have one way traffic, would have had t statistics of between 1.5 and 1.8 if they had been included in the second stage regression sets, and it was, therefore, probable that this factor would account for a significant proportion of the unexplained variance of the L_{10} which was peculiar to the sites. The correlation between the residuals was calculated after including the dummy variable in a regression equation (i.e. equation 7.21). This had the effect of reducing the correlation from 0.415 to 0.396 which was still highly significant. As a number of alternative specifications of the built form variables had been tested without any significant improvements of the residual errors, it was concluded that approximately 20% of the unexplained variance in the observed L_{10} was due to factors peculiar to the sites, and of this roughly a quarter was due to streets being either one-way or two-way.

Having come to this conclusion, the logical question to ask is whether these factors peculiar to the sites have affected the calibrations of the regression equations, or indeed the specifications of the models which was finally settled on. A crude, though the only available method of answering this question, is to include in the data set an additional variable comprising of the residual errors calculated in earlier regressions. These should not be included for the observations for which they were calculated, but for the other observations which were taken at the same sites. This was done for the Johnson-Saunders type model (i.e. equation 7.21),[1] with the following results for the first and second stage regressions:

$$L_{10} = 18.33\log Q - 4.3\log Q\log V + 18\log V + 0.15P + 0.18T - 7.3\log Cg - 3.7\log D + 0.52R + 31.6 \quad (10.1)$$

R = 0.969

R.E. = 1.43

t statistics = 4.2, 1.6, 1.9, 7.6, 3.4, 5.0, 6.4, and 4.4 resp.

$$L_{10} = 0.30f(t_1)\log D - 20.8\log D + 89.5 \quad (10.2)$$

R = 0.973

R.E. = 1.37

t statistics = 33 and 43 respectively.

It may be seen that this increased the multiple correlation significantly from 0.967 to 0.97 . However, it did not substantially alter the calibration or the t statistics of any of the regression co-efficients.

10.1.3 The Pedestrian Delay Models

It was invalid to regress the mean delay variable on the independent variables because of the degree of heteroscedasticity found in the data. A model was therefore developed for the prediction of the logarithm of mean delay. The Adams formula on its own explained 90% of the variation in "log D" and 94% for the percentage of time delayed. The accuracy of these models could be improved even further by the addition of the index of dispersion for the near side flow and the mean speed of

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1. There were 40 sites where two observations were taken, thus there were 80 observations with residual errors as an additional variable, in the remaining 30 observations a value of zero was ascribed to the variable.

the vehicles on the near side, both of which were very highly significant. The density of the traffic also made a significant contribution to the prediction of "%D". The final multiple correlations for the two models were 0.973 and 0.989 respectively.

The Adams formula was developed for predicting delay caused by freely flowing traffic, where the headways between vehicles were randomly distributed within the constraints of a poisson distribution function. However, given the goodness of fit which was found in the analysis of the survey data, there can be little doubt about the validity of applying the formula to non-free flowing traffic conditions. The other variables in the models were first in the regression sets because of the significance of their partial correlations. On the other hand the construct validity of each of them appears to be acceptable. It is reasonable to expect that a pedestrian would not cross the road until there was a clear gap in the far side flow of traffic, that he would be more sensitive to variations in the gaps in the near side flow, and that his delay would be related to the further arrival of the traffic. The very highly significant contribution of the speed variable may suggest that the observer (and therefore it is assumed the average pedestrian) was considering not only the MAH in seconds but also the distances between the vehicles, on the other hand it may be a reflection of fast moving vehicles tending to be more evenly spaced and affecting the delay in that way.

The minimum acceptable headway for the observer was calibrated at 3.5 seconds. This may be slightly on the low side for average pedestrians. Dovell recommended a MAH of 6.5 seconds in plan evaluation so that vulnerable pedestrians would be catered for. The goodness of fit was insensitive to slight changes in the MAH being tested and it would probably be valid to apply the existing models with arbitrarily inserted MAHs up to 6.5 seconds.

10.1.4 The Air Pollution Models

As in the case of mean delay it was found that it would be invalid to regress the Smoke and CO variables on the independent variables because of heteroscedasticity, and models for predicting the logarithm of the variables were therefore developed. This was achieved by using the stepwise procedure on all the independent variables which had been measured and were postulated to be related to the emission of air pollution. The resultant multiple correlations (R = 0 for smoke and R = 0 for CO) were much lower than for the delay and noise models. Further, one of the highly significant variables in both of the models was the wind speed, which could not be predicted. This raises an important issue on the accuracy of predictions from the physical environmental models, and we will return to it later. It is the distinction between estimating the environmental state for one point in time from given traffic parameters, and the estimation of the average environmental state from the same parameters. Much better estimates could be made of the latter, particularly in the case of the air pollution variables, where the average wind speed could be inserted in the equation, to predict the average air pollution levels. It was suspected that a large proportion of the residual error was caused by not being able to measure the variables which affected the dispersion of the air pollutants. Given the assumption that there was little scope for improving the goodness of fit by changing the specification of the independent variables, and the knowledge that the emission of smoke relative to CO is inversely related with respect to the fuel used by vehicles and the way in which they are driven, it is submitted that the correlation between the residual errors from the two models would indicate approximately the proportion of the residual error which could be accounted for by the factors which affect the dispersion of the pollutants. This correlation was, in fact, very highly significant at 0.98 , with the clear indication that little progress can be made in perfecting the models without tackling the problem of predicting the rate of dispersion.

10.2 THE ENVIRONMENTAL INDICES

10.2.1 The Form of the Relationship

No significant relationships were found between the annoyances which were encoded by the respondents using the lines methods and the estimates of the physical environmental variables. This was found to be due to the variance in individual's responses to given environmental states. If the individual's responses to similar environments were aggregated, the relationships between the subjective and objective data then became much stronger. The means of the aggregated responses were slightly more closely related to the estimated environmental variables than were the medians. For both the means and medians data there was little difference between the strengths of the different forms of relationships which were tested. These are summarised, for the means, in Table 10.1 for: a) the power relationship (i.e. the Stevens type, see equation 5.3) which was hypothesised as being the correct form; b) the logarithmic relationship as specified by Fechner and his successors; and c) the simple linear relationship. It was noted that the respondents appeared to ignore the effect of the aircraft noise, when encoding their annoyances with the noise from the traffic. There was also a slight tendency for the power law relationship to be stronger when a threshold was included in the environmental variable.

Environmental Variable	Sample Size	TYPE OF RELATIONSHIP		
		Power	Logarithmic	Linear
L_{10}	49	.509	.484	.492
L_{10} Threshold = 65 dBA Exc. aircraft noise	49	.593	.527	.526
L_{10} ditto	49	.566	.525	.526
Mean delay	49	.592	.567	.536
Percentage delay	49	—	—	.565
Logit % Delay	49	.596	.578	—
Smoke	49	.020	.065	.080
Smoke T = 25	49	.045	.073	.080
CO and Smoke	49	.277	.284	.279

Table 10.1: Correlations between means of "annoyances" and noise, delay and air pollution variables for three types of relationship. (The "power" correlations quoted are those between the logarithms of the variables).

There was no significant difference between the correlations on any row in Table 10.1, and therefore the null hypothesis, that the Stevens type of relationship did not give a significantly better fit than the other forms, could not be disproved. However, it should be noted that it gave better results than the other forms for noise and delay, where the relationships were significant. The log/log correlation was also the highest when annoyance with vibration was compared to the noise levels.

	Linear	Logarithmic	Power
Air Pollution	.281	.269	.245
Risk	.273	.248	.229
Noise	.436	.489	.525
Delay	.560	.573	.598
Vibration	.337	.349	.376
Appearance	.116	.089	.057

Table 10.2: The correlations between the annoyances encoded and the traffic flow, for three types of relationship.

Table 10.2 shows, for comparison, the strength of the relationships between the annoyances and the traffic flow. It may be seen that these are not significantly less than those in Table 10.1. In some cases they are greater.

