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AN EVALUATION OF STUDY DESIGNS FOR ESTIMATING A TIME-OF-DAY NOISE WEIGHTING

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TABLE OF CONTENTS

SUMMARY

The relative importance of daytime and nighttime noise of the same noise level is represented by a time-of-day weight in noise annoyance models. The high correlations between daytime and nighttime noise have been regarded as a major reason that previous social surveys of noise annoyance could not accurately estimate the value of the time-of-day weight. This report describes study designs which could reduce this correlation between daytime and nighttime noise.

Most alternatives which would reduce this correlation are dependent upon studying short-term variations in noise environments. The evidence suggests that designs based on short-term variations in nighttime noise levels would not be able to provide valid measures of response to nighttime noise, because it is likely that people can not form accurate evaluations of the long-term effects of nighttime noise over short time spans.

The accuracy of the estimate of the time-of-day weight is predicted for designs which are based on long-term variations in nighttime noise levels. An examination of various alternative long-term designs, including contrasts of areas with and without nighttime noise, suggests that accurate estimates can not be formed with cross-sectional surveys based on noise environments found around United States airports. The difficulty in creating accurate estimates occurs even if the correlation between daytime and nighttime values of LEQ can be eliminated.

INTRODUCTION

Information about the variation of noise impact with the time of day is needed to establish the effects of nighttime noise and to determine the relative impact of daytime and nighttime noise. While controlled laboratory experiments can provide some information about these issues there is also a need for field studies which would provide information about people's reactions to familiar noise sources in a residential environment.

Attempts have sometimes been made to obtain information about time-of-day issues with general purpose social surveys of noise annoyance (Langdon and Buller, 1977; Second Survey. . ., 1971; Wilson, 1963). Two major problems have limited the amount of information which can be drawn from these surveys. The first problem is that high correlations between daytime and nighttime noise levels have made it impossible to establish the independent effect of nighttime noise (Fields, 1985c). The statistical estimates are thus highly inaccurate and have large standard errors. The second problem is that the relationships between some nighttime human response measures and nighttime noise levels have been weak (Fields, 1985a). There is thus uncertainty about the validity of the nighttime human reaction measures (ie., their ability to measure nighttime noise impact).

This report first outlines some alternative study designs which might be expected to reduce the correlations between daytime and nighttime noise levels. The likely validity of these study designs is then discussed in the following section. Statistical methods for predicting the accuracy of alternative study designs are described in the following section. The predicted accuracy for several alternative designs is then presented. Finally conclusions are presented about the feasibility of obtaining information about time-of-day effects in a community setting.

SYMBOLS

a,c	Constants used in time-of-day models
A	Annoyance
B	Partial regression coefficient for time period (j) or noise index (I)
E	Error term (The part of annoyance scores which is not explained by variables in a model)
LEQ_j	Equivalent continuous sound level for period j, dB
L_I	Noise level for noise index I, dB

m	Sample size
t_j	Number of hours in period j
w_j	Weight to be multiplied by number of events (N) or relative sound pressure squared

Additional Subscripts

d	Daytime period
i	A single noise event
I	Noise index I
j	A time period
n	Nighttime period

ALTERNATIVE APPROACHES FOR REDUCING CORRELATIONS BETWEEN DAYTIME AND NIGHTTIME NOISE LEVELS IN STUDY DESIGNS

If daytime and nighttime noise levels are too hightly correlated in a study design, then it is not possible to estimate the separate effects of daytime and nighttime noise. One of the requirments for an adequate study design is thus that it include a suitable combination of daytime and nighttime noise levels. Strategies are presented which could reduce correlations for aircraft noise studies.

Strategy 1: Cross-sectional design: Contrast long-term noise environments of different areas. - This is the conventional community noise survey approach. In the past the general purpose noise annoyance surveys have not been created with specially designed samples for studying nighttime issues. Thus the possibilities for evaluating the impact of nighttime noise have not been fully explored with existing surveys. For this strategy to succeed it would be necessary to find areas with similar noise levels at one time of day (eg. daytime), but quite different levels at another time (eg. nighttime). The most extreme contrast of this type might be found between airports with and without nighttime curfews.

The fact that reactions in different study areas are compared leads to an important potential weakness in such a cross-sectional design. Past research has shown that the responses to noise are affected by unidentified area characteristics other than noise level (Fields, 1983). As a result there are uncontrolled area differences which increase the variance of estimates and make it more difficult to precisely estimate the effects of the time-of-day noise level area differences. The remaining strategies are all built on longitudinal designs in which contrasting time of day environments are experienced by the same individuals on different days. This offers the potential for controlling some of the area differences.

