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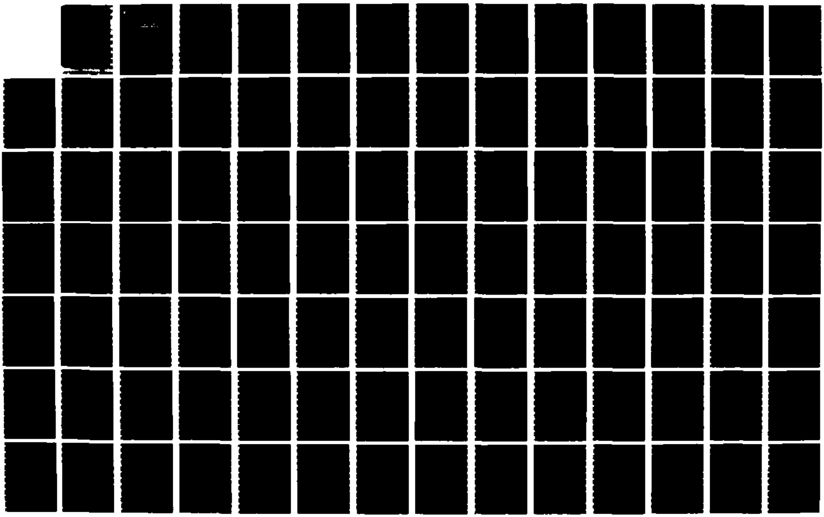

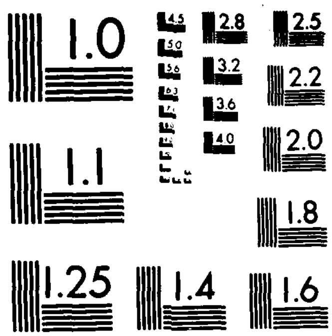

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An Assessment of Evidence for Time-of-day Weightings

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16. Abstract
The differential impact of noise on residents at different times of day is examined in analyses of the original machine-readable data from ten community surveys and in detailed reviews of the published results from 20 additional surveys. Analyses are conducted using alternative community response measures and analysis techniques.

The primary objective of these analyses is to determine the relative impact of noise during the daytime and nighttime by estimating the value of a time-of-day weighting in the adjusted energy model. Some support is found for nighttime and evening weightings, however, the estimates of these time-of-day weightings are found to be highly accurate. Examinations of the factors affecting this accuracy lead to the conclusion that studies of community response to noise will not provide a usefully accurate estimation of the time-of-day weighting parameter in the adjusted energy model.

This report provides data on proportions of the United States population engaged in noise-sensitive activities at different times of day. The report reproduces all social survey results in which averages of nighttime response are plotted by nighttime noise levels. Analyses are conducted of the relationship between daytime and nighttime noise environments around United States airports. Keywords;
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CUMULATIVE AIRPORT NOISE EXPOSURE METRICS:

An Assessment of Evidence for Time-of-Day Weightings

by

James M. Fields

EXECUTIVE SUMMARY

The time of day at which aircraft noise occurs is often considered in land use planning around airports. Existing noise indices such as Ldn (Day-Night Average Sound Level), NEF (Noise Exposure Forecast), and CNEL (Community Noise Equivalent Level) penalize noise during noise-sensitive periods by applying a time-of-day weighting to noise which occurs at night or in the evening. The noise indices differ in the numerical value which is assigned to the time-of-day weights. One criteria for choosing time-of-day weights is the extent to which the weights represent the differential impact of noise on humans at different times of day. This report draws on human response data to conduct analyses which quantify the differential impact of noise at different times of day.

Residents' reactions to existing noise environments provide the only logically sound basis for measuring the differential impact of the time of day of noise. The reactions of over 22,000 people were available for the most complex analyses conducted for this report. These responses were extracted from ten studies for which the complete machine-readable data sets were available. Publications from over 200 additional studies of community response to noise were examined. Twenty of these studies provide some additional, limited information about time-of-day weights or reactions to noise during noise-sensitive time periods.

The social surveys contain questions about reactions to particular noise sources, aircraft in aircraft studies or road traffic in road traffic studies. Two types of community response measures are available in these surveys: a single total response to the average, combined 24-hour noise environment and separate responses to the noise in each of the time periods.

Responses to entire, combined 24-hour noise environments provide the only logically satisfactory basis for evaluating time-of-day weightings. These responses are examined in differing time-of-day noise environments using multiple regression techniques. The surveys do not provide similar estimates of the optimal value for the time-of-day weighting. When the time-of-day weightings from the individual studies are examined it is found that the estimates of the time-of-day weightings are so imprecise as to not provide useful information. Separate analyses find that the lack of consistency and the imprecision can not be explained by the type of annoyance questions or the time-of-day noise model. It is concluded that existing surveys can not provide usefully accurate estimates of time-of-day weights.

Analyses of the second type of community response measure, the ratings of noise in different time periods, show that people

disagree as to whether nighttime, evening or daytime noise is the greatest problem in existing noise environments. After noise level is taken into account, it is seen that these responses are broadly consistent with the general observation that nighttime and evening noises are more annoying than daytime noises of the same noise level. However, there is no consistency across surveys as to how much more annoying noises are during the evening and night. As a result the surveys do not provide consistent information for establishing the value of a time-of-day weighting. A careful analysis of these time-period rating questions finds that the questions are seriously flawed measures of the independent effect of noise in different periods. These time-period rating questions do not clearly specify the noise which is rated, are easily distorted by feelings about other periods and can be biased by the conventional wisdom about nighttime noise.

One basis for defining the length of the time periods, though not time-of-day weights, is the numbers of people who are engaged in noise-sensitive activities. Laboratory studies consistently find that sleep and aural communication are disturbed by noise. A national time-use survey is analyzed to identify the time periods when large numbers of people are engaged in these noise-sensitive activities. The 24-hour day can be roughly divided into four noise impact periods on the basis of the number of people who are engaged in these noise-sensitive activities. The greatest number are engaged in these noise-sensitive activities during a steady state nighttime period (2400 to 0500), the lowest number are exposed during a steady state daytime period (0900 to 1600) and varying numbers are exposed during an early morning transition period and during an evening transition period. Approximately half of the population has at least some of their sleep period which is outside of the 2200 to 0700 protected period in accepted noise indices such as Ldn.

The relationship between nighttime reactions and long-term average nighttime noise environments is examined. All existing social survey results in which average nighttime response is plotted by nighttime noise level are reproduced in the report. The nighttime annoyance questions from the different surveys are found to be so dissimilar that a unified dose response relationship can not be specified.

A major weakness of existing surveys is the high correlation between daytime and nighttime noise in the study design. The possibility that improvements in study design could lead to accurate information about time-of-day weights is examined. The availability of suitable noise environments is assessed by examining the timing of flights at all large (greater than 100 flights a day) United States airports and by analyzing the noise environments on 6009 days at 128 noise monitoring sites at 11 airports. Even if the best combinations of noise environments were to be included in a study, it is predicted that it would not be possible to provide usefully accurate information about the time-of-day weighting from cross-sectional surveys based on noise environments found around United States airports. It appears to be unlikely that new designs would lead to improved estimates. The methods developed in this report could be used to assess the likely precision of new designs which have not been explicitly considered in this report.

In summary, the analyses and reviews of literature in this report find some support for nighttime and evening weightings. However, examinations of present surveys and simulations of future surveys lead to the conclusion that studies of community response to noise will not provide usefully accurate estimates of the time-of-day weighting parameter in the adjusted energy model.

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LIST OF TERMS

More details for noise indices and scales for acoustical measurements can be found in general noise references (e.g., Bennett and Pearsons, 1981).

a,c,g,h	Constants
A	Annoyance scores for 24-hour period (A) or for day (A_d) or night (A_n)
B	Partial regression coefficient for a 24 hour noise index (B_I) or for daytime (B_d) or nighttime (B_n)
CNEL	Community Noise Equivalent Level, dB
CNR	Composite Noise Rating
D_n	Regression coefficient for dummy variable for nighttime (D_n)
Ldn	Day-night Average Sound Level, dB
Leq	Equivalent Continuous Noise Level for 24-hour period (Leq or Leq_{24}), night (Leq_n) or day (Leq_d)
L_i	Sound level of noise event i which occurs in the day (L_{id}) or night (L_{in}). (Unless otherwise specified this is normalized to a 24-hour period. Thus L_i is the 24-hour Leq value for event i in the time period. The relative pressure squared value of a nighttime event is thus $10^{L_{in}/10}$.)
m	Social survey sample size
M	Dummy variable used in regression analysis (M=1 if the observation is in the category).
N	Number of noise events
NEF	Noise Exposure Forecast
NNI_{10}	A noise index which is exactly the same as the British Noise and Number Index except that the number weighting is k=10 rather than k=15. The units of this index are labeled "decibels" in this report. The decibel unit label is satisfactory in this case because the label is applied to only small differences between noise levels in different time periods.

t	Number of hours in day (t_d) or night (t_n)
w	Weight to be multiplied by number of noise events (N) or relative pressure squared. For the nighttime the weight is w_n for the evening the weight is w_e.
w(dB)	Weight, additive adjustment, to be added to the single event sound level or single hour Leq before the logarithmic transformation. For the nighttime the weight is $w(dB)_n$. This weight is measured in decibels, dB.
w(dB&T)	Weight, additive adjustment, to be added to a sound level for a period when no other method is used to adjust for period length, (decibel plus time weight), dB.
WECPNL	Weighted Equivalent Continuous Perceived Noise Level

1.0 INTRODUCTION

Noise is one of the environmental characteristics which is considered in land use planning around airports. High noise levels are often seen to be incompatible with hospital, school, residential and other uses. To aid in determining compatibility it is necessary to measure the noise in such a way as to take into account the factors which affect people's feelings about the noise. The measures of noise utilized in land use planning, noise indices, typically consider such factors as how loud each noise level becomes, how long each noise event lasts, how often the noise events occur and, the subject of this report, the time of day at which noise occurs.

Since noise at night is commonly considered to have a greater impact than noise during the day, the noise indices frequently penalize nighttime noise. These nighttime penalties are built into noise indices by weighting the nighttime noise so that a noise which occurs during the night will increase the value of the noise index more than if the same noise had occurred during the day. While it seems obvious to many people that noise at night, and perhaps the evening, should receive a weighting, it is not at all obvious how large such a time-of-day weight should be.

The uncertainty about the value of time-of-day weights is reflected in the diversity of existing noise indices. The noise indices differ in the size of the nighttime weighting and in whether weightings are applied to only the nighttime or to both the evening and nighttime. The indices also differ in the hours which are used to define these noise-sensitive periods. Some indices do not even apply a time-of-day weighting (eg. 24-hour Leq) or totally exclude the nighttime period (eg. NNI, the British Noise and Number Index).

1.1 Objective of This Report

In view of the lack of agreeement about the value of a time-of-day weight and the desirability of choosing a weight which is consistent with human reactions, the chief objective of this report is the following:

> Objective: To determine the value of the weighting factor for noise-sensitive periods which best represents the differential impact of similar noise levels on residents at different times of day.

The impact of noise has been measured in a large number of studies of community residents. A previous review of these studies found that most study publications do not contain estimates of the value of the time-of-day weighting and none contains an adequate measure of the accuracy of the findings (Fields, 1985a). This report takes the data from those studies and conducts analyses which quantify the relative impact (weight) of noise at different times of day.

Before turning to those analyses, however, it is necessary to examine some of the common-sense beliefs about night disturbance, describe the types of studies which provides data on noise impact, and understand somewhat more about the noise indices and about the method of incorporating the time-of-day weights in the indices.

1.2 Common-sense Beliefs About Time-of-Day Effects

If the average person were asked whether a noise is worse at night than during the day, the response would almost invariably be, "at night". One basis for this response is a belief which is labeled the *"Conventional Wisdom"* in this report:

> *Conventional Wisdom*: **Noise is worse at night because being kept awake by a noise is worse than anything noise can do during the day.**

The *Conventional Wisdom* expresses an important truth with which most people are familiar, being kept awake by noise is an extremely irritating experience. This truth does not, however, solve the problem of selecting a time-of-day weight for residential areas.

The chief limitation of the *conventional wisdom* is that it only considers noises which are noticed. For long-term residents a large number of nighttime noises are unnoticed because the resident is unconscious, asleep. During the daytime or the evening, on the other hand, many residents are awake and more likely to notice a noise event especially if it leads to an unavoidable disturbance to television listening or speech communication. While any nighttime awakening may be quite disturbing, it could well be that the awakenings are so infrequent that the impact of the average daytime noise event is as great or greater than that of the average nighttime noise event.

Even if the *conventional wisdom* were correct, it would only indicate that a weight should be applied to nighttime noise. It would not provide any assistance in determining what numerical weight should be applied to nighttime noise.

1.3 A Method for Assessing the Relative Impact of Noise at Different Times of Day (Total Annoyance Regression)

Given the limitations of the *conventional wisdom* and the need to determine the relative impact of noise from different periods the chief question becomes:

> **How can the relative impact of noise at different times *of* day be measured?**

The only logically satisfactory method which has thus far been devised for addressing this issue is an analysis of answers to social survey questions about residents' reactions to the average, long-term, 24-hour noise exposures. This method was developed as part of the current research effort after a careful examination of the methods used in previous time-of-day studies. The method is labeled the "total annoyance regression method." The remainder of this section describes this method and contrasts it with less satisfactory methods.

The total annoyance regression method is dependent upon social survey data, noise data, and an analysis technique. The complete approach can be broken into the following components:

Study a representative sample of residents routinely exposed to the noise source. The subjects of study for this method are a representative sample of people who have lived with the particular noise source on a daily basis for an extended period. This is to be contrasted with many laboratory studies of sleep interference or speech interference in which the subjects either are not residents of noisy areas or are not representative of the people living in a noisy area.

Measure the noise to which these residents are routinely exposed at different times of day. The noises to which the residents are exposed are measured. Enough information is obtained about the noise at different times of day to form descriptions of the long-term, average noise environments for each time period.

Record respondents' answers to uniformly administered, unbiased questions about annoyance with noise. Respondents are asked for their own feelings, not for hypothetical judgments about the timing of noise. The interview questions are printed in questionnaires so that trained interviewers read the questions in exactly the same order to all respondents. The interviewers have been trained to read the questions in an unbiased manner. Respondents are provided with the opportunity to say that they are not bothered by the noise. The main question about noise annoyance usually appears early in the questionnaire before the respondent realizes that the chief subject of the study is noise.

Ask respondents a question about their total reaction to the total (24-hour) aircraft (or other specified source) noise environment. Typical questions are the following:

Q. Please look at this scale and tell me how much the noise of the aircraft bothers or annoys you.

Very much, moderately, a little, or not at all.

[Source: 1967 Heathrow survey]

Q. I want to ask you how you feel about aircraft noise here where you live. Looking at this card would you tell me which number best represents how you feel?

Definitely satisfactory	1
	2
	3
	4
	5
	6
Definitely unsatisfactory	7

The questions do not ask about each noise period separately. If such period questions were asked there would be the danger that people would automatically respond with the *conventional wisdom* (nighttime is worse) rather than with their own experiences. The period annoyance questions are of doubtful validity for another reason, it is quite *likely* that people's experiences with noise in one period will contaminate their feelings about the same noise in another period. A bad experience with aircraft noise at night could easily contaminate the person's feelings about aircraft noise at other times of day even if it was only that nighttime experience which initially caused the negative reaction.

Analyze the responses so as to isolate the incremental impact of noise from each period. The statistical analysis technique which is used (multiple regression) examines the simultaneous influences of the noise levels in the various periods on the single, total (24-hour) noise response. A predictive equation is formed which assigns those weights to the noise in each time period which will result in the best prediction of total (24-hour) annoyance. This analysis method can be contrasted with other methods which only examine the relationships between the separate period responses and the separate period noise levels. Such analyses are not able to determine how the effects of the various periods are to be summed together.

In summary, the combination of interview survey, noise measurements and correct analysis technique provides the findings which are described in this report. The studies used in this report are described in the next major section, but first some additional background is provided on the noise indices and on the general framework for time-of-day weightings.

1.4 The Method for Combining Noise Levels: Adjusted Energy Model

The ways in which characteristics of noise come to impact humans are exceedingly complex and only partially understood. In order to deal with these characteristics at the present time, scientists have developed very simple theories about how the characteristics affect humans. These simple theories are admitted to be no more than crude representations, "models," of the actual complex processes. All of the existing noise indices agree upon a single, simple theory (model) of how humans react to noise: the adjusted energy model. The indices differ only in how much weight should be attached to the noise in the different periods.

The adjusted energy model can be concisely expressed in mathematical terms (see Appendix A). However, only a few simple aspects of the model need to be understood in non-mathematical terms in order to follow the discussion about time-of-day weights.

The noise indices are based on the adjusted energy model and are measured in decibels as are the noise levels of each individual noise event. Noise indices do represent a summation of all the individual noise events, but before the individual noise events are summed they are transformed (logarithmic transformation) into quantities (measured in units of relative pressure squared) which are related to the amount of energy which is contained in each noise event. The adjustments for different times of day can thus be applied to the noise events measured in either the decibel units or the energy-type units. Thus the time-of-day weights can be expressed in either of the two types of units.

When the time-of-day weight is expressed in decibel units it is called a "decibel weight" in this paper. The nighttime decibel weight is represented with the symbol $w(dB)_n$ and the evening decibel weight is represented with the symbol $w(dB)_e$. When the nighttime noise weight is expressed in decibels, this decibel weight is added to the noise level of each noise event. Thus if a decibel weight of $w(dB)_n=10$ is added to a 60 decibel nighttime noise event, that event is given a value of 70 decibels before it is transformed and added into the noise index. The decibel weight is thus an "additive" weight because it is *added* to make the adjustment for nighttime noise.

The time-of-day weight can just as easily be expressed in terms of the energy-like units. These units are directly related to the number of noise events. This nighttime "number weight" is represented by the symbol w_n. The evening number weight is represented by the symbol w_e. When the nighttime noise is weighted in terms of the number weight, the nighttime noise events are multiplied by the number weight. Thus with a nighttime number weight of w_n=10, the number of nighttime events is multiplied by ten before being added into the noise index. The number weight is thus a "multiplicative" weight because it is multiplied times the noise. The number weight can be directly interpreted as the number of daytime noise events which are required in order to create the same annoyance as a single nighttime noise event.

The relationship between the two alternative expressions for selected time-of-day weights can be found in Table 1.1. The relationship between the two weightings is expressed mathematically in Appendix A. The weightings in Table 1.1 include the weightings which are used in the standard indices listed in the last column of the table.

The top half of the table relates to indices in which only the nighttime events are specially weighted. (In this case, values of evening events are of course unchanged by being multiplied by a number weight of w_e=1 or by having a decibel weight of $w(dB)_e$=0 added to them.) The second half of the table contains indices which have both an evening and a nighttime weighting.

A third transformation of the time-of-day weight is provided in the third pair of columns of Table 1.1, the decibel-time weight $\{w(dB\&T)_n\}$. The time-of-day weight is commonly expressed in this form in three of the indices included in the table: CNR (Composite Noise Rating), NEF (Noise Exposure Forecast) and WECPNL (Weighted Equivalent Continuous Perceived Noise Level). The value of this "decibel-time" weighting is a function of the length of the time periods as well as of the value of the conventional time-of-day weight (see Appendix A). In Table 1.1 it can be seen that for a fixed value of 10 for the number weight, the value of the decibel-time weight can be $w(dB\&T)_n$=7.8 [15-hr day, 9-hr night], or $w(dB\&T)_n$=8.8 [12-hr day, 9-hr night] or $w(dB\&T)_e$=4.0 [12-hr day, 3-hr evening]. Because the decibel-time weight is sensitive to period length, it is not used in this report.

For the noise index Ldn, the values of the decibel weight and the number weight are the same, $w_n = w(dB)_n = 10$. This is the index which has been designated in Part 150 for measuring noise exposure around airports (F.A.A. . .1981). For the other entries in Table 1.1 it is usually important to specify the type of weight. The differences between the numerical values of equivalent weights are most easily seen by comparing the sets of lines in Table 1.1 in which alternative values are given when each type of weight has a value of 5 (second through fifth line), 20 (last three lines in top half of Table 1.1) or 5 and 10 (WECPNL and the two preceeding lines).

One characteristic of the logarithmic summation in the adjusted energy model should be noted. The value of the total noise index is significantly influenced by the noise levels in both periods only when the adjusted noise levels in the two periods are approximately equal. If, for example, there is a ten-decibel weighting and the nighttime noise level is ten decibels lower, then changes in the noise levels in either period could affect the value of the index. If, on the other hand, the noise levels at night are 20 decibels lower, even a fifteen decibel reduction in nighttime noise levels would have almost no impact on the value of the total noise index. This type of model implies that reactions to noise are not sensitive to even large changes in the noise levels at one time of day, as long as the noise levels remain substantially higher at another time of day.

1.5 Organization of This Report

Section 2 provides an overview of the data which are analyzed in this report. Section 3 presents the key analyses in the report, analyses of the time-of-day weights using the total annoyance regression method. Section 4 then considers some of the previous, logically-weaker methods which provide weaker evidence about differences in reactions at different times of day. Section 5 moves away from the problem of estimating the time-of-day weights to the problem of determining the exact hours which mark the boundaries between time periods of differing degrees of sensitivity. Section 6 focuses on only noise at night to report on relationships between nighttime disturbance and nighttime noise levels. Section 7 returns to the time-of-day weighting problem and evaluates whether or not future studies could be expected to provide better information about time-of-day weights.

2.0 DESCRIPTION OF SOCIAL SURVEYS AND OTHER DATA USED IN THIS REPORT

Three types of data are utilized in this report. The primary analyses, those which estimate the time-of-day weights, are based on data from social surveys of residents' responses to noise. The analyses which identify the boundaries between time periods are based on a different set of social survey data, a survey of the ways in which people use their time. The assessment of the feasibility of designing better time-of-day social surveys is partially based on a third type of data, data about the timing of aircraft noise events. Each of these three types of data are described in this section.

2.1 Social Surveys of Residents' Responses to Noise

Over 200 surveys of residents' responses to noise have been conducted around the world (Fields, 1981). When the reports from these 200 surveys were examined, approximately 30 surveys were identified which provide some information about responses to noise at different times of day.

The amount of information which the individual surveys provide about the time-of-day weighting varies. The complete machine-readable data tapes were analyzed for ten primary surveys which had complete information about noise levels at different times of day. Sixteen secondary surveys provide more limited information about reactions at different times of day. A further four surveys provide some useful information about nighttime reactions but not about reactions at other times of day.

The 10 primary and 16 secondary surveys are listed in Table 2.1. The surveys are divided by the major noise source which was studied; aircraft, road traffic or railway. The primary surveys are marked with the letter "P" and printed in a darker typeface. Each survey is identified with a brief title. Full titles for the surveys are given in Appendix B together with reference numbers which are keyed to a catalog containing a description of each survey (Fields, 1981). Table 2.1 also includes the numbers of interviews which were conducted in each survey and the hours which were used to define the "night" period. For the surveys which divided the remainder of the day into separate "day" and "evening" periods, the definition of the evening period is also provided. Two basic characteristics of the noise data are provided, the metric for measuring the noise and the method for determining noise levels. These two characteristics do not affect the analyses in this study.

All of the studies are based on interviews with residents in noise-impacted areas. In every case the respondents' answers were obtained from uniformly administered, unbiased questions about annoyance with noise. Questionnaires were personally administered by interviewers for all of the primary surveys and all of the secondary surveys except for the 1977 Zurich survey. The actual wording of the annoyance questions differs between surveys (see Appendix A in Fields, 1985e). The possibility of effects of differences in wording are explored later in Section 3.5 of this report.

The ten primary surveys provide the data for the key analyses in this report (Section 3.0), the analyses of the time-of-day weights based on the total annoyance regression method. These analyses are thus based on the responses of 21,928 people. The complete, machine-readable data sets were accessed for these analyses. Each of these surveys collected data about the noise to which respondents are routinely exposed at different times of day.

Information about the noise data from the 10 primary studies is provided in Table 2.2. The average noise level and a measure of the variation of the noise levels (the standard deviation, σ) are given for each survey in the first two columns of data. The remained of the table illustrates a very important feature of these data sets: the noise levels for the different time periods are highly correlated. The correlations (Pearson product-moment correlation coefficients) are measured on a scale which goes from -1.0 to +1.0 in the last four columns of Table 2.2. The 1975 Ontario survey (fifth line of the table) shows that the correlation between the 15-hour daytime noise level and the nighttime noise level is r=0.88 while the correlation between the 12-hour day (the evening period has been removed) and the nighttime noise level is r=0.85. In the entire table the lowest correlation between noise levels is r=0.81. Such high correlations suggest that the only analysis techniques which are appropriate for these data are ones which take into account the high correlations between noise levels.

The sixteen secondary surveys could not provide information required for applying the total annoyance regression method. The complete, machine-readable data sets for four of these surveys have been accessed but do not include information about noise levels at different times of day. For the remaining surveys the published reports provided some information about reactions at different times of day, but not enough information to apply the total annoyance regression method or to directly estimate the time-of-day weight.

2.2 Social Survey of Time Use: Data on the Timing of Noise-Sensitive Activities

In order to establish the time limits for periods of differential noise sensitivity, information is provided about the timing of noise-sensitive activities in Section 5 of this report. The data which provide this information come from the 1975-76 Time Use Survey conducted by the Institute of Social Research at the University of Michigan.

In the time use survey a representative sample of the population of the United States was interviewed at four times during 1975-76 about their activity patterns over the previous 24-hours. Approximately 975 respondents provided the data for the analyses reported here. Initial interviews were conducted in person with the three follow-up interviews being conducted by telephone. The information about activities and the timing of activities was gathered using a time diary technique in which the respondent describes all of his actions (and the timing of the activity) in chronological order for the previous 24-hours. For the purposes of the present analysis the activities were classified according to sensitivity to interruption by noise. The proportion of the population which is engaged in noise-sensitive activities could thus be identified for each hour of the day.

Detailed information about the procedures employed in the time use survey are available (Juster and Stafford, 1985). Some additional information about survey procedures is provided in Section 5. More detailed information about procedures employed in preparing data for the noise-sensitive activity analyses is available from a previous report (Fields, 1985c).

2.3 Data on the Timing of Aircraft Noise Events

The feasibility of obtaining better estimates of time-of-day weights from new surveys depends heavily upon the availability of suitable noise environments around airports. Two types of data were examined to provide this information: data on the timing of flights at all airports and data on the noise environments at different times of day at permanent noise monitoring locations.

The data on the timing of flights at commercial airports in the United States comes from the October 19, 1983 (Wednesday) flight schedules in the computerized version of the Official Airline Guide. The proportion of flights which occur in the daytime (0700 to 2159) and night (2200 to 0659) were calculated for all of the United States airports which have greater than 100 flights a day.

The data on noise environments at different times of day at permanent noise monitoring sites consist of the hourly aircraft noise levels (hourly values of Leq) measured on 6009 days at 128 noise monitoring sites at 11 airports. The data were gathered as part of the standard noise monitoring procedures at the airports, but then specially analyzed for this report.

3.0 EVALUATING WEIGHTS USING THE MOST LOGICALLY SATISFACTORY APPROACH: TOTAL ANNOYANCE REGRESSION

The objective for this report is to determine the value of the time-of-day weighting. The method which provides the most direct and logically satisfactory indicator of the time-of-day weighting is the total annoyance regression method. The analyses based on the total annoyance regression method are presented in this section.

The components of the total annoyance regression method were described in Section 1.4. The most important aspects of the method are described here (a mathematical description is provided in Appendix C).

3.1 Identifying Characteristics of the Total Annoyance Regression Approach

While the mathematics involved in this non-linear regression analysis technique may appear to be complex to some readers, the basic logic of the technique is quite simple. The objective of this report and this analysis is to determine how daytime and nighttime noise levels should be combined to best predict people's annoyance with the combined noise environment. Measured values of the daytime and nighttime noise levels are available from the studies' noise measurement surveys. Measured values of respondents' annoyance with the combined noise environment are available from the studies' social surveys. The multiple regression technique does nothing more than attempt to predict the annoyance scores from the noise level data. The iterative, non-linear regression technique used here takes an initial guess about the best way to predict the annoyance scores and then continues to alter the prediction method until the best possible predictions are obtained. The major limitation which is placed on the selection of the prediction method is that it be consistent with the previously described adjusted energy model, a model which is itself consistent with most conventional regulatory noise indices. The best way to predict annoyance from noise level is then expressed in terms of an equation which has the following general form (see Appendix C for some variations on this form which are entered into the computer program):

$$A = a + B_I \cdot 10 \cdot \log_{10}\{(\sum_{i=1}^{N_d} 10^{L_{id}/10} + w_n \cdot \sum_{i=1}^{N_n} 10^{L_{in}/10})/24\}$$

It is not necessary to understand the entire equation but several features are of interest. The respondent's annoyance score on the left of the equation (represented by "A") is predicted with informatio1 on the right side of the equation about the noise levels at two times of day (daytime noise levels are represented by "L_{id}" while the nighttime noise levels are represented by "L_{in}"). Changing from the noise levels which are measured in decibels (ranging from roughly 50 to 100) to an annoyance score which may be measured in values of 1 to 10 requires some transformations of the mathematical value of the decibels. Much of the equation relates to these transformations and is not critical to the present objective. What is critical is that one of the symbols in the equation represents the nighttime weighting, the symbol w_n. Thus if each respondent's annoyance score and each respondent's daytime and nighttime noise levels are put into the correct non-linear regression computer program, the program simply prints out the numbers which replace the bold face letters in the above equation. One of those numbers is the value of w_n, the nighttime weighting.

3.2 Estimates of the Time-of-Day Weights from 10 Studies

The noise level and annoyance information from each of the ten primary surveys were entered into a non-linear regression program and a value of the nighttime weighting was calculated for each study. The values of the nighttime weightings are presented in the second data column of Table 3.1. For the USA nine airport survey in the first line, for example, the nighttime weighting is calculated to be w_n=9.2. Thus the best available information from this survey is that one nighttime noise is as annoying as 9.2 daytime noises of the same physical noise level. This value of 9.2 is referred to as an "estimate". The word "estimate" is used because, even after all the data are rigorously analyzed, it is realized that it is not possible to know the perfectly accurate, "true" value of the time-of-day weighting for the entire population. The best analyses still yield an "estimate" because, for example, the data are drawn from only a sample (no matter how good the sample) of the population. Thus the surveys give only "estimates" (possibly quite good estimates) of the value of the nighttime weighting for the entire population.

From the ten surveys, 15 values of the nighttime weighting have been calculated in Table 3.1. For the surveys which contain more than one total 24-hour annoyance question, a separate calculation was performed for each annoyance question. The type of annoyance question is noted in the second column of the table together with the number of alternatives which were presented in the answer to the question. Both the "verbal" and "numeric" scales are based on questions which ask the respondent about annoyance with the noise. The questions differ in the way the alternative answers are stated.

For the numeric scale the respondent is presented with a scale of numbers such as the following:

Q. "How much are you bothered or annoyed by aircraft noise?

4 Extremely
3
2
1
0 Not at all"

[Source: USA nine airport survey]

Only the end points are given a verbal label. In the example of the numerical scale given earlier in Section 3.1 the end points were labeled "Definitely satisfactory" and "Definitely unsatisfactory". The respondent then chooses the number which best represents how far he is from the two extreme positions.

For the other type of question, a verbal scale, the respondent chooses from a list of verbal descriptors in a question such as the following:

Q. "How do you rate road traffic noise?

[1] Extremely agreeable
[1] Considerably agreeable
[1] Moderately agreeable
[1] Slightly agreeable
[1] Neutral
[2] Slightly disturbing
[3] Moderately disturbing
[4] Considerably disturbing
[5] Extremely disturbing"

[Source: 1976 Southern Ontario]

The respondent does not answer with numeric values. The scale is scored by the investigator who assigns scores from 1 (for the neutral or positive reactions) up to the number of scale points (eg. the fifth negative scale point, "extremely disturbing", is shown as scored "5" in the above example.) Another, perhaps more typical, verbal scale was presented earlier in Section 1.3. The possibility that the type of annoyance question could affect the value of the time-of-day weighting will be discussed in Section 3.6.

There is an enormous variation in the estimates of the nighttime weightings presented in Table 3.1. It would be expected that the nighttime weighting should be a positive number greater than $w_n = 1.0$ (eg. nighttime events are at least as annoying as daytime events). Within this range the estimates of the nighttime weighting range from 1.3 to 21.8. Table 3.1 also contains estimates which are outside this range. The estimates from zero to 1.0 are not totally inconceivable, they suggest that nighttime noise does increase annoyance, but that a nighttime noise has less effect than a daytime noise. The negative estimates and positive infinity (+∞) estimates, however, would not seem to be meaningful. The negative estimates imply that annoyance is increased by only daytime noise; the presence of nighttime noise actually decreases annoyance. The positive infinity estimates imply that only nighttime noise increases annoyance; the presence of daytime noise actually decreases annoyance. There is clearly no agreement between surveys on the value of the nighttime weighting.

The broad range of estimates and unlikely values for some of the nighttime weights in Table 3.1 raise questions about the accuracy of these estimates of the time-of-day weights. Two indicators of the quality of the estimates are available, 95% confidence intervals for the estimates and values of the coefficient of variation.

The 95% confidence intervals for the estimates are given in the first and third columns of data in Table 3.1. The most striking feature of these confidence intervals is that each of the upper confidence intervals is found to be positive infinity and that 13 of the 17 lower confidence intervals lie below the "reasonable" expectation that nighttime noise is at least as annoying as daytime noise ($w_n \geq 1.0$). These wide confidence intervals indicate that the estimates of the nighttime weight are so inaccurate as to be useless.

It might be wondered whether the few surveys with narrower confidence intervals provide better estimates or whether a more general measure of the quality of the data would indicate that all of the estimates are poor. The second indicator of the quality of the estimates, the coefficient of variation, answers these questions.

The coefficient of variation which is relevant for the calculation of the time-of-day weighting is given in the last column of Table 3.1. A general statistical rule of thumb is that the coefficient of variation should never be greater than 0.1. For these data the coefficient is greater than 0.1 in every case. In fact the coefficient is in every case at least five times greater than the standard, it never falls below 0.5. Thus this second indicator shows that none of the surveys has been able to provide a useful estimate of the nighttime weighting. (The definition of the coefficient of variation and the significance of the "Daytime regression coefficient" column in Table 3.1 are described in the "statistical aside" in Section 3.3).

The analyses have thus far only allowed for the possibility of a nighttime weighting and have ignored the possibility of an evening weighting. Table 3.2 presents estimates from five of the primary surveys for which evening noise data are available. The 24-hour day is divided into three periods and thus both an evening (w_e) and a nighttime (w_n) weighting can be calculated for each survey. The estimates of the nighttime and evening weights are seen to again vary widely from the unlikely negative values to the value of positive infinity.

As an indication of the accuracy of the estimates the 95% confidence intervals for the evening and nighttime weights are presented in Table 3.2. Just as for the previous nighttime analysis, all of the upper limits are an uninformative positive infinity. The lower confidence intervals are all set at unlikely values of less than $w_n=1.0$. In short, the analysis of evening weightings comes to the same conclusion as the previous analysis of the nighttime weights; none of the surveys provides a useful estimate of the time-of-day weighting.

3.3 The Elements of the Time-of-Day Weighting: A Statistical Aside

A somewhat more detailed description of the statistics involved in calculating the time-of-day weighting is presented in this subsection. The information presented is not essential to an understanding of the main conclusions of this report, but will provide a background for understanding some of the apparent anomalies which have been encountered and for understanding some of the procedures which are used.

While it is possible to have a computer program print out the values of the nighttime weights, a more fundamental understanding of the weights is gained if it is realized that the weights are actually based on a ratio of two statistics. The nighttime weight is an indicator of the relative importance of the noise levels in two time periods. It is derived by determining how much daytime noise affects annoyance, by determining how much nighttime noise affects annoyance and by then determining the relative size of these two effects. If the previous equation is rewritten slightly then the place of these two independent indicators of the daytime and nighttime effects is clear:

$$A = a + B_I \cdot 10 \cdot \log_{10}\{(B_d \cdot \sum_{i=1}^{N_d} 10^{L_{id}/10} + B_n \cdot \sum_{i=1}^{N_n} 10^{L_{in}/10})/24\}$$

The previous weight symbol (w_n) is no longer in the equation. Instead there is a coefficient which measures the effect of daytime noise (the partial regression coefficient for daytime noise, B_d) and a coefficient which measures the effect of nighttime noise (the partial regression coefficient for nighttime noise, B_n). The nighttime weight is defined as the ratio of these two coefficients:

$$w_n = \frac{B_n}{B_d}$$

This then is the statistical basis for the interpretation of the nighttime weight as a measure of the relative impact of noise at the two times of day. The weight is a direct estimate of the number of daytime events which are equivalent to a single nighttime event.

The absolute values of the two coefficients (B_d and B_n) are in a sense arbitrary and thus, for reasons which are explained in Appendix C, their values are forced to sum to one:

$$1 = B_d + B_n$$

The nighttime weight can then be described solely in terms of the values of the nighttime coefficient:

$$w_n = \frac{B_n}{1 - B_n}$$

Since the nighttime weight is a ratio, small changes in the denominator of the ratio ($1-B_n$) can have an enormous effect on the value of the time-of-day weight. Another characteristic of such a ratio is that there are discontinuities in the value of the ratio. For example, as the daytime coefficient becomes a smaller and smaller positive number, the ratio approaches positive infinity, but as soon as the daytime coefficient becomes so small that it is a small negative number, the value of the ratio flips from positive infinity to negative infinity.

These discontinuities and the fact that the sampling distribution of the ratio (time-of-day weight) is not normal (see Fields, 1985d: Appendix D) mean that many types of analyses are initially performed on the nighttime coefficient (B_n) and not on the nighttime weight (w_n). The 95% confidence interval for the nighttime weight is computed by first calculating the nighttime regression coefficient (B_n) and the precision of that coefficient (σ_{B_n}). (These two quantities are presented in the next-to-the last column of Table 3.1). The 95% confidence interval for the nighttime coefficient is then calculated and finally the upper and lower confidence intervals for the nighttime coefficient are transformed into a confidence interval for the nighttime weight. This procedure was used in Table 3.1 and Table 3.2 and explains why the confidence intervals for the time-of-day weights are not symmetrical (ie. are not an equal distance above and below the estimated value of the time-of-day weight).

The characteristics of the denominator of the ratio $(1-B_n)$ are also important for determining whether the estimate of the time-of-day weight will be a good, unbiased measure. If the value of this term is poorly estimated and could actually approach the point of discontinuity where it becomes negative then the measure of the ratio will be biased. The coefficient of variation which was presented in Table 3.1 provides an indicator of this problem. The coefficient of variation in Table 3.1 is defined as the standard deviation of the daytime coefficient divided by the value of the coefficient $\{\sigma(1-B_n)/(1-B_n)\}$. Thus a large value indicates that the value of the coefficient might not be greater than zero and might yield biased estimates.

The discontinuities in the value of the time-of-day weights and the fact that the time-of-day weights can go to infinity, also mean that the weights provide an unsatisfactory basis for calculating an average value of the time-of-day weight. In Table 3.3 in the next subsection it will be seen that the calculation of the average of the weights from several studies is, therefore, based on the average of the regression coefficients. The average of the nighttime regression coefficients can then be transformed into the time-of-day weight.

3.4 An Attempt to Combine the Weights from Different Studies

While none of the individual surveys provides a good estimate of the time-of-day weight, it might still be hoped that some type of average of the estimates from the primary surveys might yield a consistent, usable estimate of the nighttime weight. Several different methods for combining the results from the studies are possible. No single method is ideal, but if all the methods provide similar results, there would be some support for a consistent estimate of the nighttime weight.

One method for combining the estimates is to take a simple average of the estimates of the time-of-day weights from the different studies. When this is done in the first line of Table 3.3 the average is an unusable positive infinity because three of the studies have estimates of positive infinity. A second approach is to select the middle estimate, the median. In the second line of Table 3.3, the value of the median is found to be $w_n=2.6$. However, as is noted in the last column of the table, the median does not take account of the dispersion of the numerical values of the estimates of the time-of-day weights.

The remaining methods for combining the data from the different surveys are all based on averages of the nighttime regression coefficients. The nighttime regression coefficient was defined in the previous subsection of this report. At this point it need only be noted that the time-of-day weight is derived from this coefficient, but that unlike the averages of the nighttime weights in the first line of Table 3.3, the averages of the nighttime regression coefficients are not distorted by the extreme values of the nighttime weights. The first of these averages assigns equal importance to each study. The average of the nighttime regression coefficients is $B_n=0.61$, just as in the first line of Table 3.3. However, the estimate of the nighttime weight is now $w_n=1.6$ rather than $w_n=+\infty$. The method of averaging the estimates clearly affects the results.

The studies vary in the size of their samples and in other characteristics which affect the accuracy of their estimates. One deficiency of all of the methods used thus far is that they ignore the differential accuracy of the studies and weight each study's estimate equally.

An obvious method for partially adjusting for the differential accuracy of the surveys is to create a weighted average by letting the number of interviews in each study determine the influence that a study will have on the value of the average. In the fourth line of Table 3.3 this yields an estimate of $w_n=2.8$. However, as is noted in the last column, this method ignores the effects that other aspects of the study design may have on the accuracy of each survey's estimate of the nighttime weight.

The best available indicator of the relative accuracy of each survey's estimate is the size of the 95% confidence interval for the estimate of the nighttime regression coefficient. Studies with a smaller confidence interval would be expected to have better estimates. The standard method for this adjustment is to assign each estimate an importance which is inversely proportional to the square of the confidence interval. When this is done, the estimate of the nighttime weight is $w_n=24.7$. Of the five averages in Table 3.3, this average is based on the best method. Yet, even this technique has serious weaknesses. The basis for determining the accuracy of each study's estimate is the confidence interval. However, this confidence interval is estimated from the same data which have provided inadequate, inaccurate estimates of the time-of-day weight. The estimates of the confidence intervals are, in fact also very poor and thus provide only a weak basis for determining the importance which should be assigned to each study's estimate. In addition, the numerical values of these confidence intervals are affected by the estimated values of the nighttime regression coefficients. The smaller the value of the nighttime regression coefficient, the smaller the value of the confidence interval. As a result it is the studies with the smallest nighttime regression coefficients (and thus largest nighttime weights) which dominate the estimate of the average. In short, even this best indicator has serious deficiencies.

Each of the methods for combining the nighttime weights in Table 3.3 has its strengths and deficiencies. As the methods do not yield similar estimates, there is again no consistent evidence for a value of the nighttime, time-of-day weight.

The estimates of the time-of-day weight are thus found to be unsatisfactory. Three possible explanations for this finding are explored at different points in the remainder of this report. In the next subsection the possibility that the adjusted energy model is flawed is explored. In the following subsection the possibility that the wording of the annoyance questions could be creating systematically different estimates is considered. In Section 7.0, the effect of the combination of noise environments which are included in the study design is analyzed.

3.5 Alternatives to the Standard Adjusted Energy Time-of-Day Model

The total annoyance regression technique identifies the best time-of-day weights for predicting annoyance. However, as was previously noted, the choice of this best prediction method has been limited to a method which is consistent with the adjusted energy model. This subsection considers the possibility that either of two alternatives to the adjusted energy model might better explain annoyance and thus lead to more consistent evidence about the relative impact of noise at different times of day.

Just how noise from different periods combines to affect people's feelings about noise is not clear. The adjusted energy model, described in Section 1.4 is consistent with physical principles of combining the energy from noise sources. However, it is not necessarily consistent with the principles which people (unconsciously) use to combine noise.