10.2.2 The Proportion of People Annoyed

It was found in the analyses of the proportions of people annoyed that in all cases there were only very marginal differences caused by varying the transformations of either the dependent or independent variables, and that therefore little conclusion could be drawn as to what should be the correct form of relationship. This was largely due to the narrowness of the range of variables. It was also found that roughly 5 times as much of the variance in the proportions of people annoyed with noise was statistically explained when the 49 sets of interviews were aggregated to 10 sets. This suggests that this form of analysis requires a much larger sample and a wider range of data to empirically verify the merits of one form of relationship over another. This is not to say that relatively high correlations could not be achieved from a sample of 500 interviews. Table 10.3 shows how the combination of the data resulted in a correlation of 0.75 between the mean of the proportion of people annoyed and noise level. The percentage of the variance of the means of proportions which is explained by the noise levels is greater than the mean of the percentages which are explained for the separate proportions. This is because of the cancelling out of random error. (The means of the percentages are in brackets etc.). The percentages in the right hand column, (i.e. 56% and 38%) are equivalent to correlations of 0.75 and o.62.

	Proportions	Sub-Means	Grand Mean
Not annoyed with Vibration (LINES)	23.6		
Not annoyed with Vibration (EAR)	45.6	43.2	
		33.3	
Extremely annoyed with Vibration	30.6		
Not annoyed with Noise (LINES)	47.7		
			55.8
Not annoyed with Noise (EAR)	18.4	52.1	38.4
		42.8	
Extremely annoyed with Noise	71.4		
Not annoyed overall	6.4		
		51.9	
Extremely annoyed overall	71.7	39.2	

Table 10.3: Percentage of variance in proportions explained by sound pressure. (When R^2=0.56, r=0.75).

It could be argued that it would be theoretically sounder to calibrate the thresholds in the Stevens type relationships by using the noise level at which half the people were annoyed, rather than trying to calibrate it empirically. The evidence that there is suggests that the threshold is higher than the minimum noise levels estimated from the traffic variables observed during the survey of the pedestrians responses. This is compatible with the estimated level of 71.2dB(A) at which half of the respondents become annoyed with noise. The problem of the sensitivity to the values of the thresholds, cannot be resolved until further research determines the values of these thresholds.

10.4 OVERALL ANNOYANCE

10.4.1 Magnitude Estimations

The overall "annoyance" which was encoded on the lines was found to be very highly significantly related to each of the separate "annoyances". When it was regressed on them using the stepwise procedure only three of them made significant contributions to the statistical explanation, because of their multicollinearity. The multiple correlation was o.86 (N=49). The same multiple correlation was found when the logarithms of the variables were used. Much less good results were obtained when the overall annoyance was regressed on the estimates of noise, delay and air pollution using the stepwise procedure. In this case only noise was significant with a correlation of approximately 0.4 depending on the transformation of the estimated sound pressure. When the overall "annoyance" was regressed on the "annoyances" for noise, delay and air pollution the multiple correlation was 0.8. However, there was no scope for improving the model by regressing the overall "annoyance" on the estimates of the "annoyances". It was shown in the last chapter that it was not possible to test adequately the hypothesized environmental index based on equation 5.16. This rule for the additivity of utilities may be an important theoretical development, but it needs empirical verification before it can be used in the prediction of overall environmental quality.

If and when an index of overall annoyance is developed, which is formed from more than one environmental variable , it is probable that a greater proportion of the variance of that index could be explained by the traffic and built form variables, than of the weighted proportions of variances explained for the separate environmental variables. This was tested in a relatively simple case where it was assumed that the noise, delay and air pollution variables were equally weighted:

$$E.I = L_{10} + \log D + \tfrac{1}{2}\log Sm + \tfrac{1}{2}\log CO \qquad (10.3)$$

Where E.I. is the environmental index, and the environmental variables are normalised. Equation 10.4 shows the results of regressing E.I. on the traffic and built form variables:

$$E.I. = 5.74 \log Q + 0.002\, Q_n - 1.66 \log D + 0.04\, LU_r - 0.56 \log Q \log V - 9.78 \qquad (10.4)$$

$$R = 0.924$$

$$R^2 = 0.854$$

$$N = 78$$

The data set contained all of the observations where each of the four environmental variables were measured on the two-way streets. The correlations between the observed and estimated levels of these variables were. 0.96, 0.95, 0.62 and 0.71 respectively. The weighted mean of the squares of these correlations was 0.75 which was considerably less than the 0.854 from equation 10.4. The comparable correlations would be 0.87 and 0.924.

However, one factor which militates against the urgency of developing models based on the theories of the additivity of the effects of environmental variables is the very high correlation between the overall annoyance encoded and the total traffic flow. These were 0.403, 0.417 and 0.402, for the linear, logarithmic and log-log relationships respectively. It has also been noted above that the correlations between the separate annoyances and the traffic flow were very similar to those between the annoyances and the environmental variables. There are, therefore, considerable grounds for arguing that, for all practical purposes, the total flow in vehicles per hour would itself give an adequate indication of the effect on the quality of the environment of the road traffic.

10.5 IMPROVING THE ERROR IN THE PHYSICAL MODELS

The models for predicting the environmental variables could be improved by reducing the random error through taking more fieldwork measurements, and as in all research, the findings tend to become more generally accepted when they have been replicated. Apart from conducting a large scale survey, another fruitful approach would be the incremental improvement of the models by focusing research on the separate elements. This was done, for example, by Blitz (1974) on the effect of the gradient of the road on the L_{10}, though without positive results. The selection of heavy lorry routes, as required by the Dykes Act, means that particular attention should be paid to the correctness of the flow-composition element. The rate of change in the speed of the traffic caused by the position of traffic lights, intersections, pedestrian crossings and bus stops may account for a significant part of the unexplained variance.

There are two ways in which the residual errors in the models may be reduced by the methods used in their application. The first was touched on in the context of predicting the levels of air pollution where wind speed was an important determinant, but which could not be predicted. It is the question of whether the prediction is being made of the level of the pollutant from given traffic parameters or whether it is the average level of the pollutant that would exist. Some text books refer to the former type of prediction as forecasting. In addition to the error in predicting the average level of the dependent variable, there is also the error emanating from the variability of single values of the dependent variable (Huang, 1964). The standard error (which is t distributed) of the mean estimate of the dependent variable for a given value of an independent variable is

$$E\,(e_p\quad) = (R.E.)\sqrt{\frac{1}{N} + \frac{(X_o - \bar{X})^2}{(X_1 - \bar{X})^2}} \tag{10.5}$$

This is the same as equation 6.1 except that the "1" in the term under the square root sign is omitted.

10.6 THE VALIDITY OF USING ELICITED RESPONSES

The research has been concentrated on the very specialised field of predicting people's annoyance to the environmental effects of traffic.

As such, the results may be used by planners to give an indication of the environmental implications of proposed schemes. However, quantification of the quality of the environment arrived at in this way are only applicable where other things are equal, which they never are in real life situations. To ascribe the status of an objective function to these quantifications and to use them directly in the method of evaluation as the measure of people's opinions on the environmental effects of the plans, runs the risk of ignoring many relevant factors. This type of systems analysis approach involves sweeping assumptions about human needs, priorities and values (Calder, 1969).

One example of the failure of this type of approach to give valid results is the very different responses of people who are threatened with a change for the worse in their environment from those of people who have already been living in such an environment for some time. It is an unwarranted assumption that predictions of individuals' annoyances can be equated with their viewpoint on a plan. It is even questionable whether indeed people do have individual viewpoints, rather than corporate viewpoints which are arrived at through discussion and which may change rapidly on the receipt of new information, e.g. through a public meeting, (Bayley, 1974).

On the other hand, even in the context of the maximum feasible public participation, the application of the annoyance prediction models to alternative traffic flows may provide essential information, for both the public and the planners, to be used in the decision making process. From the public's point of view, access to this type of information would be of the most use in their participation in the evaluation of alternative plans. To the planners, the information would be of the most use in the earlier stages of the generation of the alternative plans, except in the case of minor schemes where it would not be feasible for the evaluation to be carried out other than by the planners.