Strategy 2: Contrast reactions before and after permanent changes in noise conditions. - For this study design people from an area (possibly the same people) can provide two long-term evaluations of two different noise environments; the noise environment before a change and the noise environment months or possibly several years after a change. Such changes could be brought about by changes in policy or, more likely, by changes in physical facilities such as new configurations of runways.

Strategy 3: Contrast reactions before, during and after temporary changes in noise conditions. - For this strategy it is necessary to be able to identify locations where there will be temporary changes in aircraft operations. The same people can then be interviewed before any changes occur, during the time when the temporary operating conditions are in effect and after the operations have returned to the pre-existing state. This design has been utilized for a study of noise (not specifically nighttime noise) around the airport in Burbank, California (Fidell, et al., 1981).

Sterategy 4: Contrast daily annoyance levels for daily variations in noise conditions. - If careful measurements are made of noise levels on particular days then repeated interviews can be scheduled to ask about contrasting types of noise environments. Respondents can be repeatedly questioned about their annoyance reactions for the previous 24 hours. This type of strategy has been used in a study of reactions to helicopter noise (Fields and Powell, 1985).

Strategy 5: Control aircraft operations from military facilities to provide contrasting temporary or daily variations in noise conditions. - With the appropriate cooperation from military authorities it is possible at some facilities to vary the noise levels at different times of day on a daily or possibly longer basis. Variations in training and operation cycles can also normally create some variations in the noise environments at different times of day around military air facilities (Fields, 1985b).

VALIDITY OF ALTERNATIVE APPROACHES

A satisfactory nighttime study design must provide a valid measure of human response. A valid measure is one which measures the concept which it is designed to measure. In the present case a valid measure must be one which successfully measures human response to noise. The precision of the measures will be considered in the next section. The effects of sample size and random errors in responses will be considered at that point. At this point, the problem is the narrow one of whether the study designs will produce interviews which will in the long run, on the average, provide measures of people's feelings about the noise.

The policy interest is in people's long-term reactions to a noise. A valid measure must provide an indicator of how people would respond to nighttime noise levels over a long period of time in residential areas. Some evidence suggests that even for long-term judgements there may be a weaker relationship between noise and annoyance during the nighttime than during the daytime (Fields, 1985a). This problem could be even more serious for short-term judgements.

For daytime noise assessments, there is evidence that reactions are responsive to short-term variations in noise level and that reactions to short-term exposures are similar to those to long-term exposures. A study of response to helicopter noise during the daytime hours found that people were sensitive to both the noise level and number of helicopter flights during the middle of the day on a daily basis (Fields and Powell, 1985). A study around Burbank airport asked about reactions to aircraft noise ". . . while you have been at home over the past <u>WEEK</u>. . ." It was found that people's reactions followed the noise levels rather closely in this study in which the interviews were conducted in as few as 11 days after a change in aircraft noise exposure (Fidell, et al., 1981). This sensitivity of general noise annoyance responses to changes in noise level contrasts sharply with the findings from an earlier study of nighttime noise by some of the same researchers (Fidell and Jones, 1975).

In a previous study of aircraft noise around Los Angeles Airport, people were interviewed both before and after a major change in nighttime noise operations (Fidell and Jones, 1975). The number of nighttime flights were almost completely eliminated from an area which had previous had approximately 50 flights a night. Residents were interviewed before the change in operations and after the change in operations. One round of the repeated interviews occurred four to six weeks after the reduction in operations. Respondents were asked about the effect of aircraft noise on sleep, about sleep disturbance and about whether they had noticed any changes in numbers of flights. When the reactions from before and after the elimination of flights were compared, there was no evidence of any change in reactions. People were not even aware of the reduction in the number of flights. The results from the study thus suggest that people are not sensitive to changes in nighttime noise environments over short periods of time. While a single study does not prove that people do not notice short-term changes in nighttime noise environments, the results of this study suggest that it can not be assumed that a valid nighttime rating can be obtained from judgements of short-term noise environments.

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 accustomed to aircraft noise to the extent that they are conscious of being disturbed by only a very 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 suggest that there may be considerable difficulties in obtaining a valid measure of the reaction to short-term changes in nighttime noise environments. Even if it were possible to find a reaction measure which was sensitive to nighttime noise, it would be likely that nighttime and daytime reaction measures would differ in the relative speed with which they could sense changes in their respective noise environments. The result of this difference in sensitivity would still lead to a biased measure of the relative effect of daytime and nighttime noise.