One of the previously described aspects of the adjusted energy model may appear to be counter-intuitive. In the adjusted energy model, noise from both periods has a significant impact on people only if the adjusted noise levels (adjusted with the time-of-day weighting) of the two periods are approximately equal. This means, for example, that a very substantial reduction in nighttime noise, or even the elimination of nighttime noise, would not be expected to affect total annoyance as long as the daytime noise levels remain high. It implies that the introduction of a nighttime curfew would have no impact as long as daytime noise levels remain high.

Two alternatives to the adjusted energy model are considered in this subsection. The models are described mathematically in Appendix A. These are the only two alternatives which have been suggested in the literature on noise effects (Taylor, 1982; Bradley, 1979: p. 119). Coefficients for the alternative models have been reported previously in the noise effects literature (Edmiston and Patterson, 1972; Fields and Walker, 1982: p. 196;

Bradley, 1979: p. 119). However, none of the previous analyses compared the relative ability of the adjusted energy model and these models to predict annoyance. Neither of these alternatives has been incorporated in a noise index which has been used for regulatory purposes.

The first of the alternative models, the independent period effect model, assumes that reductions in nighttime noise levels will always have more impact on annoyance than reductions in daytime noise levels. The independent period effect model uses the multiple regression technique to simultaneously determine how much annoyance increases with each increase in daytime noise and how much annoyance increases with each increase in nighttime noise. If nighttime noise is worse than daytime noise in this model, then an increase in nighttime noise will always result in more annoyance than an increase in daytime noise. In other words, people should be more sensitive to differences in nighttime noise levels than they are to differences in daytime noise levels.

It should be remembered that here, as elsewhere in this report, respondents were asked about established noise conditions, not about changing noise conditions. As a result, the terms "increase in noise levels" or "sensitivity" refer to contrasts between people living in different types of noise environments and not necessarily to the reactions of people who have experienced a change in their noise environment.

The ten primary surveys were analyzed to determine whether, as the independent period effect model would predict, the increase in overall (24-hour) annoyance was greater for nighttime noise than for daytime noise. The findings from the surveys are not consistent. Five of the surveys indicated that there was greater sensitivity to nighttime differences, the other five indicated that there was greater sensitivity to daytime differences. For this model as for the adjusted energy model, the survey data do not yield consistent results about the relative effect of daytime and nighttime noise.

The second alternative model, the incremental decibel difference model, assumes that reducing the nighttime noise levels, relative to the daytime levels, will always lead to reduced annoyance. This model starts with a purely physical summation of the noise for the entire 24 hours. The adjustment for time of day is based on the difference between the daytime and the nighttime noise levels. The assumption is that there is a steady increase in annoyance as nighttime and daytime noise levels become closer to each other, even if the total sum of the energy for the 24 hour period remains constant. Thus if two noise environments were compared which had the same average physical noise exposure for 24 hours, there would be expected to be greater annoyance in the environment with the relatively low daytime levels (and thus relatively high nighttime levels). The size of the penalty which would need to be assessed against this environment would be a direct function of the number of decibels which separated the daytime and nighttime noise levels.

The ten primary surveys were analyzed to determine whether, as the incremental decibel difference model would predict, the size of the day-night difference was related to annoyance. In half of the surveys there was no indication that the difference between day and night levels was related to annoyance. The remaining surveys suggested moderate to large effects (Fields, 1985d: Table VI).

The size of these effects might best be indicated by contrasting the penalty which would be assessed on two noise environments, one with relatively high nighttime levels which has a day-night difference of 5 decibels (Leq) and a second noise environment with a relatively low nighttime level which has a day-night difference of 15 decibels. The size of the day-night difference is thus ten decibels less for the relatively high nighttime noise environment. [Previous analyses have suggested that this ten-decibel range of differences encompasses most noise environments around airports(Fields, 1985b).] The measure of the size of the nighttime penalty can be illustrated by considering the nighttime penalty which the ten decibels would imply. As was noted above, five of the surveys suggest virtually no penalty (less than a two-decibel penalty). The remaining five surveys vary, the lowest suggested penalty is 5 decibels, the highest is 13 decibels. The surveys again do not give a consistent estimate of the penalty. Sampling errors for these penalties have not been computed.

The time-of-day penalties suggested by the different models can not be directly compared. The models are sufficiently different that a penalty suggested by one model can not be transformed into the value of the penalty which is suggested by another model. The models can, however, be directly compared in another respect, their ability to accurately predict annoyance scores.

Each of the models utilizes the same input data (noise levels in the evening and nighttime) to predict the value of each of the individuals' annoyance scores. The success in predicting these annoyance scores can be measured in terms of the percentage of the variance in the annoyance scores which can be explained by the noise data using the particular model. The ability of the different models to explain annoyance can then be directly compared.

The results of this comparison are presented in Table 3.4 for 21 annoyance scales from the ten primary surveys. The percentage of the variance which is explained by the conventional energy model is presented in the first column of data. The percentage explained by the unconventional independent period effect model and incremental decibel difference model are presented in the last two columns of the table. The success of the three models can be directly compared for each survey.

If, for example, the results from the 1967 Heathrow survey are examined in the second line of Table 3.4, it is seen that the various models are about equally successful in predicting annoyance: 17% of the variance is explained by the energy summation model, 16% of the variance is explained by the independent period effect model and 17% is explained by the incremental decibel difference model. Thus, for the 1967 Heathrow survey, there are no important differences between the various models.

The English traffic survey presents results for three types of questions. The "very annoyed" question is a two-point scale formed from a verbal annoyance scale when all respondents saying "very" annoyed are given a score of "2" and all other respondents are given a score of "1". Similar divisions based on the word "considerably" are presented for three other surveys in the table. For the English traffic survey there are again no important differences between models.

If the same comparison is made for the remaining 17 scales in Table 3.4, it is seen that the models are approximately equally successful (or unsuccessful) in explaining annoyance. If anything the adjusted energy model may be slightly more successful.

The purpose of this subsection was to determine whether other suggested alternatives to the adjusted energy model might be more successful in providing consistent estimates of a time-of-day weight or in predicting annoyance. It has been found that none of the models yields consistent estimates for a time-of-day adjustment from the different surveys. It has also been found that the various models are approximately equally successful in predicting annoyance. There is thus no evidence to suggest that there is a better model than the widely accepted adjusted energy model which is implicit in such indices as Leq and Ldn. The remainder of this report considers only the adjusted energy model.

3.6 An Examination of Different Types of Annoyance Questions

The estimates of the time-of-day weights have been derived by relating noise levels to answers to particular annoyance questions. Since the surveys have used different annoyance questions, one explanation for the diversity of estimates might be the diversity of annoyance questions. In this subsection, that possibility is examined with two types of annoyance questions. Questions of the first type were used earlier in this section. These questions refer to the noise from a source without any specific reference to particular times of day. The questions of the second type are different; they contain explicit references to day or nighttime activities.

Annoyance questions of the first type were presented in three forms in Tables 3.1 and 3.2, verbal scale, numeric scale, and "very annoyed". To determine whether the type of question might be affecting the estimate of the time-of-day weight, estimates of the time-of-day weight are presented by survey and annoyance question type in Table 3.5. These results are presented under the "no time-period implied" heading since none of the questions mentions a particular time period or asks about activities which might be restricted to one time period.

The effect of question type can only be examined when one survey has included several different types of questions. For the USA nine-airport survey in the first line, the only comparison for the "no time-period implied" questions is between the numeric question (w_n=9.2) and the "very annoyed" question (w_n=36.3). In this case, the "very annoyed" question provides a higher estimate. However, this pattern is not supported in the rest of the table by the four remaining surveys which have both a numeric and "very annoyed" question. Though the England traffic and 1978 Ontario surveys have at least slightly higher estimates for the "very annoyed" question, the 1976 South Ontario and British Railway questions have higher estimates for the numeric scale.

Similar comparisons can be made for the numeric vs. verbal pair of questions (four surveys provide comparisons) and the verbal vs. "very annoyed" pair of questions (seven surveys provide comparisons). Again there is not a tendency for one type of question to yield a higher estimate of the nighttime weight.

Of course there are many other more or less subtle differences in the wordings and scoring of questions which could not be examined with only the three very general types of questions considered in this paper. In order to test for the greatest possible effect of type of question, a comparison has been made between questions which ask about different times of day. The results of this comparison are presented in the last four columns of Table 3.5. In the 1978 Ontario survey, for example, respondents were asked to give their score for the road traffic noise indoors in the "day" and also in the "night". In Table 3.5 it is seen that even for the "night" question there is not a time-of-day weight (w_n=0.0). This is less, though not much less, than the weighting which was obtained for the standard "no-time-period-implied" questions in the first part of the table. Table 3.5 also contains comparisons for two surveys which contain questions about both speech interference (a daytime activity) and waking up (a night activity). If there is any pattern, it is in the opposite of the predicted direction, the speech question evoked a slightly higher weight.

One other type of annoyance scale is included in Table 3.5, the activity interference index. An activity interference index is an average score of a respondent's scores on a series of questions about the extent to which noise causes annoyance by interfering with such activities as talking, television listening, sleeping or concentrating. These are widely used in surveys to measure the overall impact of noise. They are included for completeness in Table 3.5 even though they are not of great relevance for the issues pursued here. In fact, these indices are obviously totally inappropriate for the study of time-of-day weights. The indices contain questions which explicitly refer to particular times of day. The relative numbers of daytime and nighttime questions in this index, and thus possibly the relative importance of daytime and nighttime noise events in the index, is determined by the investigator who selects the mixture of questions. The use of activity interference indices for studying the time-of-day weighting will thus not receive further consideration in this report.

The absence of the expected pattern for the explicit time-of-day questions is of enough importance that it deserves restating. Respondents are asked about daytime noise. They are also asked separately about nighttime noise. The physical noise levels are determined for both periods. Then the answers to each of the annoyance questions is in turn related to both of the time-period noise levels simultaneously. The resulting analyses have not been able to show that the measured noise level during the appropriate time period (nighttime noise for a nighttime question) has any more affect on annoyance than does the noise during the inappropriate period (the period which was not referenced in the question).

The lack of effect of the type of annoyance question shows that the results presented here have not been biased by the type of annoyance question. The type of annoyance question has no consistent effect on the estimate of the time-of-day weight in these surveys.

The lack of effect for the explicit time period questions raises some important issues. One issue is whether people are sensitive to the amount of nighttime noise. This issue can not be explored with these data because, as the previous analyses showed, the estimates of the time-of-day weights are too inaccurate. Another issue which arises is whether there are other aspects of the study design which make it difficult for a study to separate out the independent effects of daytime and nighttime noise. There is at least one such important characteristic of these studies' designs, the high correlation between daytime and nighttime noise levels. As was seen in

Section 2.1 the correlations between daytime and nighttime noise levels range from r=0.86 to r=0.98. With such high correlations it is very unlikely that the independent effects of the two time periods could be measured. This issue will be again addressed in the last section of this paper when there is an examination of the prospects for better estimates if the correlations were to be reduced in new study designs.

3.7 Conclusion

The analyses reported here have shown that the social surveys do not provide estimates of the time-of-day weights which are of satisfactory accuracy. The conclusion from this report is thus that the numerical value of the time-of-day weight can not be established with the available data.

Thus far only the total annoyance regression approach has been considered. The next section turns to other widely used, though less satisfactory approaches. While these approaches do not alter the conclusions about the nighttime weighting they do provide some other information about nighttime annoyance.

4.0 RECOGNIZING AND EVALUATING THE EVIDENCE FROM LESS SATISFACTORY APPROACHES

Statements about time-of-day weightings and the relative importance of noise at different times of day have been drawn from the results of at least 18 studies. None of the studies was specially designed to measure the time-of-day weighting. With one exception (Bullen and Hede, 1983) the time-of-day weights were not the primary subject of the original study publications. The result has been that the statements about time-of-day weightings are based on a confusing variety of ad hoc analysis methods and fundamentally different approaches to the estimation of time-of-day weights. The assumptions implicit in these alternative approaches have not been made explicit in the publications. Investigators have been unaware of the differences and similarities in the alternative approaches. The conclusions drawn from the studies have, however, been phrased in similar terms. Most publications include a finding which measures time-of-day differences in decibels: either nighttime noise should be penalized by a certain number of decibels or the differences in reactions to daytime and nighttime noise are the equivalent of a certain number of decibels. However, the methods and the implications of the methods which have been used to arrive at these findings have been difficult to identify and analyze.

This section organizes the information from existing publications by classifying the existing methods into a small number of similar approaches. The identifying features of each approach are listed, the relationships implicit in the approach are made explicit in a mathematical model, the assumptions implicit in each approach are identified, variations on each of the basic approaches are identified, the publications based on each approach are reviewed, available data are reanalyzed to extract whatever information the approach can provide, and conclusions are drawn about what has been learned about the time-of-day weighting from each approach.

4.1 Comparisons of Noise Index Performance: Noise Index Correlation Approach

The ultimate objective of many time-of-day studies is to help to choose between specific environmental noise indices which have different time-of-day weightings. The numerical values of these indices are routinely calculated in community surveys. As a result, investigators often compare the strength of the various indices' correlations with annoyance. This comparison of correlation coefficients is the chief analysis technique used in the "noise index correlation" approach.

4.1.1 Identifying Characteristics

Reaction measure The reaction to noise is measured with a single scale based on one question or a series of questions in a social survey. This annoyance scale is assumed to summarize the feelings toward the 24-hour noise environment and can be the same type of annoyance measure as was used with the total annoyance regression method described in the previous section.

Noise data The noise indices which enter into the analyses summarize the noise for the entire 24-hour period. Each of the indices differs in the weight which is assigned to noise in noise-sensitive periods. This is to be contrasted with the total annoyance regression method in which each time period is represented by a separate term in the analysis.

Analysis technique The single annoyance scale is related to one of the 24-hour noise indices and the correlation is calculated. The same annoyance scale is then related to another of the 24-hour noise indices and the correlation is again calculated. The noise index which generates the highest correlation is then identified as the best index because it is relatively successful in explaining annoyance. The time-of-day weighting in this index is then accepted as the best weighting.

4.1.2 Assumptions

Just as for the total annoyance regression method, the annoyance scale must be a good measure of the total, 24-hour annoyance. This assumption is most often violated when the annoyance scale is an activity interference index. In this case, as was noted in Section 3.6, the investigator may be affecting the balance between daytime and nighttime annoyance in the index through the choice of the relative proportion of daytime and nighttime activities which are included in the index.

4.1.3 Analyses: Noise Index Comparison Approach

Six publications have been identified in which the noise index correlation approach has been used. The results from these six analyses are presented in Table 4.1 in a format which is similar to that of Table 3.1. The type of annoyance scale is noted, as in Table 3.1, and estimated values of the nighttime weightings are provided. In the next-to-the last column, the statement which was made in the study publication is reproduced. This statement is, of course, always to the effect that one index is more highly correlated with annoyance than another index.

The first five surveys provide only one piece of information about the time-of-day weighting. Three surveys indicate that the best estimate of the weighting must be greater than some number. Two surveys indicate that the best estimate must be less than some number. The last survey, the Australian five-airport survey, has slightly modified the noise index correlation method so that the best estimate can be bracketed between two numbers.

The evidence on the value of the time-of-day weighting from the six surveys does not support a particular weighting. The first three surveys indicate that the best estimate of the time-of-day weighting is greater than $w_n=3$ or $w_n=5$, while the last three surveys indicate that the weighting should be less than $w_n=5$ or less than $w_n=2$.

4.1.4 Comparison of Results from Noise Index Correlation Approach and the Total Annoyance Regression Approach

The same basic annoyance and noise data must be collected for the noise index correlation and total annoyance regression approaches. However, an examination of Table 4.1 shows that the noise index correlation approach provides much less information than does the total annoyance regression approach. Instead of an estimate of the best value of the time-of-day weighting, there is a simple statement that the best estimate of the time-of-day weighting must be greater or less than some value. No information is provided about the confidence intervals for even this weak estimate. The 10 primary surveys could have been reanalyzed using the noise index correlation approach. This analysis was not performed because all of the information which could have been provided by such an analysis has already been included in the previous total annoyance regression analyses.

The British railway study has, however, been analyzed in both Tables 4.1 and 3.1. The same annoyance scale, "annoyance index", appears in both tables. (Two other surveys are also included in both tables, but, for reasons which are apparent from the "Comments" column of Table 4.1., the annoyance scales used in the published noise index correlation analyses were rejected for the total annoyance regression analysis.) The comparison of the results from the total annoyance regression and the noise index correlation analyses in the next paragraph illustrates their differences.

On the basis of the noise index correlation analysis of the British railway survey in Table 4.1, it appears that the time-of-day weight is less than $w_n=5$ and that an unweighted noise index (24-hour Leq) is better than the nighttime weighted index, Ldn. From the total annoyance regression analysis in Table 3.1, however, it was learned that the best estimate is $w_n=2.9$, that the lower 95% confidence limit of $w_n=0.4$ is greater than the $w_n=0$ weighting which is contained in 24-hour Leq, and that the upper

95% confidence limit is so great that the value of $w_n=10$ which is contained in Ldn can not be excluded. Thus while both methods indicate that the best estimate is less than $w_n=5$, the correlation method seems to suggest that Leq is an unambiguous best choice and that Ldn can be dismissed; however, the more informative total annoyance regression method shows that the time-of-day weighting in Leq can be excluded, but that the weighting in Ldn can not be excluded.

The modified version of the noise index correlation method which is used in the Australia five-airport survey is an improvement over the standard noise index correlation method because it more closely specifies the value of the estimate of the nighttime weight. It still does not provide as exact an estimate as does the total annoyance regression method. As currently applied, the modified noise index correlation method also does not provide confidence intervals (Fields, 1985d: Appendix C).

4.1.5 Conclusions from the Noise Index Correlation Analyses

The review of the six surveys with published noise index correlation analyses has introduced analyses of three new surveys. The analyses of these three additional surveys do not provide significant additional information about the time-of-day weighting. The noise index correlation approach is less useful than the total annoyance regression approach because it uses the same annoyance and noise data but provides less information about the time-of-day weighting.

4.2 Evaluating Responses in Time Periods: Annoyance Comparison Approach

Instead of providing a single rating for the entire 24-hour noise environment, respondents are sometimes asked to rate the noise in each of the time periods separately. The noise levels in the periods are also measured. The annoyance comparison method compares the relationships between annoyance and noise level in each of the periods.

4.2.1 Identifying Characteristics

<u>Reaction measures</u> Respondents rate the noise for each period separately with an identically worded and scaled annoyance question. In the ideal case this time period is defined by the same hours as are used for the noise measurements.

<u>Noise data</u> Noise data are available for each of the time periods separately. These are the same noise data as were used in the total annoyance regression analyses.

Analysis technique Some method is used to describe the relationship between annoyance in each time period and the noise level in each time period. Thus a dose-response relationship is specified for each period. The differences between the dose-response relationships in two of the periods (eg. day and night) are then measured in decibels: the number of decibels which would need to be added to a nighttime noise in order to correctly predict the annoyance for a daytime noise. The analysis can be performed graphically by measuring the number of decibels which separate the daytime and nighttime dose-response curves. The analysis can also be performed with multiple regression analysis techniques.

4.2.2 Questionable Assumptions Implicit in Using Period Annoyance Scales

Respondents rate their annoyance in particular time periods with questions which are very much like the total annoyance questions except that the questions refer to a single time period rather than to the sum of the noise for the 24-hour noise period. Both numeric and verbal questions are used. The questions for the different time periods usually appear together in the questionnaire and differ only in the time period which is referenced (shown in brackets "[]" below). The following examples are drawn from three surveys:

Q. **At night . . . [During the daytime] . . .do you find the traffic noise is very annoying, fairly annoying, a little annoying or not at all annoying?**

{Source: English translation of question from 1979 French Road Traffic Survey}.

Q. **I would like you to tell me at what times of the day you find you are usually most bothered by aircraft during the week. . . . Please look at this scale and pick out the number which indicates how bothered or annoyed you feel during the morning . . . [afternoon/ evening/ night]?**

7 Very much bothered
6
5
4
3
2
1 Not at all bothered

{Source: 1967 Heathrow survey}

Q. On this scale from 0 (not at all disturbed) to 10 (unbearable disturbed) how do you rate main road traffic noise? . . . [indoors day/ indoors evening/ night]

10 Unbearably disturbed
9
8
7
6
5
4
3
2
1
0 Not at all disturbed

{Source: 1978 Ontario Survey}

The answers to these questions as well as to the rather similar period ranking questions (see next section, Section 4.3) are difficult to interpret because of ambiguities in the meaning of the questions, uncertainty about the causal processes, and lack of information about the relationship between period annoyance and total annoyance. The use of the period annoyance questions for estimating time-of-day weights implies the acceptance of four questionable assumptions.

Assumption 1: All Respondents Rate the Same Noise Entity

The questions are ambiguous as to the actual noise entity which is rated in a time period. Most questions could be interpreted as referring to any of the five following noise entities:

[Summed event noise-period entities]

1. The *average hour* during each period [Average-hour Entity] This noise entity does not account for the length of a period but does account for the number of events per hour. A person who bases an annoyance rating on the average-hour entity for whom individual noises during the day are about as annoying as individual noises during the evening would rate the evening as less annoying because there are fewer noise events per hour during the evening.

2. The *sum of the noise* during each period [Sum-of-hours Entity] This noise entity takes into account the length of a period. A sum-of-hours rater for whom the average hour during the day is as annoying as the average hour in the evening would respond that the evening was less annoying because it was shorter. An average-hour rater would have rated the periods equally.

3. The sum of the noise when at home This noise entity includes the sum of the noise which occurs when a person is normally at home. If this type of rater is equally annoyed by the average hour during the day and the evening, but is only home one hour during the day, but four hours during the evening, then the rater would rate the evening noise as being worse.

[Single event noise-period entities]

4. The *average* (noticed) *noise event* during each period [Average-noise-event Entity] This noise entity does not account for the number of noise events. An average-noise-event rater for whom an evening noise event is marginally more annoying than a daytime event would say that evening noise was worse even though there are frequent daytime noise events and infrequent evening noise events. In the same situation a rater of the average-hour entity or sum-of-hours entity would probably have reported daytime noise was worse.

5. The *single worst noise event* ever experienced in the period [Single-worst-noise Entity] This noise entity is based on only one event for each period at a location. A single-worst-noise rater who had one nighttime experience in the past which was worse than any single daytime experience, would rate nighttime as worse even if, on the balance, the rater would prefer the average nighttime event to the average daytime event. In the same situation an average-noise-event rater would have rated the evening noise as worse.

The above interview questions are ambiguous as to which of these noise entities is to be considered. While the term "usually" in the Heathrow survey should eliminate the single-worst-noise entity, there are no explicit, clear statements to help the respondent choose between the other entities. The *conventional wisdom* is closest to the single-worst-noise entity: nighttime noise is worse because being kept awake by a noise is worse than anything noise can do during the day. Thus it seems likely that at least some people will interpret time-period questions as single-worst-noise questions. Unfortunately, the answers to the question are only useful for the various time-of-day weight calculations if one of the first three entities (summed event entities) is meant.

Even the researchers who design the questionnaires and analyze the data do not agree on which of the above entities is rated by respondents. Borsky interprets the following question to refer to an average-hour entity when he relates annoyance to the number of noise events per hour (Borsky, 1976; p. 21):

Q. . . . could you tell me how much the noise from airplanes bothers or annoys you during the day [evening/ night]?

{Source: 1972 JFK Airport Noise Survey}

On the other hand, the authors of the Wilson report interpret the following question to refer to a sum-of-hours entity (Wilson, 1963: p. 251).

Q. Do you find the aircraft bother you most during the morning (6-12), the afternoon (12-6), the evening (6-11) or the night (11-8)?

{Source: 1961 Heathrow survey}

This time-period question from the 1961 Heathrow survey and the next question are period ranking, rather than period rating questions (see Section 4.3); however, the ambiguity in time period questions is relevant in either case. Ollerhead attempted to remove some of the ambiguity with the following question:

Q. When do you find the noise of an aircraft most disturbing around here: during the night when you are trying to sleep, during the evening, or during the daytime?

{Source: 1972 Heathrow Survey}

The author concluded that his attempt to refer to a single aircraft with the introduction of the article "an" was too subtle a wording change to remove the ambiguities (Ollerhead, 1978). This experience suggests that considerable care may be needed to construct a question which will be understood by all respondents.

<u>Assumption 2: Period annoyance questions measure annoyance during the time periods</u>

There are at least two main challenges to the validity of the period annoyance measures.

<u>*Conventional Wisdom* Reflex</u> The *conventional wisdom*, that night noise is worse than day noise, is so pervasive that many respondents may say nighttime is worse without even thinking about their local noise environments. The *conventional wisdom* response is also the least stressful way for people to answer who think that the interview is a test with right and wrong answers.

<u>Acoustic Observer Frame of Reference</u> While the intent of the researcher is to measure the respondent's <u>feelings</u> about noise, some respondents may take the role of the objective observer of physical noise levels. When faced with consecutive questions about noises in different

periods such respondents try to "help" the researcher by choosing the period when there is the greatest amount of noise. One indication of this phenomena may be the tendency on an open question to report that the evening "rush hour" is one of the times when people are disturbed the most (1978 Ontario Survey).

<u>Assumption 3: Feelings about noise in one period are not affected by experiences with noise in other periods</u>

Even if period annoyance questions successfully measure annoyance in a period, a serious question remains about the causal processes which lead to these period annoyance responses. The wording of the period annoyance questions suggest that the respondent should only report feelings towards the noise experienced in a single period. The analyses similarly require that the period responses not be affected by noise levels in other periods (see Section 4.2.2). Careful thought about annoyance responses, however, suggests that this assumption is likely to not be correct. Instead feelings about noise in one period are likely to be contaminated by experiences with noise in other periods.

Annoyance responses to the noise in different periods are highly correlated. Past research on response to noise has shown that feelings of annoyance are closely tied up with more general attitudes toward the noise source, the extent to which the noise can be prevented and the perceived danger from the noise. It would seem to be likely that if a person were to be initially sensitized to a noise in one period, that the person would begin to form negative attitudes toward the source and its mode of operation which would carry over to other periods. If a person is awakened by motorcycles racing past in the night, it would be likely that the person would become more sensitive to motorcycle noise generally, form negative attitudes toward motorcyclists and thus report high annoyance with motorcycles at all times. It seems unlikely that very many people could remain so objective as to say that they found motorcycles terribly disturbing at night, but that they thought that motorcycle noise was acceptable during the day.

Unfortunately, it is not possible to determine whether reactions in one period are contaminated by experiences with noise in other periods. In applying the total annoyance regression method in the previous section, it was found that the period noise levels are too highly interrelated to assess the effects of each period on total noise annoyance. The same high correlations mean that the effects of each period can not be assessed on period annoyance scores. Several studies which have examined correlations between nighttime annoyance and measured noise levels, but have not reported significance tests, have reported that nighttime annoyance is more closely related to 24-hour noise levels than to nighttime noise levels (La Gene..., 1968: p. 62; Aubree, 1975: p. 31). Similarly, in the 1967 Heathrow survey, it was found that nighttime noise was less highly correlated with a nighttime activity disturbance index than with a daytime disturbance index.

Assumption 4: The relationship between period annoyance responses and total 24-hour annoyance can be derived from the adjusted energy model

No information is available about how period annoyance responses are related to total 24-hour annoyance responses. When only the period annoyance responses are studied some a prior assumptions must be made about the relationship. With only the period annoyance responses it is not possible to test the overall model (eg. adjusted energy model) for the combined effect of noise levels in different periods.

4.2.3 Analyses: Annoyance Comparison Approach

The total amount of information available from the period response comparison approach is presented in this section in four new analyses and in a review of an additional four previously published analyses. The new analyses are presented first.

4.2.3.1 New Analyses

At the center of the annoyance comparison approach are the relationships between annoyance and noise level for each time period. These relationships are presented graphically for new analyses of four surveys in Figures 4.1 to 4.4. Each of the data points in the figures represents the average annoyance and average noise level of respondents with in a noise level category (usually a 5-decibel width category). A summary of the relationship is presented in the form of a line which represents the best fit to the individuals' responses as determined by least squares regression techniques. The line is based on the logistic curve (Appendix C) but quite similar estimates of time-of-day weights were found when the more familiar linear regression techniques were used. For the analyses here the shapes of the curves for the different time periods have been found to be similar, thus one curve is assumed to fit the data for all time periods. The curves differ only in their displacement along the horizontal axis.

The differences in the reactions to similar noise levels at different times of day can be measured in decibels as the horizontal distance which separates the annoyance curves for the different time periods. In Figures 4.1 to 4.4, the horizontal dashed lines are examples of lines of equal annoyance. In Figure 4.2, for example, the level of annoyance represented by the dashed line is reached at about 70 dB(A) (Leq) for daytime noise ratings. The same level of annoyance is reached at about 64 dB with nighttime noise. As a result there is a six-decibel displacement between the equivalent nighttime and daytime annoyance reactions.

The horizontal displacements are expressed in decibels in Figures 4.1 to 4.4. The time-of-day weights in the adjusted energy model can not be automatically assumed to be numerically equal to these decibel displacements. It is only reasonable to make any time-of-day weight calculations if three of the previous questionable assumptions are made. Those assumptions were that feelings about noise in one period are not affected by noise in other periods, that period annoyance measures are good measures of annoyance, and that period annoyance scores can be simply related to total annoyance with a priori models. After these assumptions are accepted it is necessary to make assumptions about the noise entity which respondents have rated.

The five possible noise entities are listed in Table 4.2. First it must be noted that for three of the five possible entities no information is available about the weighting. Estimates of weights could be prepared for only two of the five noise entities. The results from the period response comparison approach for these two noise entities are presented in PART A of Table 4.2. (PART B will be discussed in the next section.)

For each study and noise entity the time-of-day weight is expressed as a number weight and, in brackets, as a decibel weight. The decibel weights for the average hour-entity are the same as the decibel displacements found in Figures 4.1 to 4.4 because the noise levels used in the figures (hourly Leq) are measures of the average hourly noise level. The sum-of-hours entity takes into account the length of the period as well as the noise level during the average hour. As a result, when it is assumed that the sum-of-hours entity is rated, then all time-of-day weights increase to some extent (the weighted periods contain fewer hours than the day period) and the weight for the shortest period, the evening, increases the most.

All of the estimates in PART A of Table 4.2 support a positive time-of-day weighting. The estimates of the size of these weightings do not agree. This inconsistency is due to the uncertainties about the noise entities being rated and to differences between surveys.

The uncertainties about the noise entities mean that, to take the worst case, the value of the evening weight for the 1978 Ontario survey increases from an unimportant $w_e=1$ to an important $w_e=7$ [$w(dB)_e=1dB$ to $w(dB)_e=8dB$] when it is assumed that respondents consider the number of hours in the time periods. The assumption about the noise entity also affects conclusions about the relative size of the evening and nighttime weights. If respondents have only been rating the average hour then the nighttime noise receives the higher weight in all surveys. If, on the other hand, the respondents are rating the sum-of-hours noise entity then the evening period is either more important (1967 Heathrow survey) or of equal importance (1978 Ontario survey). In short the unresolved ambiguity in the rated noise entity affects important conclusions.

There are also large differences between surveys in the estimates of the time-of-day weights. The estimates of the nighttime weight for the sum-of-hours entity vary from $w_n=60$ to $w_n=4$ (ie. one nighttime event is as annoying as either 60 or 4 daytime events). The 1967 Heathrow survey estimates are substantially higher than those of the other three surveys. None of the survey results can be simply dismissed. The Heathrow results come from only a single survey, but it is the survey with design characteristics which should yield the best estimates (largest sample size and a wider range of noise level differences). The estimates from the other three surveys are rather similar to one another, but their individual estimates are based on weaker sample designs.

The lack of agreement between the surveys cannot be traced to large confidence intervals for the individual survey estimates. The confidence intervals for the Heathrow and Ontario survey average-hour decibel weights are less than $\pm$ 1 dB. (Confidence intervals could not be computed for the Zurich and French data because the individual responses were not available for analysis.) Within anyone survey people are thus consistently rating the differences between periods. However, with the high correlations between noise levels, it is not possible to determine whether this consistency comes from similar individual time-of-day weightings, general reporting of the *conventional wisdom*, or the contamination of feelings about one period by the noise levels in another period.

An attempt was made to determine whether feelings about one period are sensitive to noise levels in other periods (ie. a test of Assumption 3). In general the annoyance reactions for a specified time period are as highly correlated with noise levels in other time periods as with the noise level from the specified time period. This may simply be due to the fact that the noise levels from all time periods are highly correlated. As a result, the data do not provide a basis for estimating the independent effects of different time periods on annoyance and it is not possible to reject the possibility that noise levels in other periods affect annoyance in a specified period.

4.2.3.2 Review of Publications: Annoyance Comparison Approach

In the course of the review of the time-of-day publications, four publications were identified in which the analyses methods fit within the annoyance comparison approach. In each case some type of annoyance scale is created for each time period and related to the noise levels in that time period.

The results from these four publications are presented in Table 4.3. Information is presented about the annoyance scales used, the finding as reported in the original publication, and an estimate of a time-of-day weight which was derived from the published results (the estimate assumes that a sum-of-noise entity was rated).

The estimates of the time-of-day weights are again found to be variable. The estimates vary from $w_n < 1$ to $w_n = 13.2$.

The 1978 Zurich study was analyzed in greater detail above. The authors' published generalization that the difference between the night and day annoyance thresholds is about the equivalent of 5 dB (Leq) [$w_n = 6$] is close to the results from the analysis in Table 4.2 [$w_n = 4$ for the sum-of-noise entity].

The time period annoyance measures in the three remaining surveys share the same flaw: the definitions of the time-period used in the annoyance questions do not match the definitions used for the physical noise measurements. The U.S. Army and Western Ontario surveys contain a number of questions about smaller sections of each time period. Thus when a summary time period annoyance measure was needed to match the noise data, the authors had to make guesses about how these shorter time-period judgments might have been related to the entire time-period annoyance. No empirical data were available for making these guesses and thus the validity of the annoyance measures for these two studies is uncertain.

The 1972 Heathrow study results are not even based on questions about the amount of annoyance, but rather on reports of the number of times a person was disturbed. The $w_n < 1$ estimate from the 1972 Heathrow survey is based on the fact that there was no evidence for a relationship between the numbers of times respondents said they were disturbed by nighttime flights and the actual numbers of nighttime flights. This lack of relationship for nighttime flights contrasted with the daytime and evening results in which there was a relationship between reported numbers of disturbances and numbers of flights.

4.2.4 Conclusions from the Annoyance Comparison Approach

The large number of questionable assumptions which are implicit in the annoyance comparison approach mean that the time-of-day weights which are calculated with this method are of doubtful validity. The various studies provide widely varying estimates of the time-of-day weights, but do consistently find that evening and nighttime noise are rated as more annoying than daytime noise.

4.3 Ranking Annoyance for Time Periods: Period Ranking Approach

Instead of being asked separate questions about each time period respondents are often asked in a single question to identify the time period which is the most annoying. Such a ranking of annoyance with noise in different time periods is the basis for the period ranking approach.

4.3.1 Identifying Characteristics

Reaction measures Some measure of the ranking of annoyance in two time periods is required. The most frequently used measure of annoyance is a question about the ranking of annoyance in different periods. The ideal question would ask for a comparison of the reactions in only two periods. The typical question, however, asks the respondent only to choose the worst period from among more than two time periods. The relative annoyance for two periods can also be derived from the period annoyance questions which were used in the annoyance comparison approach. For the present ranking approach the scores on the two period annoyance questions are ranked and each respondent is classified according to which period was rated as being most annoying.

Noise data Noise data must have been obtained for each of the separate time periods as was the case for the total annoyance regression and annoyance comparison approaches. The actual noise levels which are entered into the analysis, however, are measures of the differences between the noise levels of the two periods.

Analysis technique Some method is used to relate the ranking of the relative annoyance with noise in the two time periods to the difference between the noise levels in the two time periods. In general the analysis attempts to determine the number of decibels which separate daytime and nighttime periods when people are equally divided about which time period is worse. Respondents who say that the two periods are equally annoying are excluded from such analyses, but can be included in other analyses in which the proportion who rate the periods as equally annoying are related to the difference in noise levels of the two time periods.

4.3.2 Questionable Assumptions Implicit in the Period Ranking Approach

This approach is again based on questions about annoyance in time periods. The doubts raised about period annoyance scales in the previous section thus also apply to the period ranking approach.

While a wide range of annoyance ranking questions will be discussed in Section 4.5, the previously reproduced question from the 1961 Heathrow survey is typical of the type of period ranking question which is used in the analyses in this section:

> Q. **Do you find the aircraft bother you most during the morning (6-12), the afternoon (12-6), the evening (6-11), or the night (11-8)?**

In order to use such questions in a period ranking analysis all of the same questionable assumptions must be accepted as were accepted for the annoyance comparison method. These period ranking questions are still subject to the ambiguity about the noise entity which is rated. The possibility that noises in other periods affect feelings about noise in a particular period is still present. The likelihood that the *conventional wisdom*, rather than the respondent's real feeling, is being reported would seem to be even more likely with this type of period ranking question. On the period ranking question a respondent is asked which period is worst. The easy, unthinking response is the *conventional wisdom* that night is worst. The possibility that the respondent will adopt the acoustic observer frame of reference is still present. Once again no information is available about how the period annoyance responses should be combined to create total annoyance responses.

Carefully designed period ranking questions may be able to reduce or eliminate part of the ambiguity in the definition of the noise entity. The Australian five-airport survey includes a question which seems to clearly specify a sum-of-hours entity:

> Q. **Suppose you were able to have aircraft stopped from flying over in one of these... periods, which one would you most like to have free from aircraft noise?**

Though the question may have resolved one ambiguity, the authors felt that it introduced a new ambiguity. The question was finally rejected by the authors as being of doubtful validity because some respondents interpreted the question not as a question about their actual exposures but rather as a question about hypothetically equal exposures.

The period ranking questions in existing questionnaires have been designed to identify the worst period during the day. These questions all suffer from one weakness when used in a period ranking time-of-day analysis. They do not provide a pair-wise ranking of all periods. For an analysis of a nighttime weight it is necessary to know the relative ranking of daytime and nighttime for each person. If a person has chosen "evening" as the worst time of day then no information is available about the relative annoyance with day and night. As a result such "evening" responses must be excluded from analyses of the nighttime weight in the remainder of this section.

4.3.3 Analyses: Period Ranking Approach

The first part of this subsection contains new analyses of three surveys. The analyses provide estimates of the time-of-day weights. These analyses also illustrate a complete analysis using the period ranking approach. The remaining part of this subsection contains a review of statements drawn from period ranking analyses used in five previous publications.

4.3.3.1 New Analyses

Figure 4.5 provides a graphical representation of an analysis of the 1967 Heathrow survey using the period ranking approach. The proportion of people in each noise category are plotted who rate the noise at night as being worse than the noise during the day. The noise categories are defined in terms of the differences between nighttime and daytime noise levels. From the general trend in the data it is clear that the responses are consistent with a weighting for nighttime noise; the proportion saying that nighttime noise is worse increases as the nighttime noise levels increase relative to the daytime noise levels. A best fit line has been defined using least squares regression. The line is based on a logistic curve, but it is so close to linear that a linear regression would have yielded similar results. (The logistic curve is defined in Appendix C.) For the time-of-day weighting discussion there is one point on this curve which can be simply interpreted, the 50% point. [The problem of interpreting other points has been briefly discussed previously (Fields, 1985a: p. 16).] The 50% point is indicated on Figure 4.5 as the point where it is predicted that the population would be evenly divided about which period is worse. This is thus assumed to identify the point where daytime noise and nighttime noise are equally annoying. The vertical dashed line from that point then identifies the difference in noise levels at which there is equal annoyance. For the 1967 Heathrow survey this is seen to be at the point where the daytime noise exceeds the nighttime noise by 16 decibels.

The same analysis has been repeated for the 1978 Ontario and British railway surveys in Figure 4.6. The equal annoyance points are seen to be reached at 8 and 6 decibel differences for these surveys.

The ranking measure for the 1967 Heathrow and 1978 Ontario surveys was created by comparing respondents' answers on the period annoyance rating questions which were used in the annoyance comparison analysis. Each respondent was then classified according to which period was rated as most annoying. The British railway survey used a period ranking question:

Q.a **Do you find the train noise is more annoying at certain times of day or is it always the same?**

b **At what time do you find the train noise <u>most</u> annoying? (Morning 8-12 am, Afternoon 12-6, Evening 6-11, Night 11-8)**

This question raises a problem in a particularly acute form which is found in all surveys: a proportion of the population will always say that they are equally annoyed in all the periods which are being compared. The railway question makes it especially easy for respondents to say "equally annoying". As a result some 75% reported that their annoyance was the same in all periods. These people are excluded from the analyses in Figures 4.5 and 4.6 and from most of the period ranking analyses. A special analysis was performed which did use these "tied" responses.

The tied, equal annoyance responses are analyzed in Figure 4.7. The figure contains the same measure of noise level as was used in the previous figures, the difference between daytime and nighttime noise levels. In this figure, however, the annoyance measure is the proportion of the sample which reports that day and night are equally annoying. This annoyance measure is thus an indicator of personal indecision and would be expected to reach a maximum at the point at which the noises from the two periods are equally annoying. From a simple examination of the data points it is not at all clear whether a maximum point is reached within the range of the observed data. The best fit quadratic equation for the individual annoyance data is plotted in Figure 4.7. The point of maximum equal annoyance is the point of inflection for a parabola described by this equation. For the 1967 Heathrow survey this point of inflection is calculated to be at 3 dB, a point which is outside of the range observed in the data. The same type of analysis was performed for the British railway and Canada surveys, but there was no tendency toward a peaking of the curve and the relationship was essentially flat.

The decibel differences in Figure 4.6 can be expressed as time-of-day weights if the same problems are considered as were considered previously in the annoyance comparison analyses. The questionable assumptions about period annoyance rankings must be accepted and the fact that only two of the three possible noise entities can be evaluated must be accepted. As in the previous analysis, separate estimates of annoyance weights can be calculated for the average-hour entity and for the sum of hours entity. These calculations are presented in PART B of the previously examined Table 4.2.

The results from the three surveys in Figure 4.6 are expressed in nighttime weights in PART B of Table 4.2. Just as in PART A of the table, the estimates of the nighttime weights vary widely, from $w_n=4$ to $w_n=65$. The Heathrow and Ontario surveys have been analyzed using both the annoyance comparison approach (PART A of Table 4.2) and the period ranking approach (PART B of Table 4.2). The estimates of the time-of-day weights from the two analysis methods are quite similar, within two decibels, even though the comparison is complicated by the use of three time periods in PART A but only two time periods in PART B.

The addition of these period ranking analyses to Table 4.2 does not alter the earlier conclusions. There is still a wide range in the estimates of the time-of-day weights. The estimates of the value of the time-of-day weightings are still influenced by the assumptions about the noise entity which respondents are rating.

The estimates of the time-of-day weights using the period ranking method are not precise. The data set which should provide the most accurate estimate is the 1967 Heathrow survey. The 95% confidence interval for the estimate of the 50% annoyance point has been calculated for the 1967 Heathrow survey on the unrealistically optimistic assumption that responses and noise measurement errors at the 171 selected study sites around Heathrow are independent of one another (see Appendix C for a discussion of related problems in calculating sampling errors). The resulting 95% confidence interval for the regression line is plotted in Figure 4.8. With the optimistic assumption there is a lower confidence limit (13 dB) but no upper confidence limit for the estimate of the 50% annoyance point. The slope of the regression line for the Heathrow survey is statistically significantly greater than zero ($p<0.05$). For both the Ontario road and British railway surveys, however, the slopes are not significantly greater than zero and thus it is not even possible to be sure that the reactions are related to the differences in the day-night differences in noise levels.