10.7 AN APPLICATION PROBLEM

Throughout the analysis of the subjective responses, the emphasis has been on the prediction of the mean or median responses. This has been in common with manyother researchers. Unfortunately, however, planning decisions which are based on the estimated responses of the average man may lead to inequitable results, because the annoyances of the more susceptible members of society are not considered. It has been seen how peoples responses vary widely to given environmental conditions and the indications are that these variations are normally distributed.

Figure 10.1 shows diagrammatically the relationship between peoples subjective responses and the environmental index to which it is assumed that each persons response is linearly related. The solid line represents the response of the median man. The other lines represent equal distance bands in terms of normal equivalent deviates from the median responses. (The light lines are drawn diverging from each other to represent the existence of Weber's Law, but this is not part of the argument). The chain dotted line represents peoples mean response. The mean response approximates to the median response as the proportion of people with no response decreases, and to zero as the proportion of people with responses decreases.

The mean response to a given environment can only be calculated if the form and parameters of the distribution of peoples responses are known. If it could be taken that Thurstone's assumption, that the response of the individual to a given stimulus is distorted by random and independent factors, could be extrapolated to the responses of a group of individuals, it would follow that if an environmental stimulus was presented an infinite number of times the responses would be normally distributed about the best estimate of the response, which would of course be the response of the median person. It should therefore be possible to test the validity of this assumption, and if sound, calibrate the parameters by regressing the logistic transformations of the proportion of people annoyed with the environment on the values of the relevant index of the environment. However, in research reported above it has been shown how large the variation in response is. The corollary that there is a narrow range in the proportion of people annoyed with the different environments has also been shown. It was found that the standard deviations of these proportions were approx. 0.13 This was in spite of having conducted interviews in a relatively wide range of environmental conditions. Nevertheless, there was a highly significant correlation between the logistic transformation of the proportion of people found to be annoyed and the L_{10} levels, though the narrowness of the range of the dependent variable made it impossible to show that the logistic transformation was significantly more highly correlated to the environmental index than the straight proportions.

The purpose of dwelling on these research findings (and there are indications that they may be typical in environmental planning research) was to emphasise the seriousness of the error of regarding the subjective response of the median person being the same as that of mean population. In Figure 10.1, half of the people would be annoyed where the median response leaves the x axis, assuming a normal (or at least a symmetrical) distribution. This is the point where there is the maximum difference between the mean and median response. The narrow range of proportions in the research quoted was close to this point, being approximately between 0.2 and 0.4.

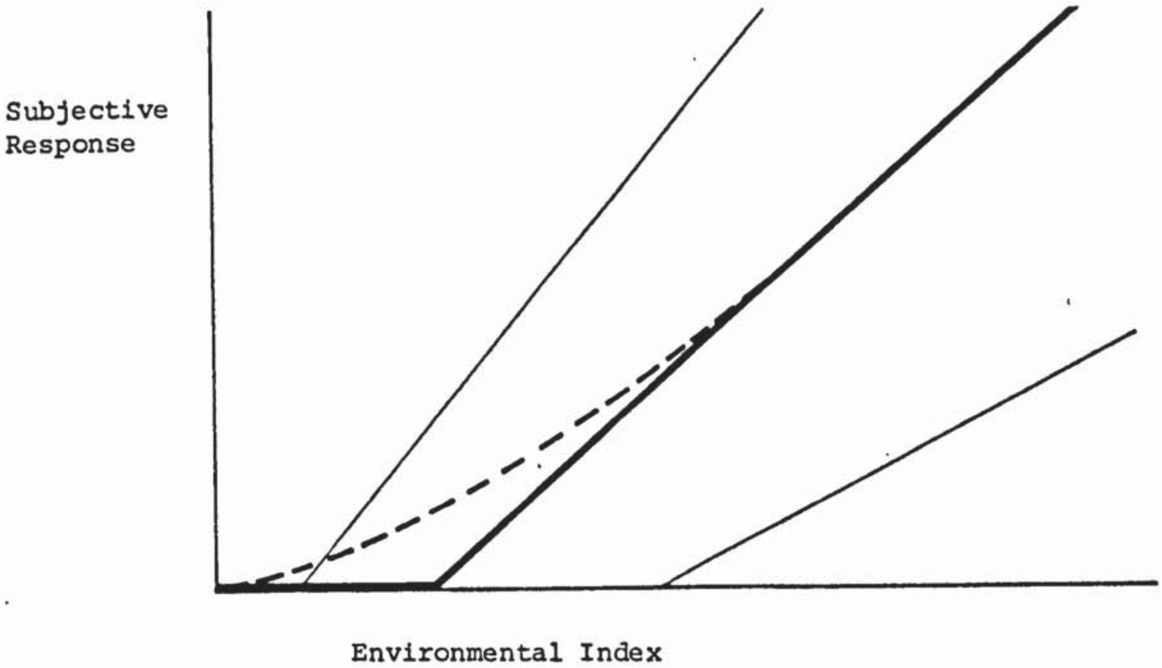


Figure 10.1: Diagrammatic relationship between mean and median response with an environmental index.

The error in the estimated number of people who would be seriously annoyed by the noise from the third London airport if it was sited at Foulness, which was caused by regarding all peoples' responses as similar, was quantified by Elliott (1971) in a discussion on the concept of "noise". He estimated that 21,000 people would be seriously annoyed by aircraft noise if the proposed airport was built. This is in contrast to the figure of 500 people, who, it was submitted to the Roskill Commission, would be seriously annoyed. The wide difference between the two figures is due to Elliott basing his estimate on the proportions of people annoyed at various N.N.I. contours, whereas the inquiry submission was based on the numbers of people within the 50 N.N.I. contour, (this was the level at which it was found in the London Airport Survey that the "average" (median) person became annoyed (Roskill Report, 1971). Elliott has also used the findings of the same report for his estimate.

If one was concerned with calculating the mean response on a ratio scale, rather than the number of people annoyed (or seriously annoyed), it would, as stated above, be necessary to know the form and parameters of the distribution of people's responses. If it could be taken that responses were normally distributed, then the mean annoyance of people for any value of an environmental index, i.e. the distance of the centre of the area of the normal distribution over the x axis, (in Figure 10.1) from the x axis, may be calculated by integration:

$$\bar{R} = \frac{\int_{x}^{\infty} XY \, dY}{\int_{x}^{\infty} X \, dY} \qquad (10.6)$$

Where $\bar{R}$ = the mean response

Y = the distance between the x axis and the mean of the normal distribution

and $X = e^{-Y^2/2\sigma^2}$

(The $\frac{1}{\sigma\sqrt{2\pi}}$ elements in the normal equation cancel out)

10.8 CONCLUSION

It is submitted in conclusion that a significant contribution has been made to knowledge of the environmental planning of road traffic. Models have been developed for predicting the kerbside L_{10} which were shown to be considerably more accurate than existing models. Very accurate models for predicting pedestrian delay have also been developed. It has been shown for both environmental variables that the recalibration of models developed for free-flowing traffic provided the best basis for this prediction from non-free flowing traffic. It has been demonstrated in the case of air pollution models that improving the accuracy of estimates depends to a very large extent on developing methods of predicting their dispersion rather than their emission.

Less progress has been made in the prediction of pedestrian response. While, in some cases, very highly significant correlations between responses and the independent variables have been observed, the wide range of responses relative to the range of the traffic variables on the non-motorway urban road network made it impossible to define the correct form of the relationship between the responses and the traffic. However, in the cases where the relationships were highly significant, the log/log relationship (i.e. that which corresponds to Stevens' Power Law of Psychophysics) was the closest.

It was found that overall annoyance with the traffic and the annoyance with the separate environmental variables could generally be predicted just as accurately directly from the traffic variables as from the estimated environmental variables. Of the traffic variables, the logarithm of the total flow accounted for almost all of the explanation of the variance explained in the dependent variables. It is concluded that the results of further fieldwork research on pedestrian response may be limited until progress has been made in developing more sensitive means of encoded responses on the kerbside and in solving the theoretical problems which have been outlined.