STATISTICAL METHODS FOR PREDICTING THE ACCURACY OF NEW STUDIES

The method for predicting the accuracy of estimates which could be obtained from future studies rests on statistical theory which utilizes information about study design variables and population parameters. After an introduction to the equations which are used to predict the accuracy of estimates of the nighttime weighting, estimates of the relevant population parameters are provided.

Theory for Predicting the Accuracy of Estimates of Nighttime Weights

A method is required for predicting the approximate variance of the nighttime weighting which can be expected for different sample designs. The conventional adjusted energy model which weights the effects of noise at different times of day can be expressed in a non-linear regression equation of the following form:

$$A=a + B_I \bullet 10 \bullet \log_{10} \left[(t_d \bullet B_d \bullet 10^{LEQ_d/10} + t_n \bullet B_n \bullet 10^{LEQ_n/10})/24 \right]$$

where a and B_I are constants, LEQ is the equivalent continuous noise level for either the day (LEQ_d) or night (LEQ_n), "t" is the length of the time period for t_d (the daytime) or t_n (the nighttime), and

B_d and B_n are partial regression coefficients for the daytime and nighttime.

The value of the nighttime weight (w_n) can then be seen to be the ratio of the two partial regression coefficients:

$$w_n = B_n/B_d$$

The sampling distribution of w_n departs severely from the normal distribution, but the sampling distribution of B_n is approximately normal. As a result the procedures in this paper are directed at first estimating B_n and the variance of B_n ($\sigma_{B_n}^2$) and then transforming the results to provide the estimates of the nighttime weight, w_n, and the confidence intervals for the estimate of the weight.

It should also be noticed that since there are only two variables representing the noise level (LEQ_d and LEQ_n) but three slopes being estimated (B_I, B_d, B_n), the equation is over-identified and there is not a unique value for each of the parameters. When it is decided to combine two of the parameters in the above ratio by setting the sum of the partial regression coefficients to one ($B_d+B_n=1$), then a unique solution is possible.

An asympotic approximation of the variance of B_n can be formed (see appendix A). For large sample sizes the sampling distribution for B_n approaches the normal distribution. The prediction for the variance of simple random samples is:

$$\sigma_{B_n}^2 = \sigma^2_e/m \bullet (\sigma^2_X/(\sigma^2_X \sigma^2_Y - (\sigma_{XY})^2))$$

where:

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

$$Y = 10 \bullet \log_{10}(e) \bullet B_I \bullet (DIF/(B_n \bullet DIF + t_d \bullet 10^{LEQ_d/10}))$$

$$\text{and } DIF = t_n 10^{LEQ_n/10} - t_d 10^{LEQ_d/10}$$

Four of the parameters which enter into the estimate of this variance are study design variables: the social survey sample size (m), the daytime noise exposure (LEQ_d), the nighttime noise exposure (LEQ_n) and the relationship between the two noise exposures (σ_{XY}).

Two of the other parameters depend upon characteristics of the human response to noise, (σ^2_e and B_I). Estimates of these parameters are provided in the next subsection.

The theory which has been presented relates to simple random samples. Noise surveys, on the other hand, are almost always based on clustered samples in which individuals are clustered into study areas. Theoretical bases for making predictions of variances of regression coefficients from complex clustered samples have been developed for two different approaches. Kalton (1983) develops a method using regression models which include a random intercept term associated with the sample clusters. Tomberlin (1985) develops a method using regression models which include a random partial regression coefficient term associated with the sample clusters. Both approaches can be applied to more complex multistage designs and provide bases for choosing the most efficient sized study areas. Estimates of the parameters which are needed to apply Kalton's approach are available in a previous publication (Fields, 1983), however, for the time-of-day design discussion in this paper a second approach is taken to evaluate the effects of clustered sample designs.

In this paper the effects of clustering are evaluated by comparing predicted simple random sampling accuracy (standard errors of partial regression coefficients) with the actual accuracy measured using the appropriate pseudo-replication sampling error calculation techniques. The results of these analyses are reported in this report.

Values of Regression Coefficients and Residual Error Variances From Previous Studies

In order to apply the simple random sample prediction equation it is necessary to have information about the relationship between the values of the residual error variance (σ^2_e) and the partial regression coefficient for the noise index (B_I). The relationship between these variables has been calculated on the bases of 24 analyses of annoyance questions used in 10 studies. The results of these analyses are presented in table I.