A number of other period ranking analyses were carried out but have not been described because in each case the estimates were so inaccurate as to not be useful. The weak relationship in the 1967 Heathrow survey (Figure 4.7) between noise level differences and the amount of reported equal annoyance is not statistically significant. Similar analyses for the Ontario road and British railway surveys did not find statistically significant relationships.

Period ranking analyses were performed for evening reactions. Daytime and evening reactions were ranked in the Ontario road and British railway surveys. These analyses did not provide support for an evening weighting. It is likely that the relationships were not statistically significant.

The inaccuracy in the estimates of the time-of-day weights which is observed for the relative annoyance ranking method is due to the same high correlation between noise levels in different periods which was observed in the total annoyance regression approach analyses. In this case the high correlation between noise levels can be seen in the small amount of variation in the differences between daytime and nighttime noise levels. In Figure 4.6, for example, the range of day-night differences is less than 10 decibels for the British railway and Ontario road surveys.

4.3.3.2 Review of Published Analyses: Period Ranking Approach

In reviewing time-of-day publications five publications were identified in which the analysis methods fit into the general frame work of a period ranking approach. In each study a single annoyance ranking question was examined. In each study the difference between daytime and nighttime noise levels was measured.

The results reported in these five publications are presented in Table 4.4. The statements from each of the first four publications are very similar. It is stated that the annoyance with daytime noise is less or equal to that with evening or nighttime noise, but that the daytime noise levels are lower. As a result it is concluded that there should be a time-of-day weighting. The first entry, the British railway study, does not provide an informative estimate of the possible size of a time-of-day weight, but an estimate of the nighttime weight of $w_n = 5$ (sum-of-hours entity) is available from the new analyses in Table 4.2. The estimates of a nighttime weighting for the next three surveys range from $w_n = 11.5$ to $w_n = 25$ (sum-of-hours entity assumption). While no special threats to the validity of the Zurich survey are noted, the comments for the 1961 Heathrow and 1980 Australian surveys raise additional problems which throw doubt on the validity of their findings.

As was seen earlier the 1961 Heathrow survey asked for a rating of four periods, morning, afternoon, evening and night. In fact only a small proportion of the sample chose either of the daytime (ie. morning or afternoon) periods. Most chose the evening or night periods. For the time-of-day weighting analysis a direct comparison is needed between the ranking of daytime and nighttime. These data were not available, thus the authors decided to put together the day and evening into one category (24% of the sample) to be compared to the night (28%). This procedure may provide some information about the relative importance of the evening and nighttime periods, but certainly does not provide the required evidence about the relative importance of daytime and nighttime noise which is needed to derive a traditional time-of-day weight.

The problem with the Australian survey was mentioned earlier when the period ranking question was presented (Section 4.3.2). The authors dismissed the validity of the estimate on the grounds that some respondents interpreted the question incorrectly as referring to a question about hypothetically equal noise environments rather than as a question about their experiences with the existing noise environment. The authors also note that the estimate of $w_n > 11.5$ was well above the estimate of $w_n < 2$ which was based on the noise index correlation approach (Table 4.1).

The estimate from the last entry in Table 4.4 (1972 Heathrow survey) was also rejected as invalid by the author. In this case the question asked about response to _an_ aircraft (ie. to a single aircraft event) but the author concluded that many respondents interpreted the question to refer to the sum of the noise exposure in the period. The author also noted that the results from this question ($w_e < 2$) are inconsistent with the results derived from the annoyance comparison approach in Table 4.3 ($w_e = 4$).

The analyses from all five publications differ in one fundamental respect from the new period ranking analyses presented earlier. The publications present a single point estimate of annoyance and noise level from each survey. The new analyses relate the variations in the relative rankings of the periods to the variations in day-night noise level differences. The new analyses found that in two of the three surveys it was not possible to determine whether respondents were sensitive to variations in the differences between day-night noise levels. The new analyses thus raise additional questions about the assumptions which must be accepted if period analyses are to be accepted as valid. The analysis methods used in previous publications did not make these assumptions explicit.

4.3.4 Conclusions from the Period Ranking Approach

The same questionable assumptions which limited the annoyance comparison approach similarly throw doubts on the validity of the period ranking approach. The surveys do consistently find that evening and nighttime periods are rated as more annoying than the daytime. The estimates of the time-of-day weights derived from these analyses are not precise and vary greatly between surveys.

4.4 Ratio of Numbers Analysis

Data on the number of noise events at different times of day are often economically obtained while the data on noise levels are expensive to obtain. As a result several published analyses have attempted to derive time-of-day weights without any information about noise levels. These attempts do not in fact provide weights which are consistent with the adjusted energy model. This section provides enough information to aid the reader in recognizing a ratio of numbers of analysis. The section does not provide additional information about time-of-day weights.

4.4.1 Identifying Characteristics

Reaction measures. The basic data come from the same types of period annoyance measures as were used in the annoyance comparison approach. However, it is the ratio of the period annoyance scores which is entered into the analysis, not the period annoyance scores individually.

Noise data. Data are not available on the noise levels of the noise events. The number of noise events during each time period are available. The ratio of the numbers of noise events during the time periods is used in the analyses.

Analysis technique. An annoyance ratio of the nighttime annoyance score divided by the daytime annoyance score is formed. A number-of-events ratio of the number of nighttime events divided by the number of daytime annoyance events is also formed. The annoyance ratio is divided by the number-of-events ratio. The resulting ratio of annoyance and number ratios (or the logarithm of the ratios) is then considered to be a time-of-day weight.

4.4.2 The Flaw in the Ratio of Numbers Analysis: Inconsistency with the Adjusted Energy Model

The adjusted energy model assumes that the effects of noise level, numbers of events and other unmeasured factors are additive; that is, the effects of these factors must be added together. The model is written:

$$\text{Annoyance} = a + B_L \cdot L + B_N \cdot (\log_{10} N)$$

The effects of the unmeasured variables (a) and of noise level ($B_L \cdot L$) are added to the effect of number. The ratio of numbers analysis derives a weight from the following ratio.

$$\frac{\frac{A_n}{A_d}}{\frac{N_n}{N_d}} = \text{time-of-day adjustment}$$

The ratio can be rewritten with a multiplicative constant term (K) to represent any factors which have been left out of the model:

$$\frac{A_n}{A_d} = \frac{N_n}{N_d} \cdot K \cdot \text{time-of-day adjustment}$$

It thus follows that only multiplicative terms can be included in the model which relates annoyance to noise level. The method is thus unsuitable for calculating weights which are to be used in the adjusted energy model. The publications in which the ratio of numbers analyses have appeared have not proposed an alternative to the adjusted energy model; thus it must be supposed that they were unaware of the inconsistency with the adjusted energy model

The ratio of numbers analysis uses period annoyance measures. Thus all of the questionable assumptions which were made for the annoyance comparison and period ranking approaches must also be made for the ratio of numbers analyses.

4.4.3 Analyses Using the Ratio of Numbers Analysis

Two survey reports have included ratio of numbers analyses. In an aircraft noise survey around JFK airport in New York it was found that the ratio was equal to 2 (Borsky, 1976: p. 21). In a US Army survey of annoyance with several different sources it was found that the ratio varied from 2.5 to 5.3 (Schomer, 1983: p. 546). Confidence intervals are not available for the estimates. Because the additive effects of other variables have not been included the values of the time-of-day weights for the adjusted energy model would be higher than the adjustment calculated for the ratio of numbers analyses. (For a more complete discussion see Fields, 1985a: p. 47). Other information from these reports which is not dependent on the ratio of numbers analysis has been used in the present report.

4.4.4 Conclusions about the Ratio of Numbers Analysis

This approach is unsuitable for estimating weights for the adjusted energy model. The time-of-day weights which have been calculated using this approach are numerically less than the weights which would be consistent with the adjusted energy model.

4.5 Comparisons of Periods which Ignore Noise Level

A large number of surveys have obtained some information about annoyance during different time periods but have not related that information to the noise levels in those periods. The reports of these annoyance responses, without concurrent analyses of noise levels, are not directed at estimating a time-of-day weighting, but rather at answering a related question:

> **When is noise having the greatest impact in residential areas?**

This is quite a different question from the one which leads to estimates of the time-of-day weights. The answer to this question might help a local regulatory body to identify the noise sources which were causing the greatest noise problems. Even if a very high nighttime weighting were correct, it could easily be the case in some areas that the greatest noise impact would be during the day because the daytime noise levels were much higher.

4.5.1 Identifying Characteristics

Reaction measures. The same types of annoyance comparison or period ranking questions are used as were used for the annoyance comparison and period ranking approaches. The questions used in the different surveys vary in the number and definition of the time periods which are mentioned. Questions also differ in the extent to which they allow or encourage respondents to report that they are not annoyed in any period or to report that they are equally annoyed in all periods.

Noise data. No noise data are used in the analyses.

Analysis technique. The answers to the single period ranking question or to the series of annoyance rating questions are presented for the sample as a whole and not for subgroups of the sample. The analysis consists of a calculation of the percentage which choose each period as being the worst period or of a calculation of the average annoyance score for each period.

4.5.2 Assumptions which Affect the Interpretation of the Questions

Most of the same questionable assumptions which were seen to limit the validity of the annoyance comparison approach and the period ranking approach also mean that the results from this approach cannot be unambiguously interpreted.

The ambiguity in determining whether the noise entity is the sum of the noise during a period or is the worst noise event ever during the period is obviously a serious problem for a policy maker who is trying to use survey results for a decision about reductions in routine nighttime operations. In this case, ratings of the worst noise event ever are almost irrelevant for the policy maker's decision, but ratings of the sum of the nighttime noise are of considerable importance. If a policy maker attempts to use such interview questions, the questions should be examined on a case by case basis to determine whether they contain ambiguities about the noise entity which are important for a particular purpose. Some interview questions about how noise-control resources should be allocated might be directly applicable for policy decisions.

The uncertainty about whether annoyance responses in one period are affected by noise levels in another period continues to be important. If noise levels have a diffuse effect then there will be an underestimation of the relative importance of the noise in noise-sensitive periods.

The possible effects of the *conventional wisdom* and of the acoustic observer frame of reference are still relevant. There is still the danger that people who do not carefully consider the question are saying that nighttime is worst without considering their own environment. This is still the danger that other people are simply trying to identify the periods when there is the greatest noise rather than reporting their feelings.

4.5.3 Analyses Using this Approach

The chief objective for these analyses is to obtain some type of ranking of the annoyance in the different time periods. The measures of degree of annoyance are either percentages of people choosing a period as worst or the mean annoyance scores in each period. Both types of data are conveniently presented in the 21 bar charts based on 18 surveys in Figures 4.9 to 4.14.

Many of the most important differences between the questionnaire items are evident from the labels in the figures. When respondents are asked to rank the periods (eg. 1961 Heathrow survey in Figure 4.9.a.) the figure displays the percentage of the respondents which choose each time period to be most annoying. When respondents are asked to score each of the periods separately on a scale (eg. 1967 Heathrow survey, Figure 4.9.b) the figure displays the average of the scores for each period.

The interview questions also differ in the number and definitions of the periods which were presented to respondents. Two questions mention only two periods (day and night) but the remaining questions refer to at least three periods. The number of periods which are offered to respondents can affect the answers. In Figure 4.13 an identically worded question about the allocation of $100 for noise control is used twice in a single survey. When the question concerns only two periods then the nighttime period receives an average allocation of $40 (Figure 4.13.c). When the question is asked about three periods (the daytime is divided into daytime and evening) then the same nighttime period receives only $27 (Figure 4.13.d).

All but one of the surveys are based on personal interviews administered by interviewers. Only the 1977 Zurich road traffic survey utilized a postal questionnaire.

The questions differ in how the time periods are defined. When information is available about the hours which are to be included in the period, these hours are given below each of the bar charts (eg. 1961 Heathrow survey in Figure 4.9.a). If the periods are only defined with a verbal label then the labels are presented in quotation marks below the chart and the boundary between the periods is marked with a wavy line (eg. 1967 Heathrow survey in Figure 4.9.b).

From the examination of the 21 bar charts several conclusions emerge. There is not a single period which is uniformly identified as the biggest problem. Within any one survey there is considerable diversity in the choice of the most annoying period. Between the different surveys there is not a simple unanimity about which period is responsible for the greatest amount of annoyance.

Part of the diversity is probably due to the variations in the relative noise levels at different times of day at different sites (ie. the subject of the previous sections of this paper). Part of the diversity in the responses may also be generated by methodological artifacts. Different respondents probably interpret the questions to refer to different noise entities. Some respondents are reporting the *convention wisdom* and thus say night is worse while other respondents are faithful acoustic observers and thus report that the day is worst. Nonetheless if these annoyance questions have any validity, then it must be concluded that the noise problem is a diffuse problem which is not primarily limited to a particular time of day.

While there is clearly diversity in the responses, it is still possible that there may be a tendency toward choosing one period as the worst. In an attempt to discover any such tendency the findings from the 21 bar charts are summarized in Table 4.5.

The first column of Table 4.5 contains the study title together with an identification number which is keyed to the list of surveys in Appendix B and to a description of the survey in a catalog of noise surveys (Fields, 1981). The next three columns contain information about the most annoying time of day. An "X" is placed in the "day", "evening", or "night" column depending upon which of the periods was given the highest annoyance rating in the survey. The remaining columns contain information which helps to interpret the results and serves to remind the reader that the results from the different surveys are not strictly comparable.

From an examination of Table 4.5 it is seen that in five cases the daytime noise is most annoying, in eight cases the evening is most annoying and in seven cases the night is most annoying (there is one tie between evening and night). While this would seem to indicate that all the periods are about equal, it should be noted that the five cases which provide the daytime estimate are unusual. These five "daytime" cases include the only survey questions which do not offer an "evening" alternative (Figure 4.10.a and Figure 4.13.c), the questions with the more restrictive "when you are trying to sleep" nighttime definition (Figures 4.9.c and 4.10.a), and an open question which only asks about "times when you are disturbed most" without explicitly mentioning the nighttime (Figure 4.11.b). Of the remaining fifteen cases, in only one is the daytime period rated worst (figure 4.12.c). In the other 14 cases either the evening or nighttime is rated worst (two of these are for "early morning"--06:00 to 09:00). This examination of the data in Table 4.5 thus provides some evidence that evening and nighttime periods are rated worse than daytime but that there is not a basis for choosing between nighttime and evening periods.

4.5.4 Conclusions from this Approach

There is considerable diversity between people and between surveys in the periods which are identified as the most annoying. While the uncertainties in interpreting the answers to questions about time-period annoyance are important, the evidence generally suggests that the noise experienced during the night and evening time periods is more annoying than the noise experienced during the daytime.

4.6 Analyses of Complaints

All of the analyses up to this point have measured the response to noise with questions in social surveys. Airport operators and other authorities are routinely exposed to another indicator of human response to noise, complaints from residents. Personal complaints can usually be categorized according to the time-of-day at which the offending noise occurred. Since these indicators of human response come to the authorities at no cost they may appear to be an economical method of studying the relative importance of noise at different times of day.

4.6.1 Identifying Characteristics

Reaction measures. The single identifying characteristic of complaint analyses is the dependent variable, complaints to authorities. A large number of different types of actions may be included. Residents may complain to any of a number of different authorities by telephone, mail, or in person. The complaints may be individually presented or may be presented by a group in a petition or in a public meeting. Most analyses use a simple count of the number of individual complaints at certain times of day. One analysis has categorized the complaints according to the seriousness of the complaint (Report. . ., 1971).

Noise data. Either period noise levels or 24-hour time-of-day weighted indices (such as are used in the noise index correlation analyses) are used.

Analysis techniques. Any of the previously described analysis techniques could, in theory, be applied to this new dependent variable, complaints.

4.6.2 Serious Weaknesses in Complaints as Indicators of Noise Impact

Comparative studies of complaints and of annoyance in social surveys have found that both complaints and annoyance are affected by some of the same factors including noise level. However, a number of additional processes affect complaints.

Complaints are generated by people who are willing to take the unusual, possibly uncomfortable, step of directly dealing with authorities in a verbal confrontation. Studies consistently show that, as would be expected, complaints are likely to come from the more verbally confident, better educated, higher income sectors of the population (TRACOR, 1971: p. 25; McKennell, 1963: p. 7.2). These same studies have shown that such factors have little or no effect on annoyance.

Complaints are also generated in situations in which people not only feel annoyed but also believe that they have an especially legitimate basis for contacting authorities. One study found that many more people were annoyed by traffic noise than by factory noise in a section of Sydney, Australia, but that many more people complained about the factory noise (Avery, 1982: p. 222). One partial explanation for this finding is that automobiles are believed to be a necessary and rather universally noisy feature of urban life about which little can be done. Factory noise, on the other hand, is seen as an unusual and unnecessary noise in a residential setting.

Some analyses of complaints have found that complaint rates are consistent with a nighttime noise weighting (Beranek, et. al, 1959: Report. . .1971). However, it seems quite likely that, quite apart from any differences in annoyance, people would be more likely to make nighttime than daytime complaints because the *conventional wisdom* about the seriousness of nighttime disturbance gives more support to a person who is contemplating a complaint about nighttime noise. In addition, daytime noise is an acknowledged characteristic of urban settings, where as nighttime noise can still be regarded as the basis for a legitimate complaint. In short the factors which affect complaint rates, but not annoyance, may well be factors which are related to the timing of noise events. Complaints thus have serious weaknesses as indicators of the relative annoyance during the daytime and nighttime.

4.7 Conclusions

The examination of the analysis techniques reviewed in this section has shown that they can not provide logically satisfactory estimates of the time-of-day weighting. They do, however, provide some information about response to nighttime noise. It is clear that there is considerable variation between people as to the time at which noise causes the greatest annoyance. Nonetheless the findings are broadly consistent with the observation that evening and nighttime noise are more annoying than daytime noise.

5.0 THE TIMING OF NOISE-SENSITIVE ACTIVITIES

Time-of-day noise regulations must consider not only the weight which is to be attached to noise at different times of day but also the exact definition, in hours, of the different time periods. The previous sections of this report have shown that direct studies of reactions to noise at different times of day have difficulty establishing whether or not there is a difference in reactions to two broad periods, day and night. Such studies will obviously not be able to perform the task of establishing gradations in sensitivity on an hourly basis. Other types of studies can provide some useful information.

Field studies of the ways that people use their time provide information about the exact hours during which people are at home and exposed to noise in residential areas. These time-use studies also give the hours when people are engaged in two activities, communication and sleeping, which laboratory studies have consistently shown to be sensitive to the presence of noise.

The time use study reviewed in this section provides information about the timing of noise-sensitive activities. While this information does not clearly indicate that particular hours must be chosen as boundaries for noise-sensitive periods, it does provide the information for assessing the impact of alternative boundaries. It also provides information about whether or not different boundaries are required for different subgroups of the population.

5.1 Information about Noise-Sensitive Activities

The general population time-use surveys provide the information about the timing of activities. Laboratory studies have identified two types of activities which are noise-sensitive.

Reviews of laboratory studies of sleep interference have consistently shown that sleep can be disturbed by noise (Lukas, 1975). Similarly laboratory studies of communication show that communication is disturbed by noise. These studies have even been able to develop enough information about the situations which affect communication interference so that recognized standards have been developed for predicting levels of communication interference (American. . ., 1977). Laboratory studies of the effects of noise on concentration and work performance have not consistently shown effects. Recent reviews show that there is considerable disagreement about the effects of noise on task interference (Loeb, 1980; Broadbent, 1983; Kryter, 1984). For the purposes of these analyses two activities are thus assumed to be sensitive to noise, sleep and aural communication (ie. any communication which takes place though the medium of sound). Any other activities are accounted for only by the designation as to whether or not people are at home.

The nationally representative, 1975-76 social survey which provides the information about time use was described in Section 2.2, Social Survey of Time Use. Some 970 respondents from this survey provided the data for the present analyses. These respondents provided at least three interviews when they were interviewed at different times of the year. The information about activities and the timing of activities was gathered using a time diary technique in which the respondent provided a detailed description of activities during the 24-hours of the previous day. Each respondent was asked:

> Q. "...we would like to know about the things you did on...(DIARY DAY). At one minute before midnight, the beginning of...(DIARY DAY)...what were you doing?"

The interviewer then recorded a description of the activity and the time at which each activity began and ended (to the nearest minute) as well as recording answers to the following questions:

> Q.a. "Where were you? [HOME, TRANSIT, WORK, OTHER]"
> Q.b. "Who was with you?"
> Q.c. "Were you doing anything else at the same time (like <u>talking</u>, <u>watching TV</u>, <u>listening to the radio</u>, <u>eating</u>, <u>or caring for children</u>)?"

Space was provided in the standard interview for the recording of 65 activity episodes in the time-diary. The activities were coded into several hundred categories. Forty of these activity categories were identified and combined with information about being at home (and in some cases with information about whether another person was present) in order to determine whether people at home were engaged in either of the two noise-sensitive activities, sleeping or aural communication. [The exact coding procedures have been described in a previous report (Fields, 1985c)].

The results from these 970 respondents have been combined so as to represent the population of the United States by taking into account the discrepancies between the sample and the age, sex, education, and degree of urbanization for 1975 census statistics. Adjustments were also made for changes between the characteristics of the initial sample and the sample at the end of four waves of interviewing.

5.2 General Pattern of Noise-Sensitive Activities for the Population

The number of minutes spent in each noise-sensitive activity during each hour has been calculated for each respondent. The information from each respondent was then summed for the entire sample to give the percentage of the time during each hour which is spent in each noise-sensitive activity. This percentage is also an indicator of the percentage of the population which is engaged in an activity at any particular moment in an hour. The results from these calculations are presented in tabular form in Appendix D. The results for weekdays (Monday through Friday) are presented graphically in Figure 5.1.

The top line in Figure 5.1 indicates the percentage at home for each hour beginning at midnight. The levels of sleep and aural communication are at a lower level since only people who are at home are included in these categories. At night virtually all of the people at home are sleeping (the at-home line and sleep line almost coincide). Aural communication is highest in the evening.

Figure 5.2 presents the same data as in Figure 5.1 except that the amount of aural communication is not presented separately,but is instead summed with the sleep activity to indicate the total amount of noise-sensitive activity. The middle line in Figure 5.2 thus shows the total who are engaged in either of the two categories of noise-sensitive activities. This line clearly displays the general pattern of gradually increasing sensitivity during the evening hours.

Figures 5.3, 5.4 and 5.5 present these activity patterns for four different sets of days, weekdays (Monday through Thursday), Friday, Saturday and Sunday. A careful examination of each of these figures provides the most complete information about the activity patterns for the population as whole. For each of the activities two main features are of interest. The first characteristic is the extent of the activity at different times of day and different days of the week (ie. the vertical displacement of the lines). The second characteristic is the timing of the activity during the day and for different days of the weeks (ie. the horizontal displacement of the lines).

Figure 5.3 contains the information about the time that people are at home. There is considerable variation over the day and over the days of the week in the percentage at home. The highest rates of about 95% are reached at night. The lowest rates of about 30 to 40 percent are achieved in the middle of the day on weekdays. Friday differs from the other days of the week in having an even lower percentage at home during the day. The transition from the high nighttime level to the low daytime level does not occur instantaneously but rather gradually over at least five hours in the morning. The evening transition back up to the high level occurs even more gradually. The lowest daytime levels are found for only about six hours. During the weekends in the daytime about half again as many more people are at home than during the weekdays in the daytime.

The daytime and nighttime pattern is most clearly divided between the five similar weekdays and the two similar weekend days. The evening period presents a different division. Friday and Saturday have similar evening patterns while Sunday most closely resembles the pattern for the remaining four weekdays.

While there is enormous variation in the percentages at home in Figure 5.3, it also should be noted that there are limits to this variation. The residential areas are never empty. Even during the lowest 6 hours in the midday, a very significant proportion of the population (30% to 40%) are at home and thus exposed to any possible noise sources. More people are at home during the daytime on weekends than weekdays, but, not everyone is at home. About 50% to 60% are at home, a percentage which is similar to late afternoon hours on weekdays, but not quite as high as the high weekday evening rates. Though there are differences in the numbers at home on the weekends, the timing of the relatively low and relatively high exposure periods are rather similar for weekends and weekdays.

The reports of aural communication in Figure 5.4 include interactions with children, socializing with people at home, any conversations, meals when another person is present and listening to TV, radio or other audio equipment. Such communication was often recorded as a secondary activity which occurred at the same time as another (primary) activity (ie. watching television while eating). The timing of aural communication activities appears to be more similar for the different types of days than is the timing for being at home. There is virtually no communication in the middle of the night. Rates increase in a morning transition period, then remain relatively steady during the midday hours on weekdays (there is a slow increase on weekends). The communication levels increase steadily during the evening until an evening high is achieved in the late evening hours (1900 to 2200). Daytime communication rates are considerably higher for weekends than for weekdays.

The reports of sleep in Figure 5.5 show a remarkable similarity for different days of the week. The only striking difference is in the fact that people arise about one hour later in the mornings on Saturday and Sunday than on weekdays. This is the only case where the boundaries for noise-sensitive periods are clearly different for weekdays and weekends.

There is of course an enormous difference in the daytime and nighttime sleeping rates. Virtually all of the people who are at home at 0300 are sleeping, while only about five percent are sleeping at any point during the daytime period (daytime naps are coded as sleeping). The transition periods between these nighttime and daytime extremes are long enough to be important. The low daytime level is not achieved until about 0900 on weekdays and the rates for sleeping begin to increase in the evening as early as 2100. The standard nighttime period for time-period weighted noise indices such as Ldn (Day-Night Sound Level) begin at 2200 after approximately a quarter of the population have already begun to sleep and end at 0700 when approximately a quarter (probably a different quarter) are still sleeping. While the exact percentages of the population which are protected by a 2200 to 0700 period can not be calculated directly, it does appear that roughly half of the population has at least some of their sleep period which is outside of the 2200 to 0700 period.

5.3 Examination for Possible Departures from the Basic Pattern

Thus far the timing of noise-sensitive activities has been assumed to be the same for the entire population. Analyses have been carried out, however, in which the timing of noise-sensitive activities has been examined for subgroups defined on the basis of region of country, urbanization of area, sex and age. Activity patterns have also been examined for different times of year. Tabulations for all of these subgroups are presented in Appendix D. The most important patterns are reproduced in figures which are described in the text.

The timings of noise sensitive-activities were found to be essentially the same for four different regions of the country and for areas which vary in the degree of urbanization (the smallest category was places with less than 50,000 population). There is no support for the belief that people in urban areas are at home less or have later sleeping periods. The interviews were conducted during spring, winter and autumn, but not during the summer months when activity patterns might be affected by summer vacations or by children being home from school. For the three periods studied, any differences between seasons were small and of doubtful reliability (there was some correlation between day of week of the interview and the season of the year of the interview--See Fields, 1985c: p. 11).

Women and men have virtually the same sleeping patterns, but did differ substantially in this 1975-76 survey in other weekday activities. Women were at home more and engaged in aural communication at home much more than men during the day and slightly more than men in the evening. While women's rates of being at home during the day on weekdays were almost twice as high as men's in 1975-76, it is not known to what extent the increased employment of women outside of the home may have changed these figures in the intervening 10 years.

Age is a characteristic which clearly affects the extent of noise-sensitive activities. People over 65 are more likely to be at home during the day (Figure 5.6) and are more likely to be engaged in aural communication during the day (Figure 5.7). They are also more likely to take naps during the middle of the day (figure 5.8). In the four early afternoon hours (1200 -1599) on weekdays) the percentages of those over 65 attempting to nap during each hour are 12%, 18%, 15% and 12%.

5.4 Summary

This examination of the timing of noise-sensitive activities has shown that the 24-hour day can be roughly divided into four noise-sensitivity periods consisting of one period of consistently high sensitivity (night from 2400 to 0500), one period of relatively low sensitivity (day from 0900 to 1600) and the early morning and evening transition periods. The percentage of the population engaged in aural communication begins to increase from 1600 and the percentage sleeping begins to increase from as early as 2100. Approximately one-half of the population has at least some of their sleep period which is outside of the 2200 to 0700 protected period in accepted noise indices such as Ldn.

Weekends differ from weekdays in that the morning transition period is one hour later and the numbers of people engaged in aural communication during the day at home is approximately one-half to three-quarters greater. Even during the weekday, daytime period there is a substantial proportion of the population which is at home (over 35%). Activity patterns appear to be similar for different sections of the country, different degrees of urbanization, and three seasons of the year (no information is available about summer activities). Women are at home more than men in this 1975-76 survey. People over 65 years of age are at home more and spend more time engaged in noise-sensitive activities than the younger population. There is less than a one-hour difference between the times for carrying out noise-sensitive activities in any of the population subgroups.

6.0 THE NIGHTTIME DOSE-RESPONSE RELATIONSHIP

The chief subject of this report is the relative impact of daytime and nighttime noise. In this section, however, only the nighttime noise and accompanying nighttime response is considered. Many of the previously published analyses of nighttime response have been largely irrelevant for developing a nighttime dose-response relationship because the analyses related nighttime response to 24-hour noise levels, rather than to nighttime noise levels (Schultz, 1978). This report reproduces all of the previously published graphs of the relationship between nighttime responses and nighttime noise levels. These 19 figures come from eight surveys. Four are English aircraft surveys: 1967 Heathrow survey (Figure 4.1), 1972 Heathrow survey (Figure 6.5), 1979 Heathrow and Gatwick night noise survey and 1982 Manchester night-noise survey (Figures 6.6 to 6.14). Figures are also reproduced from the London road traffic survey (Figure 6.1), the 1978 Ontario survey (road traffic data in Figure 4.2), the Zurich nighttime survey (Figures 4.3 and 6.2), the French expressway survey (Figures 6.3 and 6.4) and the 1979 French road traffic survey (Figure 4.4). All of the surveys obtained the annoyance data with interviewer administered questionnaires except for the Heathrow-Gatwick and Manchester night noise surveys which primarily used postal questionnaires. These two later surveys used quite similar methodologies, included many of the same questions and are presented together in the figures in this report. Because the surveys are so similar the 1979 Heathrow-Gatwick and the 1981 Manchester night survey are referred to as the English night surveys in this section.

6.1 Types of Nighttime Noise Effects

Nighttime noise can disturb sleep in a variety of ways, lead to attempts to reduce the noise effects and affect attitudes toward nighttime noise. The 19 figures provide information about these effects. The information pertains to several different degrees of severity of impact. Before interpreting the figures it is important to carefully note the definitions of nighttime noise effects which are used.

People are conscious that noise disturbs sleep either when they are awakened or when they are prevented from getting to sleep. The figures provide information about both types of sleep disturbance. Being awakened appears to happen more often than either being prevented from getting to sleep at the beginning of the sleep period or from getting back to sleep in the middle of the sleep period. The evidence for this assertion comes from the figures which present the results from four surveys [Zurich nighttime survey (Figure 6.2), 1978 French survey (Figure 6.3 compared to Figure 6.4), and the English night surveys (Figure 6.7 compared to Figure 6.10 and Figure 6.8 compared to Figure

6.11).] The most frequently mentioned time for awakening is early in the morning (Figure 6.2).

The ten figures reporting sleep disturbance include information about several different definitions of frequency of sleep disturbance. In some cases the information relates to some type of more-or-less specifically defined regular experience with sleep disturbance [London traffic survey (Figure 6.1) and the 1978 French survey (Figures 6.3 and 6.4)]. The 1978 Zurich traffic survey relates to "almost daily" disturbances (Figure 6.2). The English night surveys include information about three frequencies of sleep disturbance: "ever" during the past three months (Figures 6.8 and 6.11), more than once a week during the past three months (Figure 6.9) and the previous night (Figures 6.6, 6.7 and 6.10).

Nighttime noise not only leads to reports of sleep disturbance, but also leads people to take a variety of steps in an attempt to reduce the effects of the noise. The figures present information about three of these. People wear earplugs (Figure 6.2), take sleeping pills (Figure 6.2), and close windows (Figures 6.2, 6.12, 6.13).

People also form attitudes toward the nighttime noise. The relationships between nighttime noise levels and nighttime annoyance have been presented in four figures: Figures 4.1, 4.2, 4.3 and 4.4.

The figures provide information about a range of different types of nighttime effects. This diversity in the measurement of types of effects means that the results can not be synthesized to provide a single nighttime dose-response relationship.

6.2 Noise within the Context of Other Causes of Sleep Disturbance

Awakening during the sleep period appears to be a rather regular occurrence even in the absence of high noise levels. Over 50% of the population at the lowest noise levels in the English night surveys report that they are awakened by aircraft noise (Figure 6.7). With some people having multiple awakenings there is a rate of almost 100 awakenings per 100 people on any particular night (Figure 6.6). Other causes for awakenings, in addition to noise, reported in the London traffic survey include anxiety, pain, and unexplained habitual insomnia (Figure 6.1).

At the highest aircraft noise levels it is still clear that factors other than aircraft noise create sleep disturbance. The figures from the English night surveys show that this happens for awakening (Figures 6.6, 6.7, 6.8, 6.9) and for difficulties in getting to sleep (Figures 6.10, 6.11).

The prevalence of sleep disturbance in the absence of noise means that considerable caution must be exercised in interpreting any reports of sleep disturbance in noisy areas.

6.3 Cautions about Interpreting Respondents' Reports of Nighttime Disturbance

The figures reviewed in this section clearly provide information about people's perceptions of nighttime disturbance. However, it is not equally clear that they provide information about the amount of actual nighttime disturbance. From laboratory studies of sleep disturbance it has been found that actually measured sleep disturbance and people's reports of sleep disturbance may be only weakly related (Wilkinson and Campbell, 1984). A close examination of the figures presented in this section provides some information about the relationship between reports of the sleep disturbance from noise and the total amount of sleep disturbance.

The figures generally show that, as would be expected, as the noise level increases the number of people who report nighttime disturbance from noise increases. For the London road traffic survey, for example, the percentage saying that "noise from outside" is the main reason for "trouble getting to sleep" increases from less than 10% to greater than 20% for the 20 decibel increase in noise level in Figure 6.1. This 10% increase in number of people mentioning noise as the main reason does not, however, mean that 10% more of the population experiences sleep disturbance. In Figure 6.1 the accompanying increase in the total percentage experiencing any sleep disturbance is smaller, about 5%. A similar pattern can be found in the figures for the English night surveys in which aircraft sleep disturbance is compared with total sleep disturbance (Figures 6.6 to 6.9 and 6.11). In each case there is an increase in the number of people attributing sleep disturbance to aircraft noise. This increase in aircraft noise sleep disturbance does not however come entirely from people who would not otherwise have experienced any sleep disturbance over the study period: the increase in the total number of people disturbed is less than the increase in the number of people disturbed by aircraft noise.

There are a number of possible explanations for the greater increase in noise-attributed sleep disturbance than in total sleep disturbance. Though it is possible that people are over-reporting the instances of sleep disturbance from aircraft noise, none of a number of alternative explanations can be totally dismissed on the basis of the existing evidence. In Figure 6.8, for example, as noise level increases there is a very substantial increase in the percentage who report ever having been awakened by aircraft noise but virtually no increase in the total percentage who report being awakened. This does not necessarily mean that aircraft noise did not increase sleep disturbance. An explanation which is totally consistent with Figure 6.8 is that though new people are not experiencing sleep disturbance, those who were previously disturbed are having their sleep disturbed more often because of the addition of aircraft noise. There may be roughly 15% of the population which is unlikely to have their sleep disturbed under any normal conditions (Figure 6.8). The people who suffer from aircraft noise sleep disturbance would then be those who are generally more susceptible to other types of sleep disturbance as well. Further support for this assertion comes from the finding that when the frequency of sleep disturbance is considered, the increase in total disturbance becomes more consistent (though not totally consistent) with the increase which could be expected from the reports of aircraft-caused sleep disturbance (Figure 6.6 and 6.8). A comparison of Figures 6.6 and 6.7 is especially instructive. In Figure 6.6 it is seen that the total number of awakenings per hundred people increases (over a thirty-decibel increase in aircraft noise) by roughly forty awakenings per night, a figure which is close to the increased number of awakenings which are attributed to aircraft noise. In Figure 6.7, however, it is seen that there is only a slight increase in the total number of people awakened. The main effect of aircraft noise thus appears to be to repeatedly awaken individuals who also suffer from other types of sleep disturbance.

The fact that the reported increase in aircraft-attributed sleep disturbance is never completely matched by increases in total sleep disturbance suggests that some other mechanisms are also at work. Some people may be awakened by other sources, but hear aircraft noise after awakening or know that there is aircraft noise in the area and thus report that aircraft noise was responsible. Others may awaken with a certain frequency during the night even in the absence of noise so that the effect of aircraft noise may only be to change the timing, rather than the total number of those awakenings.

6.4 Is the Dose-Response Relationship the Same for the Entire Nighttime Period?

Laboratory studies have shown that people are somewhat more susceptible to awakening from noise at the beginning and end of their sleep period than in the middle of the period. It is occasionally asserted that this must mean that particular hours during the night (eg. 22:00 to 24:00) must be characterized by greater sleep disturbance (Ollerhead, 1978). Several reports have sought to support this assertion with the finding that there is greater reported sleep disturbance in the early nighttime and early (0600 to 0800) morning hours (Nemecek et al., 1981: p. 228). However, as previously noted, such studies do not show whether people are more sensitive during these periods since the noise levels are also likely to be higher during these two periods. When these differences in noise levels have been at least roughly considered then the apparent differences in sensitivity disappeared in the London road traffic survey (Langdon and Buller, 1977; p. 17) and in studies around Orly and Charles de Gaulle airports (Francois, 1977; p. 10). There is thus no firm evidence that particular hours during the night are more susceptible to noise disturbance than other nighttime hours. This is consistent with the general conclusion in this paper that it is very difficult to establish whether there is a difference between even the much larger and more divergent daytime and nighttime periods.

7.0 PROSPECTS FOR DESIGNING STUDIES TO PROVIDE ACCURATE INFORMATION ABOUT TIME-OF-DAY WEIGHTS

In Section 3.0 it was found that the estimates of the time-of-day weights from existing surveys are so inaccurate as to not provide useful information. However, those surveys were not designed to study the time-of-day weighting issue. As a result, the noise environments included in the surveys were not specifically chosen to provide accurate estimates of the time-of-day weights.

The noise environments included in the surveys have an important characteristic which weakens the survey designs: the daytime and nighttime noise levels are highly correlated. In Table 2.2 it can be seen that correlations between the daytime and nighttime noise levels in the surveys are never lower than r=0.86. With nighttime and daytime noise levels being so closely related, it is to be expected that such study designs would not permit the evaluation of the independent effect of nighttime noise on human reactions.

This section considers new survey designs which, within the limitation of the existing environmental noise conditions, could be created for the specific purpose of estimating time-of-day weights. The existing universe of noise environments from which noise environments would have to be drawn for a time-of-day study is first identified. Then, the accuracy of studies based on the best combinations of existing noise environments is predicted. The section concludes by examining some alternatives to the conventional community survey.

7.1 Noise Environments at Different Times of Day around U.S Airports

In order to assess the availability of noise environments, two sets of data have been examined, aircraft scheduling data in the Official Airlines Guide (OAG) and noise data collected by permanent noise monitoring systems. The chief characteristic of the noise environment which is estimated with these data is the range of values for the differences between daytime and nighttime noise levels.

The computer file of the Official Airlines Guide (OAG) includes the departure and arrival times of scheduled flights at commercial airports in the United States. Airports were examined which have at least 100 scheduled flights a day. The proportion of nighttime flights at each airport was calculated for a typical weekday in 1983 (Wednesday, October 20, 1983). Five airports were found to have at least 15% of their flights at night. At the other extreme, 13 airports had 4% or less of their flights at night. The differences between daytime and nighttime noise levels (Leq) are estimated from the timing of the flights by assuming that the average noise levels from daytime and nighttime flights are equal. With 15% of the flights at night the difference between daytime and nighttime noise levels is 8 dB (Leq). With 4% of the flights at night there is a difference of 14 dB (Leq). For the purpose of the study design evaluation in this section it is thus assumed that noise environments could be included which range from an 8 to a 14 dB (Leq) difference in noise levels.

A second set of noise data were also examined, data from permanent noise monitoring sites. After collecting information on all aircraft noise monitoring systems in the United States, it was found that eleven of the systems routinely accumulate data on hourly aircraft noise levels (dB(A), Leq). The 11 airports have a total of 128 permanent noise measurement sites. For the analyses in this report, hourly noise level (Leq) data were analyzed from 6009 noise measurement days. The characteristics of the noise environments at the sites are presented in Table 7.1.

The number of sites at each airport varies from four at Van Nuys to 22 at San Francisco (Table 7.1). The range of differences between daytime and nighttime noise levels (5.7 dB to 14.4 dB in the second column of data) is somewhat wider than was indicated for airports by the OAG data. (Discrepancies between OAG and noise monitoring data have been discussed in a previous report (Fields, 1985b)). Correlations between daytime and nighttime noise levels are given for each airport and for the combined set of 128 sites (last column of Table 7.1).

The single most important statistic presented in Table 7.1 is in the lower right-hand corner, the correlation between daytime and nighttime noise levels for the 128 sites. This correlation has the quite high value of r=0.91. The correlations at the individual airports are over r=0.85 for seven of the eleven airports. The daytime and nighttime noise levels tend to be highly correlated with in a single airport because there is relatively little variation in the day/night noise level differences (eg. small standard deviation of the difference in Table 7.1). Around the Seattle-Tacoma airport (Figure 7.1), for example, the differences only vary from 5 dB to 8 dB. The three airports with correlations of r=0.45 or less have noise environments which would not yield a strong study design for a different reason, they have a small variance in the daytime noise levels. All airports have noise environments with standard deviations for the daytime noise levels of less than 4.2 dB (third column of data in Table 7.1).

A major difference between the OAG and permanent noise monitoring data is that the OAG data consist of a single estimate for the entire airport. It is assumed that all sites at an airport have the same proportion of nighttime flights. In fact, of course, the proportion of nighttime flights will vary between different areas at the same airport (See Table 7.1). However, a comparison of the results from the OAG and noise monitoring data has shown that the OAG data provide a useful indicator for the types of predictions which are made in this section (Fields, 1985b).

7.2 Predictions of the Accuracy of Time-of-Day Study Designs

A statistical model has been developed to predict the accuracy of the estimate of the time-of-day weight (standard deviation or confidence interval) which would be expected for alternative study designs. (The statistical model is described in Appendix E.) The factors which affect accuracy are the characteristics of the noise environments, characteristics of the human response to noise, the size of the sample (numbers of people and numbers of study areas), and the value of the time-of-day weight. All of these factors are taken into account in the predictions made in this report. (The equations which are used to make the predictions are described in Appendix E.)

The necessary information about human response comes from previous studies of community response to noise. These studies were drawn on to estimate two quantities: the amount of agreement about noise annoyance which can be expected with in each study area (ie. neighborhood) and the size of the differences between the average of the reactions to noise in different study areas. (The sources of this information are described in more detail in Appendix E.) With the required information about human response the accuracy of alternative study designs can be predicted.

The accuracy will first be predicted for a study based on the permanent noise monitoring systems. The remainder of the section will then consider designs which are consistent with the noise environments described by the OAG data.