APPENDIX 1: THE CONSTANT RATIO OF LOUDNESS

Proof that the statement "loudness is doubled by the addition of 10 dB(A)" implies a power law relationship between sound pressure and loudness with an exponent of 0.6.

Let D = any sound in dB(A)

and L = the loudness of D

P_1 = the sound pressure of D dBA in n/m^2 (i.e. $10^{D/20}$)

P_2 = the sound pressure of (D + 10) dBA

k = an arbitrary constant

It is required to prove that if $L = k(P_1)^{0.6}$ then $k(P_2)^{0.6} = 2L$

It can be shown that by substituting dB(A) for sound pressures that P_2 divided by P_1 equals the square root of 10:

$$P_2/P_1 = 10 \log P_2/P_1$$

$$= 10^{1/20} (20 \log P_2/P_1)$$

$$= 10^{1/20} (20 \log P_2 - 20 \log P_1)$$

$$= 10^{1/20} ((D + 10) - D)$$

$$= 10^{1/2}$$

as $k(P_2)^{0.6} = k (P^2/P_1 \; P_1)^{0.6}$

$$k(P_2)^{0.6} = k (\sqrt{10}\, P_1)^{0.6}$$

$$= k (\sqrt{10})^{0.6} (P_1)^{0.6}$$

$$= k\, 2(P_1)^{0.6}$$

and substituting L for $k(P_1)^{0.6}$ as given:

$$k(P_2)^{0.6} = 2L$$

Q.E.D.

APPENDIX 2: COMPUTER ANALYSIS

The computer analysis was conducted on the University of Aston I.C.L.1904S computer. Special programs were written for the data preparation. The I.C.L. Statistical Analysis applications package was used for the analysis. This program package allows for a number of different computational procedures by the insertion of control cards and Fortran sub-routines.

Regression analysis results consist of :

(a) The regression coefficients of the variables in the regression set, their standard errors, and their t statistic, partial correlation, and the multiple correlation and error sum of squares if they were omitted from the regression set.

(b) The t statistic and partial correlation of each variable in the observation matrix, but not in the regression set, and the multiple correlation and error sums of squares if they were included.

(c) The error sum of squares after the regression, the residual error, the multiple correlation and the intercept term.

(d) The residuals may also be requested. This output contains the observed and estimated values for each observation, their difference, the percentage of the error sum of squares accounted for by that observation and the ratio of the error to the observed value of the dependent variable. The Durban-Watson D statistic is output, so that tests for auto-correlation may be conducted.

Dependent variables could either be regressed on specified independent variables or a stepwise procedure could be used to select from a set of independent variables those which made a significant contribution to the statistical explanation of the variance in the dependent variable. The stepwise routine ensured that the maximum variance was explained by variables whose t statistics were significant at a specified level.

APPENDIX 3: LIST OF SITES AND MAP SHOWING THEIR LOCATION

Table A3.2 shows the number of observations which were taken at each site for both peak and off-peak periods. For a number of reasons successful measurements of all the dependent variables were not made at each site. Separate columns have therefore been ascribed to noise, delay and air pollution. The large discrepancy between the delay column and the others is because delay observations in one-way streets were not included in the analysis. The right hand column relates to the periods of interviewing at the sites. Table A6.1 shows a summary of the sets of data for all the sites, sub-divided into peak and off-peak periods.

Data set	Number of Observations		
	Peak	Off-Peak	Total
Noise	48	62	110
Delay	40	46	86
Air pollution	53	64	117
Pedestrian response	15	34	49

Table A3.1: Numbers of observations taken, by type and time period.

Figure A3.1 is a street map of the London Borough of Hammersmith showing the location of the sites at which the observations were made. The heavy line drawn across the map is the approximate centre of the flight path to London Airport at Heathrow.

SITE No	STREET NAME	PHYSICAL ENVIRONMENTAL SURVEY						PEDESTRIAN SURVEY	
		Noise		Delay		Air Pollution			
		P.	O.P.	P.	O.P.	P.	O.P.	P.	O.P.
001	Barlby Road		2		2		2		1
002	Scrubbs Lane		2		2		2		
003	Scrubbs Lane	1	1	1	1	1	1	1	1
004	Dalgarno Gardens	1	1	1	1	1	1		
005	Wood Lane	1				1			
006	Du Cane Road	1	1	1	1	1	1	1	1
007	Uxbridge Road		1				2		
008	Western A venue	1	1			1	1		
009	Old Oak Road		2		2		2		
010	Old Oak Road	1	1	1	1	1	1	1	
011	Uxbridge Road	1	1	1	1	1	1		2
012	Bath Road	1	1	1	1	1	1	1	1
013	Chiswick High Rd	1	1	1	1	1	1		2
014	Great West Road		1				1		
015	Hartswood Road								
016	King Street		2		2		2		1
017	Emlyn Road	1	1	1	1	1	1		
018	Paddenswick Road	1	1	1		1	1		2
019	Addison Gardens	1	1			1	1		
020	Holland Road	1		1		2		1	1
021	Uxbridge Road	1	1	1	1	1	1		1
022	Hammersmith Bridge Road	1	1	1	1	1	1		
023	Greyhound Road		3		3	3	3	1	2

SITE NO	STREET NAME	PHYSICAL ENVIRONMENTAL SURVEY						PEDESTRIAN SURVEY	
		Noise		Delay		Air Pollution			
		P.	O.P	P.	O.P.	P.	O.P.	P.	O.P.
024	Fulham Palace Rd.	1	1	1		1	1	1	1
025	Great West Road					1	1		
026	Talgarth Road								
027	Lena Gardens	1	1	1	1	1			
028	Shepherd's Bush Road		2		2	2	2	1	1
029	Fulham Palace Rd		2		2		2	1	1
030	Holland Road		2		2		2		
031	Hammersmith Grove	1	2	2		2		1	1
032	Brook Green	2		2		2		1	
033	Edith Road	1				2			
034	Hammersmith Road	1	1	1	1	1	1		2
035	Brompton Road	1	1	1	1	1	1		1
036	Addison Road		1				1		
037	Vereker Road	1	1	1	1		1	1	
038	Talgarth Road	1				2			
039	North End Road	1		1		1			
040	King's Road		2		2		2		1
041	North End Road	1		1		1	1	1	1
042	Eardley Crescent	1	1				1		
043	Homestead Road	2		2		2			
044	King's Road			2		2		1	1
045	Wandsworth Bridge Road	1	1	1	1	1	1	1	1
046	Studdridge Street	1	1	1	1	1	1		
047	Fulham Road	2		2		2			2

SITE NO.	STREET NAME	PHYSICAL ENVIRONMENTAL SURVEY						PEDESTRIAN SURVEY	
		Noise		Delay		Air Pollution			
		P.	O.P.	P.	O.P.	P.	O.P.	P.	O.P.
048	Fulham Palace Rd	1	1	1	1	1	1		1
049	Fulham Palace Rd	1	1	1	1	1	1		1
050	Stephendale Road	1	1	1	1	1	1		
051	Townmead Road	1	1	1	1	1	1		
052	Eatown Gardens		1		1		1		
053	Hammersmith Road		1		1		1		
054	Hammersmith Road	1		1		1			
056	Shepherds Bush Green		1				1		
057	Shepherds Bush Rd								1
058	Shepherds Bush Rd	1	1	1	1	1	1	1	1
059	Addison Gardens		1				1		
060	Addison Gardens	1		1		1			
061	Richmond Way	1		1		1			
062	Blythe Road		1				1		
063	Blythe Road	1				1			
064	Blythe Road		1		1		1		
065	Blythe Road	1		1		1			
066	Sinclair Road		1		1		1		
067	Hazlitt Road		1				1		1
068	Dewhurst Road		1				1		
069	North End Road		1				1		
070	Brook Green		1				1		
071	Brook Green	1				1			
072	Rowan Road	1				1			

SITE NO.	STREET NAME	PHYSICAL ENVIRONMENTAL SURVEY						PEDESTRIAN SURVEY	
		Noise		Delay		Air Pollution			
		P.	O.P.	P.	O.P.	P.	O.P.	P.	O.P.
074	Sinclair Gardens	1				1			
075	Rockley Road		1		1		1		
076	Minford Gardens		1		1		1		
077	Machin Road		1				1		
078	Bolingbrook Road	1				1			

Table A3.2: List of sites and measurements taken by time period. (P = Peak. O.P = Off-Peak).