References to the studies are included in the first column of table I. The type of annoyance index is described in the second column. The "Verbal" scales come from annoyance questions which present a set of verbal descriptors from which the respondent must choose. The "Numeric" scales come from questions in which only the end points of a numerical scale are given verbal labels. Dichotomous measures of high annoyance are described in table I with the verbal label which was presented to the respondent in the interview. One index based on activity interference items and another index based on the average of several general annoyance items are also included. (The exact wording of all these questions has been presented in appendix A of a previous report (Fields, 1985c)).

The values of the first two quantities in table I are dependent upon the scaling of the annoyance variable. It is the relationship between the values of the two quantities which affects the variance of the time-of-day weighting. The variance of the weighting is directly related to the standard deviation of the error term and inversely related to the value of the partial regression coefficient. The last column thus presents the ratio of these two quantities. The lowest values identify the analyses which would lead to the greatest predicted accuracy of study designs. The values of this ratio differ by study and type of annoyance question. In general the high annoyance dichotomy provides the least predicted accuracy.

The values of the partial regression coefficients and residual error variances from the first two columns of data will be directly entered into the previously presented equations to predict the variance of the time-of-day weighting in a later subsection of this report. In planning future surveys investigators might base design decisions on the particular surveys in table I which most closely approximate the conditions which are to be expected in their planned surveys.

Design Effects from Clustered Sample Designs Used in Noise Surveys

Community noise annoyance surveys are generally based on clustered samples. Individuals are selected from houses which are clustered together at a number of study locations. This design is relatively efficient for overall study costs because the noise measurement costs are dependent on the number of study areas, not the number of respondents. Past research has shown that people from the same study area have more similar annoyance reactions than would be expected from their shared noise levels. As a result the effective sample size is smaller than would be indicated by the number of respondents in the sample. How much smaller depends upon the amount of clustering (ie. degree of similarity) of annoyance reactions within study areas.

In order to measure the effects of this clustering of responses eight studies have been examined. Table II lists the eight studies and the annoyance questions which were examined from each study. The effects of the clustering are indicated for two statistics from each study, the partial regression coefficient for the total noise index (B_I) and the nighttime partial regression coefficient (B_n). (The nighttime coefficient has been standardized as described earlier so that : $B_n + B_d = 1$.)

The incorrect simple random sample estimates of the sampling variances are provided for each of the two regression coefficients. The table also includes the estimates of the standard errors which do take into account the clustered sample design. These later estimates are based on a pseudo-replication technique, jack-knife repeated replication. For this technique estimates of the regression coefficients are made repeatedly on subsets of the total sample from which individuals have been removed on the basis of their study-area membership. The variance of these estimates can be used to estimate the accuracy of the entire sample. A more detailed description of the technique appears in appendix B.

In table II the ratio of the standard error of the regression coefficients (based on the jack-knife) to the incorrect estimate of the standard error (based on simple random sampling formula) is labeled the "design effect" (deff). The design effect can be used to estimate the accuracy of any future sample which would be based on the same design. If a standard error of a new study design has been calculated using simple random sampling procedures and if the new cluster design is similar to one of the designs in table II then the predicted simple random sampling standard error can be multiplied by the design effect from the similar study in table II to predict the expected standard error for the new design.

For the total noise index partial regression coefficient, the design effects range from 1.4 to 2.6. For the nighttime noise partial regression coefficient the design effects vary much more widely, from 0.9 to 9.6. Previous analyses of these same data sets found that accurate estimates of the nighttime partial regression coefficients could not be obtained (Fields, 1985c). This has the secondary effect of providing poor estimates of all statistics including the estimates of these design effects for the nighttime partial regression coefficients. The estimates of the total noise index partial regression coefficients are much more accurate. The corresponding estimated design effect of roughly deff=2 is probably the best estimate.

PREDICTING THE ACCURACY OF TIME-OF-DAY STUDY DESIGNS

The accuracy of estimates of time-of-day weights can be predicted for alternative study designs on the basis of the methods outlined in the previous section. In order to make these predictions, estimates are needed of the value of the residual error variance, of the overall noise index partial regression coefficient and of the design effect. Alternative noise exposure designs and alternative true values for the time-of-day weight can then be specified and the resulting accuracy of the estimates of the time-of-day weights can be predicted.