A study based on permanent noise monitors would be restricted to the number of dwellings which could be found near the 128 noise monitoring sites at the eleven airports. Such a study would have the advantage of costing less per study site than other study designs because the noise data could be obtained without a special noise measurement program. If it were possible to locate 100 dwellings around each of the 128 noise monitoring sites and if 78% of the dwellings yielded an interview, then a large scale, and thus extremely expensive, study might be able to obtain 10,000 interviews. For a time-of-day weight of $w_n=10$, such a design would be expected to yield a 95% confidence interval which ranges from $w_n=4$ to $w_n=+\infty$. Such a wide confidence interval would mean that an estimate derived from such a study design would be of little value. The conclusion is thus that an extremely large study based on surveys at existing permanent noise monitoring sites would not provide an estimate with a satisfactory level of accuracy. The permanent noise monitoring system approach will not provide the desired estimate of the time-of-day weight.

The remaining study designs draw on the analysis of the OAG data to determine the range of nighttime noise conditions which might be available for a survey. Three designs are considered: a normal nighttime noise design which only includes variations in nighttime noise levels which were found in the OAG data, a no-night-noise design which includes some study areas which have no nighttime aircraft noise, and an extreme design which further modifies the no-night-noise design by including some extremely high night noise areas. In all the designs it is assumed that the daytime noise levels would vary from 60 dB(A) to 80 dB(A) Leq at every study airport.

For the normal nighttime noise design it is assumed that differences between daytime and nighttime noise levels will range from 8 to 14 dB(A), Leq. (To simplify the computations the sample is assumed to be evenly divided between 8, 10 and 14 decibel difference environments.) The assumptions about human response variability are the same as were made previously for the noise monitoring design. Under these conditions it is predicted that a sample size of 10,000 would yield an unacceptably large 95% confidence interval of $w_n=3$ to $w_n=+\infty$ (nighttime weight assumed to be $w_n=10$). In order to examine accuracy under more favorable conditions it is optimistically assumed that the difference in daytime and nighttime noise levels could be extended to include differences of 5, 10 and 20 dB(A). In this case the correlation between the noise levels in the design is reduced to $r=0.75$. Even with these unrealistically favorable conditions a very expensive study of $n=4,000$ interviews would yield a 95% confidence interval of $w_n=4$ to $w_n=+\infty$. Even if the number of interviews were increased to $n=10,000$, the 95% confidence interval would be an unacceptable $w_n=5$ to $w_n=63$ (nighttime weight assumed to be $w_n=10$). In short, the examination of these normal nighttime designs leads to the conclusion that a conventional, survey based solely on normally available nighttime environments could not provide a satisfactorily accurate estimate of a time-of-day weighting.

The no-night-noise design was next considered. This strength of this design comes from comparisons of reactions to noise in areas with nighttime noise and areas without nighttime noise. Such conditions may occasionally occur if nighttime operations are not permitted on some flight paths or if the imposition of a nighttime curfew means that nighttime noise is totally eliminated in some areas. It is again assumed that daytime noise levels range from 60 to 80 dB(A) in all study areas and that in areas with nighttime noise, the daytime/nighttime difference is either 8, 10 or 14 dB(A). In the other half of the study areas, the areas with no nighttime noise, the daytime/nighttime difference thus ranges from 60 to 80 dB(A), Leq. It should be noted that the efficiency of this design relies on the contrast between the nighttime noise areas and the no-night-noise areas. The resulting discontinuity in the range of day/night differences (ie. no data between the day/night differences of 14 dB and 60 dB) means that a proper estimate of the nighttime weighting could not be obtained. None-the-less, if it were successful, the resulting estimate of the "nighttime weight" would at least give some indication of the impact of a complete elimination of nighttime flights.

For this no-nighttime-noise design the correlation between the two noise variables (daytime and nighttime noise) is reduced to $r=0.14$. However, in spite of this improvement in design, the 95% confidence interval is predicted as remaining at an unacceptably high level of $w_n=4$ to $w_n=+\infty$ for a sample size of 10,000. Thus it is concluded that the no-night-noise design would not be able to provide estimates of satisfactory accuracy.

The last design considered is an extreme design which includes both the no-night-noise areas as well as some areas with very high nighttime levels, levels which are almost equal to the daytime levels. While airports with these types of environments were not identified with the OAG data, it might be that a detailed examination of specific airports might identify a few such residential areas. Differences between daytime and nighttime noise levels are assumed to be only 2, 5 or 8 dB(A) for the areas with nighttime noise. Reactions in these areas are to be compared with reactions in areas with no nighttime noise (ie. daytime/nighttime differences of from 60 to 80 dB(A)). A sample size of 4,000 provides an unacceptably wide 95% confidence interval of $w_n=5$ to $w_n=1050$. Even a sample size of 10,000 yields an estimate of a marginally acceptable 95% confidence interval of $w_n=5.8$ to $w_n=28$. As before, this confidence interval would be obtained if the nighttime weighting were $w_n=10$. If, for example, the actual value of the nighttime weighting were $w_n=8$, then the same sample design would provide a 95% confidence interval of $w_n=4$ to $w_n=24$ and the study would no longer be able to distinguish between a nighttime weighting of $w_n=5$ and $w_n=10$.

A range of alternative study designs have been studied in this section. In spite of the fact that some designs had quite low correlations between daytime and nighttime noise environments it is still predicted that accurate estimates of the time-of-day weighting could not be obtained. The problem is thus not simply the problem which has been identified before, the high correlation between daytime and nighttime noise levels. The problem is that a good estimate of the time-of-day weight requires an extraordinarily precise estimate of a statistic which was discussed earlier in this report, the partial regression coefficient for nighttime noise.

In Section 3.3 it was shown that the nighttime weight is actually a ratio of two partial regression coefficients. The regression coefficients sum to a value of one. Thus the ratio can described in terms of only a nighttime regression coefficient. The time-of-day weight is then defined as:

$$w_n = \frac{B_n}{1-B_n}$$

Small changes in the value of this nighttime regression coefficient (B_n), the statistic which is being estimated in the analyses, have extraordinary effects on the estimate of the nighttime weight. A nighttime coefficient of B_n=.9090 yields a nighttime weight of w_n=10.00. An increase of only 0.0434 in the nighttime coefficient (B_n=0.9524) doubles the value of the nighttime weight to w_n=20.01. A further increase of only 0.0233 (B_n=0.9757) again doubles the nighttime weight to w_n=40.15. The standard errors of the nighttime regression coefficients for the study designs considered in this section vary from 0.12 to 0.01. These standard errors are being simultaneously applied to the denominator as well as the numerator of the ratio. With denominators of the order of 0.0810 (for B_n=0.9090; $1-B_n$=1-0.090=0.0810) to 0.0243 it is clear that accurately estimating the nighttime weight is very difficult.

7.3 The Validity of Some Unconventional Study Designs

All of the designs thus far considered evaluate long-term average noise levels. It might be possible to build in much greater variation in noise levels by considering shorter time periods. If noise levels were examined at a single site, there might well be considerable variation from one day to the next in the proportion of flights which occurred at night. There might even be days when the normal pattern was reversed and there were more nighttime than daytime flights. An unconventional study could be created around repeated daily interviews in which people were asked about their evaluations of the total noise for single, 24-hour periods. This single-day evaluation could then be regressed on the daytime and nighttime noise levels for that 24-hour period. Whether or not such a design might yield estimates of the time-of-day weight which would be judged to be numerically accurate can not be judged with the data analyzed for this report. The day-to-day variations in noise environments have not been analyzed and the variations in human responses to daily noise environments have not been examined. However, quite apart from these questions about the statistical properties of the estimates are some doubts about the validity of such a procedure.

Some research results and characteristics of the nighttime period suggest that people may not respond as quickly to differences in nighttime noise levels as they to differences in daytime noise levels. Two surveys of reactions to short-term variations in daytime noise levels have shown that people are aware of day-to-day variations in daytime noise levels (Fields and Powell, 1985; Fidell et al., 1981). But a very similar study of reactions to the virtual elimination of nighttime flights over areas near Los Angeles International Airport could find no evidence that people were aware of the change in nighttime noise levels (Fidell and Jones, 1975).

While a number of interpretations of the results from this study are possible, there are several characteristics of the sleep period which could account for an absence of a rapid response to changes in nighttime noise environments. Some of these characteristics point to problems with any survey measure of response to nighttime noise. People may often not be aware of disturbances to sleep when they are not actually awakened. People may become sufficiently accustomed to aircraft noise so that they are conscious of being disturbed by only a small proportion of nighttime aircraft noise events. Even a month-long period may not then be long enough to detect the difference in the number of times they are disturbed at night. People may also have their sleep disturbed and be awakened but still not be able to accurately identify the source of the disturbance. All of these characteristics can be contrasted with the daytime period when people are conscious and can readily assess the noise environment.

The results of the Los Angeles study and the characteristics of the sleep period thus raise serious doubts about the possibility of obtaining valid measures of human response to short-term variations in nighttime noise. The most obvious alternative to the inaccurate conventional surveys thus appears to be flawed because the annoyance measures would be of doubtful validity.

It is, of course, possible that some unusual combinations of circumstances in the future might present opportunities for more favorable study designs than have been considered in this report. Long-term changes in noise environments around a number of airports might provide opportunities for a longitudinal study of changes in individual reactions. Such opportunities could not be identified at the present time. The methods presented in this section and in Appendix E could, however, serve as a starting point for the evaluation of any future designs.

8.0 SUMMARY

Existing community noise surveys differ in the numerical value of the penalizing weights which are assigned to nighttime noise. This report has examined the evidence which relates to one criteria for choosing between those weights, the extent to which the weights represent the differential impact of noise on humans at different times of day.

Residents' reactions to existing noise environments provide the only logically sound basis for measuring the differential impact of noise at different times of day. For this report the reactions of over 22,000 people have been examined by analyzing the original machine-readable data sets from 10 studies. Approximately twenty other studies provide limited, additional information about time-of-day weights and reactions to noise during noise-sensitive time periods.

Two types of measures of individuals' reactions to noise have been examined: a single total response to the average, combined 24-hour noise environment and separate responses to the noise in each of several different time periods.

Responses to the total 24-hour noise environments provide the only logically satisfactory basis for evaluating time-of-day weightings. These responses were examined in differing time-of-day noise environments using multiple regression techniques. It was found that the existing studies do not provide similar estimates of the optimal value for the time-of-day weighting. When the time-of-day weightings from the individual studies were examined, the estimates were found to be so imprecise as to not provide useful information. Separate analyses find that the lack of consistency and the imprecision can not be explained by the type of annoyance questions or the time-of-day noise model. It is concluded that existing surveys can not provide usefully accurate estimates of time-of-day weights.

Analyses of a second type of community response measure, the ratings of noise in different time periods, show that people disagree as to whether nighttime, evening or daytime noise is the greatest problem in existing noise environments. After noise level is taken into account, it is seen that these responses are broadly consistent with the general observation that nighttime and evening noises are more annoying than daytime noises of the same noise level. However, there is no consistency across surveys as to how much more annoying noises are during the evening and night. As a result the surveys do not provide consistent information for establishing the value of a time-of-day weighting. A careful analysis of these time-period rating questions found that the questions are seriously flawed as measures of the independent effect of noise in different periods. These time-period rating questions do not clearly specify the noise which is rated, are easily distorted by feelings about other periods and can be biased by the conventional wisdom about nighttime noise.

One basis for defining the length of the time periods, though not of time-of-day weights, is the numbers of people who are engaged in noise-sensitive activities. A national time-use survey was analyzed to identify time periods when large numbers of people are engaged in noise-sensitive sleep and aural communication activities. The 24-hour day can be roughly divided into four noise impact periods. The greatest number of people are engaged in these noise-sensitive activities during a steady state nighttime period (2400 to 0500), the lowest number are exposed during a steady state daytime period (0900 to 1600) and varying numbers are exposed during an early morning transition period and during an evening transition period. Approximately half of the population has at least some of their sleep period which is outside of the 2200 to 0700 period which is protected in accepted noise indices such as Ldn.

The relationship between nighttime reactions and long-term average nighttime noise environments was examined. All existing social survey results in which average nighttime response is plotted by nighttime noise level have been reproduced in this report. The nighttime annoyance questions from the different surveys are found to be so dissimilar that a unified dose response relationship can not be specified.

A major weakness of existing surveys is the high correlation between daytime and nighttime noise in the study designs. The possibility that improvements in study design could lead to accurate information about time-of-day weights was examined. The availability of suitable noise environments was assessed by examining the timing of flights at all large (greater than 100 flights a day) United States airports and by analyzing the noise environments on 6009 days at 128 noise monitoring sites at 11 airports. Even if the best combinations of noise environments were to be included in a study, it is predicted that it would not be possible to provide usefully accurate information about the time-of-day weighting from cross-sectional surveys based on noise environments found around United States airports.

In summary, the analyses and reviews of literature in this report find some support for nighttime and evening weightings. However, examinations of present surveys and simulations of future surveys lead to the conclusion that studies of community response to noise will not provide usefully accurate estimates of the time-of-day weighting parameter in the adjusted energy model.

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APPENDIX A: DEFINITIONS OF TIME-OF-DAY WEIGHTINGS IN THREE TIME-OF-DAY MODELS

The equations which describe the three time-of-day models are given in this appendix. The implications of the different models for time-of-day weights have been described in the text and in a previous publication (Fields, 1985a: p.8). Two have been only occasionally mentioned in the literature and are not incorporated in any recognized noise indices. These two indices are only briefly described before turning to a model which is the basis for many noise indices, the adjusted energy model.

Independent Period Effect Model

This model has been labeled the "independent effect" model in a previous time-of-day publication (Fields, 1985a) and in a publication which defined alternative models for describing the combined effect of different noise sources (Taylor, 1982: p. 125). Annoyance is predicted with the following model:

$$A = c + B_{L_d} \cdot Leq_d + B_{L_n} \cdot Leq_n$$

The differential impact of noise in different periods is assumed to occur in the form of a more rapid increase in annoyance with changing noise levels in the more sensitive periods. If this difference in the rate of increase in annoyance were to be represented mathematically it could be defined as the ratio of the nighttime partial regression coef.icient over the daytime partial regression coefficient. Values for this ratio are available in a previous publication (Fields, 1985d).

Decibel Difference Model

This has been previously labeled an "energy difference" model in a description of models which combine the effects of different noise sources (Taylor, 1982: p. 125). This model implies that annoyance is independently affected by the value of Leq for the total 24-hour period and by the number of decibels which separate the noise levels of the two time periods. Annoyance is predicted from the noise levels in two periods with the following model:

$$A = g + B_{L_{24}} \cdot Leq_{24} + B_{d-n} \cdot (Leq_d - Leq_n)$$

A time-of-day adjustment can in this case be defined as the difference between daytime and nighttime noise levels which has an effect which is equivalent to that of a one-decibel change in the 24-hour noise level (24-hour Leq). This is the ratio defined if the partial regression coefficient for the noise level difference term is divided by the partial regression coefficient for the 24-hour noise level term. Values for this ratio are available from a previous publication (Fields, 1985d).

<u>Adjusted Energy Model</u>

This is the conventional time-of-day model which is the primary model discussed in this paper. In this section the model is presented in the form of an equation for predicting annoyance from noise level. The complete response model would also include a residual "error" term to represent the effects of unmeasured variables.

There is only a single adjusted energy model, but because the noise levels may be represented in several different ways and because of the alternative expressions for the time-of-day weights, the prediction model may take several forms.

For the multiplicative "number" weight (w_n) used in this article annoyance is predicted from the characteristics of the individual noise events (measured in terms of the value of Leq for a single hour for a single event) with the following equation:

$$A = a + B_I \cdot 10 \cdot \log_{10}\{(\sum_{i=1}^{N_d} 10^{L_{id}/10} + w_n \cdot \sum_{i=1}^{N_n} 10^{L_{in}/10})/24\}$$

If the time-of-day weight is expressed as an additive decibel weight [$w(dB_n)$] which is to be added to the value of each individual noise event then the annoyance prediction equation is:

$$A = a + B_I \cdot 10 \cdot \log_{10}\{(\sum_{i=1}^{N_d} 10^{L_{id}/10} + \sum_{i=1}^{N_n} 10^{[w(dB)_n + L_{in}]/10})/24\}$$

If the noise level which is used is the hourly noise level which is the sum of the individual noise events (hourly Leq level for all relevant noise events) then the annoyance prediction equation is:

$$A = a + B_I \cdot 10 \cdot \log_{10}\{(t_d \cdot 10^{Leq_d/10} + t_n \cdot 10^{[w(dB)_n + Leq_n]/10})/24\}$$

It will be noted that additional multiplicative terms are included, the numbers of hours in each noise period (t_d or t_n). These terms are needed because the noise levels are average hourly noise levels. Each average hourly noise level must be multiplied by the number of hours before being summed to obtain the sum of the total noise exposure).

If the same type of average hourly noise measurement were used, but the number of hours is left out of the equation then a new type of weight is defined:

$$A = a + B_I \cdot 10 \cdot \log_{10}\{t_d \cdot (10^{Leq_d/10} + 10^{[w(dB\&T)_n + Leq_n]/10})/24\}$$

This additive weight [$w(dB\&T)_n$] is actually a decibel and time (period-length) adjustment. The value of this decibel and time weight is a function of both the previously defined decibel weight and the relative length of the time periods:

$$w(dB\&T)_n = w(dB)_n + \log_{10}(t_n/t_d)$$

The "number" weight and the standard decibel weight are simple functions of one another:

$$w(dB)_n = 10 \cdot \log_{10}(w_n)$$

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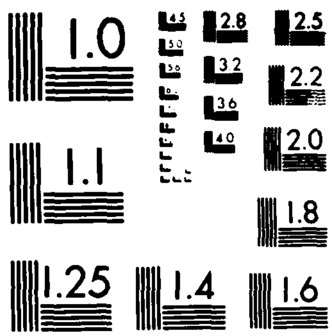

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APPENDIX B: LIST OF SOCIAL SURVEYS REFERENCED IN ANALYSES

The six-digit identifier preceding each title includes the identification number used in a catalog of social surveys of noise annoyance (Fields, 1981).

UKD-008	1961 Heathrow Aircraft Noise Survey (First Heathrow Survey)
FRA-016	1965 Four French Airport Noise Study
USA-022	1967 U.S.A. Four Airport Survey [Part of USA Nine-Airport study (Phase I of TRACOR Survey)]
UKD-024	1967 Heathrow Aircraft Noise Study (2nd Heathrow)
USA-032	1969 U.S.A. Three Airport Survey [Part of USA Nine-Airport Survey (Phase II of TRACOR Survey)]
USA-044	1970 U.S.A. Small City Airports [Small City phase of the USA Nine-Airport Survey (TRACOR Survey)]
UKD-052	1971 Gatwick Airport Noise Survey
SWI-053	1971 Three City Swiss Noise Survey
USA-059	1972 JFK Airport Noise Survey
UKD-061	1972 Heathrow Airport Noise Pilot Survey
FRA-063	1972 Paris Area Railway Noise Survey
UKD-071	1972 B.R.S. London Traffic Noise Survey
UKD-072	1972 English Road Traffic Survey
USA-082	1973 Los Angeles Airport Night Study
FRA-092	1973 French 10-City Traffic Noise Survey
USA-102	1974 U.S.A. 24-Site Community Noise Survey
UKD-116	1975 British National Railway Noise Survey
CAN-120	1975 Western Ontario University Traffic Noise Survey
CAN-121	1975 Southern Ontario Community Survey
CAN-121	1976 Southern Ontario Community Survey
SWI-133	1976 Zurich Street Traffic Noise (Apartments) Survey
SWI-158	1977 Zurich Pilot Traffic Noise Survey
UKD-162	Greater Manchester Traffic Survey
CAN-168	1978 Canadian Four-Airport Survey
CAN-169	1978-79 Canadian Five Railway Yard Survey
USA-170	1978 U.S. Army Impulse Noise Survey
SWI-173	1978 Zurich Time-of-Day Survey
UKD-182	1979 Heathrow and Gatwick Sleep Study (Aircraft Noise and Sleep Disturbance)
FRA-197	1979 French Behavioral Effects of Road Noise Study
USA-203	Burbank Change in Aircraft Noise Study [Not in 1981 catalog]
AUL-210	1980 Australian Five-Airport Study [Not in 1981 catalog]
UKD-224	1982 Manchester Night Noise Survey [Not in 1981 catalog]
USA-XXX	1983 Helicopter Controlled Noise Exposure Study [Not in 1981 catalog]

APPENDIX C: STATISTICAL TECHNIQUES FOR ESTIMATING THE TIME-OF-DAY WEIGHTS IN THE ADJUSTED ENERGY MODEL

The first section of this appendix describes the transformation of the adjusted energy model which is entered into a computer program when the time-of-day weights are estimated using the total annoyance regression method. The next section describes the form of the equations used in the period annoyance analyses. The last section describes the analyses techniques which are required for calculating standard errors and 95% confidence intervals from the complex samples used in social surveys of noise annoyance.

Formula for Estimating the Time-of-Day Weight for the Total Annoyance Regression Method Using Existing Non-linear Regression Computer Programs

As was explained in section 3.3 of the text, the equation for predicting annoyance from noise levels in two time periods can be written with partial regression coefficients for daytime and nighttime periods:

$$\dot{A} = a + B_I \cdot 10 \cdot \log_{10}\{(B_d \cdot \sum_{i=1}^{N_d} 10^{L_{id}/10} + B_n \cdot \sum_{i=1}^{N_n} 10^{L_{in}/10})/24\}$$

The ratio of these two partial regression coefficients defines the time-of-day weight in the adjusted energy model:

$$w_n = \frac{B_n}{B_d}$$

In this article, the sum of the two partial regression coefficients is set to one and the night-time weight can then be defined in terms of only the night-time partial regression coefficient:

$$B_d + B_n = 1 \qquad\qquad w_n = \frac{B_n}{1 - B_n}$$

A non-linear regression analysis is performed to directly estimate the value of this nighttime partial regression coefficient. To carry out this analysis one other term must be defined, a term which measures the difference between the daytime and nighttime noise level:

$$DIF = \sum_{i=1}^{N_n} \cdot 10^{L_{in}/10} - \sum_{i=1}^{N_d} \cdot 10^{L_{id}/10}$$

The final regression equation which is used in the non-linear regression analysis is the following:

$$A = a + B_I \cdot 10 \cdot \log_{10}\{(B_n \cdot DIF + \sum_{i=1}^{N_d} \cdot 10^{L_{id}/10})/24\}$$

The adjusted energy model is non-linear in its parameters, thus a nonlinear iterative regression procedure is used to find values of the parameters which give a best fit. Most of the analyses in this report are based on the use of the Marquardt minimization technique to find values of the parameters which minimize the residual sums of squares. This technique is incorporated in the Nonlinear Regression program in Version 8.3 of the Statistical Package for the Social Sciences (SPSS . . , 1981). Some of the results from these analyses were compared with those obtained from a modified Gauss-Newton method which is used in the P3R program included in the BMDP package of programs (Dixon, 1983).

Formula for Estimating the Time-of-Day Weight Using Period Annoyance Analysis Techniques

The relationship between annoyance and noise level for a single time period is assumed to follow the form of a logistic curve. The curve for a single time period (daytime in this case) can thus be described with the following equation:

$$A_n = \frac{1}{1 + e^{-[(h + Leq_n)\cdot B_n]}}$$

The curve is a logistic curve which is based on a cumulative logarithmic distribution. The curve has a sigmoid shape and is symmetric around the midpoint of the annoyance scale. If the annoyance variable is scored so that it ranges from zero to one then the curve is symmetric about the A=0.5 point with the two tails being asymptotic to A=0 and A=1. The intercept parameter, "h", locates the noise level (-h) where the curve passes through the midpoint (A=0.5). The B_n parameter is a measure of the steepness of the curve which is related to the partial derivative of the curve at the point A=0.5.

Such an equation can be formed for each time period. If the curves are forced to have the same value for the slope parameter ($B_d = B_n = B_e$) then the curves for each of the periods will have the same shape and will only differ in their horizontal displacements along the noise level axis. The differences between the curves can be estimated directly from a non-linear regression analysis in which a dummy variab'· is introduced to represent the nighttime (M_n) period:

$$A_n = \frac{1}{1 + e^{-[[h + Leq_d + D_n \cdot M_n) \cdot B_d]}}$$

In this equation the dummy regression coefficient measures the decibel displacement of the nighttime ($-D_n$) curve from the daytime curve. It is the value of this dummy regression coefficient which is used to measure the horizontal displacement of the curves in Figures 4.1 to 4.4.

One of the advantages of describing the noise annoyance relationship with a logistic rather than linear relationship is that the analysis directly provides an estimate of the decibel displacement of the two curves. The logistic form also allows both curves to approach but not cross the zero annoyance axis. The time-period annoyance analyses were also repeated with linear regression techniques. For the linear regression analysis, a decibel displacement was calculated from ratios of time-period dummy variable partial regression coefficients divided by the noise level partial regression coefficient. The estimates of the decibel displacement were almost the same for the logistic and the linear regression analysis (within a decibel of each other).

For the other period annoyance analysis, Period Ranking, the relationship between the dependent variable (proportion choosing one of the two periods as more annoying) and the independent variable (difference in noise levels) is again assumed to be logistic. Thus the following equation is used to describe the relationship:

$$A_n = \frac{1}{1 + e^{-[(h + Leq_{d-n}) \cdot B_{d-n}]}}$$

In this case the intercept term (-h) locates the difference in noise levels at which there is predicted to be equal annoyance. This is the term which can then be transformed into a time-of-day weight.

<u>Estimates of Sampling Errors for Community Noise Surveys</u>

All of the surveys described in this report are based on area samples in which there is a clustering of respondents into study areas. In previous analyses of noise surveys it has been found that after the effects of noise level are removed, the area of residence affects annoyance (Fields and Walker, 1982; Fields, 1983; Fields, 1984: p.462). Sampling error calculations (including calculations of 95% confidence intervals) must thus take into account the clustering of respondents into study areas. In order to take account of the clustered sample in this report, all estimates of sampling errors are based on a pseudo-replication technique, jackknife repeated replication. For the studies in this report it is assumed that the responses in each study are independent of the responses in all other study areas. Estimates of the sampling variance are thus based on the extent to which estimates of a parameter vary when whole study areas are excluded from the sample.

The jackknife repeated replication technique consists of an examination of the variation in the estimates of the noise model parameter (eg. B_n) as that parameter is repeatedly calculated for subsets of the sample which are defined when single study areas are excluded. That is, the first estimate is made by including all of the sample except for the first study area, the second estimate excludes only the second study area, the third excludes the third study area. . .and so on until the last estimate is formed by excluding only the last of the study areas. The jackknife repeated replication technique manipulates these different estimates of the study parameter so that it is possible to determine the variance of the estimate for the sample as a whole.

The jackknife estimate of the variance can be concisely defined mathematically at this point. Further details and descriptions of other pseudo-replication techniques can be found in the literature on variance estimation for complex samples (Miller: 1974; Efron, 1979).

Let Y denote the estimate of the parameter (eg. B_n) obtained from the complete sample which consists of a certain number (represented by m) study areas. The symbol Y(i) then denotes that corresponding estimate of the parameter obtained if the ith study area is left out. A "pseudo-value of the parameter (Y_i) is then defined as follows:

$$Y_i = m \cdot Y - (m-1) \cdot Y(i)$$

The jackknife estimate of the variance of the parameter for the entire sample is then:

$$\mathrm{Var}\ (Y) = \frac{\sum \{Y_i - [\sum Y_i / m]\}^2}{m \cdot (m-1)}$$

For clustered noise surveys this procedure always indicates that study results are less precise than would have been estimated from the simple random sampling formula.

Even with the use of the jackknife it is likely that the precision of estimates in aircraft surveys is overstated. The procedure assumes that the annoyance levels and the errors in specifying noise levels are not correlated across study areas. This assumption is probably relatively satisfactory for road traffic surveys where the study sites are widely spread and are located on different roads in different neighborhoods. For aircraft studies, however, there are likely to be correlations between different study sites. As a result these studies are probably somewhat less accurate than has been indicated in the analyses presented in this report. This problem is likely to be especially acute for the 1967 Heathrow survey in which the 171 study areas are assumed to be completely independent of one another even though they are impacted by a relatively small number of flight paths.

APPENDIX D: DETAILED HOURLY ACTIVITY DATA FOR 19 SUBGROUPS FOR WEEKENDS AND WEEKDAYS

The six tables in this appendix give the percentage of the time in each hour which is spent in the particular activity (sleeping at home, aurally communicating at home, or just being at home). The data are drawn from the national time use survey which was described earlier in this report. Additional details on the coding of the activities and the definitions of the subgroups can be found in an earlier report (Fields, 1985c).

The day of week in the tables refers to the day of the week for which the activity information is presented. The extent of urbanization is based on types and boundaries of the Standard Metropolitan Statistical Areas (SMSA) as defined by the Bureau of the Census in 1974. The definitions of the three categories used in the tables are: 100,000+=cities and central cities in SMSA's with a population of at least 100,000; OTH. SMSA= places with populations of 50,000 to 99,999 in SMSA's; NON-SMSA= all other places. The section of country definitions follow the standard U.S. Census Bureau region definitions.

TABLE D-1. PERCENT OF TIME AT HOME BY HOUR (WEEKDAYS)

SUBGROUP	HOUR OF THE DAY																						
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DAY OF WEEK																								
MON-THRU	93.7	94.8	95.6	95.8	95.7	93.9	87.4	70.0	53.3	44.8	39.5	38.4	39.0	36.7	36.8	40.1	48.5	62.2	68.6	65.5	68.8	76.3	83.4	88.5
FRIDAY	91.2	92.8	93.6	94.4	94.6	91.6	81.5	61.8	42.3	34.2	29.1	26.5	29.0	28.7	27.4	30.1	39.9	53.0	60.8	56.4	59.4	64.9	74.5	80.8
INTERVIEW WAVE (PRIMARY MONTH)																								
NOVEMBER	94.4	95.3	96.1	96.1	95.9	94.0	86.9	68.5	49.9	41.0	36.8	36.0	36.5	34.2	34.3	38.3	47.1	62.7	69.7	64.2	67.7	76.1	84.4	90.0
MARCH	90.1	91.2	91.5	92.1	92.5	90.2	81.2	64.2	49.9	41.3	36.4	34.4	36.4	36.6	36.5	38.6	49.5	61.8	66.9	64.9	66.2	72.1	79.1	83.6
MAY	92.2	93.3	94.4	94.9	94.7	92.3	84.7	70.8	56.4	47.2	40.4	39.2	40.4	38.0	36.6	37.4	45.2	54.2	61.7	60.3	61.7	68.4	76.7	84.8
SEPTEMBER	92.9	94.4	95.5	96.2	96.1	93.8	86.9	67.9	49.9	42.6	36.3	34.1	35.5	33.8	33.3	36.5	44.7	57.4	64.2	62.2	66.4	72.2	79.3	84.0
EXTENT OF URBANIZATION																								
100,000+	94.1	94.9	95.2	95.6	95.7	94.2	87.3	69.0	53.2	43.7	38.1	34.4	32.4	32.4	32.3	36.4	46.3	62.3	68.8	67.3	68.8	75.0	82.3	86.7
OTH. SMSA	92.5	93.4	93.9	94.3	94.3	93.0	85.5	67.4	46.7	36.3	30.5	29.1	30.7	29.4	29.9	33.7	43.4	55.6	63.2	60.2	63.3	69.1	76.8	83.1
NON-SMSA	93.0	94.3	95.6	95.8	95.7	93.1	85.6	67.8	51.0	43.8	38.9	38.3	40.3	37.6	37.0	39.6	47.5	60.6	67.1	62.7	66.7	74.5	82.4	87.8
SECTION OF COUNTRY																								
WEST	93.2	93.9	94.7	95.0	95.1	93.4	86.4	67.2	50.6	41.1	33.6	31.4	32.6	31.6	31.3	36.0	45.2	59.1	65.5	63.0	67.1	75.9	83.3	88.4
N CENTRAL	91.7	93.1	94.5	94.8	94.5	92.1	83.8	67.9	51.1	42.4	37.8	35.6	37.5	34.7	33.6	36.7	47.3	59.5	64.9	58.9	61.9	69.6	78.4	84.3
N EAST	93.0	94.9	95.5	96.0	96.3	94.9	88.7	72.2	52.8	43.2	36.9	36.0	35.4	32.5	33.5	37.3	47.9	60.5	65.2	62.5	64.3	70.3	78.3	83.6
SOUTH	94.7	95.4	95.9	96.2	96.1	93.6	86.2	65.8	48.6	42.0	38.3	37.8	38.9	38.4	38.3	39.9	45.2	60.5	70.3	68.7	72.4	78.1	84.7	89.7
SEX OF RESPONDENT																								
MALE	90.3	91.6	92.7	93.1	93.1	90.0	79.4	55.4	35.6	29.3	26.2	25.5	27.1	24.1	23.2	24.7	34.3	50.5	60.2	58.2	62.0	69.9	78.2	84.3
FEMALE	95.6	96.6	97.2	97.5	97.5	96.2	91.7	79.0	63.8	53.6	46.4	44.3	44.8	44.1	44.5	49.0	57.1	68.2	72.4	67.7	70.4	76.6	83.8	88.6
AGE OF RESPONDENT																								
18-24 YR	91.4	93.9	95.2	96.5	96.4	93.7	86.1	68.0	48.1	37.5	30.3	28.8	28.2	26.4	28.4	29.9	37.7	52.3	59.7	54.8	56.0	61.8	71.4	79.6
25-44 YR	92.5	93.7	94.7	94.8	94.8	92.5	83.7	62.5	44.0	36.2	31.7	29.4	30.3	30.0	30.5	33.7	42.8	55.9	62.8	57.3	61.9	70.3	79.1	84.9
45-64 YR	94.2	95.4	96.0	96.5	96.4	94.6	87.6	67.6	48.6	40.8	35.7	34.7	37.1	33.2	31.4	35.3	46.5	62.1	70.1	68.4	70.1	76.8	83.3	88.4
65-97 YR	94.4	94.4	94.6	94.8	94.7	93.8	92.8	90.2	80.7	71.3	65.2	65.7	63.8	60.9	58.5	63.0	68.5	74.8	78.3	77.5	81.4	85.1	91.0	93.5
TOTAL SAMPLE																								
	93.1	94.3	95.1	95.5	95.4	93.3	85.9	67.9	50.6	42.2	36.9	35.5	36.5	34.7	34.5	37.6	46.4	59.9	66.6	63.2	66.5	73.5	81.2	86.6

TABLE D-2. % OF TIME IN AURAL COMMUNICATION BY HOUR (WEEKDAYS)

SUBGROUP	HOUR OF THE DAY																							
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DAY OF WEEK																								
MON-THRU	5.4	2.1	.9	.4	.6	1.4	7.0	12.1	10.9	10.4	11.0	12.4	15.6	12.8	12.6	14.2	17.9	26.4	35.3	39.8	45.4	45.2	32.1	13.5
FRIDAY	3.8	1.6	.2	0	.7	2.8	7.2	11.0	7.9	8.0	6.8	7.7	10.9	10.0	9.6	9.6	13.6	24.5	31.7	34.4	39.7	40.1	31.5	15.1
INTERVIEW WAVE (PRIMARY MONTH)																								
NOVEMBER	6.3	2.8	1.0	.3	.4	1.8	6.9	11.5	9.9	9.8	9.9	11.4	14.6	10.9	11.3	12.9	17.1	26.8	36.3	39.3	44.6	44.8	33.7	15.2
MARCH	3.4	1.5	.7	.3	1.2	1.8	8.1	11.2	9.5	7.7	8.5	10.4	12.6	14.0	13.9	14.3	20.4	28.1	37.5	42.5	45.3	42.5	26.3	9.8
MAY	3.6	1.1	1.0	.9	1.1	2.3	5.7	12.0	8.8	10.8	10.3	11.7	14.5	14.1	10.8	10.5	15.0	22.0	27.7	31.2	36.3	37.1	26.1	12.8
SEPTEMBER	4.4	1.5	.3	.2	.5	1.6	7.2	12.4	11.0	10.3	10.5	11.2	14.8	12.4	12.1	13.4	15.8	25.1	32.9	37.9	44.8	45.3	33.5	14.2
EXTENT OF URBANIZATION																								
100,000+	7.5	3.0	1.1	.5	.5	1.8	7.0	12.0	11.3	12.1	11.2	11.1	13.1	11.1	12.8	14.7	18.6	30.3	38.2	40.8	46.1	45.4	34.4	16.0
OTH. SMSA	5.1	1.7	.6	.5	.6	1.5	6.7	11.4	9.8	8.5	8.1	8.9	12.2	10.5	11.1	13.3	15.7	23.9	32.9	34.2	41.3	43.5	34.1	16.7
NON-SMSA	4.0	1.7	.6	.2	.6	1.8	7.2	11.9	9.9	9.4	10.2	12.2	15.8	13.2	11.8	12.3	16.6	25.0	33.5	39.1	44.1	43.5	30.2	12.1
SECTION OF COUNTRY																								
WEST	3.9	1.5	.6	.1	.6	1.3	7.4	10.6	10.8	10.0	8.9	9.4	13.1	10.4	10.6	13.2	16.2	25.4	34.5	39.9	45.0	46.8	31.3	10.7
N CENTRAL	5.5	2.1	.9	.2	.4	1.5	5.7	11.8	10.6	10.3	10.0	11.1	14.5	12.9	11.0	13.3	16.5	25.4	32.4	33.9	38.9	41.5	29.6	14.1
N EAST	8.0	3.5	.4	.5	.5	1.7	6.0	10.8	9.8	8.9	9.0	10.7	13.3	10.3	11.4	13.4	17.2	26.6	34.4	38.0	44.3	45.8	39.6	19.6
SOUTH	3.3	1.3	.8	.6	.9	2.4	9.1	13.4	9.5	9.7	11.2	13.0	16.0	13.7	14.0	12.4	17.5	26.5	36.6	42.8	48.7	43.4	30.3	12.5
SEX OF RESPONDENT																								
MALE	3.9	1.6	.8	.3	.3	1.2	6.3	9.4	6.7	5.8	5.7	7.1	10.4	7.2	6.6	7.3	12.8	22.9	32.6	38.0	42.4	43.2	32.5	13.6
FEMALE	5.9	2.4	.6	.3	.8	2.2	7.8	14.0	13.2	13.3	13.8	14.9	18.0	16.5	16.5	18.1	20.4	28.6	36.0	38.9	45.4	44.6	31.4	14.2
AGE OF RESPONDENT																								
18-24 YR	7.9	4.0	1.2	.9	1.2	2.0	4.1	8.0	9.4	10.4	11.0	13.8	13.6	13.5	12.2	12.4	17.5	28.1	32.6	38.1	42.7	43.2	35.4	21.1
25-44 YR	5.6	2.2	.8	.1	.5	1.5	7.4	12.0	8.7	7.7	8.8	8.7	11.5	10.7	10.5	12.4	16.0	23.6	31.6	34.7	40.2	40.6	31.6	14.5
45-64 YR	4.0	1.8	.6	.4	.5	2.4	9.2	12.4	10.9	10.2	9.0	10.9	15.6	11.6	10.6	12.6	17.1	27.7	35.7	38.1	45.4	48.2	33.8	13.0
65-97 YR	3.2	.5	.4	.4	.6	1.6	7.5	19.0	17.3	17.1	16.8	20.9	25.7	18.8	20.6	20.0	23.3	33.5	47.2	52.8	52.5	44.9	29.1	8.8
TOTAL SAMPLE																								
	5.0	2.0	.7	.3	.6	1.7	7.1	11.8	10.2	9.8	10.0	11.2	14.4	12.1	11.9	13.0	16.8	25.9	34.4	38.4	44.0	43.9	32.0	13.9

TABLE D-3. PERCENT OF TIME SLEEPING BY HOUR (WEEKDAYS)

SUBGROUP	HOUR OF THE DAY																							
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DAY OF WEEK																								
MON-THRU	85.3	90.5	93.4	94.4	93.2	85.0	57.5	27.1	13.1	7.6	5.1	3.5	3.9	5.8	6.0	5.3	3.9	3.1	2.8	3.5	5.9	14.9	37.5	66.7
FRIDAY	84.7	89.2	92.1	93.4	91.4	78.7	49.7	22.1	10.6	5.9	3.5	2.6	2.8	3.5	2.7	3.2	2.9	2.2	2.2	2.3	3.9	11.3	30.2	58.6
INTERVIEW WAVE (PRIMARY MONTH)																								
NOVEMBER	84.8	90.3	93.6	94.6	93.6	83.9	55.3	25.9	11.8	6.6	4.8	3.0	3.4	5.4	5.1	4.8	3.2	3.0	2.6	3.5	6.5	16.1	36.6	66.1
MARCH	84.0	88.2	90.0	91.2	89.3	80.3	53.6	24.7	11.5	7.0	3.9	3.7	3.4	4.7	4.3	2.9	2.3	2.2	2.6	2.1	4.8	13.6	39.1	66.9
MAY	86.1	90.4	92.3	93.1	91.7	82.0	55.3	26.0	13.4	9.4	6.6	3.4	5.0	7.6	8.7	6.7	2.8	2.3	2.0	3.4	5.0	12.3	36.0	63.7
SEPTEMBER	85.7	90.6	93.7	95.0	93.2	84.4	56.6	26.2	13.5	7.4	4.3	3.4	3.7	4.7	4.6	4.9	4.9	3.0	2.8	3.2	4.4	12.1	33.3	62.4
EXTENT OF URBANIZATION																								
100,000+	83.3	90.2	92.9	94.3	93.3	83.8	56.6	27.5	15.3	8.3	5.2	3.7	3.7	5.4	4.4	5.0	5.1	3.8	3.3	3.8	5.8	13.1	35.2	61.8
OTH. SMSA	84.2	89.0	92.2	93.2	92.1	83.8	56.6	26.7	12.2	6.7	3.5	2.1	2.7	3.5	3.8	3.3	3.7	2.9	2.7	3.3	4.7	9.5	27.6	56.4
NON-SMSA	86.3	90.6	93.4	94.5	92.8	83.2	54.7	24.8	11.5	7.0	4.9	3.5	4.0	5.9	6.0	5.2	3.1	2.5	2.3	3.0	5.5	16.0	39.0	68.9
SECTION OF COUNTRY																								
WEST	85.8	90.6	92.4	94.0	93.3	85.1	57.7	25.6	10.4	5.0	3.8	3.3	3.6	4.3	4.7	4.0	3.5	2.3	1.9	1.8	4.6	14.5	38.5	68.6
N CENTRAL	82.3	88.1	91.9	93.4	91.5	82.0	57.2	27.8	13.5	8.2	4.6	3.0	3.3	5.0	5.2	4.7	3.8	2.8	3.0	3.6	5.3	11.7	32.8	62.1
N EAST	82.1	89.0	93.9	95.3	95.2	87.2	63.0	31.4	16.5	9.2	5.2	3.1	2.8	5.0	3.8	3.4	3.5	3.2	3.0	2.9	4.5	9.5	26.9	54.6
SOUTH	89.9	92.9	94.3	94.4	92.1	81.6	47.3	20.3	10.4	6.4	5.0	3.7	4.6	6.4	6.4	6.3	3.7	3.1	2.4	4.0	6.6	18.9	42.6	71.0
SEX OF RESPONDENT																								
MALE	83.9	88.4	90.8	91.9	90.7	79.8	51.0	23.4	13.0	8.0	6.1	4.8	5.0	5.7	5.4	4.8	3.5	3.3	2.8	3.5	6.3	14.1	34.7	63.8
FEMALE	86.3	91.8	95.1	96.2	94.6	86.7	59.6	28.0	12.1	6.5	3.4	1.9	2.4	4.9	5.0	4.8	3.8	2.4	2.4	3.0	4.6	13.9	36.6	65.4
AGE OF RESPONDENT																								
18-24 YR	79.2	85.5	91.6	94.4	93.7	86.0	67.0	39.7	21.5	13.5	6.2	3.1	2.6	2.5	3.6	3.6	3.8	3.4	2.3	1.6	2.0	7.3	24.0	51.1
25-44 YR	83.8	89.8	92.6	93.9	92.6	83.7	51.2	21.1	11.6	7.0	4.6	3.3	2.9	4.0	4.1	3.6	2.8	2.8	2.9	2.9	4.4	12.2	31.8	61.2
45-64 YR	87.6	91.4	94.2	94.9	93.2	81.7	52.0	24.0	10.7	5.8	4.0	2.8	3.0	3.9	4.5	3.8	3.7	2.3	2.3	3.9	6.7	13.6	37.6	67.8
65-97 YR	88.6	92.1	93.2	93.7	92.9	87.7	67.3	30.5	11.5	5.0	4.5	4.3	8.2	13.7	10.1	9.6	5.6	3.5	2.1	3.3	7.2	23.3	52.2	80.3
TOTAL SAMPLE																								
	85.2	90.2	93.0	94.2	92.7	83.5	55.5	25.8	12.5	7.2	4.7	3.3	3.7	5.3	5.2	4.8	3.7	2.9	2.6	3.2	5.4	14.0	35.7	64.6