TEXT BOUND INTO

THE SPINE

Aston University

Illustration removed for copyright restrictions

Figure A3.1. Map of the study area, showing the location of the observation sites. The centre flight path to London Airport is described by the horizontal line at the base of the map.

APPENDIX 4: EQUIPMENT USED IN SURVEY AND ANALYSIS

Measurement - Traffic Noise

Quantity	Description	
3	Uher Tape Recorders	4200 Stereo
2	B & K Sound Level Meters (1" 4117 Mic.)	2205
2	" Precision S.L.M. (½" 4148 Mic.)	2206
1	" Impulse Precision S.L.M. (1"4145)	2209
2	" Rain Covers and Windshields	UA0381
1	" Sound Level Calibrator (94dB)	4230
1	" 2-channel Mic.Power Supply Unit	2807
2	" Preamplifier (for ½" 1" mics.)	2615
1	" 1" Microphone	4145
2	Portable Equipment Trolleys	
	Traffic Data	
3	Cassette Tape Recorders (+3 Mics.)	
1	Speed Meter (James Scott))	
1	Speed Meter Dish Antennae)	
1	V.T.R. System	
	Pedestrian Delay	
1	Cassette Tape Recorder	
2	Modified Mics. with pushbutton Signal Generator boxes	
	Atmospheric Pollution	
1	Draegar Multi Gas Detector	
1	Smoke Meter	
1	Portable Wind Speed	

Data Processing

1	Reflectometer	
1	B & K 25dB Logarithmic Potentiometer	ZR004
1	" 10-35mV. Linear "	ZR001

Data Processing (contd.)

2	B & K Level Recorders	2305
1	" Stat. Distribution Analyser	4420

Analysis and Prediction

1	Frequency Spectrometer (2606	LINKED)	
		)	2113
1	Measuring Amplifier (1615)	UNITS)	
1	Nikon Photomic Auto Camera		

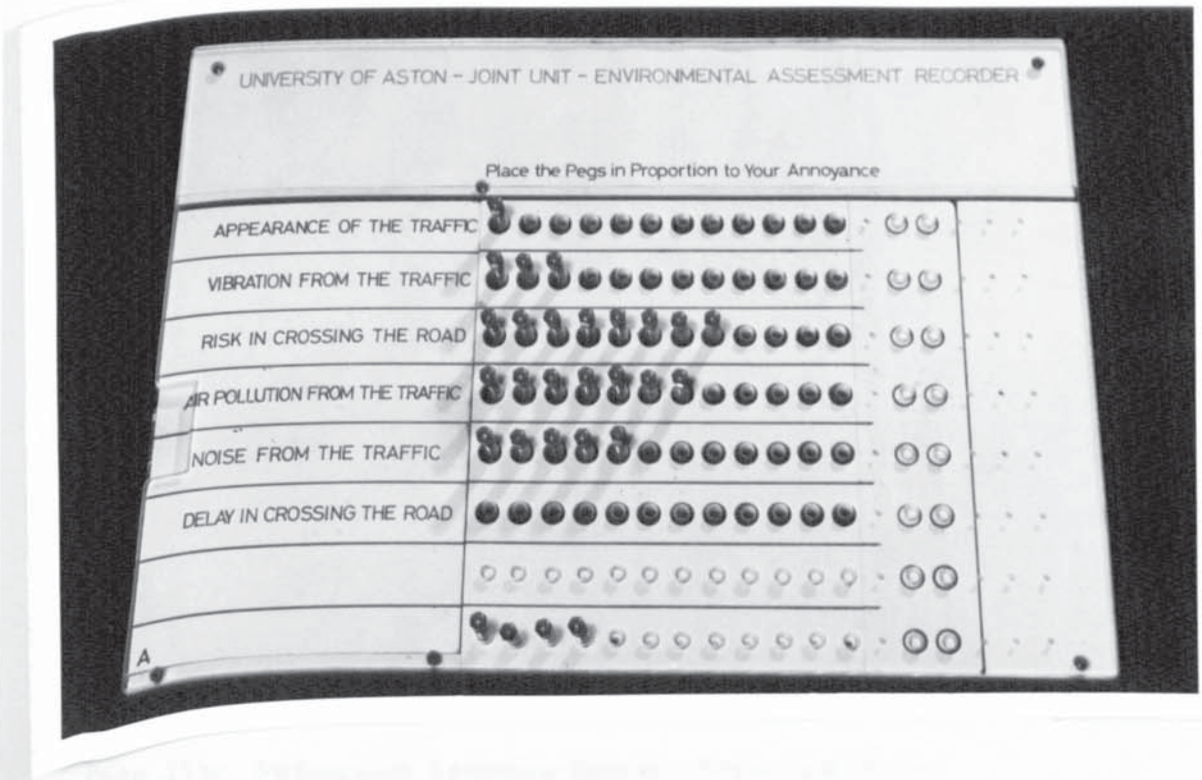


FIGURE A4.1: Photograph of the Environmental Assessment Recorder (EAR) which was developed for the pedestrian response survey

APPENDIX 5: REFERENCE SHEETS AND GRAPHICAL REPRESENTATIONS OF DATA

List of fieldwork reference sheets and examples of graphical representations of the data collected during the physical environmental survey which may be found in the following pages:-