The estimates of the residual error variance and the partial regression coefficient for the overall noise index come from the London noise survey. The estimate from this study was selected after examining the values in table I. For each study the combination of error variance and regression slope which would yield the best estimate (ie. lowest value of the ratio in the last column of table I) was identified. Using this criterion the study with the poorest such estimate was the 1976 Ontario survey. The study with the next poorest estimate was the London noise survey. This estimate was accepted as a conservative estimate for the present analysis. The residual error variance is thus set at 3.55 and the slope (the partial regression coefficient) is set at 0.08.

The estimate of the design effect which will be used in the analyses is deff=2.0. This estimate comes from an examination of the data in table II. The value of deff=2.0 is close to the mean of the estimates of the design effect for the partial regression coefficients for the overall noise index (1.9). The design effect is sensitive to factors such as the size of study clusters and thus could vary for different designs.

A baseline noise environment matrix is presented in table III. Daytime noise levels vary from 60 to 80 dB(A) (LEQ), nighttime levels vary from 46 to 72 dB(A), and the differences between daytime and nighttime levels are assumed to be either 8, 10 or 14 dB(A). These differences were selected for the baseline environment on the assumption that there was a reasonable possibility of finding such differences around United States airports. This assessment as to the availability of noise environments is based on the examination of an earlier report (Fields, 1985b) which presented data on the proportion of nighttime flights at United States airports and data on noise environments at different times of day at permanent noise monitoring sites at 11 airports.

The noise environments found in 10 previous community noise surveys were also considered (Fields, 1985b: Table II). The standard deviation of the daytime noise for the baseline noise environment is similar to that found in previous aircraft surveys and better (higher) than that found in most previous road traffic surveys. The standard deviation of the baseline nighttime noise levels (${}^{\sigma}LEQ_n$) is similar to that found in two other aircraft noise surveys (${}^{\sigma}LEQ_n$=2.4 in 1967 Heathrow survey, ${}^{\sigma}LEQ$=3.2 in USA nine airport survey) but toward the lower end of the range of nine values in six road traffic surveys (${}^{\sigma}LEQ_n$ varied from 1.5 to 5.7). The correlation between daytime and nighttime noise levels is still high (r_{dn}=0.94).

Table IV contains predictions of the 95% confidence interval for the estimate of the nighttime weighting. The nighttime weighting is expressed as a number weight, the number of daytime noise events which would be required to produce the same annoyance as a single nighttime noise event. The results from the baseline case for a value of the nighttime weighting of w_n=10, are presented in the first panel of table IV.

The first columns of table IV describe the design. For the baseline case the daytime noise levels are at 60, 65, 70, 75, and 80 dB(A) (LEQ) as was previously specified in table III. The differences between daytime and nighttime noise levels are also as given in table III. With an assumed multiplicative weight of w_n=10, the nighttime partial regression coefficient is B_n=0.909. Results are provided for samples of four different sizes. For the baseline case a sample size of 1,000 provides a standard error of the nighttime regression coefficient of 0.12 and a resulting 95% confidence interval for the nighttime weight of from w_n=0.79 to wn=+∞. Thus the 95 percent confidence interval includes the possibility that nighttime noise is less important than daytime noise as well as the possibility that nighttime noise has an infinitely greater effect than daytime noise. A sample size of 1,000, thus, does not provide useful information about the value of the nighttime weighting for the baseline design. The three remaining sample sizes (2000, 4000, 10000) also fail to establish upper confidence intervals, but could establish lower confidence intervals. However, these 95% confidence intervals are so broad as to not be able to distinguish between quite large differences in the values of the nighttime weighting.

The next two conditions in table IV are based on alterations in the baseline sample. In the first case the range of noise levels is increased (daytime levels are extended down to 50 dB). This has no effect on the estimated 95% confidence intervals for the nighttime weighting. The other condition is based on the optimistic expectation that noise environments could be found so that the differences between day and night noise levels could be expanded to evenly cover the range from a 5 dB difference to a 20 dB difference. This later design could establish an upper confidence interval for a prohibitively expensive study of 10,000 respondents but still has a very wide confidence interval.

The remaining conditions in table IV give confidence intervals for the baseline sample for four different values of the nighttime weighting (w_n=5, 10, 20, 100). In no case is it possible to establish an upper confidence interval, even with a sample size of 10,000. The lower confidence intervals would be considered to be unacceptably large for most purposes. If, for example, the value of the nighttime weighting is w_n=100, a sample size of 1,000 would only be able to establish that the weight is greater than w_n=9.9 (rounded to w_n=10 in Table IV).