TABLE D-4. PERCENT OF TIME AT HOME BY HOUR (WEEKENDS)

SUBGROUP	HOUR OF THE DAY																							
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DAY OF WEEK																								
SATURDAY	86.4	88.6	90.4	91.7	91.8	91.0	87.8	82.6	73.6	62.7	55.3	52.7	52.0	49.4	49.1	51.4	56.7	60.3	61.4	61.1	61.4	65.4	71.1	74.8
SUNDAY	84.0	86.5	89.3	90.6	91.3	91.1	89.7	86.5	80.0	68.9	57.7	53.0	56.2	56.9	55.6	55.2	58.7	63.3	64.7	66.0	71.3	77.4	82.7	86.9
INTERVIEW WAVE (PRIMARY MONTH)																								
NOVEMBER	84.4	88.4	91.6	93.0	93.9	93.8	91.4	88.0	79.7	67.5	60.6	55.1	56.0	55.6	55.2	58.8	63.7	67.6	69.2	69.5	73.4	79.7	85.9	90.4
MARCH	85.4	87.4	90.1	91.6	92.1	91.8	90.4	86.0	78.4	67.9	57.1	54.1	56.5	56.2	54.8	54.4	59.6	63.9	65.9	64.9	67.6	72.0	76.7	79.9
MAY	85.1	87.3	89.0	89.9	90.2	89.7	86.2	81.7	74.4	63.6	54.8	51.6	51.9	49.6	49.2	51.5	54.8	59.2	59.6	60.5	62.8	68.2	74.1	78.5
SEPTEMBER	86.0	87.8	89.9	91.7	91.2	90.4	88.2	85.4	76.4	64.5	55.1	49.8	51.4	52.5	51.6	49.4	53.7	56.8	58.1	62.2	65.8	71.4	76.5	80.9
EXTENT OF URBANIZATION																								
100,000+	83.1	86.1	89.0	91.3	91.7	91.9	88.9	84.0	76.1	66.7	58.6	56.0	55.9	53.2	54.2	55.3	58.3	61.7	62.8	64.1	67.0	72.3	76.4	79.9
OTH. SMSA	82.4	85.7	88.3	90.0	90.7	90.6	88.4	84.4	77.1	64.4	56.1	50.7	52.4	54.0	51.9	50.2	55.8	60.2	59.9	61.3	62.6	67.1	73.5	79.7
NON-SMSA	87.1	88.8	90.8	91.5	91.7	91.0	88.8	84.8	77.0	66.0	55.8	52.4	54.1	52.9	51.8	53.7	58.2	62.5	64.4	64.2	67.6	72.7	78.4	81.8
SECTION OF COUNTRY																								
WEST	83.8	86.8	90.3	91.0	91.9	91.3	88.4	83.4	74.2	63.8	55.8	52.5	51.6	50.0	48.9	49.4	55.7	60.1	63.2	63.8	66.0	73.2	78.8	81.9
N CENTRAL	83.2	86.0	88.2	89.5	89.9	89.5	87.1	83.6	75.1	63.6	55.2	50.2	52.3	52.4	52.8	54.5	58.2	63.5	64.2	64.4	67.2	71.0	75.3	80.2
N EAST	87.0	89.3	92.1	94.2	94.7	94.2	92.1	86.9	79.7	69.8	60.7	57.6	56.9	54.5	54.1	55.3	60.3	63.7	63.0	61.9	63.8	67.4	73.3	78.0
SOUTH	87.3	88.7	90.0	91.1	91.0	90.7	88.6	85.0	78.6	67.2	55.7	52.9	56.1	55.5	53.3	53.4	56.8	59.8	61.8	63.6	67.4	73.3	79.7	82.9
SEX OF RESPONDENT																								
MALE	82.9	85.4	88.1	89.4	90.0	89.5	86.3	80.5	71.3	60.5	52.4	49.2	50.8	50.8	49.5	50.5	54.4	60.0	60.5	62.1	65.4	69.8	74.8	79.1
FEMALE	87.1	89.3	91.3	92.6	92.8	92.4	90.7	87.9	81.5	70.3	59.9	55.8	56.9	55.2	54.8	55.7	60.4	63.3	65.3	64.8	67.2	72.8	78.7	82.4
AGE OF RESPONDENT																								
18-24 YR	72.2	76.3	81.0	84.4	86.1	86.4	83.4	79.6	74.4	66.8	58.6	49.8	42.9	42.3	40.0	38.6	40.8	48.2	51.8	53.3	51.3	53.9	60.5	69.2
25-44 YR	81.1	84.3	87.3	89.2	89.6	89.1	86.9	82.6	74.6	62.1	51.7	48.9	49.1	47.5	48.3	50.2	55.3	60.0	59.0	59.0	63.6	69.0	74.6	79.0
45-64 YR	91.9	93.0	93.6	93.8	93.7	93.4	90.7	85.6	76.4	64.7	55.3	52.6	57.0	56.4	55.0	56.5	61.9	63.8	67.9	67.6	69.3	75.5	81.7	84.8
65-97 YR	95.3	96.0	97.2	97.2	96.9	96.4	95.8	94.1	88.1	77.7	69.5	66.4	73.0	73.5	68.6	68.5	71.7	76.4	76.0	76.7	80.9	85.9	88.9	89.5
TOTAL SAMPLE																								
	85.2	87.5	89.9	91.1	91.5	91.1	88.7	84.6	76.8	65.8	56.5	52.8	54.1	53.2	52.4	53.3	57.7	61.8	63.1	63.6	66.4	71.4	76.9	80.9

TABLE D-5. % OF TIME IN AURAL COMMUNICATION BY HOUR (WEEKENDS)

SUBGROUP	HOUR OF THE DAY																						
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DAY OF WEEK																								
SATURDAY	6.7	4.2	1.8	.8	.5	1.3	3.5	9.2	12.5	14.5	14.4	14.7	17.6	17.5	18.6	20.6	23.9	25.9	32.3	37.5	40.9	39.9	29.8	15.7
SUNDAY	7.4	3.9	1.7	.9	.6	1.1	2.9	7.7	13.8	17.5	17.2	17.9	21.7	23.5	23.6	24.5	26.9	30.5	37.0	43.7	47.1	43.8	27.4	11.7
INTERVIEW WAVE (PRIMARY MONTH)																								
NOVEMBER	7.4	3.6	.8	.4	.6	1.2	4.2	7.3	13.1	17.8	17.3	17.7	21.6	23.3	24.7	26.8	28.9	32.3	41.0	44.4	47.3	42.3	34.0	14.4
MARCH	6.5	4.1	2.4	.9	.5	1.2	3.7	10.7	14.5	16.5	15.0	16.0	20.7	21.5	21.4	21.7	27.2	30.5	35.6	42.1	44.9	42.5	27.3	13.6
MAY	6.7	3.9	1.7	.9	.5	1.1	2.6	7.0	12.4	15.3	15.7	16.4	17.6	17.8	19.4	22.5	22.8	25.7	32.3	38.2	42.4	41.8	29.3	13.7
SEPTEMBER	9.4	4.5	.9	.6	.8	1.5	2.4	7.4	11.6	14.6	16.8	15.2	20.5	23.2	21.4	20.4	23.7	24.4	31.7	39.4	42.7	39.3	24.3	12.9
EXTENT OF URBANIZATION																								
100,000+	8.8	4.6	2.7	1.8	1.3	2.0	4.3	7.3	11.2	17.0	17.0	16.6	21.1	23.4	23.4	25.5	27.2	28.3	35.0	40.3	43.7	43.3	28.7	15.3
OTH. SMSA	9.1	5.6	2.2	.9	.4	1.1	2.1	6.5	12.8	14.8	15.0	15.0	19.4	20.9	19.4	20.6	22.7	26.9	32.9	39.8	44.3	43.8	33.2	16.3
NON-SMSA	5.6	3.2	1.3	.4	.3	.9	3.2	9.6	14.1	16.0	15.6	16.7	19.2	19.3	20.8	22.1	25.7	28.7	35.1	41.0	44.1	40.5	26.8	12.0
SECTION OF COUNTRY																								
WEST	4.7	3.1	1.7	.9	.5	1.3	3.4	9.4	13.7	17.6	17.6	19.0	20.1	19.6	19.6	20.0	23.2	29.9	35.6	44.4	46.5	44.8	25.6	9.9
N CENTRAL	9.9	5.0	2.2	1.1	.4	1.1	2.0	7.5	12.0	14.2	14.6	14.2	19.0	19.4	20.7	21.9	24.8	27.4	35.1	41.3	45.8	43.2	32.1	17.8
N EAST	6.9	4.5	1.6	.5	.6	.8	3.3	6.9	12.5	15.9	16.1	16.1	19.9	21.3	21.9	25.0	29.0	30.3	32.8	35.5	39.2	39.2	32.2	14.5
SOUTH	5.5	3.3	1.4	.6	.6	1.6	4.3	9.8	14.6	17.0	15.8	16.9	19.8	21.9	22.0	23.5	25.2	26.8	34.6	40.5	43.5	40.0	24.4	11.0
SEX OF RESPONDENT																								
MALE	6.7	3.4	1.4	.8	.3	.7	2.7	8.2	12.2	14.3	14.9	16.4	21.4	21.1	21.9	23.4	26.2	29.8	35.4	41.0	45.0	42.5	28.4	13.2
FEMALE	7.4	4.5	2.1	.8	.7	1.6	3.6	8.6	14.0	17.4	16.5	16.2	18.1	20.1	20.4	21.8	24.7	26.9	34.0	40.3	43.2	41.3	28.7	14.1
AGE OF RESPONDENT																								
18-24 YR	8.5	4.9	2.8	1.1	.2	.7	1.6	3.4	7.7	13.2	19.2	18.8	18.8	20.3	16.9	17.2	19.7	23.8	28.7	35.1	34.5	34.8	26.6	17.0
25-44 YR	8.7	4.8	2.3	1.2	1.0	1.6	3.2	8.8	13.2	16.9	15.8	16.4	19.0	19.4	20.5	21.6	24.8	27.9	32.1	37.8	41.8	41.2	30.6	15.2
45-64 YR	6.7	4.1	1.5	.6	.3	1.1	3.8	9.8	15.2	16.6	14.5	14.7	20.5	22.8	22.7	24.1	27.2	29.6	37.4	42.4	46.1	45.0	29.2	12.8
65-97 YR	1.7	.8	0	0	.2	1.0	5.0	13.1	18.8	19.1	17.7	18.6	26.4	23.9	26.1	29.8	31.7	35.6	47.6	52.6	54.5	45.1	24.4	8.1
TOTAL SAMPLE																								
	7.0	4.0	1.8	.8	.5	1.2	3.2	8.4	13.2	16.0	15.8	16.3	19.6	20.5	21.1	22.6	25.4	28.2	34.6	40.6	44.0	41.8	28.6	13.7

TABLE D-6. PERCENT OF TIME SLEEPING BY HOUR (WEEKENDS)

SUBGROUP	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	HOUR OF THE DAY																							
DAY OF WEEK																								
1 SATURDAY	76.8	82.1	87.5	90.0	90.2	86.4	74.5	52.3	27.7	14.4	7.3	4.4	3.7	6.1	6.7	6.6	6.1	5.0	3.4	3.5	5.3	11.9	29.8	51.7
SUNDAY	73.6	80.6	86.3	88.8	89.6	87.1	78.6	57.4	32.2	14.9	7.5	4.9	4.2	6.7	8.5	7.6	6.2	4.7	3.8	4.3	6.9	17.6	42.0	67.9
INTERVIEW WAVE (PRIMARY MONTH)																								
NOVEMBER	73.4	82.8	89.8	91.9	91.9	88.7	79.0	60.2	31.6	14.2	8.6	5.0	2.8	5.3	6.5	7.7	6.4	5.6	3.8	4.5	9.1	21.0	40.5	66.5
MARCH	76.3	80.8	86.6	89.9	90.8	88.1	78.2	54.2	31.6	17.1	9.0	5.6	4.2	6.4	7.8	6.8	6.0	4.6	3.4	4.3	6.9	14.8	36.6	59.1
MAY	75.6	81.4	86.2	88.0	88.3	84.7	73.4	53.4	27.8	12.2	5.2	2.9	3.5	6.0	6.5	6.1	6.1	4.8	3.4	2.9	4.1	12.2	33.3	57.8
SEPTEMBER	72.2	81.2	86.8	89.6	89.7	86.5	78.4	56.0	29.4	15.2	8.4	6.6	6.3	8.9	11.8	10.5	6.2	5.1	4.6	5.2	6.8	15.7	36.8	61.2
EXTENT OF URBANIZATION																								
100,000+	70.4	78.3	84.7	88.1	89.0	86.2	75.6	57.6	35.8	18.1	10.6	7.9	5.2	6.7	9.0	7.5	6.8	6.2	4.8	4.9	7.2	13.5	33.4	56.1
OTH. SMSA	70.2	78.5	84.7	87.6	89.4	86.8	79.1	60.5	33.1	15.7	6.9	4.1	2.8	4.6	5.8	5.9	4.8	3.4	2.1	2.4	3.3	9.5	27.5	54.0
NON-SMSA	78.9	83.6	88.6	90.6	90.4	86.9	75.9	51.7	26.5	12.9	6.4	3.5	3.9	6.3	7.0	7.4	6.4	4.9	3.7	4.1	6.8	17.3	40.1	63.6
SECTION OF COUNTRY																								
WEST	76.1	81.5	86.9	89.0	90.0	86.7	76.9	54.6	27.6	11.4	5.6	3.9	3.8	7.0	8.0	7.6	6.6	4.1	2.1	1.6	5.3	15.5	42.0	64.9
N CENTRAL	70.3	79.2	85.0	87.4	88.4	85.4	77.2	54.7	30.9	16.3	7.0	4.9	3.5	5.2	7.4	7.3	6.3	5.2	3.3	3.3	4.9	12.5	31.0	56.2
N EAST	76.4	82.0	89.3	92.9	93.2	91.0	80.8	62.0	36.8	17.6	8.0	3.7	3.7	4.6	4.7	5.1	3.7	4.0	3.7	5.1	7.5	12.7	29.3	53.6
SOUTH	79.2	83.3	87.5	89.7	89.2	85.5	72.8	50.7	26.0	13.1	8.8	5.5	4.7	8.5	9.5	7.8	7.2	5.6	4.9	5.4	7.1	18.2	41.6	64.6
SEX OF RESPONDENT																								
MALE	74.2	80.6	86.0	87.7	88.6	85.2	73.4	53.1	29.7	15.6	9.1	5.8	4.8	7.5	7.3	7.2	6.1	5.2	4.0	4.8	7.0	16.0	36.9	59.3
FEMALE	75.9	82.0	87.7	90.8	90.9	88.0	79.1	56.4	30.1	13.9	6.1	3.6	3.3	5.5	7.9	7.0	6.1	4.5	3.2	3.1	5.3	13.7	35.1	60.3
AGE OF RESPONDENT																								
18-24 YR	60.7	68.8	77.5	82.6	85.3	83.8	78.6	67.8	50.7	22.7	14.9	7.0	4.6	4.8	5.1	5.8	5.4	5.5	4.7	3.6	3.1	8.1	22.7	43.5
25-44 YR	69.1	77.2	83.7	86.5	87.4	84.8	76.4	57.0	31.5	14.0	6.2	3.5	2.4	3.8	5.4	6.0	5.7	4.5	3.1	3.2	5.1	11.2	31.0	55.6
45-64 YR	82.6	86.7	90.9	92.6	92.1	88.3	74.9	50.1	24.8	10.0	4.6	3.5	3.8	6.0	8.3	7.1	6.1	4.6	3.9	4.9	7.3	16.3	39.7	64.9
65-97 YR	91.9	94.0	96.5	96.7	96.0	92.4	78.3	47.5	18.4	9.1	9.0	7.5	8.6	15.6	14.3	11.8	8.3	5.6	3.9	5.0	9.8	27.2	54.1	78.1
TOTAL SAMPLE																								
	75.2	81.3	86.9	89.4	89.9	86.7	76.5	54.9	29.9	14.6	7.4	4.6	4.0	6.4	7.6	7.1	6.1	4.9	3.6	3.9	6.1	14.8	35.9	59.9

APPENDIX E: THE METHOD FOR PREDICTING THE ACCURACY OF FUTURE STUDY DESIGNS

Section 7 of this report predicts the accuracy of the estimates of time-of-day weights which could be expected from a variety of alternative study designs. This appendix describes the methods which are used to make the predictions.

In Section 3.3 it was explained that estimates of the time-of-day weights are obtained by first calculating the estimates of the nighttime partial regression coefficient. Similarly the 95% confidence intervals for the time-of-day weights are derived form the variances and 95% confidence intervals for the nighttime partial regression coefficients. The calculation of the variance of the partial regression coefficient is carried out in two steps. First the variance is predicted for a simple random sample of size m. Then this estimate of the variance is increased to adjust for the clustered sample design.

The simple random sampling estimate for the variance of the nighttime partial regression coefficient is defined as:

$$\sigma^2_{B_n} = \frac{\sigma^2_e}{m} \cdot \frac{\sigma^2_X}{\sigma^2_X \cdot \sigma^2_Y - (\sigma_{XY})^2}$$

where;

$$X = 10 \cdot \log_{10}(B_n \cdot DIF + t_d \cdot 10^{Leq_d/10})$$

$$Y = 10 \cdot \log_{10}(e) \cdot B_I \cdot \frac{DIF}{B_n \cdot DIF + t_d \cdot 10^{Leq_d/10}}$$

and

$$DIF = \sum_{i=1}^{N_n} 10^{L_{in}/10} - \sum_{i=1}^{N_d} 10^{L_{id}/10}$$

[The source of the derivation of this prediction equation can be found in an earlier report (Fields, 1985e: p. 16)]. Four of the parameters which enter into the estimate of this variance are study design variables: the social survey sample size (m), each of the daytime noise exposure conditions (Leq_d), each of the nighttime noise exposure conditions (Leq_n), and the relationship (covariance) of the daytime and nighttime exposures (σ_{XY}). In general, it can be seen that the accuracy of the estimate of the nighttime partial regression coefficient is increased by increasing the variation in the nighttime and daytime noise levels and in decreasing the correlation between these two noise variables. Since all of the calculations are based on the noise expressed in relative pressure squared units, the objective is to increase the variances and covariance as measured in relative pressure squared units (antilog of the decibel values).

The two remaining parameters in the prediction equation are characteristics of the human response to noise: the residual error variance (σ^2_e) and the coefficient for the regression of annoyance on the noise index (B_I). Their combined effect is related to their ratio. The accuracy of a sample is increased when the residual error variance is small relative to the value of the regression coefficient for the noise index.

For the prediction of the variance of the nighttime partial regression coefficient, it is thus necessary to make assumptions about the values of the residual error variance and the noise index regression coefficient. These values were taken from the London road traffic survey. The value for the residual error variance is 3.55. The value of the regression coefficient is 0.08. These values were selected after an analysis of the values from 24 annoyance scales used in 10 surveys (Fields, 1985e: p. 8) determined that these were conservative estimates of the accuracy which could be expected from a survey. Nine of the 10 surveys would have predicted a more accurate estimate, one would have predicted a less accurate estimate.

The above equations predict the variances for simple random sample designs. However, as was explained in Appendix C, noise surveys are never based on simple random samples. Instead the samples consist of individuals who are clustered together into study areas. The result is that the actual variances and standard deviations of sample estimates are greater than would be predicted from the simple random sample estimates. The relative sizes of the actual and simple random sample variances can be predicted on theoretical grounds for different sized study groups if estimates of the sizes of group effects are available. The methods are described in two publications (Kalton, 1983; Tomberlin, 1985).

For the predictions in this report a simpler approach was adopted which is dependent upon the assumption that future studies will have study areas which are similar to study areas used in past surveys. For this simpler approach eight noise surveys were examined. For each survey both the incorrect simple random sample standard deviation and the actual standard deviation (based on jackknife repeated replication) were calculated. The relative size of these two standard deviations is expressed as a "design effect", the ratio of the true to simple random sampling standard deviation. For the eight surveys the size of this design effect for nighttime partial regression coefficients was found to vary from 0.9 to 9.6 (Fields, 1985e: p. 10). For the predictions in this report the design effect is set at 2.0. Thus, after a simple random sampling standard deviation is predicted for the nighttime partial regression coefficient, that standard deviation is multiplied by two.

After the standard deviation of the nighttime partial regression coefficient is calculated, the 95% confidence intervals for the nighttime partial regression coefficient is calculated. Finally, these confidence intervals are transformed into confidence intervels for the time-of-day weight with the formula:

$$w_n = \frac{B_n}{1 - B_n}$$

TABLES

Table 1.1: Equivalent values for three alternative expressions for time-of-day noise weights

Hours in each period	Number weight		Decibel weight		Combined decibel and time adjustment		Comments (Noise indices with weight)
	Evening w_e	Night w_n	Evening $w(dB)_e$	Night $w(dB)_n$	Evening $w(dB\&t)_e$	Night $w(dB\&t)_n$	
	1	1.0	0	0	0	-2.2	Leq (24-hr)
	1	5.0	0	7.0	0	4.8	Values for
	1	3.2	0	5.0	0	3.8	weightings
15-hour	1	5.3	0	7.2	0	5.0	of 5
day							
and	1	10.0	0	10.0	0	7.8	Ldn
9-hour	1	16.7	0	12.2	0	10.0	CNR, NEF
night							
	1	20.0	0	13.0	0	10.8	Values for
	1	100.0	0	20.0	0	17.8	weightings
	1	166.7	0	22.2	0	20.0	of 20
	1.0	1.0	0.0	0.0	-6.0	-1.2	Leq (24-hr)
12-hour	3.0	10.0	4.8	10.0	-1.2	8.8	CNEL
day							
and	5.0	10.0	7.0	10.0	1.0	8.8	Values for
3-hour	3.2	10.0	5.0	10.0	-1.0	8.8	5 and 10
evening	12.6	13.3	11.0	11.2	5.0	10.0	WECPNL
and							
9-hour	10.0	10.0	10.0	10.0	4.0	8.8	
night							
	20.0	20.0	13.0	13.0	7.0	11.8	

a. The mathematical functions relating these three weightings are given in Appendix A.

Table 2.1: Description of twenty-six surveys of residents' response to noise

Study title (Main reference) [P=primary survey]	Number of interviews	Definition of time period (e=evening, n=night)	Noise metric	Method for determining noise levels
PART A: AIRCRAFT SURVEYS				
USA nine-airport [P] (Connor and Patterson, 1976)	**8255**	**n=22:00-07:00**	**CNR**	**Measurements and interpolation**
1967 Heathrow [P] (Second..., 1971)	**3755[a]**	**e=19:00-23:00[b] n=23:00-07:00**	**NNI_{10}[c]**	**Model from measurements at Heathrow**
1972 Heathrow (Ollerhead, 1978)	600	e=19:00-23:00 n=23:00-07:00	NNI	Prediction from model
1961 Heathrow (Mckennell, 1963)	1731	e=18:00-23:00 n=23:00-08:00	NNI	Measurements, interpolation
1971 Gatwick (Ollerhead and Cousins, 1975)	1030	e=18:00-23:00 n=23:00-06:00	NNI	Predictions from observed flight tracks
1973 LAX night (Fidell and Jones, 1975)	940	n=22:00-07:00	Ldn	Record of number of flights
1980 Australia 5-airport (Bullen and Hede, 1983)	3575	e=19:00-22:00 n=22:00-07:00	Leq	Predictions and measurements
1972 JFK (Borsky, 1976)	1465	e=19:00-23:00 n=23:00-07:00	none	Record of number of flights
1971 Swiss 3-airport (Graf. et al., 1974)	3939	e=18:00-22:00 n=22:00-06:00	NNI	Measurements, predictions
1979 JFK Question Devel. (No publication[d])	40	e=19:00-22:00 n=22:00-07:00	none	No noise data
1978 US Army (Schomer, 1983)	2147	e=19:00-22:00 n=22:00-07:00	Ldn	Predicted contours

Table 2.1 (Continued)

PART B: ROAD TRAFFIC SURVEYS

England traffic [P] (Morton-williams, et al., 1978)	1195	n=22:30-07:30[e]	Leq	Measurements and interpolation
London traffic [P] (Langdon and Buller, 1977)	2903	n=22:00-06:00[f]	L10	Measurements
1975 South Ontario [P] (Hall, et al., 1977)	560	e=19:00-23:00 n=23:00-07:00	Leq	Measurements
1976 South Ontario [P] (Hall, et al., 1977)	850	e=19:00-23:00 n=23:00-07:00	Leq	Measurements
1978 Ontario [P] (Hall, et al., 1981)	912	e=19:00-23:00 n=23:00-07:00	Leq	Measurements
Western Ontario [P] (Bradley and Jonah, 1979)	1100[g]	n=22:00-07:00	Leq	Measurements
French expressway [P] (Vallet, et al. 1978)	975	e=20:00-24:00 n=24:00-08:00	Leq	Measurements
1978 Zurich time-of-day (Nemecek, et al., 1981)	1607	e=19:00-22:00 n=22:00-06:00	Leq	Measurements
1979 French road (Lambert et al., 1984)	1486	e=20:00-24:00 n=24:00-05:00	Leq	Measurements
1974 USA 24-community (Fidel, 1978)	2037	n=22:00-07:00	Ldn	Measurements
1976 Zurich street (Wanner et al., 1977)	800	e=19:00-23:00 n=23:00-06:00	Leq	Measurements
1977 Zurich street (Wanner et al., 1977)	1297	e=19:00-22:00 n=22:00-06:00	Leq	Measurements
Manchester traffic (Yeowart, et al., 1977)	846	n=22:00-07:00	Leq	Measurements

PART C: RAILWAY SURVEYS

1975 British railway [P] (Fields and Walker, 1982)	1453	e=19:00-21:00 n=21:00-07:00	Leq	Measurements
1978-79 Canada RW yard (Dixit and Reburn, 1980)	544	n=22:00-07:00	Leq	Measurements

Table 2.1 (footnotes)

a. Although 4655 interviews are present in the data set, only 3755 have noise data for both daytime and nighttime. For the remaining interviews, the average peak level of flights during at least one period was less than the conventional definition of an aircraft noise event for NNI (80 PNdB).

b. The definition of the end of the evening period is not reported in the study publications. It is assumed to be 23:00 in accord with the definition of the beginning of the nighttime period for flight regulations.

c. NNI_{10} is equivalent to the conventional British NNI index except that the weighting for the number of noise events is 10 rather than 15.

d. This study was conducted under the supervision of Eugene Galanter at Columbia University, New York, New York. The original data were analyzed for this report. The study was conducted to test new types of annoyance questions.

e. Daytime noise levels are based on measurements over the 06:00 to 24:00 period.

f. Daytime noise levels are based on measurements over the 08:00 to 20:00 period.

g. One hundred interviews from the original data set are excluded which were obtained on repeated visits to two sites.

Table 2.2: Summary of noise data for the ten primary surveys

Study title (Noise metric)	Noise level (24-hr) [Decibels]		Correlations between period noise levels:[a]			
	Average	Standard deviation	Two periods	Three time-periods		
			r_{dn}	r_{dn}	r_{de}	r_{en}
PART A: AIRCRAFT NOISE STUDIES						
USA nine airport (CNR)	108	10.9	0.96	No evening noise data		
1967 Heathrow (NNI_{10})	92	6.8	.94	.94	.82	.87
PART B: ROAD TRAFFIC SURVEYS						
England (L10)	59	10.5	.86	No evening noise data		
London (Leq)	73	4.0	.86	No evening noise data		
1975 Ontario (Leq)	61	7.0	.88	.85	.91	.91
1976 Ontario (Leq)	66	4.7	.88	.89	.85	.81
1978 Ontario (Leq)	57	5.5	.91	.92	.90	.86
Western Ontario (Leq)	58	7.2	.98	No evening noise data		
French expressway (Leq)	66	4.4	.93	.92	.97	.95
PART C: RAILWAY SURVEY						
British railway (Leq)	56	10.7	.91	.90	.94	.97

a. The Pearson product-moment correlations are between pairs of noise levels. The daytime period for the "two-period" division has been further split into an evening period and a shorter daytime period for the "three time-period" division.

Table 3.1: Estimates of nighttime weights from the ten primary surveys

Study title	Annoyance scale (number of scale points)	Nighttime weight (w_n)[a]: Lower 95% confid-ence limit	Estimate of night-time weight	Upper 95% confid-ence limit	Indicators of accuracy: Daytime[b] regression coefficient ($1-B_n$) [σ_{1-B_n}]	Coefficient of variation[c] for $1-B_n$
PART A: AIRCRAFT SURVEYS						
USA nine airport	Numeric (5)	-0.4	9.2	+∞	0.10 [0.75]	7.5
1967 Heathrow	Verbal (4)	-1.0	-1.0	+∞	121.95[d] [>239.9]	0.5
PART B: ROAD TRAFFIC SURVEYS						
England traffic	Verbal (4)	-0.3	1.3	+∞	0.43 [0.54]	1.3
	Numeric (7)	-0.2	0.6	+∞	0.62 [0.34]	0.5
London traffic	Numeric (7)	-0.4	4.2	+∞	0.19 [0.81]	4.3
1975 South Ontario	Verbal (5)	-0.8	-0.4	+∞	1.70 [1.14]	0.7
1976 South Ontario	Verbal (5)	1.7	21.8	+∞	0.05 [0.17]	3.4
	Numeric (11)	2.6	+∞	+∞	-0.01 [0.15]	15.0
1978 Ontario	Verbal (5)	-0.2	1.3	+∞	0.43 [0.42]	1.0
	Numeric (11)	-0.6	0.1	+∞	0.90 [0.87]	1.0
Western Ontario	Numeric (7)	4.0	+∞	+∞	-0.02 [0.11]	6.0
French Expressway	Verbal (4)	<7.6[e]	+∞	+∞	-0.04 [>0.08]	2.0
PART C: RAILWAY SURVEY						
British Railway	Verbal (4)	-0.3	0.9	+∞	0.52 [0.51]	1.0
	Numeric (7)	0.1	2.6	+∞	0.28 [0.34]	1.2
	Index (11)	0.4	2.9	+∞	0.26 [0.24]	0.9

Table 3.1 (footnotes)

a. The 95% confidence interval for the nighttime weight is based on the standard deviation of the nighttime partial regression coefficient, not on the standard deviation of the nighttime weight. This procedure is discussed in the text and in Appendix C. The standard deviation for the nighttime partial regression coefficient (σ_{B_n}) is the same as for the daytime partial regression coefficient (given in brackets in this table [σ_{1-B_n}]).

All estimates of confidence intervals and sampling errors in this paper are based on a pseudo-replication technique, jackknife repeated replication, which is appropriate for the complex clustered samples found in these surveys. The jackknife technique is briefly described in Appendix C.

The symbol "$+\infty$" indicates that nighttime noise is estimated to have an infinitely greater effect than daytime noise, because increases in daytime noise are estimated to reduce annoyance.

b. Since, as was explained in the text, the sum of the daytime and nighttime partial regression coefficients is set to one ($1=B_d+B_n$), the daytime partial regression coefficient is $B_d=1-B_n$.

c. The coefficient of variation is defined as:

$$\text{coefficient of variation}=(\sigma_{1-B_n})/(1-B_n)$$

d. This estimate for the partial regression coefficient did not converge even after 50 iterations. The nighttime partial regression coefficient continues to become a larger negative number while the value of the daytime partial regression coefficient continues to become a larger positive number. As a result the value for the nighttime weight approaches $w_n=-1.0$.

e. The "$<$" symbol indicates in this instance that the lower confidence limit is almost certainly less than 7.6. The value of the standard error could be based on only 8 of the 10 jackknife pseudo-replicates. The non-linear regression program could not provide estimates of w_n for the two remaining replicates.

Table 3.2: Estimates of evening and nighttime weights from five of the primary surveys

Study title	Annoyance scale (number of scale points)	Confidence limits and time-of-day weights[a]					
		Nighttime weight (w_n)			Evening weight (w_e)		
		Lower 95% limit	Estimate of nighttime night	Upper 95% limit	Lower 95% limit	Estimate of evening weight	Upper 95% limit
PART A: AIRCRAFT SURVEY							
1967 Heathrow	Verbal (4)	-b-	-1.4	+∞	-b-	0.4	+∞
PART B: ROAD TRAFFIC SURVEYS							
1975 South Ontario	Verbal (4)	-0.5	8.1	+∞	-0.3	-1.6	+∞
1976 South Ontario	Verbal (4)	-10.3	+∞	+∞	-5.6	+∞	+∞
	Numeric (11)	-94.3	+∞	+∞	-68.0	+∞	+∞
1978 Ontario	Verbal (4)	-0.3	0.4	+∞	-0.5	1.0	+∞
	Numeric (11)	-0.3	0.5	+∞	-0.7	0.0	+∞
PART C: RAILWAY SURVEY							
British Railway	Verbal (4)	0.5	7.3	+∞	-0.1	1.0	+∞
	Numeric (7)	-1.1	8.4	+∞	-1.7	3.4	+∞

a. See Section 3.2 and Appendix C for the method of setting the confidence intervals.

b. The estimates for the partial regression coefficients do not converge even after 50 iterations. The value for the evening weight approaches $w_e = -1.0$ and for the nighttime weight approaches $w_n = +1.0$. No attempt is made to describe a lower confidence limit.

Table 3.3: Five attempts to create a combined estimate of the nighttime weight

Elements of method to combine study estimates		Results from this method		
Measure of central tendency	Method to determine importance of study[a]	Nighttime time-of-day weight (w_n)	Nighttime regression coefficient (B_n)	Weaknesses of this method
Average of nighttime weightings	Equal importance	$+\infty$	0.61	Three studies with $w_n = +\infty$ dominate the estimate
Median	Equal importance	2.6	0.72	Ignores dispersion of estimates
Average[b] of the nighttime regression coefficients	Equal importance	1.6	0.61	Ignores study differences in reliability
	Number of interviews	2.8	0.74	Only considers one aspect of reliability
	Reliability (inverse of variance)	24.7	0.96	Estimates of reliability are (1) inaccurate (2) biased by the value of B_n

a. Each of the fifteen estimates from Table 3.1 is counted as a separate estimate. The combined study estimates still do not agree if a single estimate is taken from each study.

b. The averages for the last three rows are computed from an average of the nighttime partial regression coefficients which are then transformed into the nighttime weights (See Section 3.3).

Table 3.4: Comparison of the predictive ability of three time-of-day (nighttime) models

Study title	Annoyance scale[a]	Proportion of variance explained by: Adjusted energy model	Independent period effect model	Incremental decibel difference model
PART A: AIRCRAFT STUDIES				
USA nine-airport	Numeric	0.21	0.21	0.21
1967 Heathrow	Verbal	0.17	0.16	0.17
PART B: ROAD TRAFFIC				
England traffic	Verbal	0.19	0.19	0.19
	Very	0.06	0.05	0.06
	Numeric	0.31	0.31	0.31
London traffic	Numeric	0.03	0.03	0.03
1975 South Ontario	Verbal	0.22	0.21	0.21
	Considerably	0.15	0.14	0.14
1976 South Ontario	Verbal	0.03	0.03	0.03
	Considerably	0.02	0.02	0.02
	Numeric	0.02	0.02	0.02
1978 Ontario	Verbal	0.19	0.19	0.19
	Considerably	0.11	0.11	0.11
	Numeric	0.27	0.27	0.27
Western Ontario	Numeric	0.18	0.18	0.18
French expressway	Verbal	0.09	0.09	0.09
	Very	0.07	0.07	0.07
PART C: RAILWAY STUDY				
British railway	Verbal	0.10	0.10	0.10
	Very	0.03	0.03	0.03
	Numeric	0.14	0.14	0.15
	Index	0.18	0.18	0.18

a. The high annoyance measures are created by dividing the verbal annoyance scales at the most extreme of four or five categories ("very" or "considerably").

Table 3.5: Comparison of nighttime weightings for eight types of annoyance scales

Study	Type of Annoyance Questionnaire Item							
	No time period implied			Time period defined or implied:				
	Numeric	Verbal	Very/ Considerably	Activity interference	Reference is to:[a]			
					Daytime (Numeric)	Speech	Nighttime (Numeric)	Waking up
PART A: AIRCRAFT SURVEYS								
USA nine airport	9.2		36.3	9.1				
1967 Heathrow		-1.0	4.6	-1.0	-1.0		3.1	
PART B: ROAD TRAFFIC SURVEYS								
England traffic	0.6	1.3	0.9			3.0		2.6
1975 South Ontario		-0.4	-0.5					
1976 South Ontario	+∞	21.8	10.1					
1978 Ontario	0.1	1.3	1.8		-0.5		0.0	
French expressway		+∞	+∞					
PART C: RAILWAY SURVEY								
British railway	2.6	0.9	0.2			2.2		-0.5

a. The speech and sleep interference questions are divided into two categories based on whether or not the interference is reported.

Table 4.1: Findings from the noise index correlation approach

Study title (Source)	Annoyance scale	Confidence limits and Nighttime weight (w_n): Lower 95% limit	Estimate of nighttime weight	Upper 95% limit	Original finding reported (r= correlation)	Comments
USA 3 airport[a] (Edmiston and Patterson, 1972: p.15)	Activity index	?	>5.0	?	$r_{CNR} \geq r_{Leq}$	Activity index is a mix of day and night activities
1978-79 Canada RW yard (Dixit and Reburn, 1980: p.885)	Verbal	?	>3.0	?	$r_{Ldn} > r_{Leq}$	
W. Ontario traffic (Bradley and Jonah, 1979a:p.595; 1979b:p.398; 1979c:p.412)	Index	?	>3.0	?	$r_{Ldn} > r_{Leq}$	Annoyance index is mix of day and night questions
British Railway (Fields and Walker, 1982; p. 200)	Annoyance Index	?	<5.0	?	$r_{Leq} > r_{Ldn}$	
Manchester traffic (Yeowart,et al., 1977; p.135)	Numeric	?	<5.0	?	$r_{Leq} > r_{Ldn}$	Leq more highly correlated over all sites, Ldn more highly correlated for motorway sites
1980 Australia 5-airport (Bullen and Hede, 1983: Table 2)	Index	?	>0,<2	?	-b-	Annoyance index includes day and night activity questions.[b]

a. This study is part of the USA nine airport study which is described in Tables 2.1 and 2.2.

b. This modified noise index correlation method compared a series of indices which differed in weightings by 3-decibel steps. Both daytime and evening weights were varied. It was found that a noise index with $w(dB)_e=3, w(dB)_n=1$ was more highly correlated with annoyance than were indices based on combinations of evening decibel weightings with $w(dB)_e=1$, $w(dB)_e=6$ or night decibel weightings of $w(dB)_n=0$, $w(dB)_n=3$.

Table 4.2: Number and decibel time-of-day weights for five alternative assumptions about the noise entity which is rated

Study title	Weightings on assumption that noise entity is:						
	Average hour		Sum of noise		Sum when at home	Average noise event	Single worst noise
	Evening We [w(dB)e]	Night Wn [w(dB)n]	Evening We [w(dB)e]	Night Wn [w(dB)n]	We Wn	We Wn	We Wn
PART A: ANNOYANCE COMPARISON APPROACH							
1967 Heathrow	32 [15 dB]	40 [16 dB]	95 [20 dB]	60 [18 dB]	No appropriate data available	Entity not suitable for weight analysis	Entity not suitable for weight analysis
1978 Ontario	1 [1 dB]	4 [6 dB]	7 [8 dB]	7 [8 dB]			
1978 Zurich (Road)	-	2 [3 dB]	-	4 [6 dB]			
1979 French (Road)	-	4 [6 dB]	-	6 [7 dB]			
PART B: PERIOD RANKING APPROACH							
1967 Heathrow		44 [16 dB]		65 [18 dB]			
1978 Ontario (Road)		6 [8 dB]		8 [9 dB]			
British Railway		4 [6 dB]		5 [7 dB]			

Table 4.3: Findings from four published analyses based on the annoyance comparison approach

Study title (Source)	Annoyance scale	Estimate of w_e, w_n (Sum of hours)	Finding reported	Comments
1978 Zurich time-of-day (Wehrli, et al., 1978: p. 142)	Numeric	$w_n \simeq 6$	Threshold at which annoyance begins is about 5 dB(Leq) higher for day than night.	The analysis was not planned to estimate time-of-day weighting.
U.S. Army (Schomer, 1983: p. 554)	Verbal	$w_n = 13.2$	Equal period annoyance scores if 9 dB (Leq) shift in exposure.	Separate questions about day and evening were added for "day". Weekday and weekend were also combined.
W. Ontario traffic (Bradley, 1979: p.120)	Numeric	$w_n = 13.2$	Day and night reactions are separated by 9 dB (Leq).	Separate questions about shorter periods were combined for the period ratings.
1972 Heathrow (Ollerhead, 1978: p.75)	Number of times disturbed	$w_e = 4$ $w_n < 1$	Day and evening reactions are separated by 6 dB (peak noise level). Night response not related to number of noise events.	Reaction is number of times disturbed. Amount of disturbance for each day and night event is not differentiated.

Table 4.4: Findings from five published analyses based on the period ranking approach

Study title (Source)	Estimate of w_e, w_n (Sum of hours)	Finding reported in publication	Comments
1975 British railway (Fields and Walker, 1982: p.195.)	$w_e > 1$ $w_n > 1$	Day annoyance is less, but evening and night noise levels (Leq) are lower.	No numerical estimate.
1977 Zurich traffic (Wanner et al., 1977: p. 112)	$w_n > 12.6$	Night annoyance is worse even though the daytime values for Leq are 8 dB higher.	
1961 Heathrow (Wilson, 1963: p.215)	$w_n = 25$	Approximately equal annoyance ever though night peak level 8 dB lower and 1/4 as many aircraft.	Most "day" worst respondents said "evening" worst. The 24% "day" (ie. day and evening) is only approximately equal to the 28% night.
1980 Australia 5 airport (Bullen and Hede, 1983: p. 1628)	$w_e > 6.0$ $w_n > 11.5$	Annoyance is greater for evening and night 3-hr. periods even though noise for 3-hr. day periods are 10.6 dB above night and 7.8 above evening noise levels (Leq).	1) Authors not certain if respondents interpret questions as ratings of actual exposure or hypothetically equal exposures. 2) No attempt to specify anything but lower bounds for w_e or w_n since these results are inconsistent with annoyance comparison estimates.
1972 Heathrow (Ollerhead, 1978: p.75)	$w_e < 1$ $w_n < 1$	Day worse than evening. Day worse than night.	1) Evening result is inconsistent with annoyance comparison results. 2) Author suggests that respondents did not realize that question was about individual noise events.