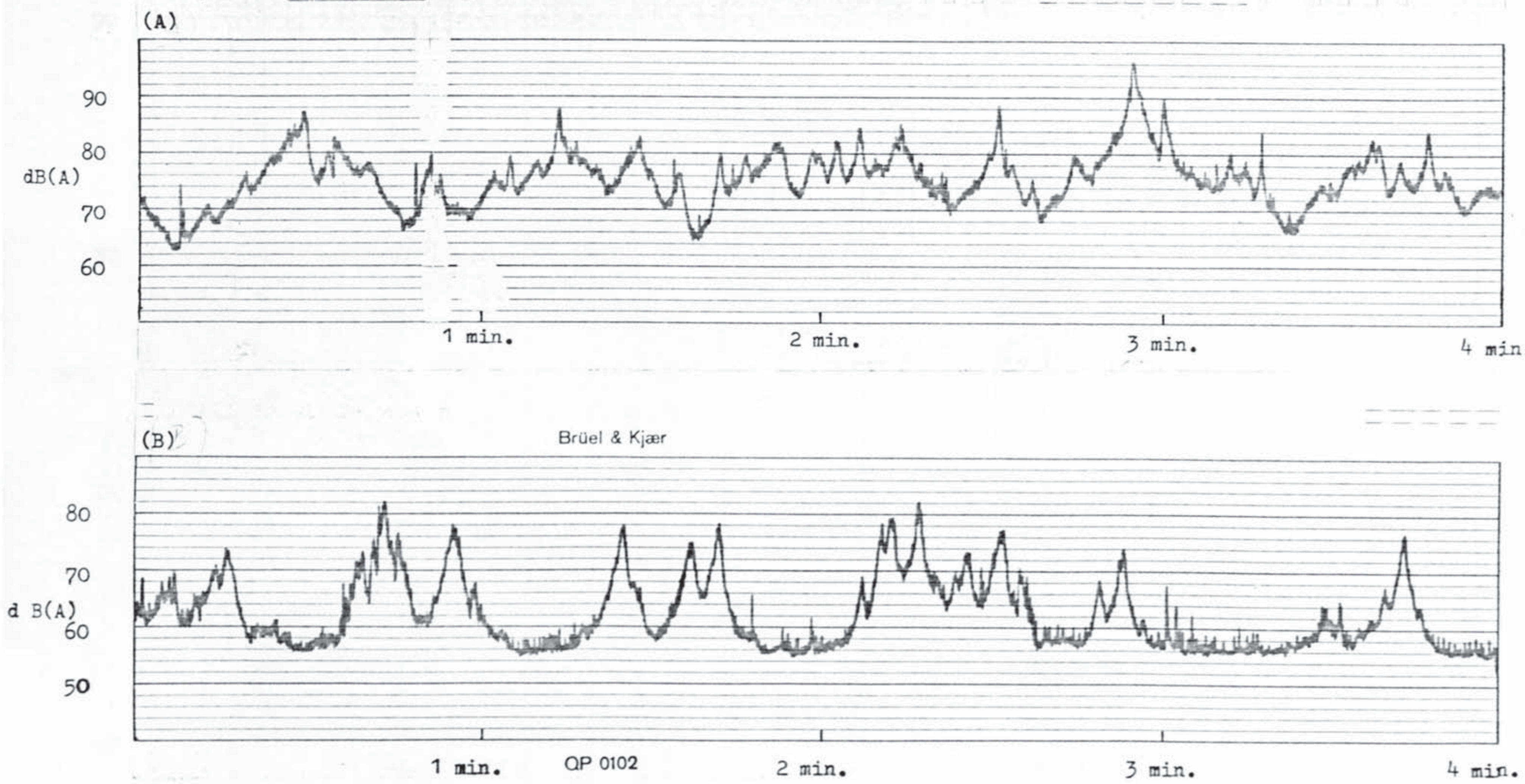
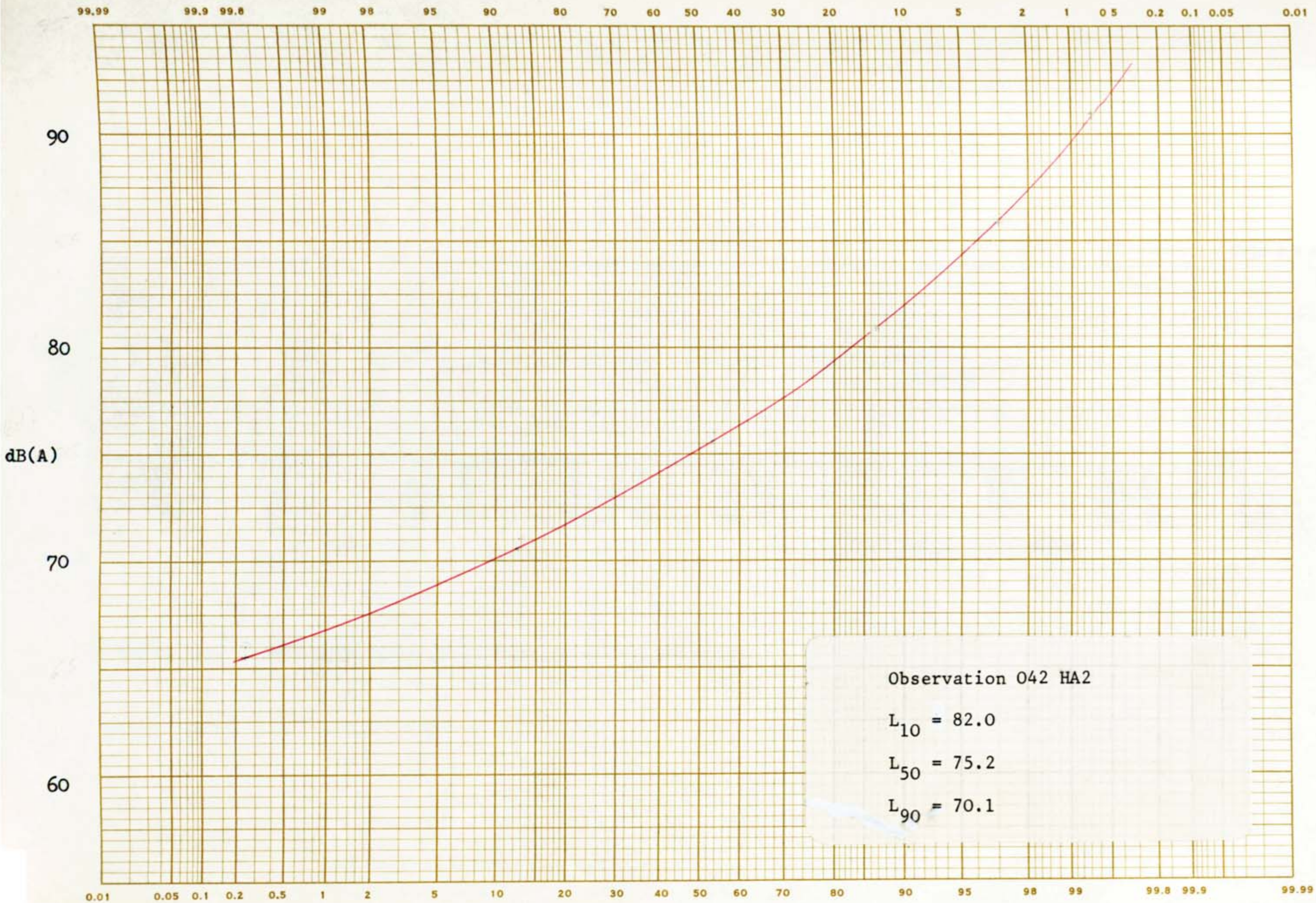


Figure A5.1 Noise Level Charts (see page 246).


99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
90
80
dB(A)
70
60
Observation 042 HA2
L10 = 82.0
L50 = 75.2
L90 = 70.1

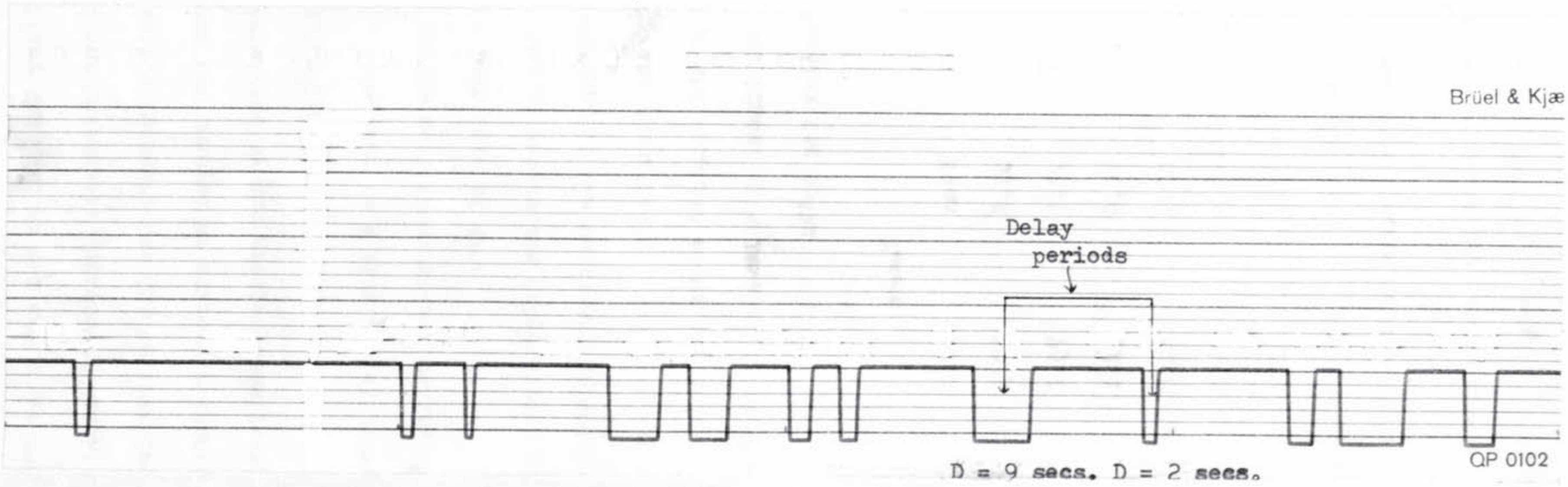


Figure A5.3 Chart from which pedestrian delay was measured.