Thus far only the conventional cross-sectional study design has been considered, a design in which all environments contain some nighttime aircraft noise. Table V presents a new set of baseline noise conditions for comparisons between aircraft noise environments with and without nighttime noise. Such conditions might be found by comparing the normally operating airports which have nighttime noise to unusual airports which have no nighttime noise. The noise conditions might also be found if surveys were conducted before and after a nighttime curfew were instituted or if surveys were conducted before and after a new runway were opened. The publicity attending such aircraft operation changes might raise some additional questions about the validity of a questionnaire study, but as this point only the sampling aspects are considered.

The no-night-noise comparison design in table V results in a design with much greater variances in nighttime noise levels and in differences between daytime and nighttime noise levels. The correlation between daytime and nighttime noise levels (measured in decibels) is also reduced to almost zero (r_{dn}=-0.06).

The predicted 95% confidence intervals for this design are presented in table VI. When this new no-night-noise design (first entry of table VI) is compared to the previous baseline in table IV, it is seen that the confidence intervals have only improved slightly. Upper confidence intervals can still not be established. The lower confidence interval for a size 2,000 sample, for example, is improved from $w_n=1$ to $w_n=2$. The next design in table VI is similar to that in table IV in that those areas with nighttime noise have a wider spread of values. This design results in modest improvements in the confidence intervals. In an attempt to create a better design, in the next part of the table the areas with nighttime noise are assumed to have unrealistically high nighttime noise levels which differ from the daytime levels by only 2, 5, or 8 decibels. This results in an additional improvement in the confidence intervals, but still gives confidence intervals which would be too large for most uses. The prohibitively large 10,000 sample size would barely establish a lower confidence interval which was greater than $w_n=6$. All of the confidence intervals are affected by the value of the weight. If the true value of the nighttime weight was $w_n=8$ then the last panel of table VI shows that even with this very optimistic sample design it would not be possible to set an upper confidence interval with a sample size of 4,000.

The interpretation of the results from any of these types of night noise elimination studies would be limited by the fact that the reduced standard errors for the estimates of the nighttime weighting actually derive mainly from the contrast between areas with noise at night and areas without noise at night. The resulting estimates of the nighttime weight (if sufficiently accurate) would provide a good indication of whether the effect of eliminating nighttime noise is substantially greater than would have been expected from an equivalent reduction in daytime noise. The estimates could not necessarily be extrapolated to the more normal situation in which at least some nighttime noise is present.

The predicted levels of accuracy in tables IV and VI suggest that satisfactory estimates of the time-of-day weighting could not be obtained from surveys which contrast the noise environments around different airports or from surveys which compare areas with nighttime noise with those without nighttime noise. The accuracy of the later design might be improved somewhat if a longitudinal design were used in which the same people were interviewed first when there was normal nighttime noise and then again later after the nighttime noise was eliminated. Such a longitudinal design typically results in some increased precision because some of the individual differences can be controlled. Just how much the precision might be expected to improve can not be evaluated without analyses of longitudinal data. These analyses have not thus far been carried out.

Other patterns of changes in noise environments could be assessed with longitudinal designs and might yield better estiates, however, it is uncertain as to whether such patterns of changes could actually be found. Additional accuracy would be possible if daytime noise levels remained unchanged but if some respondents experienced substantial increases in nighttime noise levels while other respondents experienced substantial decreases in nighttime noise levels. Short-term changes of this nature may occur in airport operations, but as was suggested earlier the validity of studies of reactions to any such short-term changes is doubtful. No routine reasons for expecting such long-term changes have been identified. However, if such changes were identified greater accuracy might be predicted than has been possible for the designs described in this report.

A broad range of day and night noise enviroments has been considered in this report, but they have not been found to provide satisfactorily accurate estimates of the time-of-day weighting. The high level of inaccuracy is present in spite of the fact that some of the designs have overcome the primary problem which was identified at the beginning of the report: the high correlations between daytime and nighttime noise levels. For example, the designs in table VI have low correlations of either $r_{dn}=0.13$ or 0.14. The problem in survey design is not simply to eliminate the correlation between daytime and nighttime noise values of the noise index LEQ. An optimal design would need to focus directly on the complex parameters which were identified in the theory for predicting the accuracy of estimates of nighttime weights. Given the range of designs already considered, it seems unlikely that a careful application of this theory would be able to identify combinations of existing noise environments which would provide accurate estimates.