Table 4.5: Time when most annoyed (summary of Figures 4.9 to 4.14)

Study (Catalog ID number[a])	Most annoyed by noise in:[b] Day	Evening	Night	Number of time periods	Are hours defined?	Comment
STUDIES FROM FIGURE 4.9: ENGLISH AIRCRAFT SURVEYS						
1961 Heathrow (UKD-008)			X	4	YES	
1967 Heathrow (UKD-024)		X		4	NO	
1972 Heathrow (UKD-061)	X			3	NO	Night is when "trying to sleep"
1971 Gatwick (UKD-052)		=	=	4	YES	
STUDIES FROM FIGURE 4.10: USA AND AUSTRALIAN AIRCRAFT SURVEYS						
1973 Los Angeles night (USA-082)	X	Not asked		2	NO	Night is when "trying to sleep"
1970 USA two small airport (USA-044)		X		8	YES	Questioned about weekdays
1980 Australia airport (AUS-210)		X		8	YES	Excludes "not bothered"
1972 JFK airport (USA-059)			X	3	YES	Included only if home at all times
STUDIES FROM FIGURE 4.11: CANADIAN AND USA ROAD TRAFFIC SURVEYS						
1975 West Ontario (CAN-120)		X		6	YES	
1976 South Ontario (CAN-121)	rush hour			6	NO	Questioned about weekdays
1978 Ontario (CAN-168)			X	3	NO	Asks about indoors
1974 USA 24-community (USA-102)			X	4	NO	54% "never bothered"
STUDIES FROM FIGURE 4.12: FOUR SWISS SURVEYS						
1971 Swiss three airports (SWI-053)		X		6	YES	Could choose more than one period
1976 Zurich road (SWI-133)			X 6-9am	4	YES	Excludes "not bothered"
1977 Zurich road (SWI-158)	X			4	YES	Excludes "not bothered"
1978 Zurich time-of-day (SWI-173)			X 6-9am	6	YES	
FOUR QUESTIONS FROM FIGURE 4.13: 1979 JFK AIRPORT STUDY (NO. XXX-200)						
1979 JFK [Period rating Question]		X		24	YES	
1979 JFK [Period ranking Question]		X		12	YES	
1979 JFK [Divide money, 2 periods]	X	Not Asked		2	YES	
1979 JFK [Divide money, 3 periods]		X		3	YES	
STUDY FROM FIGURE 4.14: BRITISH RAILWAY SURVEY						
1975 British railway (UKD-116)			X	4	YES	

Table 4.5 (footnotes)

a. This identification number is the index number used in a catalog of 200 noise surveys (Fields, 1981) and is the key to the full title for the survey presented in Appendix B.

b. An equals sign "=" indicates that the two periods were ranked equally. "Not asked" indicates that only the daytime and nighttime periods (not evening period) were asked about.

Table 7.1: Relations between daytime and nighttime noise levels at permanent noise sites (dB(A), Leq)

Airport	Number of sites	Mean difference (Day-night)	Standard deviation of noise levels[a]			Correlation of day and night noise
			Daytime	Nighttime	Day minus night	
Washington National	15	11.7	5.3	5.6	2.6	0.89
San Jose	12	11.5	5.6	6.2	2.1	.94
John Wayne	9	14.4	7.2	5.7	5.9	.61
Seattle	9	6.1	4.7	5.0	1.2	.97
Torrence	11	14.1	4.8	7.1	3.4	.91
San Diego	15	7.6	5.2	5.0	2.7	.86
Los Angeles	12	5.7	5.4	6.3	1.8	.96
Ontario	8	11.4	4.2	7.7	6.9	.45
Van Nuys	4	13.3	1.8	2.8	3.8	.34
San Francisco	22	9.5	5.0	5.3	2.7	.86
Burbank	11	9.4	2.9	2.4	2.9	.44
Mean of all sites[b] (N=128)	11.6	10.1	7.6	9.7	4.2	.91

a. This is the standard deviation of the mean at each airport when the observations are the mean noise level at each site.
b. The computations of the means and correlations for all sites are based on the 128 observed site means (ie. not the 11 airport means).

FIGURES

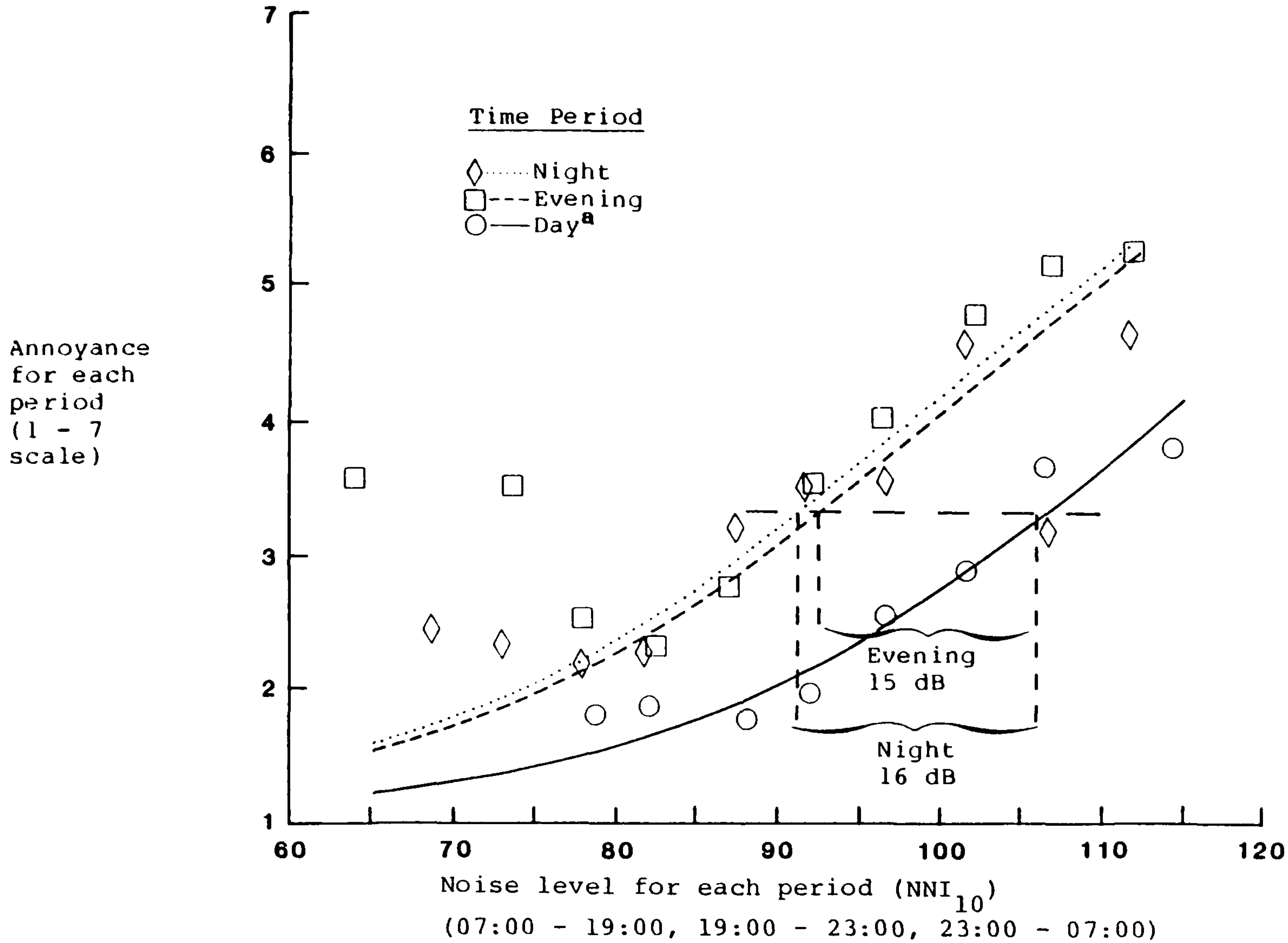


Figure 4.1: Relationship between period annoyance scores and noise level in three periods (1967 Heathrow)

(Source: Analysis of original data set at NASA)
[a. The 1967 Heathrow survey questions referred to morning and afternoon separately, not to "daytime". The "day" score is the morning or afternoon score, whichever is higher.]

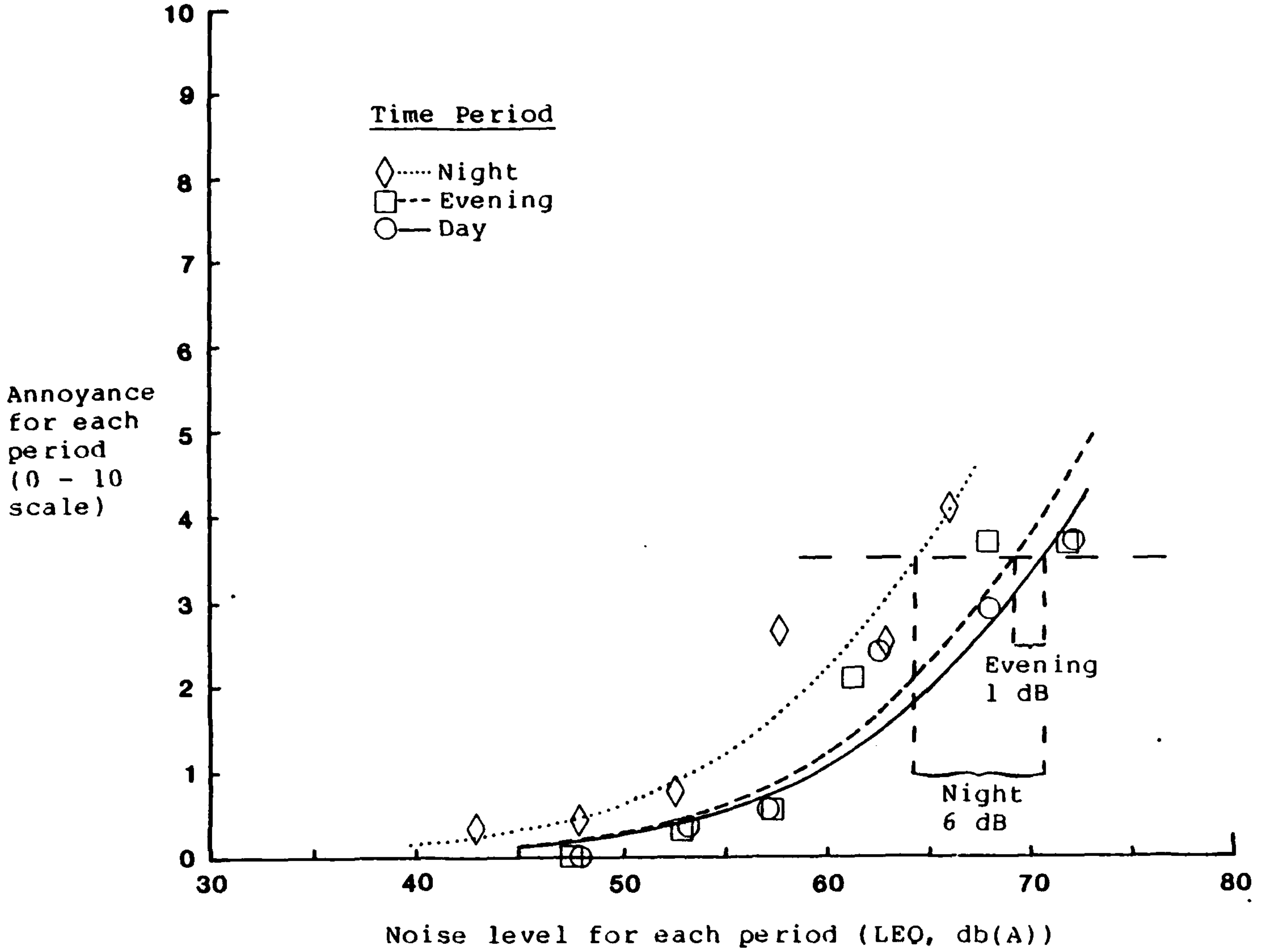


Figure 4.2: Relationship between period annoyance scores and noise level in three periods *(1978 Ontario Road Traffic)*

(Source: Analysis of original data set at NASA)

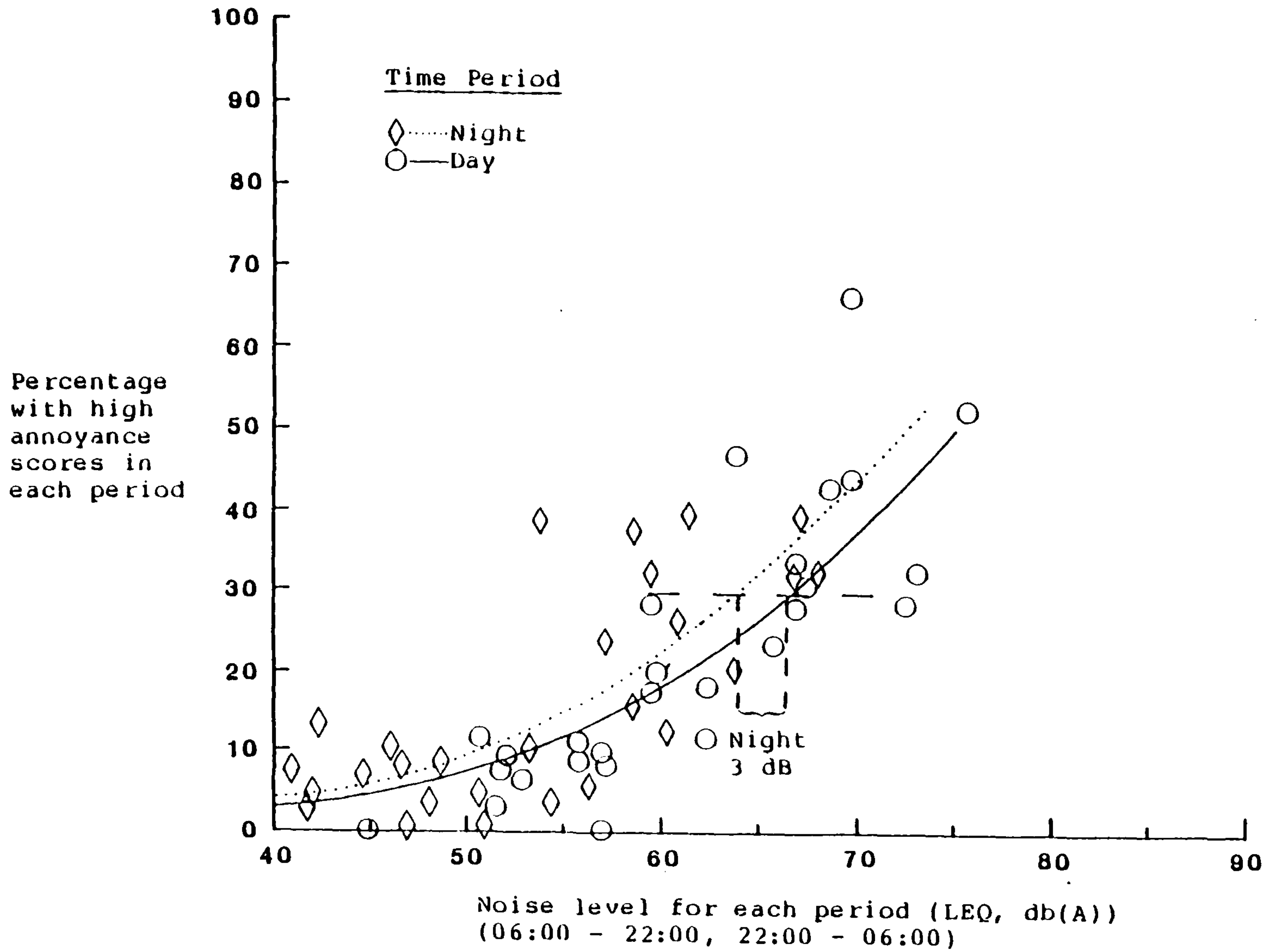


Figure 4.3: Relationship between period annoyance scores and noise level in two periods (1978 Zurich Road Traffic)

(Source: Nemecek, et al., 1981: Fig. 3)

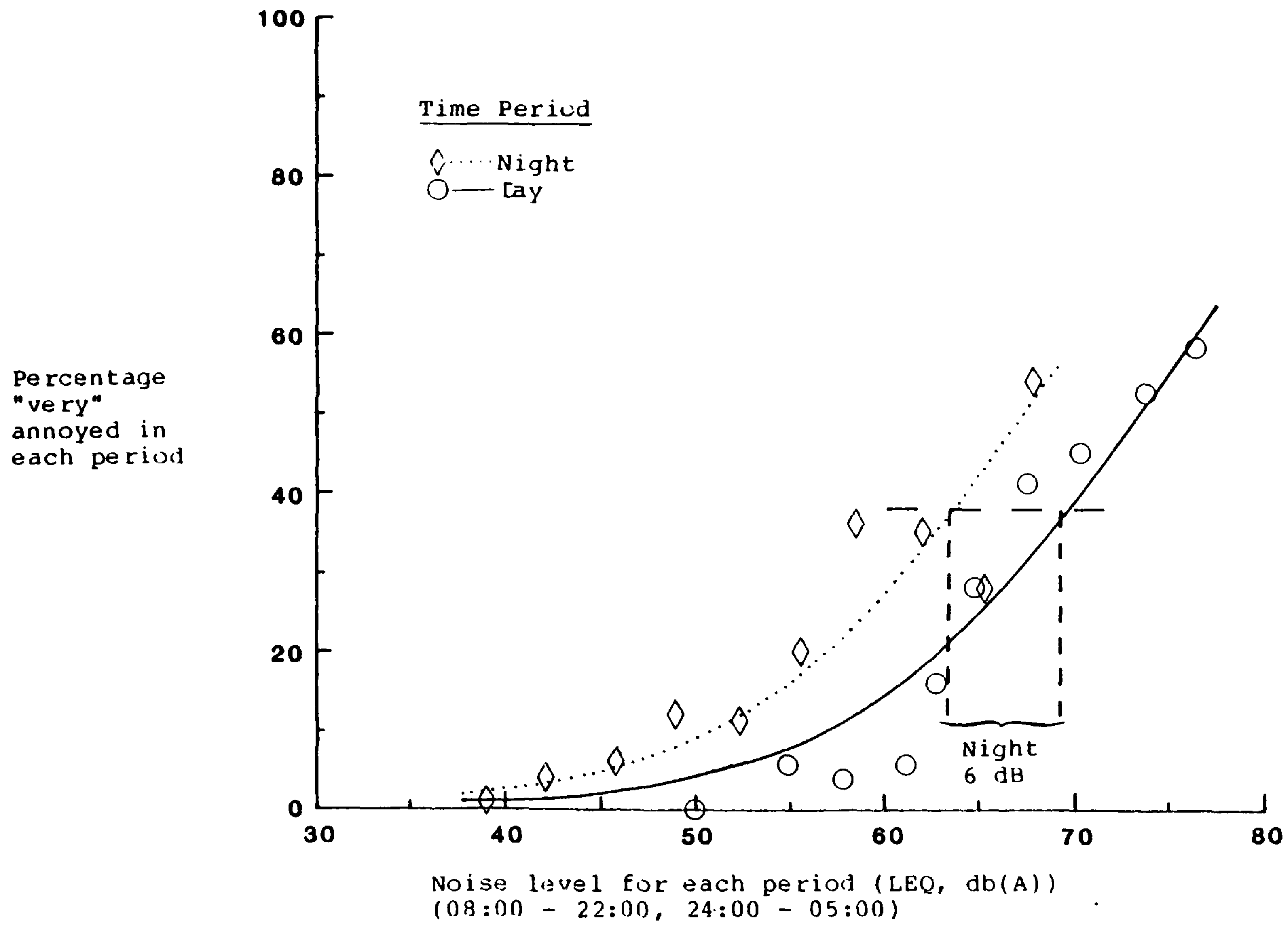


Figure 4.4: Relationship between period annoyance scores and noise level in two periods (1979 French Road Traffic)

(Source: Lambert et al., 1979 Fig. 3 and 4)

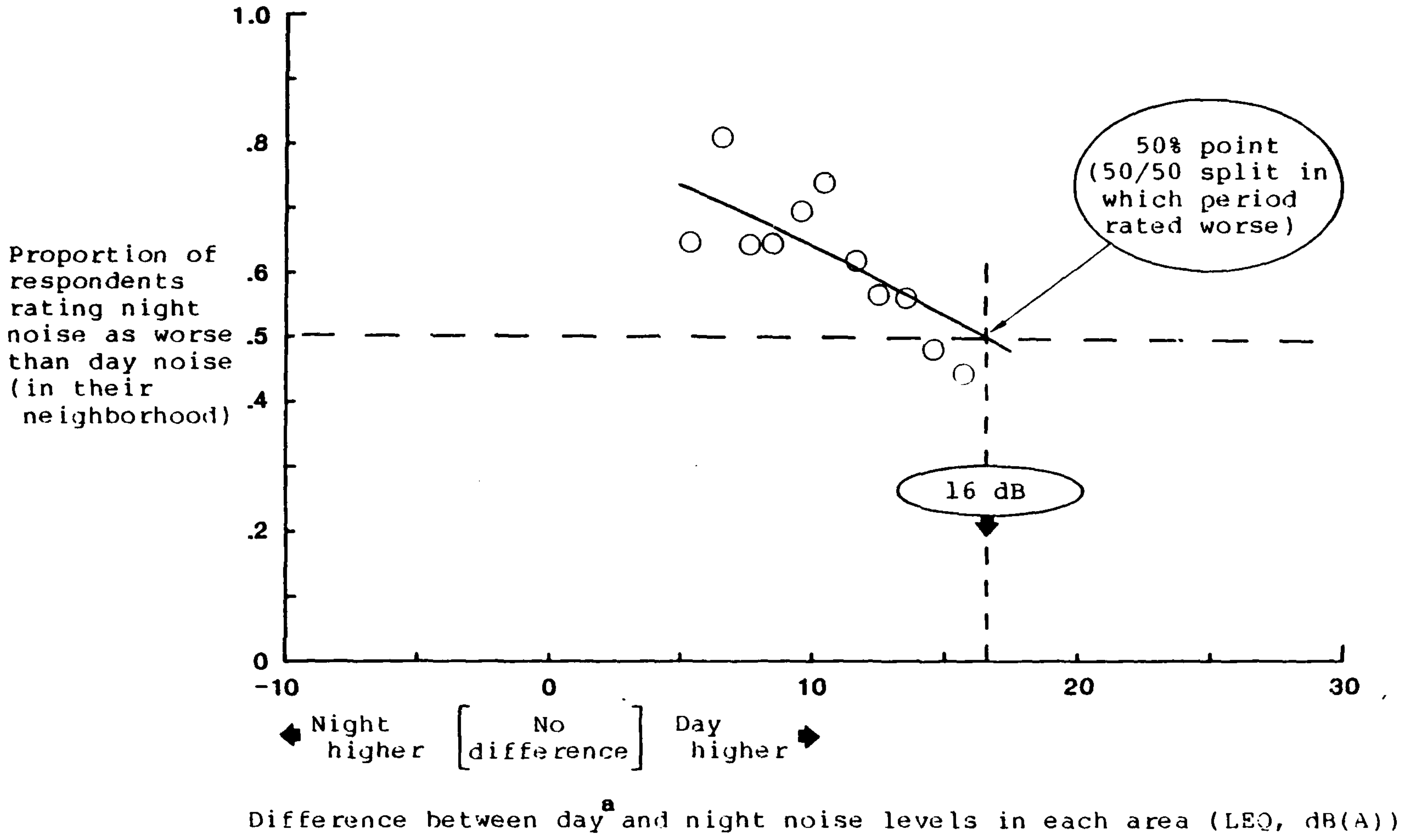


Figure 4.5: Proportion rating nighttime noise as worst by difference between daytime and nighttime noise levels (1967 Heathrow)

(Source: Analysis of original data set at NASA)
[a. "Day" combines morning and afternoon. See footnote a, Figure 4.1.]

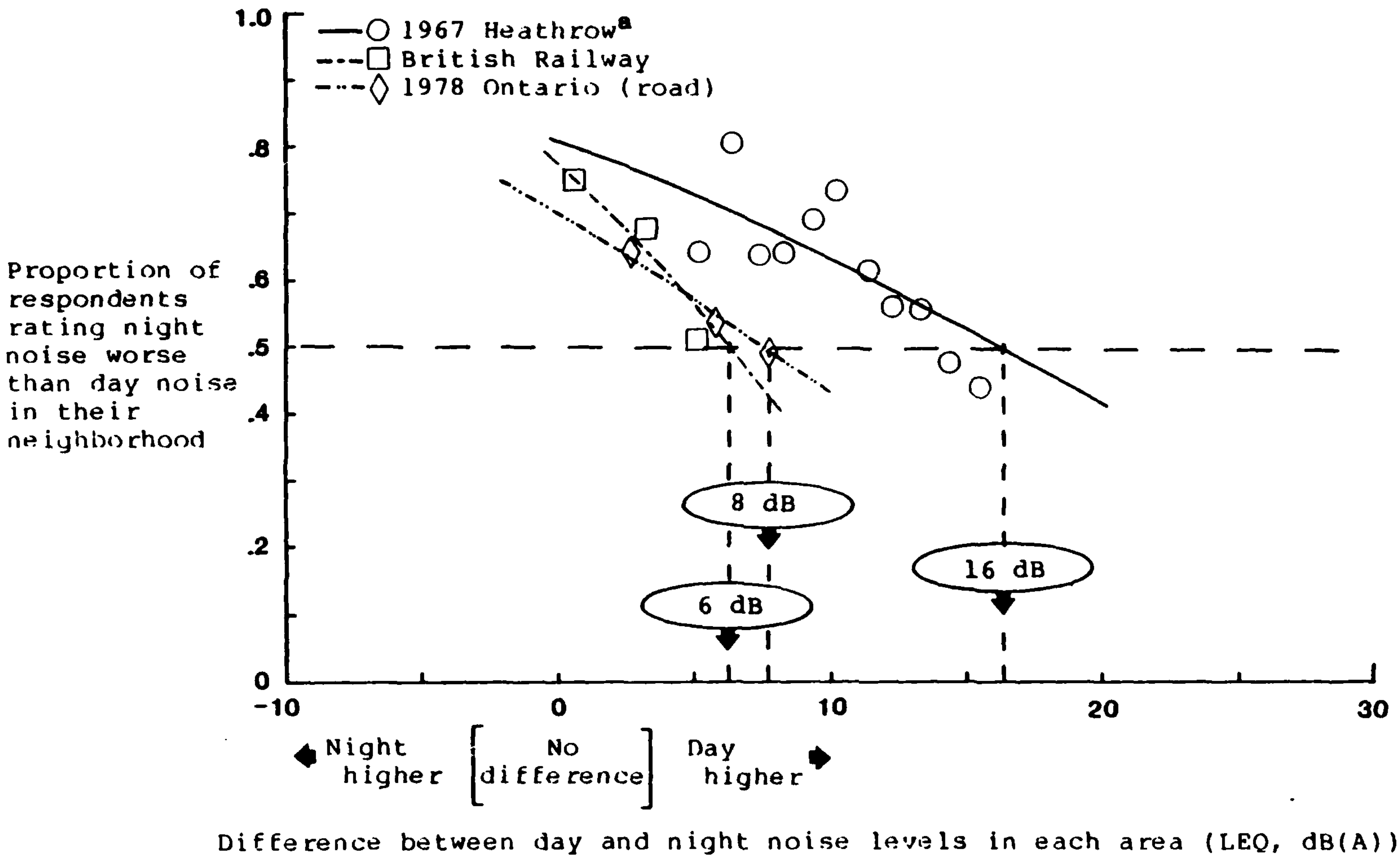


Figure 4.6: Proportion rating nighttime noise as worst by difference between daytime and nighttime noise levels for three surveys

(Source: Analysis of original data set at NASA)
[a. "Day" combines morning and afternoon.]

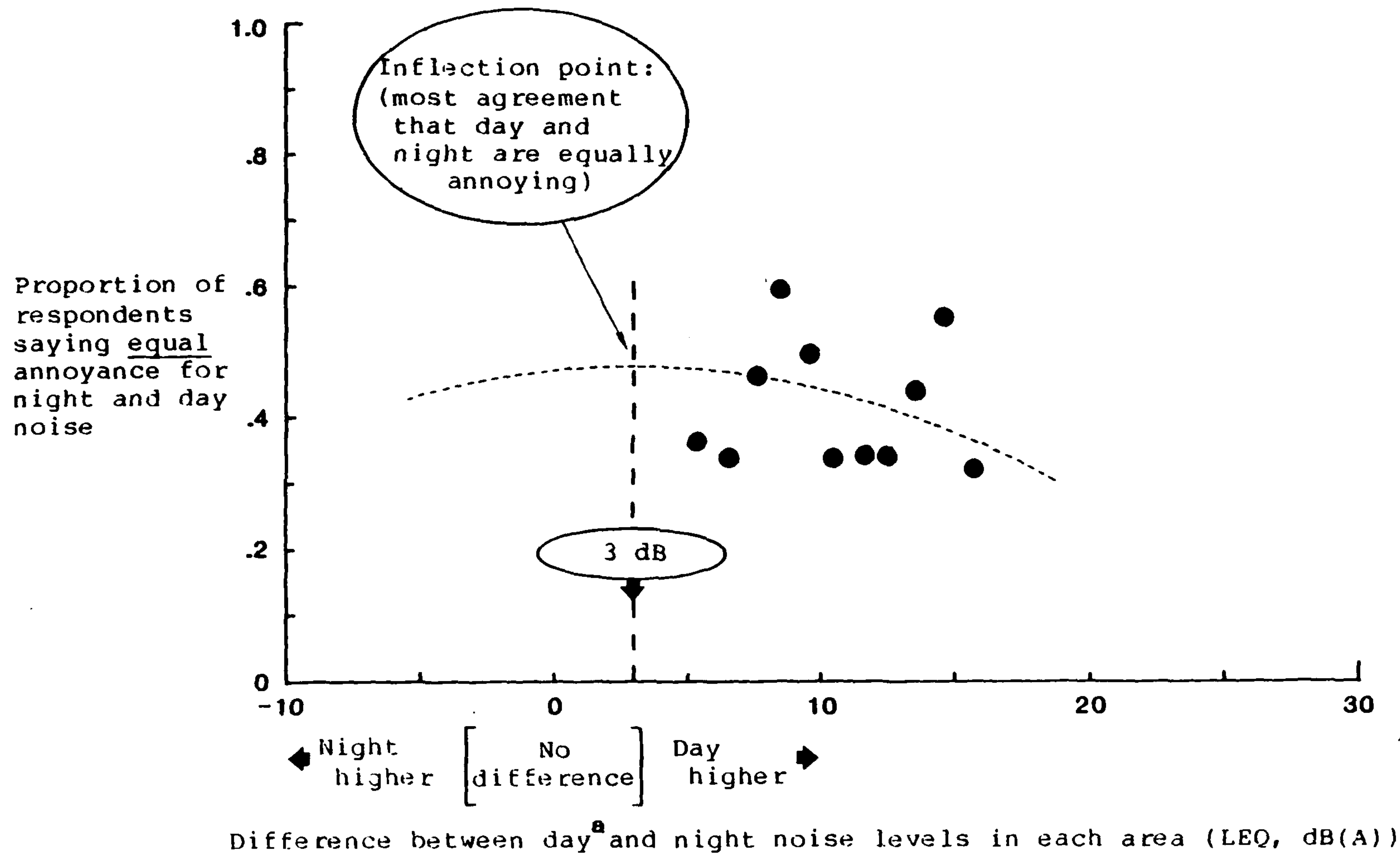


Figure 4.7: Proportion rating daytime and nighttime noise as equally *annoying* (1967 *Heathrow*)

(Source: Analysis of original data set at NASA)
[a. "Day" combines morning and afternoon.]

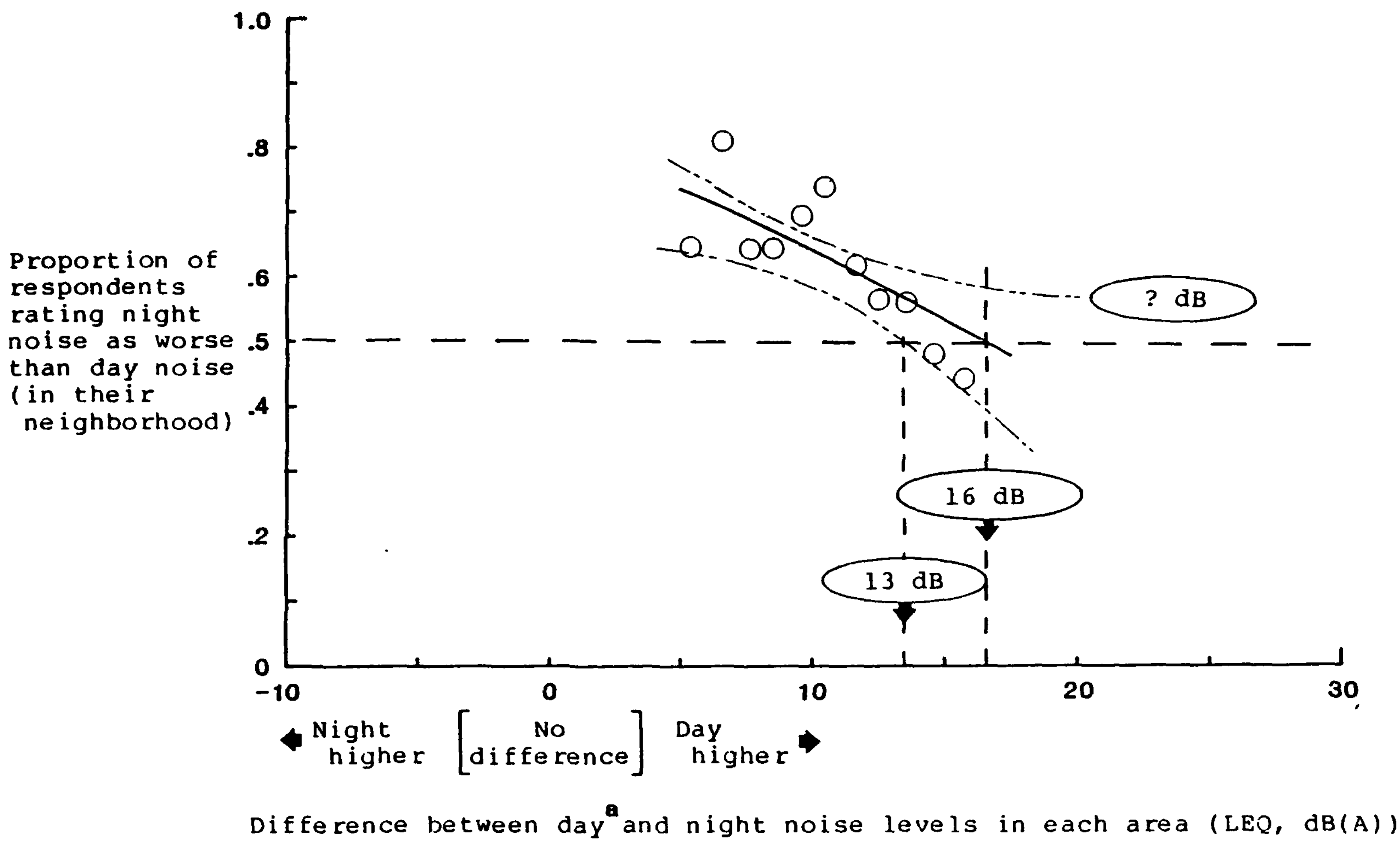


Figure 4.8: Confidence interval (95%) for the difference in noise levels at which day and night noise are equally annoying (1967 Heathrow)

(Source: Analysis of original data set at NASA)

[a. "Day" combines morning and afternoon.]

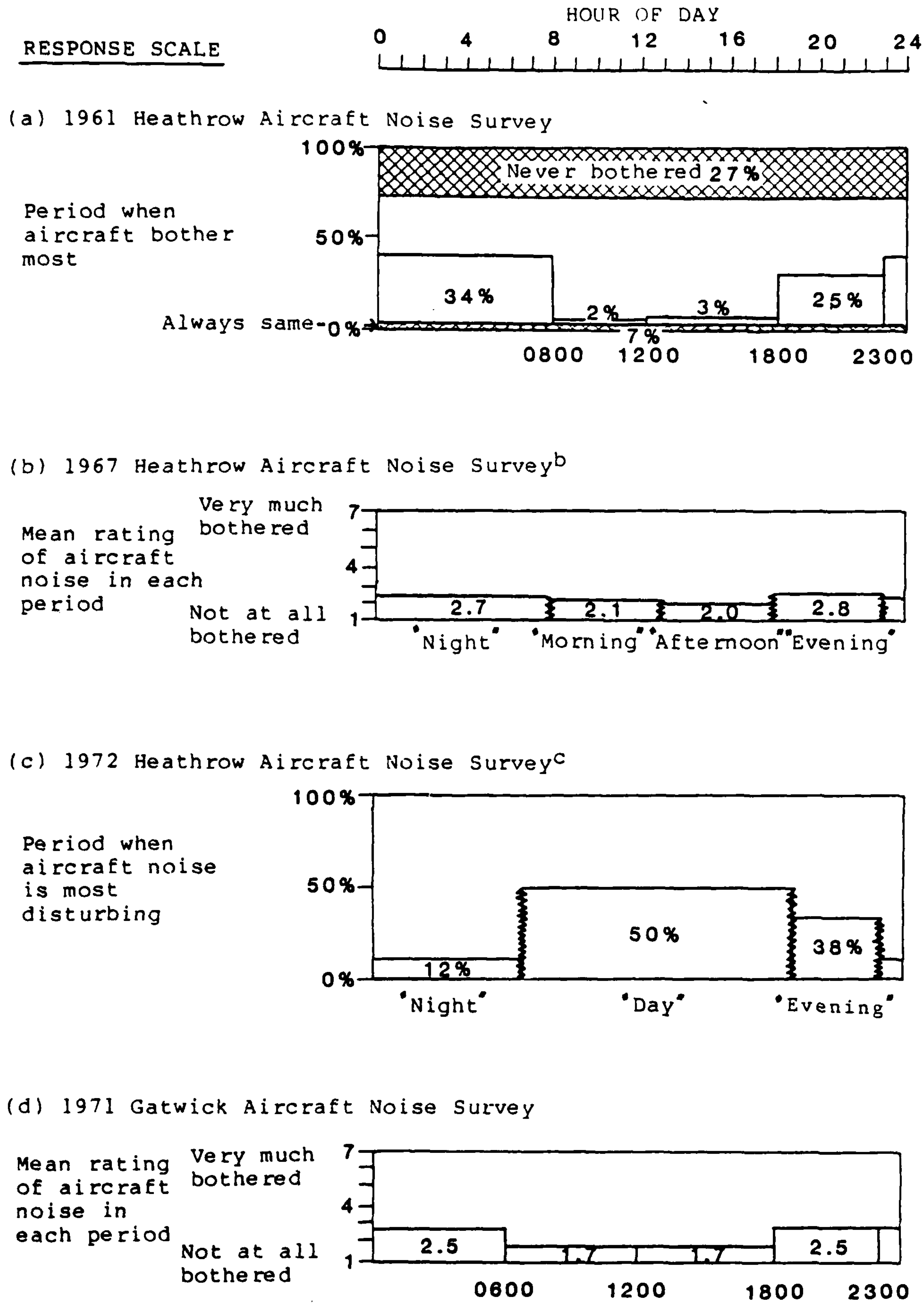


Figure 4.9: Noise annoyance by time-of-day in four English aircraft surveys[a]

(Sources: Figure 4.9a-- McKennell, 1963: Appendix P., p.11.
Figure 4.9b-- Analysis of original data set at NASA.
Figure 4.9c-- Ollerhead, 1978: p.76.
Figure 4.9d-- Ollerhead and Cousins, 1975: p. 98.)

a. When the questionnaire defines the hours for the time periods (eg. Figure 4.9a), the times for each period are entered below the figure and boundaries between periods are marked with straight vertical lines. When the questionnaire only contains verbal descriptors (eg. Figure 4.9 b), the labels are entered below each figure and boundaries between periods are marked with jagged lines.

b. Respondents who answer "don't know" are excluded from the analysis. Those saying they do not hear aircraft are given a score of "1".

c. Respondents are excluded from Figure 4.9c who answered "don't know", "not disturbed" or "do not hear" the aircraft. Night is defined as the time when "trying to sleep."

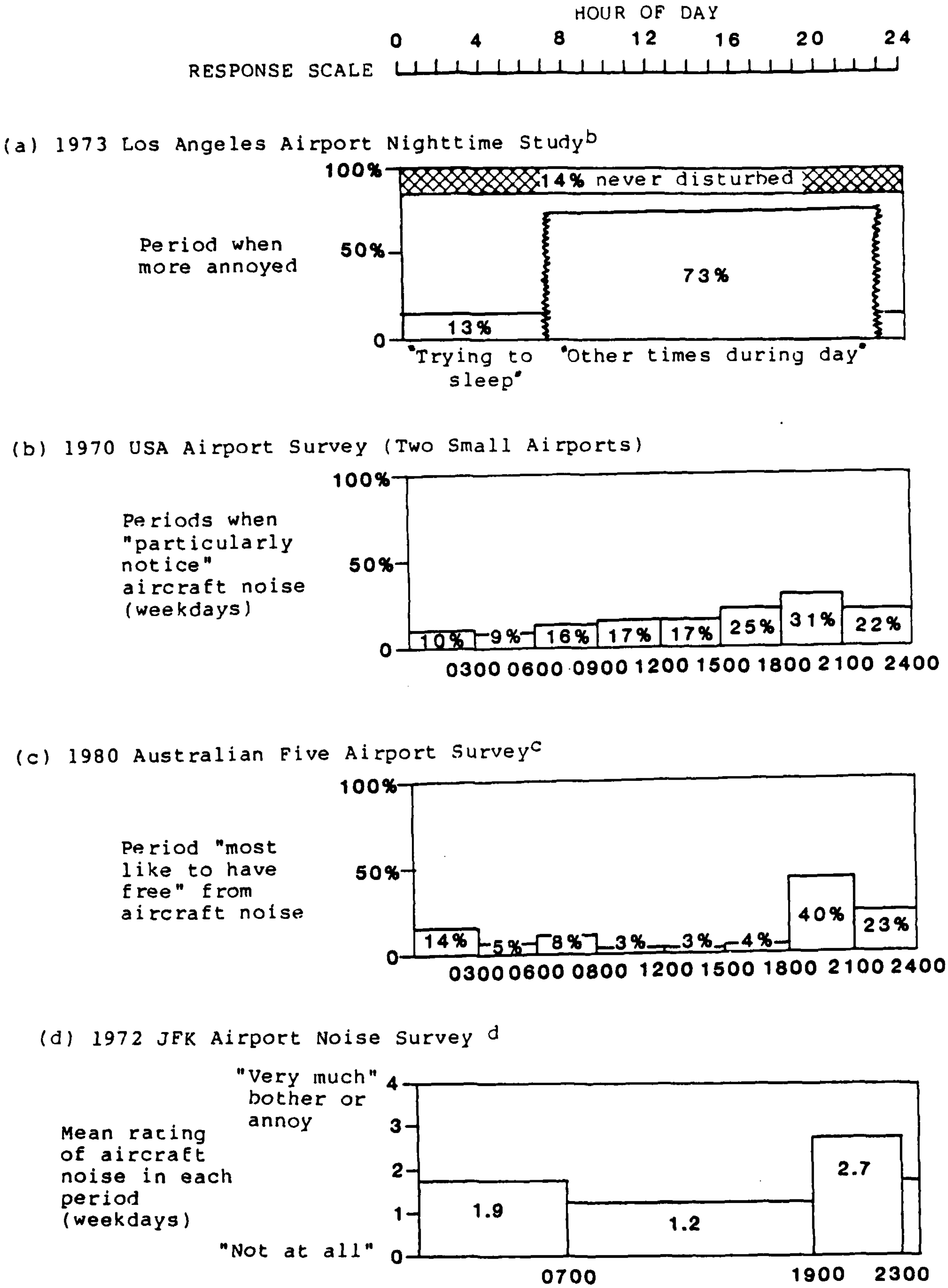


Figure 4.10: Noise annoyance by time-of-day in USA and Australia aircraft surveys[a]

(Sources: Figure 4.10a-- Analysis of original data set at NASA.
Figure 4.10b-- Analysis of original data set at NASA.
Figure 4.10c-- Bullen and Hede, 1983: p.1629.
Figure 4.10d-- Borsky, 1976: p. 20.)

a. See Figure 4.9, *footnote a*.

b. Respondents are excluded from the analysis who answered "don't know". The study was conducted in three waves of interviews. Answers from all three waves are reported together here because the time of the interview did not appear to affect the responses.

c. Respondents are excluded from the analysis who answered "don't know" or "not bothered" by aircraft noise.

d. Only people "usually at home during" most of all three time periods are included.