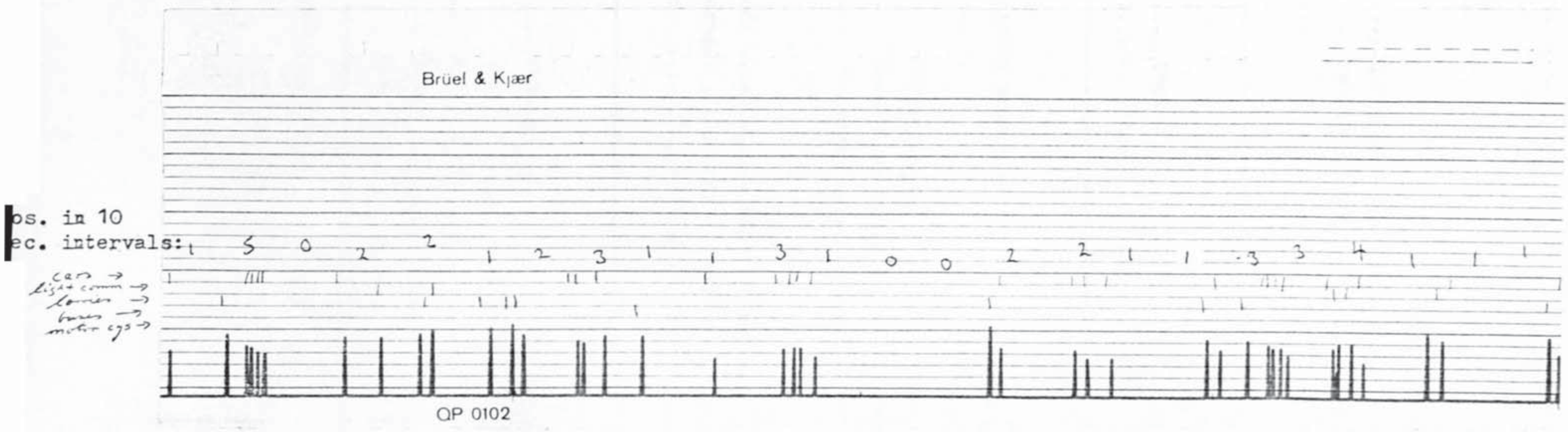


Figure A5.4 Pattern of arrival of traffic.

JOINT UNIT FOR RESEARCH ON THE URBAN ENVIRONMENT

Project: The Environmental Effects of Traffic in Hammersmith.

FIELDWORK REFERENCE SHEET

Observation References: Observation No. ....

Street: .... Photo Ref: .... Date: ....

Site Identify: .... Network Nos: .... Day of week: ....

O.S. Map No: .... Time: ....

Measurements Taken:

Noise: .... Smoke: .... Veh. Count: ....

Speed: .... P. Delay: .... CC, No of drags: ....

Site Characteristics:

Distance to nearest pedestrian crossing: Near side: ....

(state type: Z,P, or Signals). Far side: ....

Distance to bus stops: Cars parked: No. of storeys: ....

near side: .... near side: .... near side: ....

far side: .... far side: .... far side: ....

Road surface: ....

Dry: ....Good: .... Tar - rough: ...... Rel.Gradient: ......

Damp: .... Average: .... smooth: ...... One/Two way:........

Wet: .... Bad: .... Cement: .... No. of lanes each way: ....

Weather Conditions:

Wind speed: .... Visability: Wind direction relative to pavement: (draw arrow).

Good: ....

Temp. average: .... Dull: ....

Very cold: .... Dark: ....

Fog: ....

Other Information not on Reference Tape:

UNIVERSITY OF ASTON : JOINT UNIT FOR RESEARCH ON THE URBAN ENVIRONMENT : PEDESTRIAN SURVEY

OBSERVATION REFERENCE SHEET

Street Name ________________ Date ________ Obs. Status ______ Obs. No. ____________

Location of Site __________________________ Time: from _____ to _____ (___ mins.)

CASSETTE NOS.	First Period	Middle Period	Last Period
Near side	______	______	______
Far side	______	______	______
Time beg.	______	______	______

ACCELERATION (on near side)

- Accelerating ☐
- Decelerating ☐
- Cruising ☐
- Varying ☐

TRAFFIC LIGHTS (name streets)

Left of site ________________

Right of site ________________

PARKING

- NL ☐
- NR ☐
- FL ☐
- FR ☐

SURFACE

- Dry ☐
- Damp ☐
- Wet ☐

LAND USE	Prim.	Sec.
Resid.	☐	☐
Shops	☐	☐
Offices	☐	☐
Industry	☐	☐
Open sp.	☐	☐

NO. OF INTERVIEWS	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Type A														
Type B														
Type C														

COMMENTS

Figure A5.7

A

PEDESTRIAN SURVEY

Street Name ______________ Date Time Interview No. ______________

Please put an "X" on these lines which represents the extent of your annoyance with the following items as they are at the moment on this road:
e.g. If you are moderately annoyed, put the "X" someplace along the line:

Not Annoyed ——————————————————— Extremely Annoyed

Not Annoyed — ANNOYANCE WITH THE APPEARANCE OF THE TRAFFIC — Extremely Annoyed

Not Annoyed — ANNOYANCE WITH THE VIBRATION FROM THE TRAFFIC — Extremely Annoyed

Not Annoyed — ANNOYANCE WITH THE RISK IN CROSSING THE ROAD — Extremely Annoyed

Not Annoyed — ANNOYANCE WITH THE AIR POLLUTION FROM THE TRAFFIC — Extremely Annoyed

Not Annoyed — ANNOYANCE WITH THE NOISE FROM THE TRAFFIC — ExtremelyAnnoyed

Not Annoyed — ANNOYANCE WITH THE DELAY IN CROSSING THE ROAD — Extremely Annoyed

Not Annoyed — OVERALL ANNOYANCE WITH THE TRAFFIC — Extremely Annoyed

What is the purpose of your trip ?
- Shopping ☐
- Work ☐
- To/from work ☐
- Other ☐

Sex and marital state
- Married ☐
- Single ☐
- Widowed/separated ☐

Age
- 15-19 ☐
- 20-44 ☐
- 45-59 ☐
- 60 + ☐

Does your household have the use of a car ? ☐

What is your occupation ? ☐

____

EAR (A) ☐☐☐☐☐☐

(B) ☐☐☐☐☐☐

PLEASE DESCRIBE THE TRAFFIC AS IT IS HERE AT THE MOMENT BY PUTTING AN "X" IN THE APPROPRIATE BOX :

HARMFUL	☐	☐	☐	☐	☐	☐	☐	☐	☐	BENEFICIAL
PLEASANT	☐	☐	☐	☐	☐	☐	☐	☐	☐	UNPLEASANT
GOOD	☐	☐	☐	☐	☐	☐	☐	☐	☐	BAD
COMFORTABLE	☐	☐	☐	☐	☐	☐	☐	☐	☐	UNCOMFORTABLE
ANNOYING	☐	☐	☐	☐	☐	☐	☐	☐	☐	PLEASING
UGLY	☐	☐	☐	☐	☐	☐	☐	☐	☐	BEAUTIFUL
EXCITING	☐	☐	☐	☐	☐	☐	☐	☐	☐	DEPRESSING
OFFENSIVE	☐	☐	☐	☐	☐	☐	☐	☐	☐	INOFFENSIVE

PLEASE INDICATE HOW MUCH YOU AGREE OR DISAGREE WITH THE FOLLOWING STATEMENTS :

People should have to put up with unavoidable noise

DISAGREE ☐☐☐☐☐☐☐☐☐ AGREE

Traffic is destroying life in the city.