A major difficulty in estimating the time-of-day weighting may be that the distinction between the different weights is too fine for any combination of noise environments. The quantity which is being directly estimated (the nighttime partial regression coefficient coefficient, B_n) must be very exactly specified. For example for the range of estimates of the nighttime weight from $w_n=5$ to $w_n=20$ the value of the nighttime regression coefficient only varies from $B_n=0.833$ to $B_n=0.952$. Similarly the distinction between a weighting of $w_n=20$ and $w_n=100$ is represented by only a 0.038 difference in the nighttime partial regression coefficients of $B_n=0.952$ and $B_n=0.990$.

CONCLUSIONS: THE FEASIBILITY OF STUDYING TIME-OF-DAY EFFECTS IN A COMMUNITY SETTING

The high correlations between daytime and nighttime noise have been regarded as a major reason that previous social surveys of noise annoyance could not accurately estimate the value of the time-of-day weight. This report has described study designs which would reduce this correlation between daytime and nighttime noise.

Most alternatives which would reduce this correlation are dependent upon studying short-term variations in noise environments. The evidence suggests that designs based on short-term variations in nighttime noise levels would not be able to provide valid measures of response to nighttime noise, because it is not likely that people can form accurate evaluations of the long-term effects of nighttime noise over short time spans.

The feasibility of basing a study on long-term differences in nighttime noise levels has been assessed for combinations of noise environments which have been specially selected so as to increase the accuracy of the estimates of the time-of-day weights. These designs are based on analyses of noise environments around United States airports and on optimistic assumptions concerning the availability of daytime and nighttime noise environments. Some designs include contrasts between areas with and without nighttime noise. Some designs virtually eliminate the correlation between daytime and nighttime noise levels. The analyses in this report predict that even with these improved designs a cross sectional survey could not provide a useful, accurate estimate of the time-of-day weight.

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APPENDIX A:
SOURCE OF EQUATION TO PREDICT SAMPLING VARIANCES OF NONLINEAR REGRESSION COEFFICIENTS

The conventional adjusted energy model for the effects of noise at different times of day can be represented as:

$$A = a + B_I \bullet 10 \bullet \log_{10} \left[(t_d \bullet B_d \bullet 10^{LEQ_d/10} + t_n \bullet B_n \bullet 10^{LEQ_n/10})/24 \right] + E$$

As was noted in the text, a regression equation based on this model would be over identified. If the sum of the two partial regression coefficients is set to one ($B_d + B_n = 1$) then a new regression equation can be defined which includes only the nighttime partial regression coefficient.

$$A = a + B_I \bullet 10 \bullet \log_{10} \left[(B_n \bullet DIF + t_d \bullet 10^{LEQ_d/10})/24 \right]$$

where DIF is given by

$$DIF = t_n \bullet 10^{LEQ_n/10} - t_d \bullet 10^{LEQ_d/10}$$

This in a non-linear multiple regression model. Least squares estimates of the parameters of this model can be achieved via iterative algorithms. See, for example, Neter Wasserman and Kutner (1985), Chapter 14.

In designing samples for the purpose of estimating the parameters of this non-linear equation, one must be able to predict sampling variances for estimators as a function of sample size and of the distribution of the predictor variables, in this case the daytime and nighttime noise measures, LEQ_d and LEQ_n. Formulas for this purpose can be obtained in a manner analogous to that used for the more common linear model.

First consider the following linear model:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + E$$

Then the sampling variances for the least squares estimates of β_1 and β_2 can be expressed as a function of the sample size m and the variances of the two predictor variables, x_1 and x_2 as well as their correlation coefficient.

$$Var(\beta_1) = \sigma_\varepsilon^2/m \left[\sigma_1^2 (1-r^2) \right]$$

$$\mathrm{Var}(\hat{\beta}_2) = \sigma_\varepsilon^2/m \left[\sigma_2^2(1-r^2)\right]$$

where, σ_ε^2 is the variance of the error term E, r is the correlation between the two predictor variables, and σ_1^2 and σ_2^2 are the variances of the predictor variables x_1 and x_2 respectively. Thus for small sampling variances, one wants a small error variance σ_ε^2 (i.e. a good prediction model), a large sample size, large variances in the predictor variables, and a small correlation between the two predictor variables.