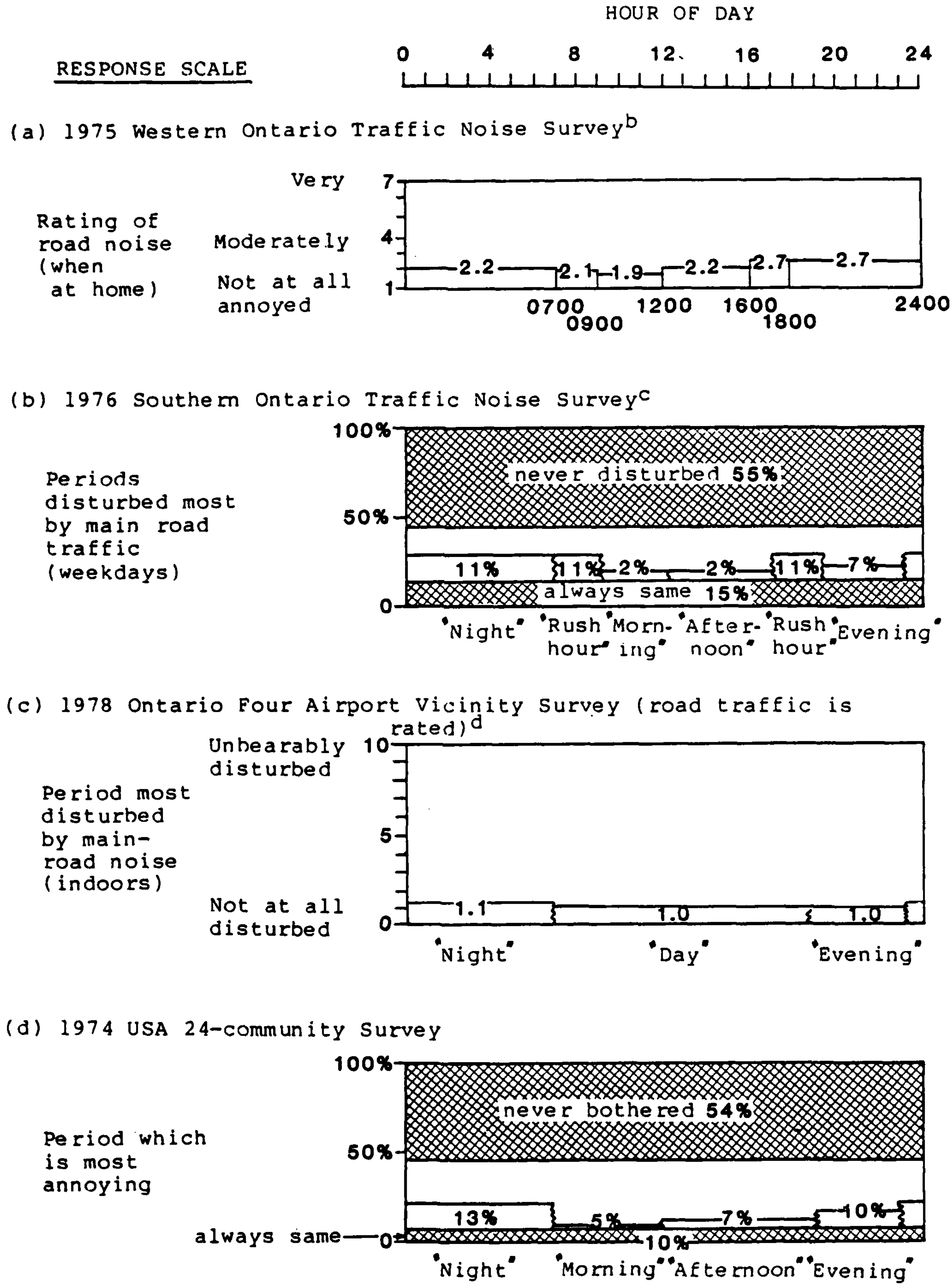


Figure 4.11: Noise annoyance by time-of-day in four road traffic surveys[a]

(Sources: All figures are based on analyses of original data sets at NASA.)

a. See Figure 4.9, footnote a.

b. Respondents were not asked about periods when they were not usually home on weekdays. Thus the same respondents do not provide ratings during all periods.

c. For this survey the respondents were asked when they were most disturbed in an open question. Respondents could thus use verbal descriptors for time periods (eg. "morning rush hour") which were not presented as alternatives in other studies. Multiple designations of "worst" periods were permitted.

d. Respondents are scored zero if they had previously said they were not disturbed.

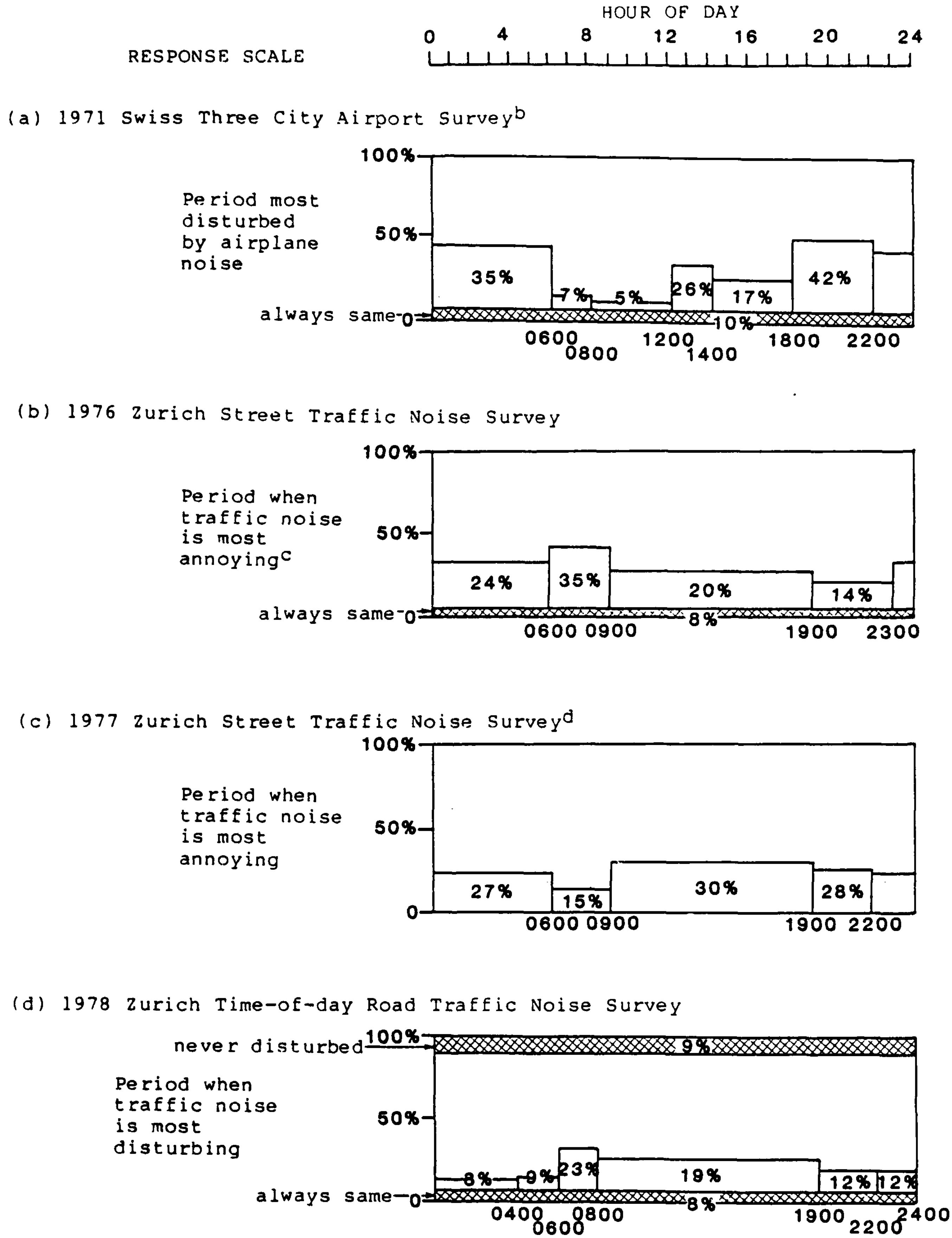


Figure 4.12: Noise annoyance by time-of-day in four Swiss surveys[a]

(Source: Figure 4.12a-- Graf et al., 1974: p. 51.
Figure 4.12b-- Wanner et al., 1977: p. 701.
Figure 4.12c-- Wanner et al., 1977: p.701.
Figure 4.12d-- Analysis of original data set at NASA.)

a. See Figure 4.9, footnote a.

b. Multiple designations of the "most disturbed" periods were permitted.

c. Respondents are excluded who reported they were never bothered by traffic noise.

d. Respondents are excluded who reported they were never bothered by traffic noise. This question did not include a response category for being bothered the same amount during all periods.

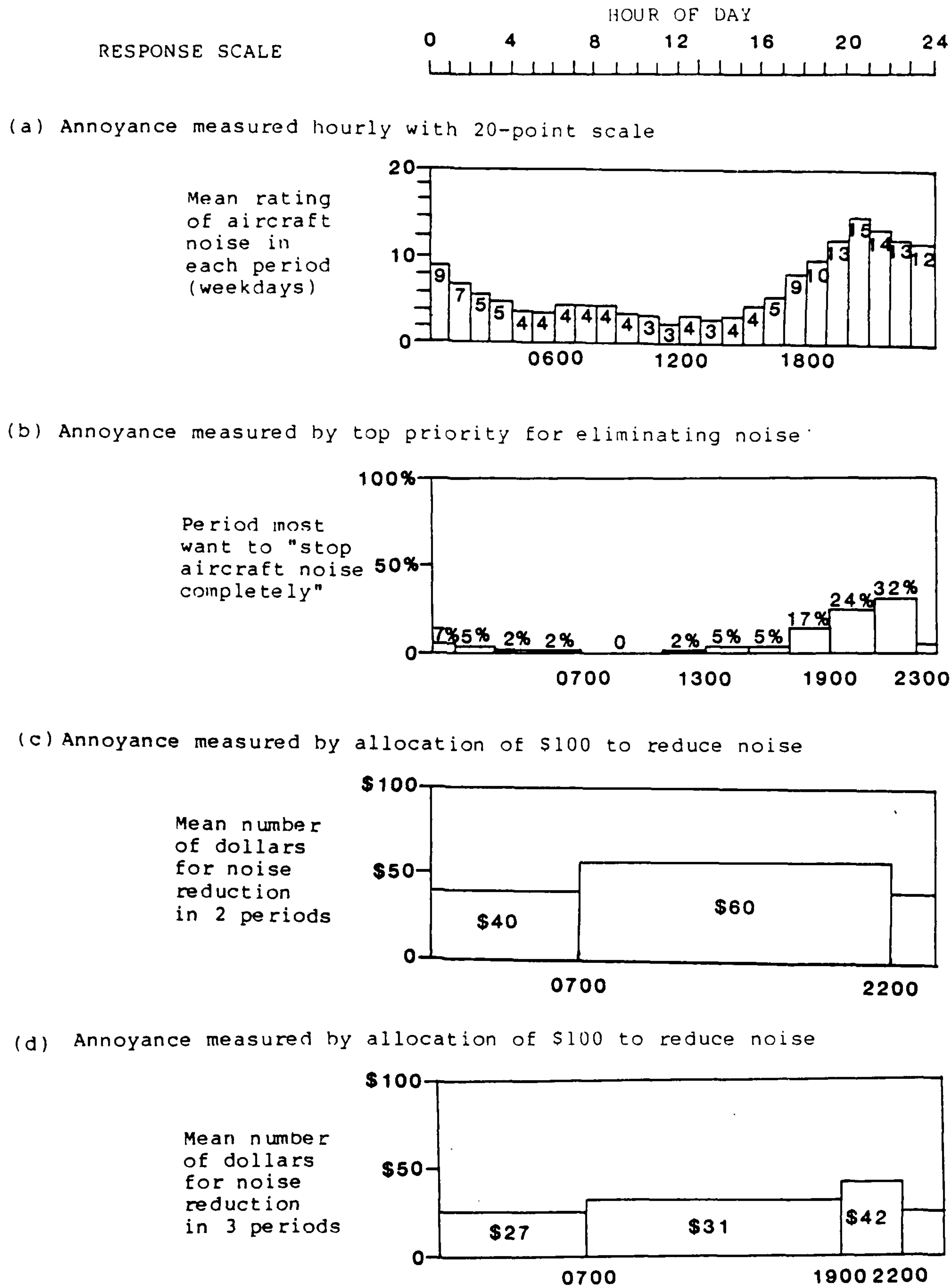


Figure 4.13: **Noise annoyance by time-of-day in JFK (New York) questionnaire development study for four questionnaire items[a]**

(Source: Analyses at NASA of the data from an unpublished study conducted under the direction of Eugene Galanter at Columbia University, New York. The study was performed to evaluate alternative questions for time-of-day surveys.

1975 British National Railway Noise Survey

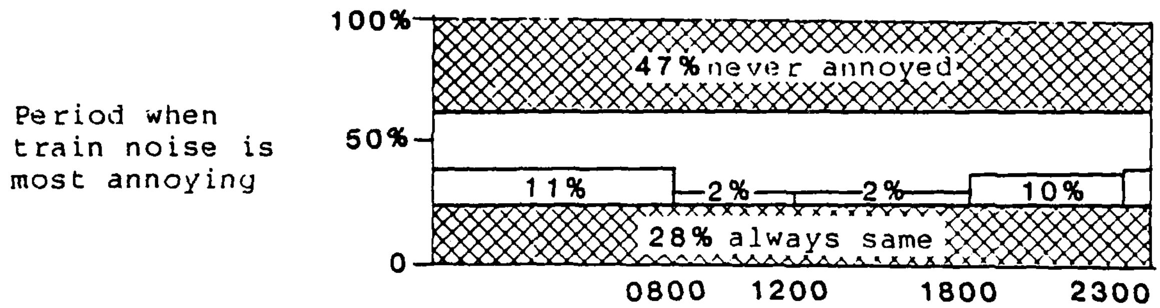


Figure 4.14: Noise annoyance by time-of-day in British railway survey[a]

(Source: Analysis of original data set at NASA)

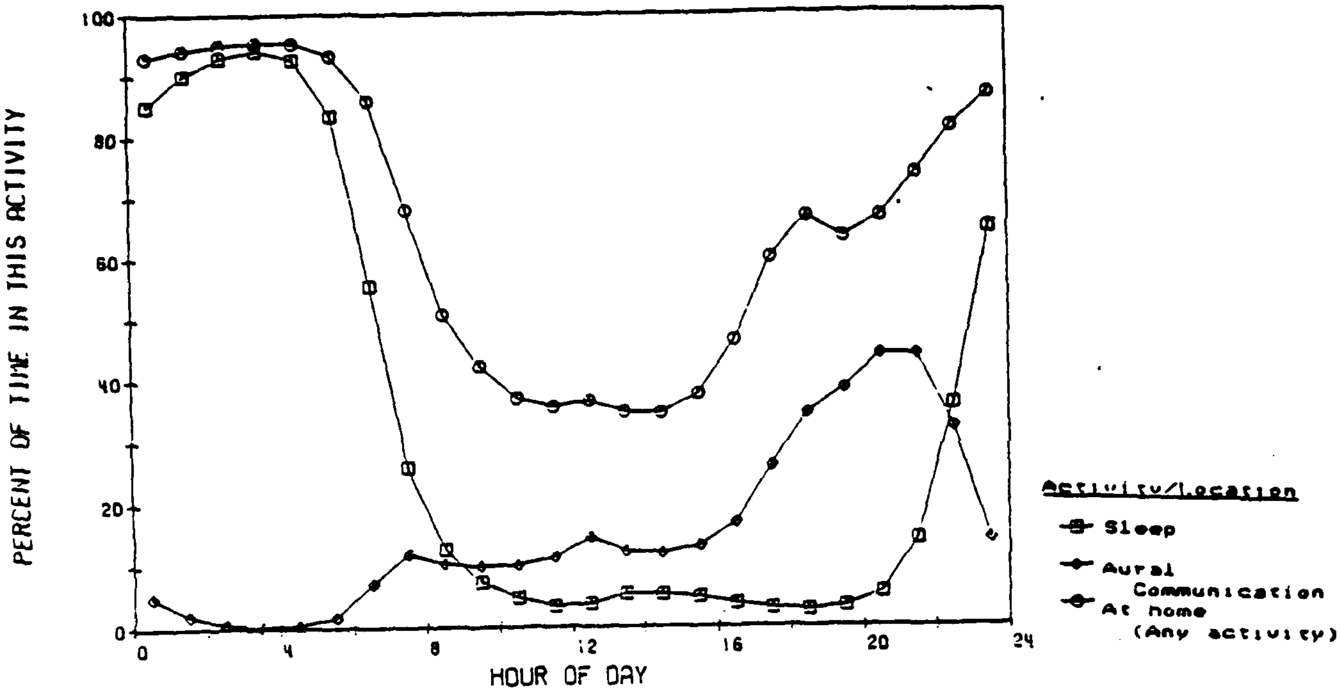


Figure 5.1: Average time (percentage) at home and in two activities (at home) on weekdays (Monday-Friday)

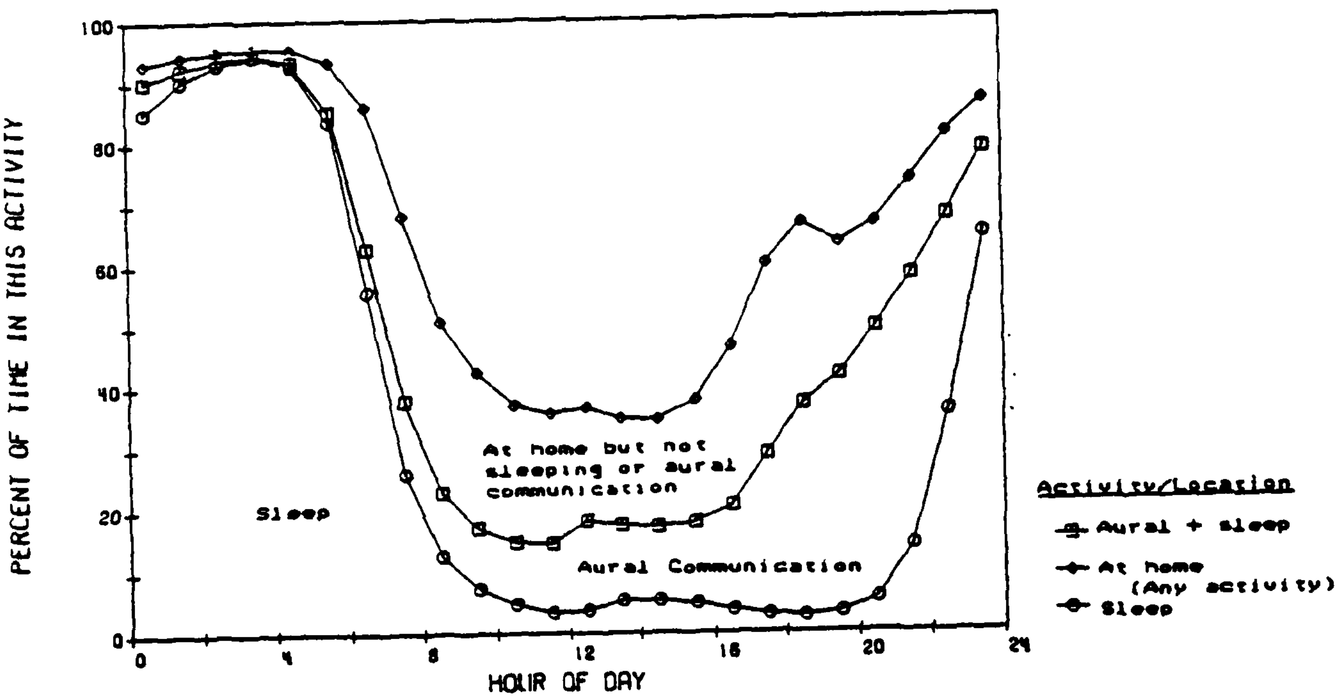


Figure 5.2: Average time (percentage) at home and cumulated for two activities on weekdays (Monday-Friday)

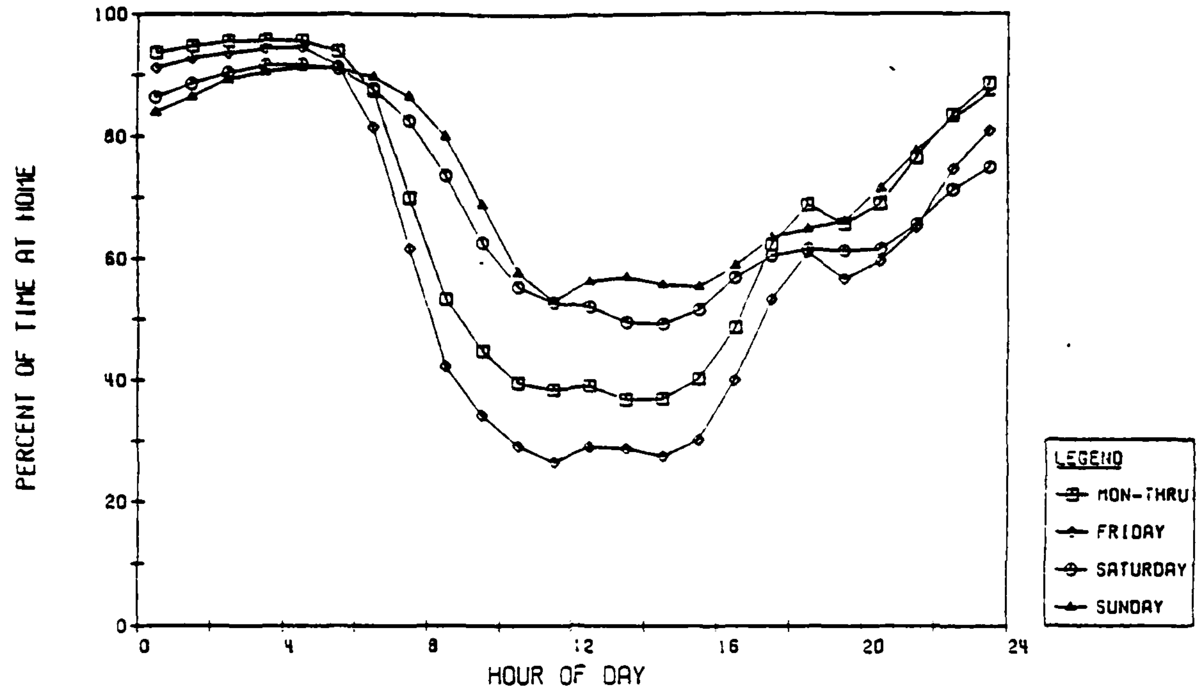


Figure 5.3: Average time (percentage) at home on four types of days

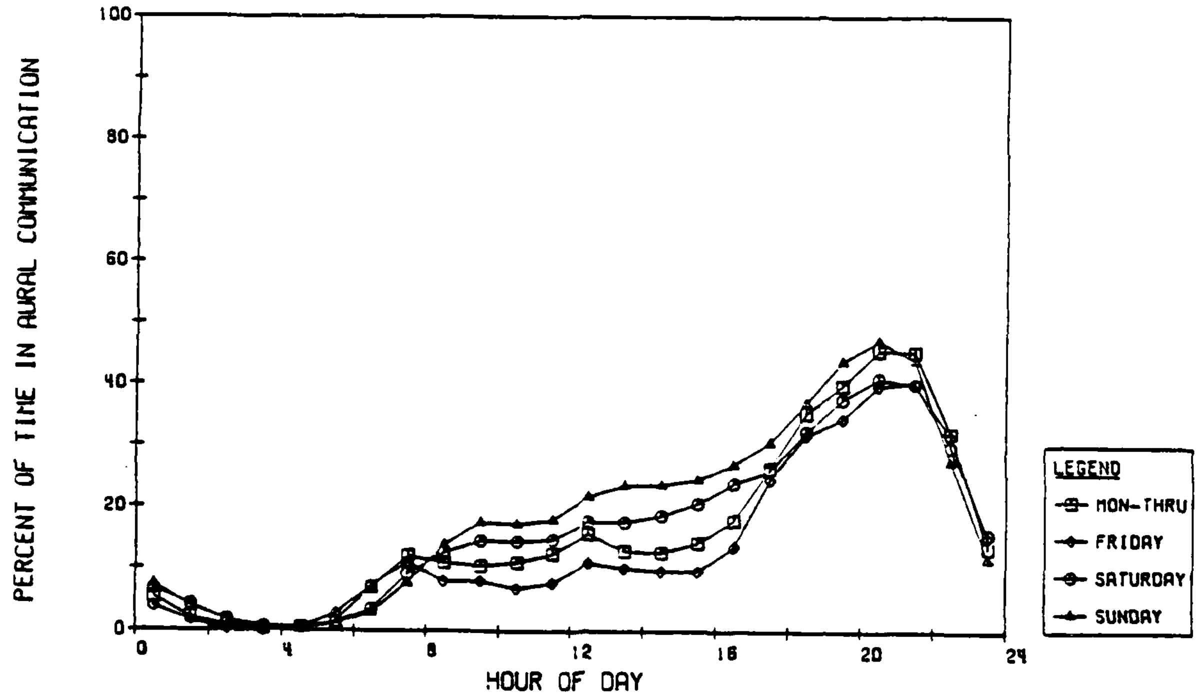


Figure 5.4: Average time (percentage) engaged in aural communication on four types of days

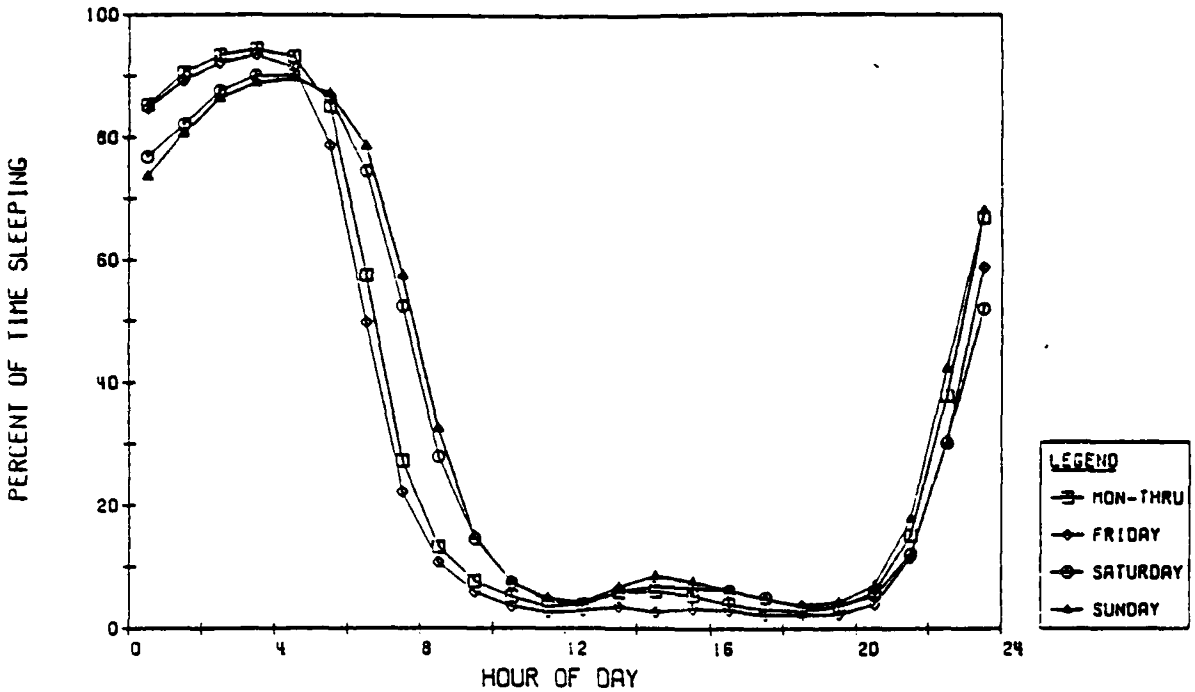


Figure 5.5: Average time (percentage) sleeping on four types of days

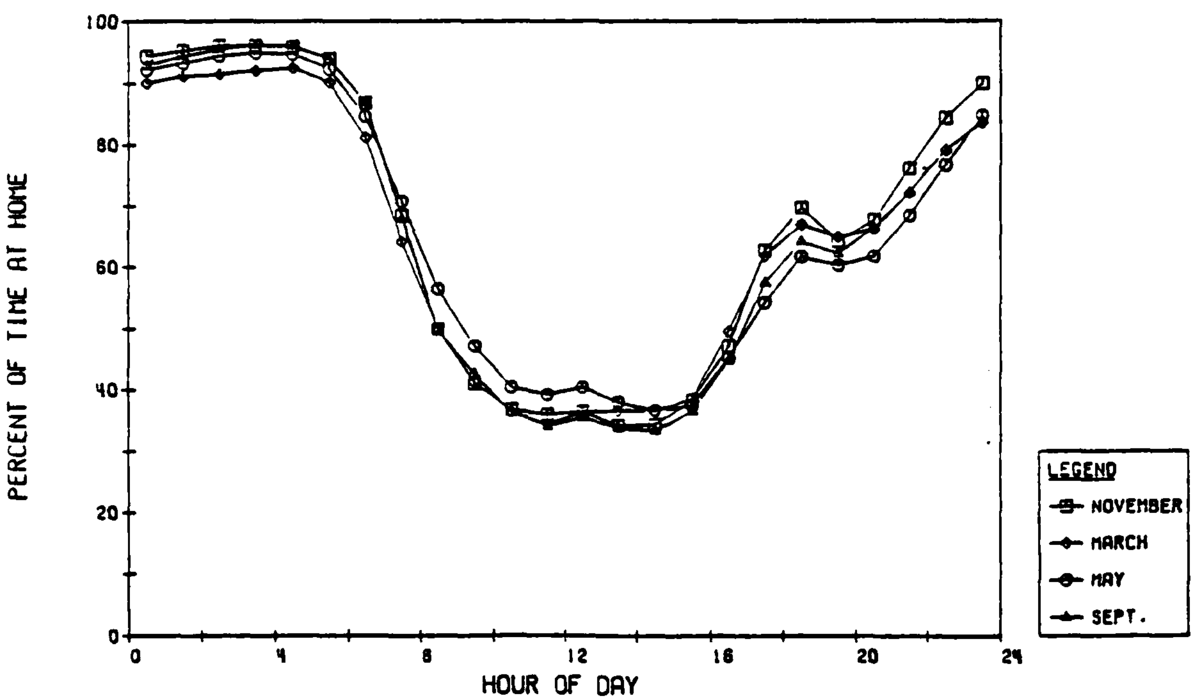


Figure 5.6: Average time (percentage) at home for four age groups (weekdays)

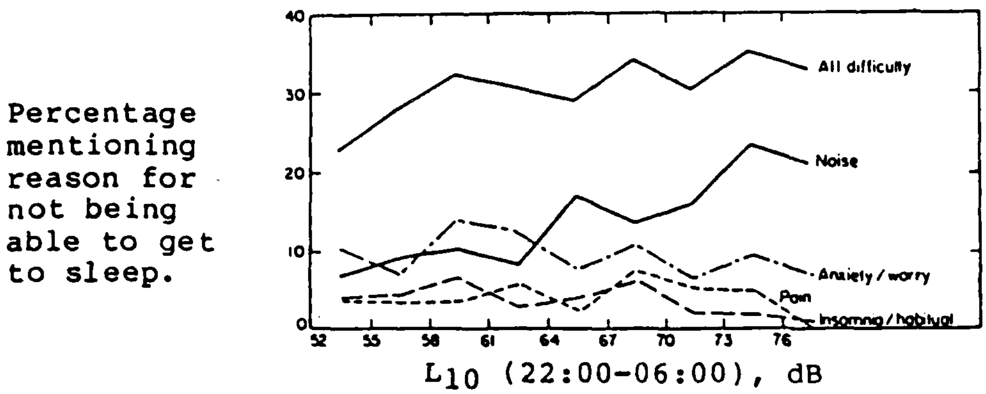


Figure 6.1: Reasons given for difficulty in getting to sleep (1972 London road traffic survey)

(Source: Langdon and Buller, 1977; Fig. 3.

Question:

Q.a I'd like to ask you some questions about going to sleep. Do you yourself have trouble getting to sleep? ALWAYS/VERY OFTEN, SOMETIMES, NEVER/HARDLY EVER, DON'T KNOW?

ALL ANSWERING "ALWAYS", "VERY OFTEN" OR "SOMETIMES"

Q.b What do you think is the main reason? NOISE FROM OUTSIDE, PAIN/PHYSICAL DISCOMFORT/ILLNESS, WORRY/TENSION/ EXHAUSTION, ALWAYS FOUND IT DIFFICULT, OTHER REASON, DON'T KNOW)

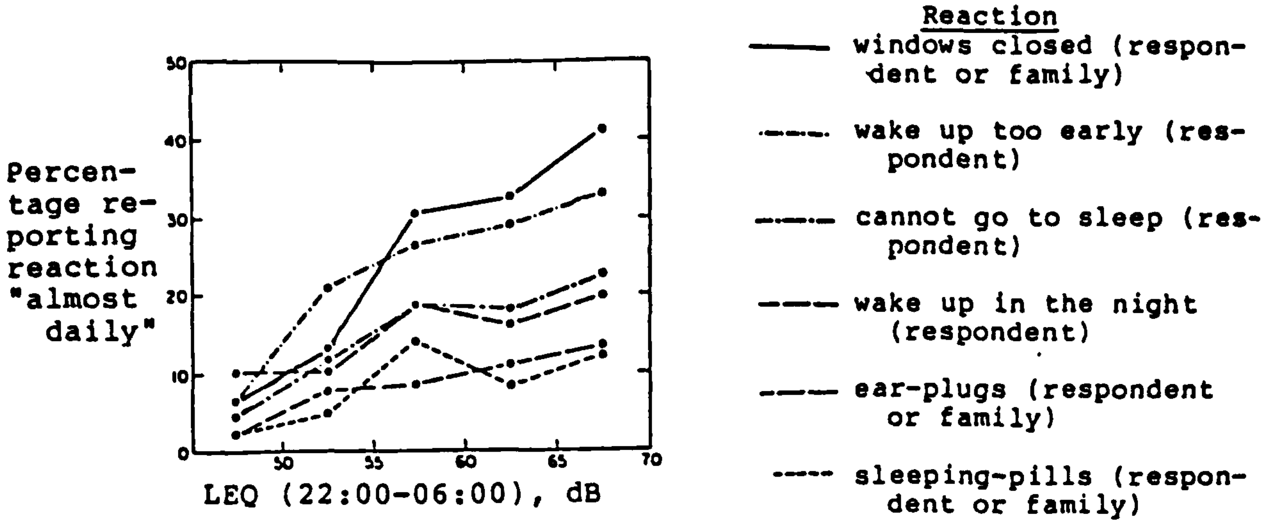


Figure 6.2: Indications of nighttime disturbance (1978 Zurich nighttime survey)

(Source: Nemecek, et. al., 1981; Fig. 5. These figures appeared in bar chart form as Figures 6 and 7 in an earlier publication

(Wehrli et al., 1978) in which the reaction is dichotomized between "several times a week" and "almost daily". Question: (Note that this follows in a series of questions about road traffic noise).

Q.20 Are there times when you or members of your family because of the traffic noise at home:
(a) put cotton, earplugs, or something similiar in during the night?
(b) take sleeping pills or sedatives
(c) keep the bedroom windows closed during the night
(Almost daily, several times a week, sometimes, never)

[Q.20 Kommt es vor, dass Sie oder Ihre Angehorigen wegen des Verkehrslarms:
(a) in der Nacht Watte, Ohropax oder ahnliche Mittel verwenden
(b) Schlaf - oder Beruhigungsmittel einnehmen
(c) in der Nacht das Schlafzimmer fenster geschlossen halten
(fast taglich, nehrmals pro Woche, hie & da, nie)]

Q.24 Does it happen that because of the traffic noise at home you:
(a) cannot fall asleep
(b) wake up suddenly during the night
(c) wake up too early in the morning
(almost every night, several times per week, sometimes, never)

[Q.24 Kommt es vor, dass Sie zuhause wegen des Verkehrslarms:
(a) nicht einschlafen konnen
(b) nachts plotzlich aufwachen
(c) morgens zu fruh erwachen
(fast jede Nacht, mehrmals pro Woche, hie & da, nie)]

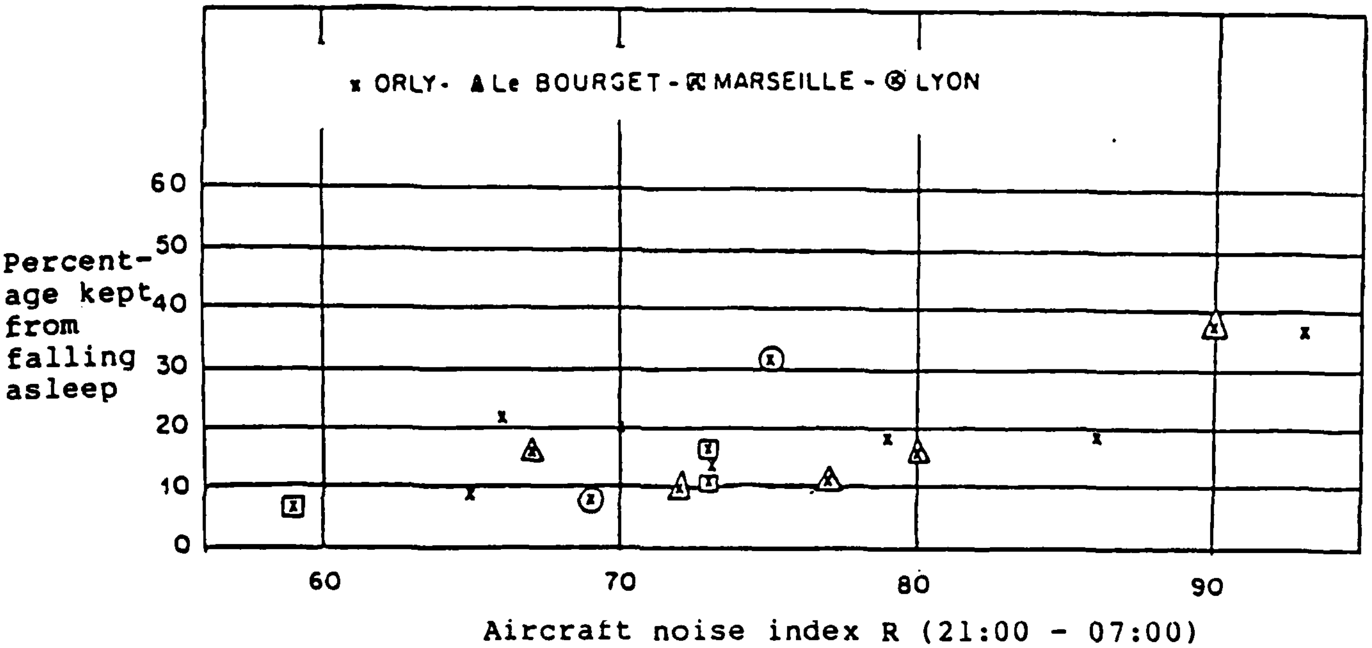


Figure 6.3: Effect of aircraft noise on falling asleep at three French airports

(Source: La Gene Causes Par le Bruit Atour des Aeroports, 1968: p. 93

Question:

Q. Does aircraft noise do the following to you . . . stop you from falling asleep? (No, Sometimes, Quite Often)

[Q. Arrive-t-il que le bruit des avions . . . vous empeche de vous endormir? (Non, Parfois, Assez souvent)])

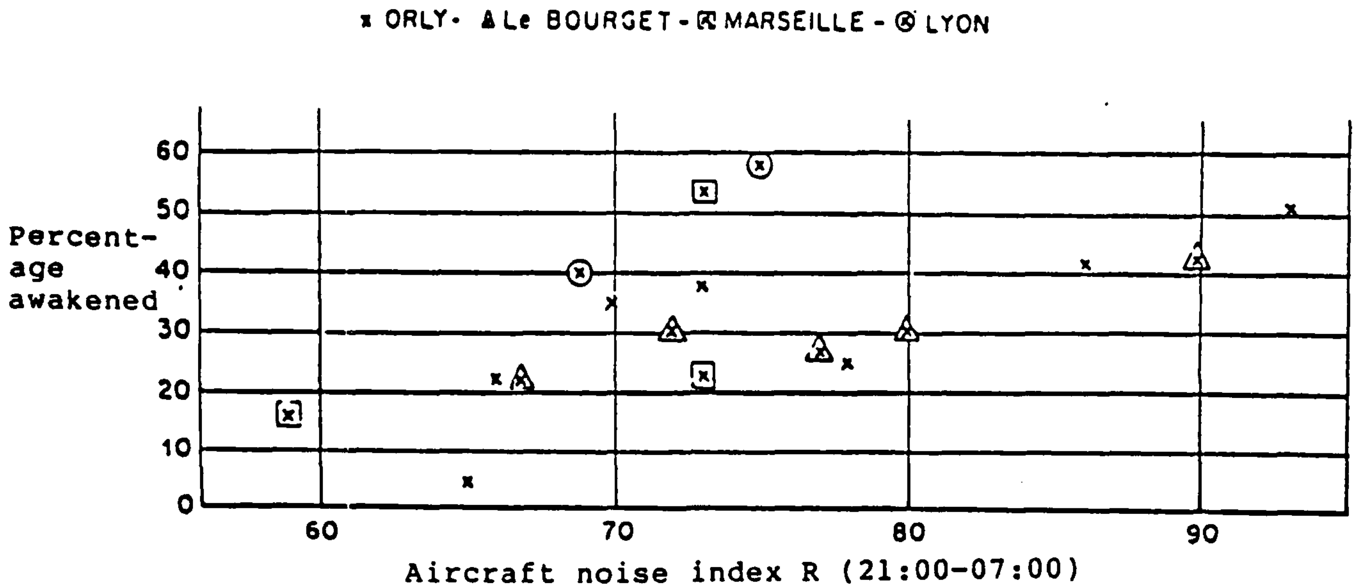
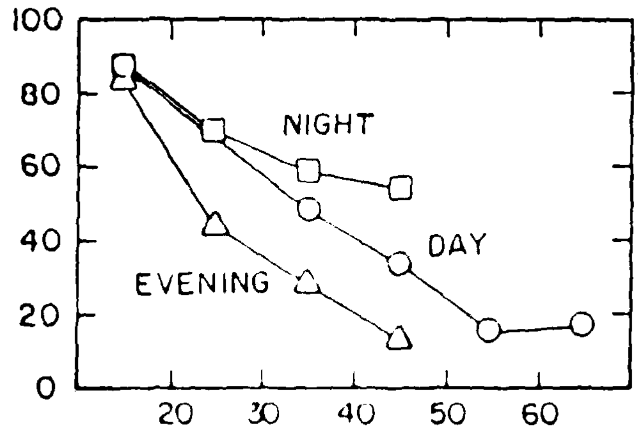


Figure 6.4: **Effect of aircraft noise on being awakened at three French airports**

(Source: La Gene Causes Par le Bruit Atour des Aeroports, 1968: p. 93
Question:
Q. Does aircraft noise do the following to you . . . wake you up? (No, Sometimes, Quite Often)

[Q. Arrive-t-il que le bruit des avions . . . vous reveille? (Non, Parfois, Assez souvent)])

Percentage with not even one disturbance in last four weeks.