AGREE ☐☐☐☐☐☐☐☐☐ DISAGREE

Generally I am a nervous person.

AGREE ☐☐☐☐☐☐☐☐☐ DISAGREE

APPENDIX 6: FIELDWORK MEASUREMENTS: DISTRIBUTION CHARACTERISTICS

The following tables show the mean, the minimum and maximum values, and the standard deviation of the main variables which featured in the regression models. The first table shows the distribution characteristics for the environmental variables measured. The following three tables give the statistics for the sets of data used in developing the noise, delay and air pollution models.[1] Table A6.5 refers to the estimated environmental variables used in the analysis of the data from the pedestrian response survey. The last table refers to the traffic flow and composition observed during the pedestrian survey. The codes which were used in the text are given in each of the tables

Variable	Code	Mean	Minimum	Maximum	S.D.
L10 dB(A)	L10	76.5	62.6	86.0	5.6
L50 dB(A)	L50	68.8	52.5	79.7	6.6
L90 dB(A)	L90	63.3	49.5	75.8	5.9
Mean delay (secs.)	D	14.6	1.4	107	22.7
% delay	%D	59	6.9	98	28
Smoke microgr/m^3	Sm	6.4	1.0	28	4.8
CO p.p.10^6	CO	6.4	0	69	9.0

TABLE A6.1 Environmental survey; dependent variables

1 i.e. prior to the omission of outlying observations

Variable	Code	Mean	Minimum	Maximum	S.D.
Total flow (vph)	Q	1130	54	5880	1050
% Heavy vehicles	P	14.8	0.4	31.4	7.4
Mean speed (kph)	V	29.7	4.1	48.2	8.0
Ratio of flows	Ra	1.1	0.1	6.2	0.7
Index of parking	Pk	0	-2	2	0.9
Width of street (m)		10.9	7.2	23.5	3.2
One way streets		0.15	0	1	0.36
Index of reflection	T	4.0	0	20	2.7
%Gradient		0	-1.5	1.5	0.5
Distance from flight path (km)	D	2.3	0.6	6.5	1.4

TABLE A6.2. Noise Observations: Independent Variables

Variable	Code	Mean	Minimum	Maximum	S.D.
Total flow	Q	1096	72	2676	730
% Heavy vehicles	P	14.9	3.5	31.4	7.2
Vehicle speed	V	29.6	4.1	48.2	8.3
Ratio of flows	Ra	1.2	0.11	6.2	0.8
Vehicle dispersion (near side)	Dnv	2.0	0.1	7.0	1.6
Index of Density		47	2.7	506	62
Width of street		10.8	7.2	16.1	2.9

TABLE A6.3. Delay Observations: Independent Variables

Variable	Code	Mean	Minimum	Maximum	S.D.
Total Flow (vph)	Q	1280	54	6906	1260
Near side flow (vph)	Qn	625	27	3510	665
% of Heavy vehicles	P	15.2	0.4	31.6	7.2
Mean speed (kph)	V	29.6	4.1	48.2	8.3
Ratio of flows	Ra	1.1	0.1	6.2	0.7
Vehicle dispersion (near side)	Dnv	2.8	0.1	34.0	4.6
Wind speed	Wv	2.4	0	15.0	2.7

TABLE A6.4. Air Pollution Observations: Independent Variables

Variable	Code	Mean	Minimum	Maximum	S.D.
L10 dB(A)	L10	78.8	71.0	83.3	3.1
L50 dB(A)	L50	71.4	61.8	76.9	3.7
L90 dB(A)	L90	65.5	57.4	70.0	3.3
Range (L10-L90)		13.3	8.6	16.4	1.1
L10 (a/c controlled)		77.3	67.4	82.2	3.4
Mean delay (Sec.)	D	17.8	57.6	48.8	13.8
% delay	%D	62	19	98	21
Smoke mc.gr.p.m^3	Sm	6.0	1.8	8.4	1.8
CO p.p.m.	CO	6.1	2.0	10.9	2.3
Total flow (vph)	Q	1308	188	2628	679
% Heavy vehicles	P	14.7	2.0	25.8	5.4

TABLE A6.5. Pedestrian Survey: Independent variables

APPENDIX 7: ANALYSIS OF OBSERVERS' RESPONSES

During the survey of the pedestrian responses, and at the end of each interviewing period, the two observers encoded their own subjective responses on the lorries part of the questionnaire. This appendix reports the analysis of these data. The results are submitted in partial collaboration of those of the pedestrian survey, with a caveat on the possible subjective bias in the responses. However, this is to some extent outweighed by the greater consistency in the response criteria than in the case of the pedestrians because the same people were making the responses at the different sites.

Equation A7.1 shows the results of regressing the logarithm of the ratio of the annoyance encoded for noise to that for delay on the L10 and the logarithm of the mean delay:[1]

$$\text{Log } \frac{An}{Ad} = 0.27\ (L10) - 0.30 \log D - 0.49 \qquad (A.71)$$

$$N = 47$$

$$R = 0.39$$

t statistics = 1.50 and 2.49

where An and Ad are the means of the observers responses. However, when the logarithm of the noise response was regressed on the L10 the regression coefficient (i.e. the exponent in the Power Law type of relationship) was 1.68 which was very highly significantly different from the 0.27 in equation A7.1. On the other hand the higher an effective threshold was assumed to be, the lower the exponent became. If the effective threshold was assumed to be 67.5dB(A), the exponent became 0.71. As in the case of the pedestrians' responses, the

[1] This was the method developed for the analysis of the EAR data

correlation between the annoyance with noise and the noise level increased as the effective threshold was raised. It increased from 0.71 to 0.76 when the threshold was raised from zero to 67.5dB(A). These correlations were higher than those for the linear and logarithmic type relationships. Table A7.1 shows these correlations and those for the other dependent variables.

Dependent Variable	Independent Variable	Type of relationship Linear	Logarithmic	Log/log
An	L10	.59	.59	.71
Av	L10	.46	.49	.58
Ad	Mean Delay	.46	.49	.54
Ar	Mean Delay	.74	.76	.77
Ap	Smoke	.33	.39	.62

Table A7.1: The Correlations Between the Observers Responses and the Environmental Variables for the Three Types of Relationship

For each of the dependent variables in Table A7.1 the log/log relationship is the strongest. This clearly indicates that the power law relationship describes the relationship between the annoyance and environment variables than the Fechner or linear types of relationship. However, it should also be noted that in each case the logarithm of the total flow had a higher correlation with the logarithm of the annoyance than the log/log correlations in Table A7.1.

APPENDIX 8: A MEASUREMENT ADJUSTMENT TO THE PEDESTRIAN DELAY VARIABLES

The fieldwork measurements of the physical environmental variables were conducted in four stages over a period of eight months. Towards the end of the first stage it was felt that the pedestrian delay observer was being slightly over optimistic in his judgement about when he could cross the road and a conscious effort was made to make more realistic estimates in the remaining stages. It was possible, by the use of dummy variables in the regression analysis, to determine whether this had any effect on the results. It did in fact have a slight but highly consistent effect in all the models tested. Almost all of the effect could be controlled for by either assuming that the regression coefficient of the main variable was changed or that the constant was changed. Varying the minimum acceptable headway in the Adams type specification did not help as would be expected.

In the regression analyses the stages of the survey were represented by dummy variables. The calibrations in the regression equations published refer to the second and remaining stages of the survey. For example equation 7.31 was based on the regression equation:

$$\%D = 108.6d_1\ (i - e^{-3.5Q}) + 116.3d_2\ (i - e^{-3.5Q}) - 0.0259D_{hv} - 0.427V + 12.7 \quad \text{(A 8.1)}$$

Where "d_1" and "d_2" are dummy variables signifying whether the observations were taken during the first stage of the survey or the latter stages. When zero is inserted for "d_1" and one for "d_2" the equations reads as in equation 7.31. The t statistics given in Chapter 7 refer to the D_2 elements. 18 of the 86 observations were taken during the first stage of the survey.

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