Noise and Number Index (07:00-19:00, 19:00-23:00, 23:00-07:00)

Figure 6.5: Reports of no disturbance by noise level in three time periods (1972 Heathrow survey

(Source: Ollerhead, 1978, Fig. 4.)

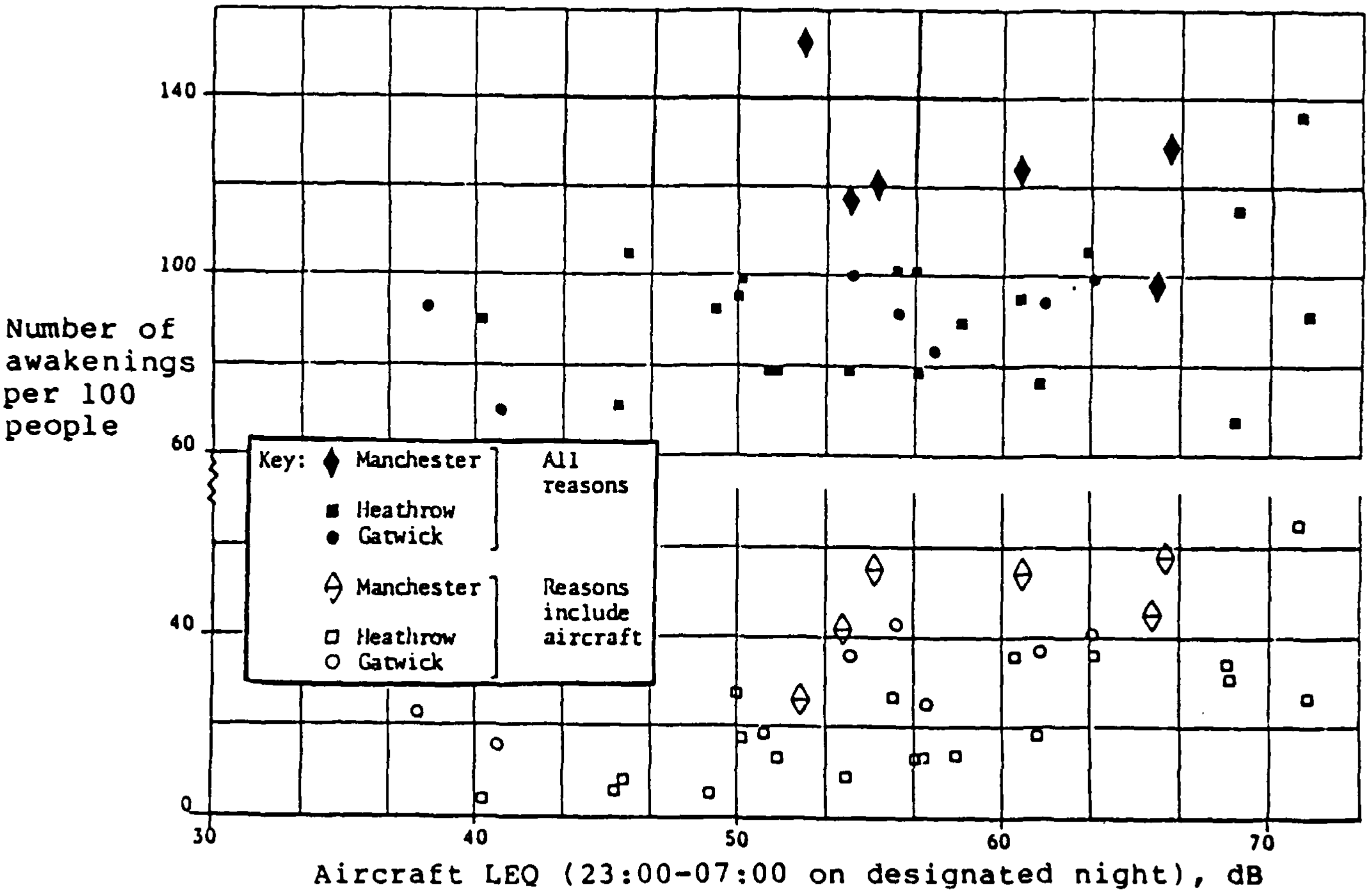


Figure 6.6: **Numbers of total awakenings and number attributed to aircraft noise on designated nights (English Airport Night Surveys)**

(Source: Brooker and Nurse, 1982; Fig. 10.
Question:
Q.a Did you wake at all during <u>that night</u>? (Yes, No)

<u>IF YES</u>
Q.b How many times did you wake during that night (PLEASE TICK ONE ONLY) Once, Twice, 3 or 4 times, 5 or more times)

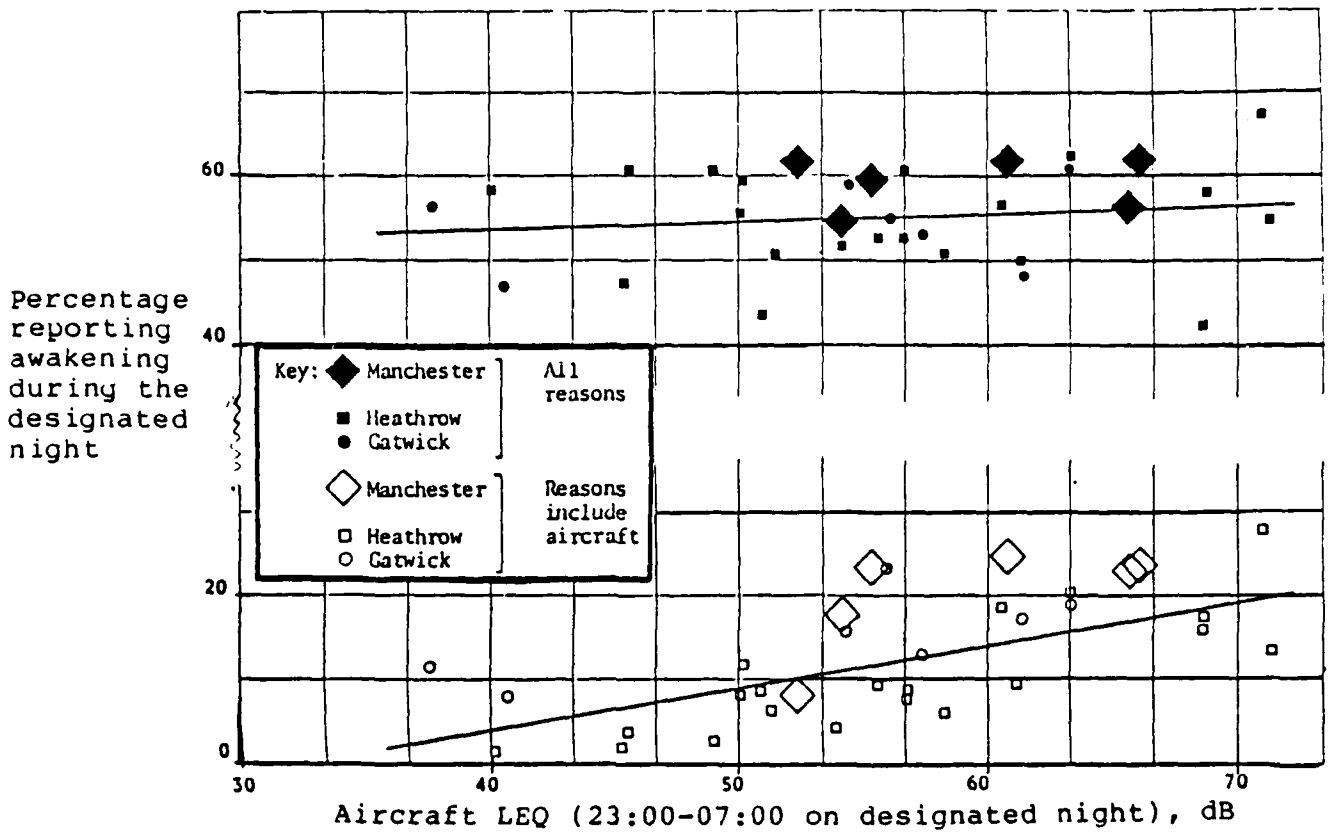


Figure 6.7: **Percentage reporting any awakening and percentage attributing an awakening to aircraft noise on designated nights (English Airport Night Surveys)**

(Source: Brooker and Nurse, 1982; Fig. 9.
Question:
Q.a Did you wake at all during that night? (Yes, No)

IF YES
Q.b What were the reasons you woke that night? (PLEASE TICK ALL WHICH APPLY) Road traffic noise/ Aircraft noise, Noise from people outside/neighbours, Other noise (inside or outside), Ill health, Worry/nerves, Need to use toilet, Other reason, no particular reason)

(Note: Regression lines exclude Manchester).

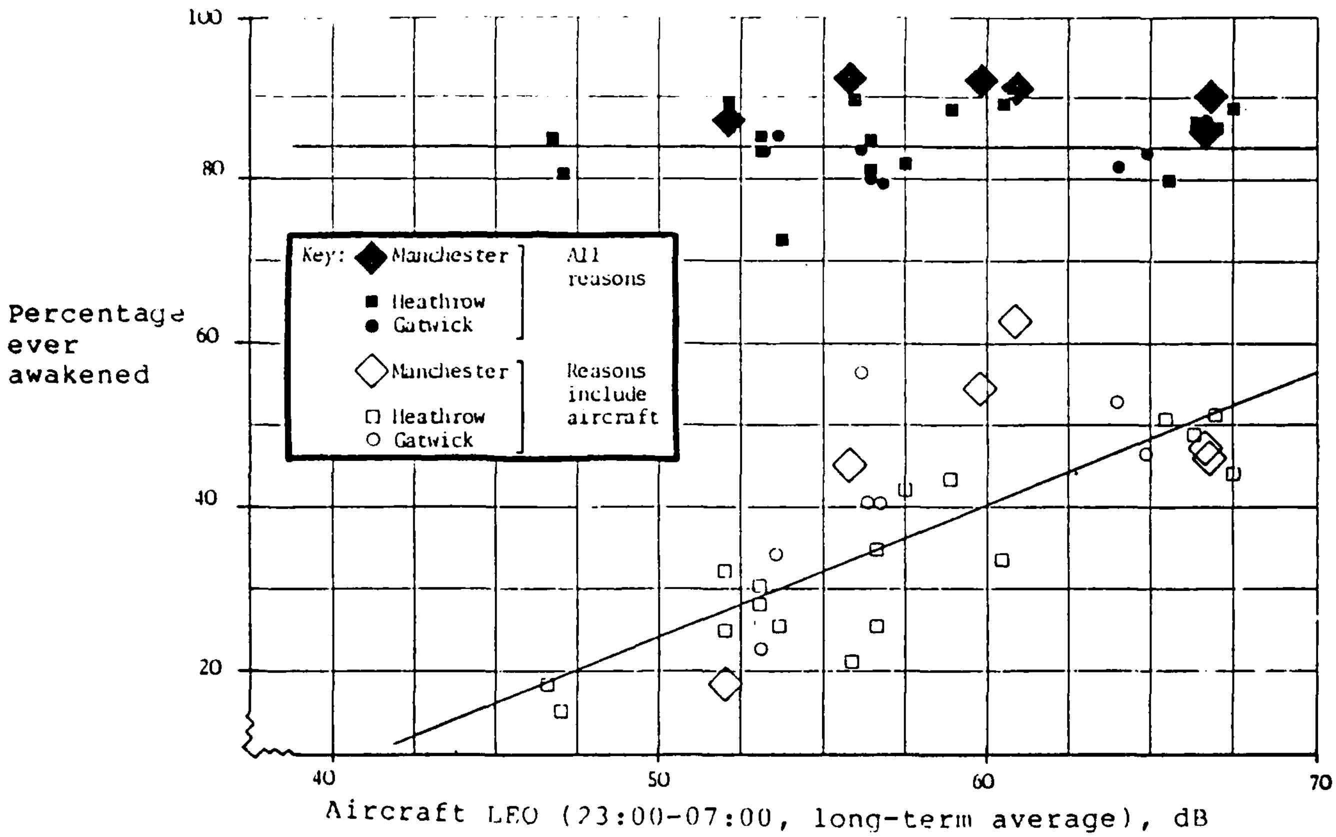


Figure 6.8: Percentage reporting any awakening and percentage attributing an awakening to aircraft noise in the past three months (English Airport Night Surveys)

(Source: Brooker and Nurse, 1982; Fig. 11.

Q.a Still thinking about the past three months or so, have you ever been woken up once you were asleep? (Yes, No)

<u>IF YES</u>

Q.b What were the main things that woke you once you were sleep? (PLEASE TICK ALL WHICH APPLY) Road traffic noise, Aircraft noise, Noise from people outside/neighbours, Other noise (inside or outside), Ill health, Worry/nerves, Need to use toilet, Other reason, No particular reason)

(Note: Regression lines exclude Manchester).

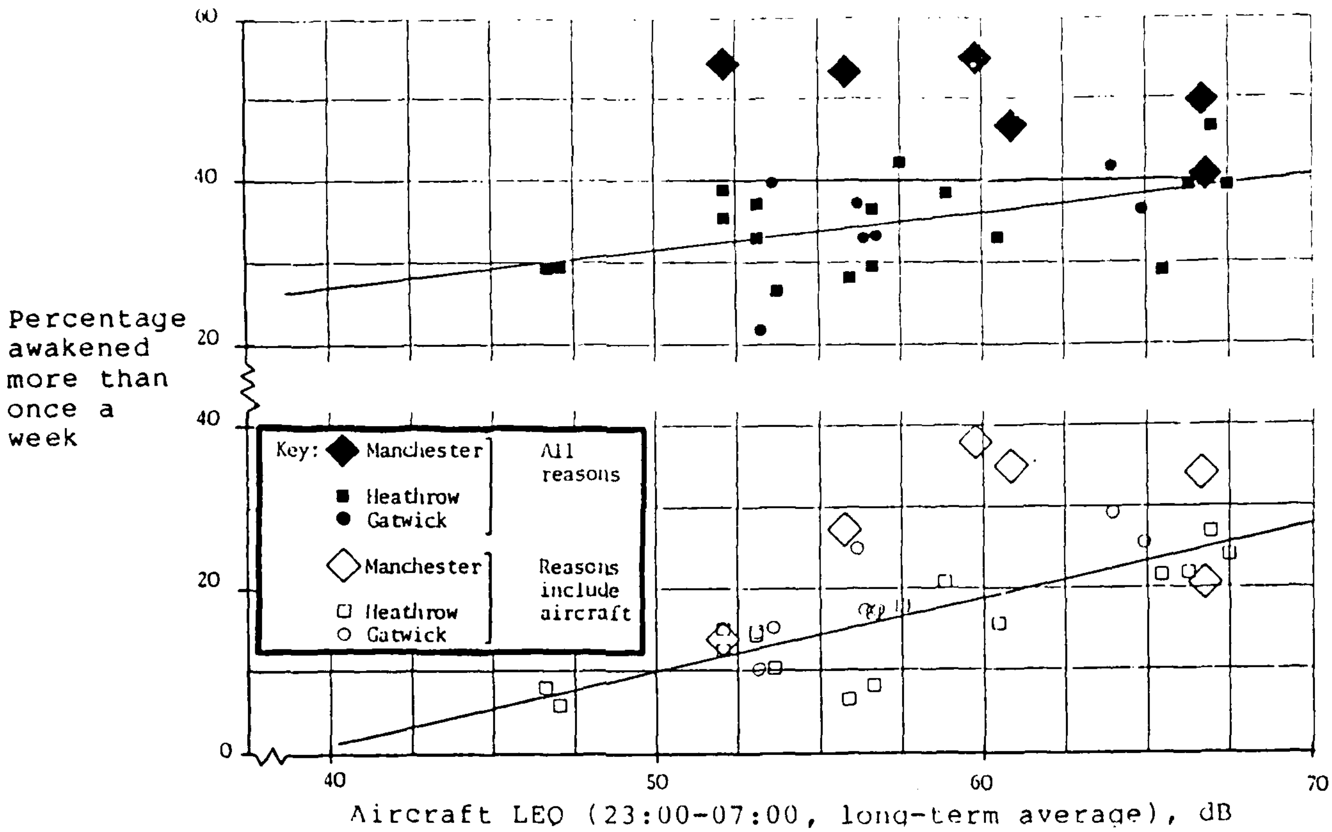


Figure 6.9: Percentage reporting any awakening and percentage attributing an awakening to aircraft noise more than once a week (English Airport Night Surveys)

(Source: Brooker and Nurse, 1982; Fig. 12.

Question:

Q.a Still thinking about the past three months or so, have you ever been woken up once you were asleep? (Yes, No)

<u>IF YES</u>

Q.b On about how many nights were you woken up once you were asleep? (PLEASE TICK ONE ONLY) Less than one night a month, One or two nights a month, About one night a week, 2 or 3 nights a week, Almost every night)

(Note: Regression lines exclude Manchester).

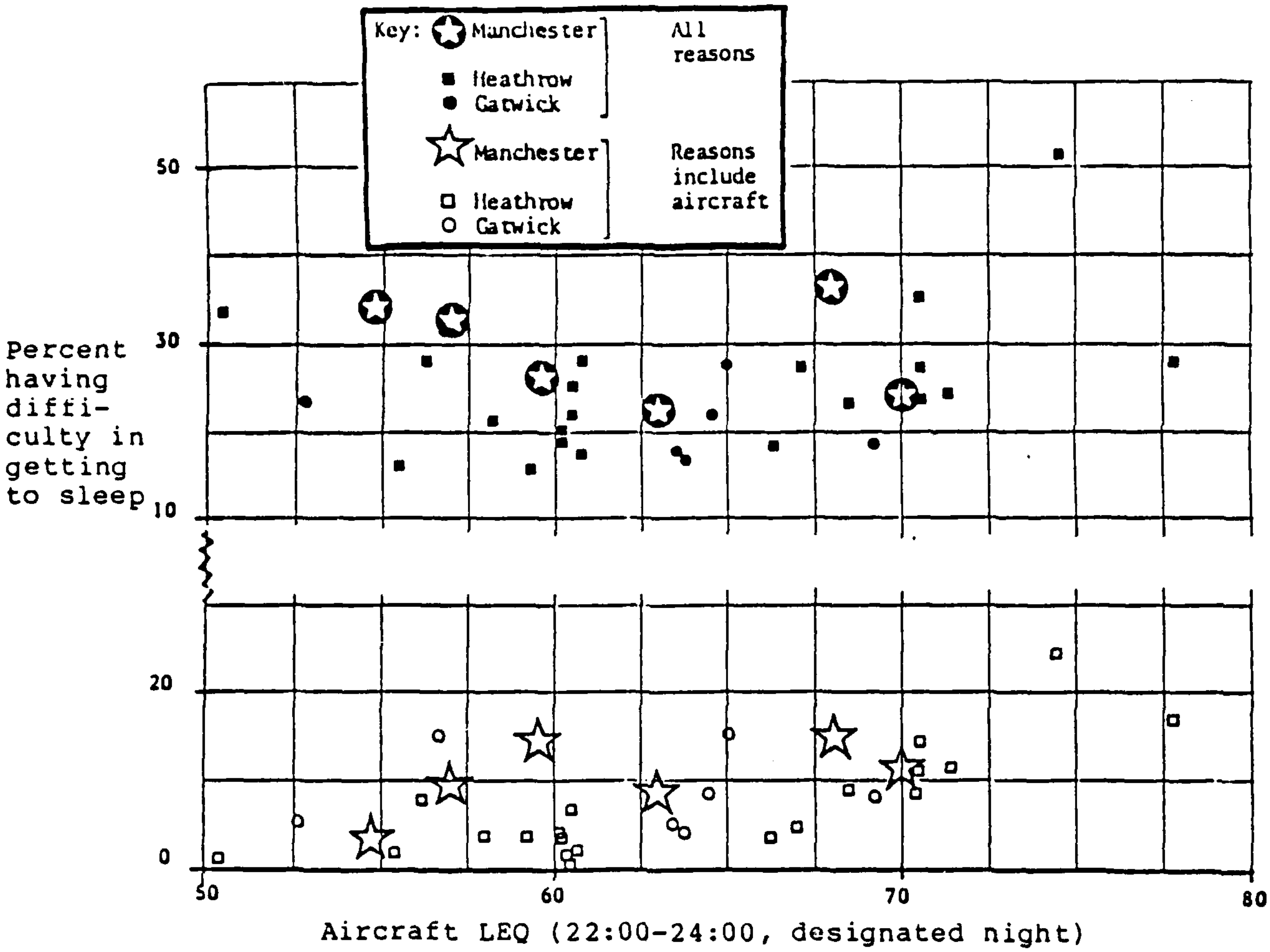


Figure 6.10: Percentage reporting difficulties in getting to sleep and percentage attributing difficulty in getting to sleep to aircraft on designated nights (English Airport Night Surveys)

(Source: Brooker and Nurse, 1982; Fig. 14

Q.a Still thinking only of that night, did you have any difficulty getting to sleep? (Yes, No)

IF YES

Q.b What was the main reason you had difficulty getting to sleep that night? (PLEASE TICK ONE ONLY) Road traffic noise, Aircraft noise, Noise from people outside/ neighbours, Other noise (inside or outside), Ill health, Worry/nerves, Other reason, no particular reason)

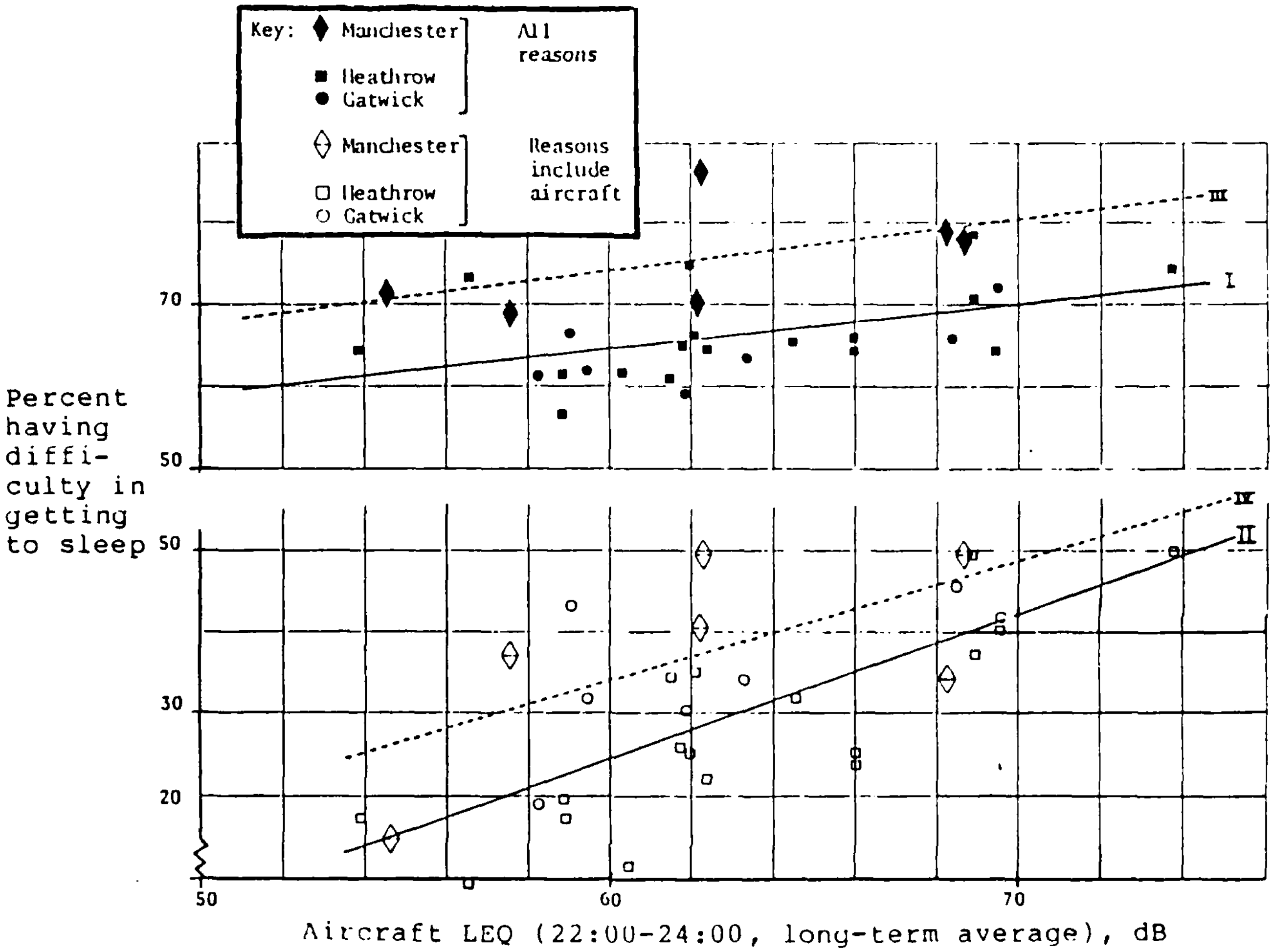


Figure 6.11: **Percentage reporting difficulties in getting to sleep and percentage attributing difficulty in getting to sleep to aircra`t in the last three months (English Airport Night Surveys)**

(Source: Brooker and Nurse, 1982; Fig. 13.
Question:
Q.a Thinking back over, say, the past three months, have you ever had difficulty in getting to sleep? (Yes, No)

IF YES
Q.b What were the main things that made it difficult for you to get to sleep? (PLEASE TICK ALL WHICH APPLY) Road traffic noise, Aircraft noise, Noise from people outside/ neighbours, Other noise (inside or outside), Ill health, Worry/ nerves, Other reason, No particular reason)

(Note: Solid regression lines are for Heathrow and Gatwick. Broken lines are for Manchester).

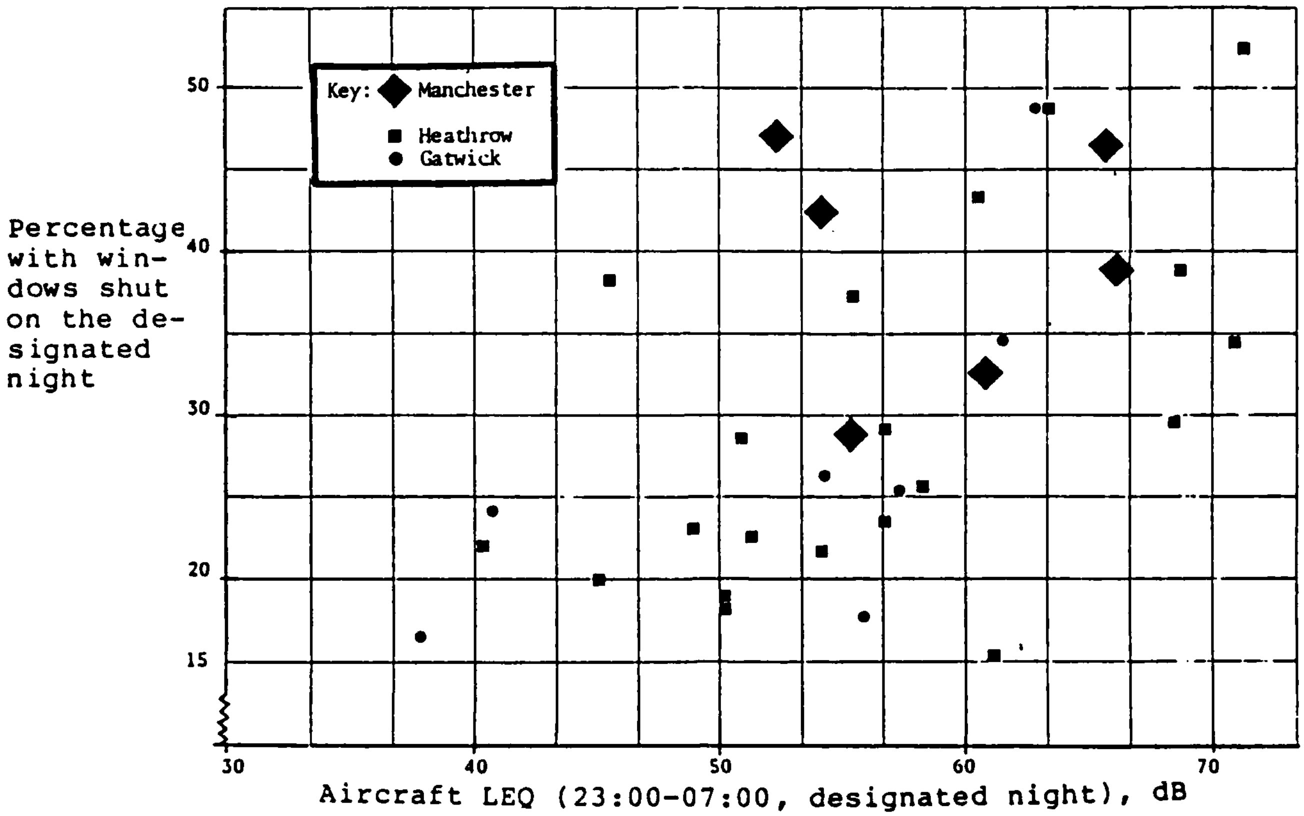


Figure 6.12: Percentage sleeping with windows shut on designated nights (English Airport Night Surveys)

(Source: Brooker and Nurse, 1982; Fig. 7.
Question:
Q. Did you sleep with your bedroom windows open or shut that night? (PLEASE TICK ONE BOX ONLY) (All or some open, All shut)

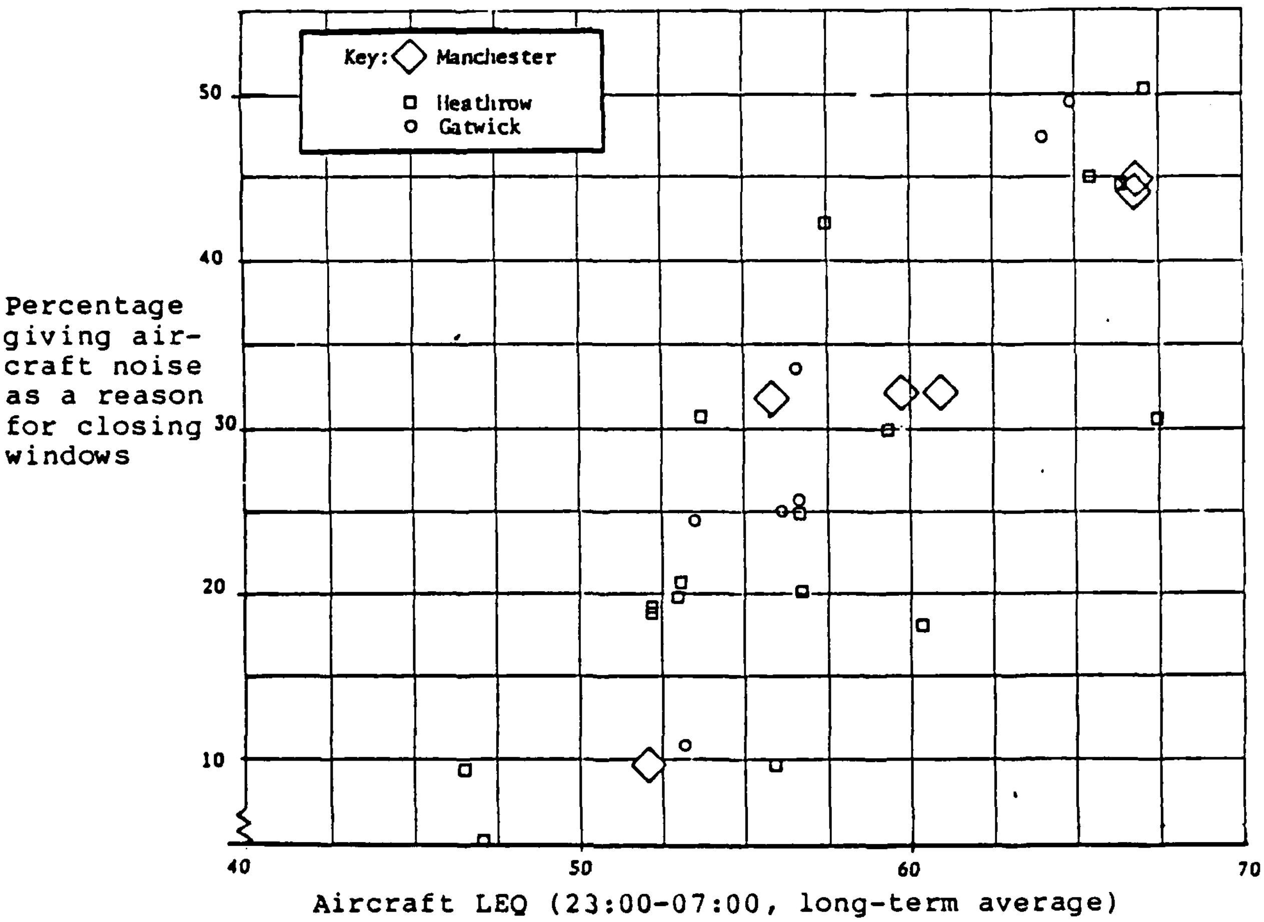


Figure 6.13: Percentage reporting that aircraft noise is a main reason for ever sleeping with all windows closed in the last three months (English Airport Night Surveys)

(Source: Brooker and Nurse, 1982; Fig. 8.
Question:

Q.a Over the past three months or so, have you usually slept with your bedroom windows open or shut? (Open - some or all, Shut - all)

IF OPEN

Q.b During that time have you ever slept with all your bedroom windows shut? (Yes, No)

IF OPEN ON a OR b

Q.c What are the main reasons you slept with all your bedroom windows shut? (PLEASE TICK ALL WHICH APPLY) Road traffic noise, Aircraft noise, Noise from people outside/ neighbours, Other noise (inside or outside), Weather/ temperature, Security, Other reason, No particular reason)

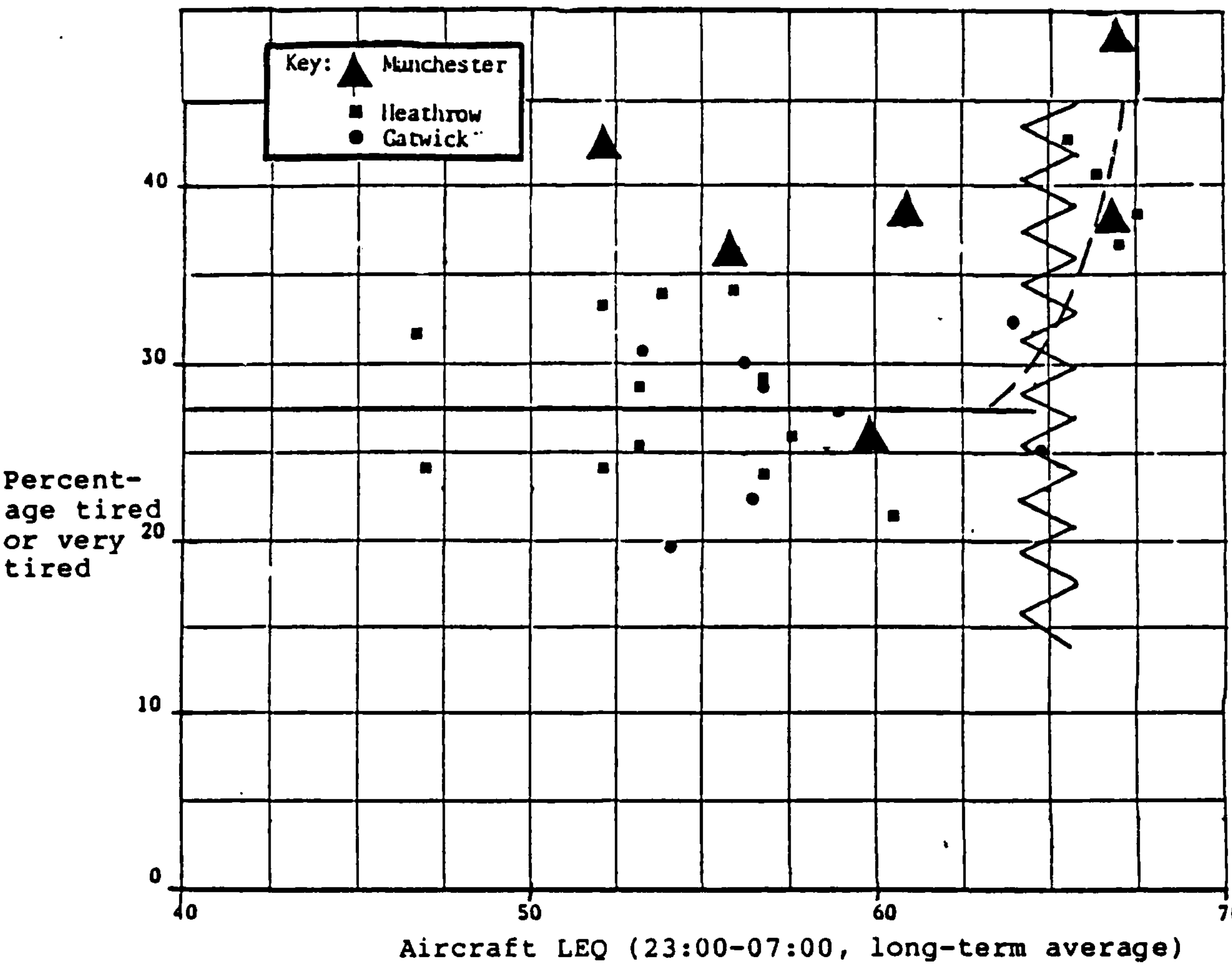


Figure 6.14: Reports of feelings after typical night's sleep (English Airport Night Surveys)

(Source: Brooker and Nurse, 1982; Fig. 15.
Question: When you wake up in the morning, after a typical night's sleep, how do you feel? (PLEASE TICK ONE ONLY) Very refreshed, Refreshed, Neither refreshed nor tired, Tired, Very tired)

(Note: The solid line is the mean response around Heathrow and Gatwick below 65 LEQ).

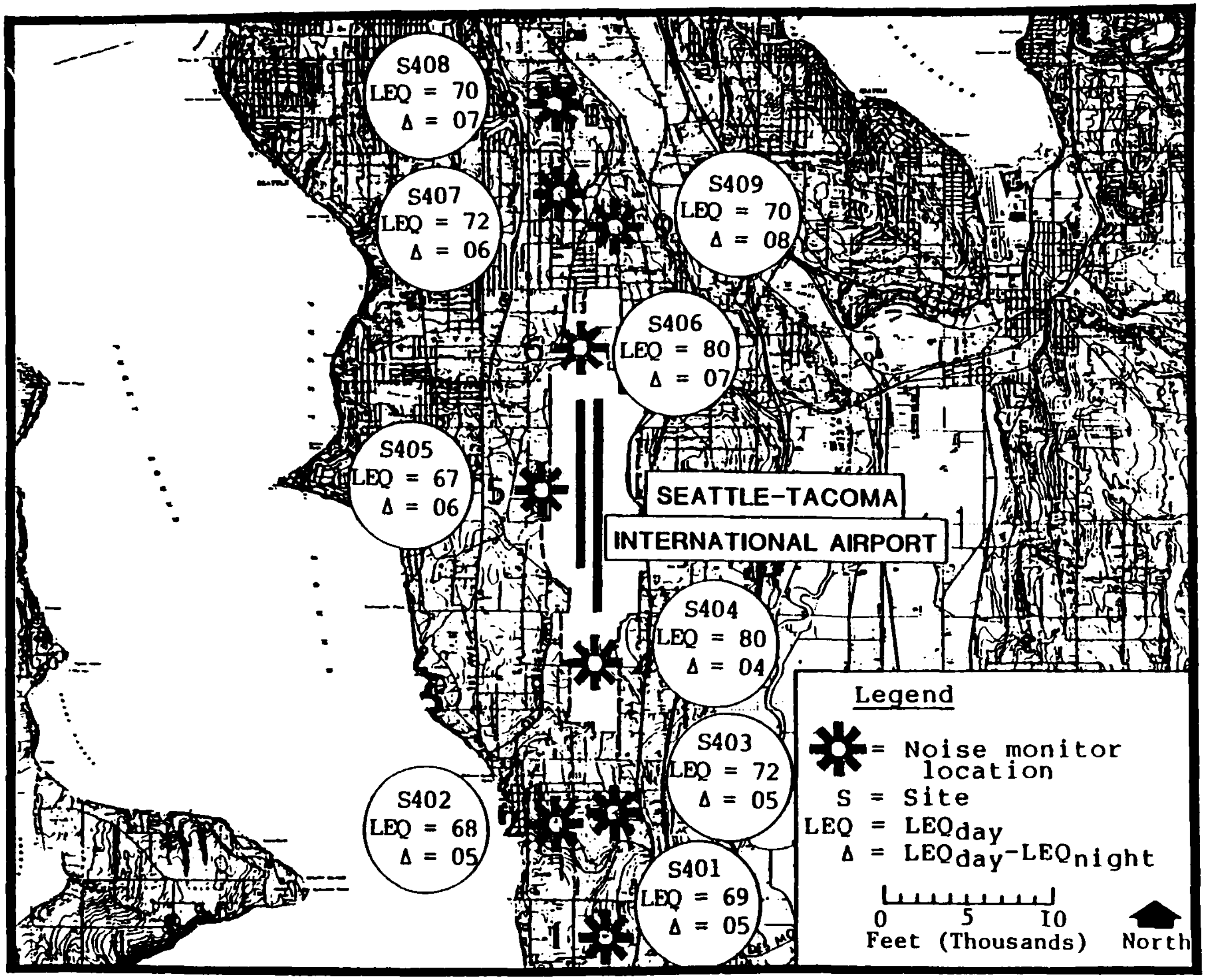


Figure 7.1: Permanent noise monitoring sites: Seattle-Tacoma International Airport

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