For the time-of-day non-linear regression model similar requirements are necessary for functions of the predictor variables, x_1 and x_2. These functions are the first partial derivatives of the non-linear function, taken with respect to the parameters in question. (See Neter, Wasserman and Kutner, 1985.) Thus, the two "design variables" for the model are,

$$\frac{\partial A}{\partial B_I} = \log_{10}(B_n \bullet DIF + t_d \bullet 10^{LEQ_d/10})$$

$$\frac{\partial A}{\partial B_n} = \log_{10}(e) \bullet B_I \bullet (DIF/(B_n \bullet DIF + t_d \bullet 10^{LEQ_d/10}))$$

These equations provide the definition of the x and y terms used in the section "Theory for Predicting the Accuracy of Estimates of Nighttime Weights".

Thus, for small sampling variance in the estimate of the nighttime regression coefficient B_n, one requires again, a small error variance, σ_ε^2, a large sample size, large variance in the functions $\partial A/\partial B_n$ and $\partial A/\partial B_I$, and small correlation between $\partial A/\partial B_I$ and $\partial A/\partial B_n$.

For sampling variance prediction, one requires a preliminary estimate of the error variance σ_ε^2, as well as of the parameters to be estimated, B_I and B_n.

APPENDIX B:
JACKKNIFE VARIANCE ESTIMATES

The adjusted energy summation model can be represented by a non-linear multiple regression model. Estimates of parameters and functions of parameters can be obtained via iterative procedures. All three major statistical computer packages, SAS, SPSS, and BMDP, contain routines for this purpose. See Brown (1977); Nie et. al. (1975); and SAS Institute, Inc., (1979).

Since the principal computer used for data analysis at NASA Langley Research Center is a CDC machine, the most convenient of these computer packages is SPSS. The SPSS subprogram, NONLINEAR, developed at Northwestern University (Robinson, 1977), produces the required parameter estimates from SPSS when the program is installed on a CDC (Control Data Corporation) machine.

Although the standard packages can provide estimates for parameters of the adjusted energy model they cannot, by themselves, provide estimates for standard errors based on complex sampling designs. Standard errors produced automatically by these "canned" programs are based on simple random sampling assumptions. For complex samples, a pseudo-replication procedure is appropriate. Pseudo-replication refers to a class of estimation methods. Of these, the jackknife is perhaps best suited for use with SPSS. This technique requires repeated computation of sample estimates using samples which differ slightly from each other.

Specifically, the estimation procedure is carried out repeatedly, each time leaving out a single primary sampling unit (PSU). Each individual replication yields a single "pseudo-value". Consider the following notation. Let Y denote an estimate obtained from the complete sample and Y(i) denote the corresponding estimate obtained from the sample leaving out the ith PSU. Then,

$$Y_i = mY - (m-1)Y(i)$$

is called the ith pseudo-value, where m is the number of PSU's in the sample.

The jackknife estimate of the sampling variance is then obtained as,

$$\mathrm{Var}(Y) = \sum[Y_i - \overline{Y}_\bullet]^2/m(m-1),$$

where,

$$\overline{Y}_\bullet = \sum Y_i/m$$

is the mean of the n pseudo-values. See Miller (1974) and Efron (1979) for further details of jackknife variance estimation as well as other pseudo-replication techniques.

These jackknife calculations require the re-analysis of the results of m intermediate analyses. Specifically, parameter estimates based on each jackknife replication, the Y_i's, must be converted into pseudo-values, and the variance of these pseudo-values calculated. This was accomplished for routine variance calculations by writing a FORTRAN program which read the output from the SPSS NONLINEAR Subprogram, and calculated the appropriate summary statistics.

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TABLE I: REGRESSION COEFFICIENT AND RESIDUAL ERROR VARIANCE FOR 10 STUDIES

Study[a]	Annoyance scale (number of scale points)	Regression analysis		
		Regression coefficient for noise index (B_I)	Residual error variance (σ^2_e)	Indicator of accuracy (σ_e/B_I)
PART A: AIRCRAFT SURVEYS				
USA nine airport	Numeric (5)	0.07	2.09	21
	Very	1.23	1817.83	25
1967 Heathrow	Verbal (4)	0.08	1.01	13
	Very	1.97	1146.74	17
	Activity	0.13	2.30	11
PART B: ROAD TRAFFIC SURVEYS				
England traffic	Verbal (4)	0.03	0.55	21
	Numeric (7)	0.11	3.16	16
	Very	0.48	421.84	42
London traffic	Numeric	0.08	3.55	23
1975 South Ontario	Verbal (5)	0.07	0.84	13
	Considerably	1.48	592.23	16
1976 South Ontario	Verbal (5)	0.04	1.07	29
	Numeric (11)	0.06	7.41	44
	Considerably	0.81	789.78	35
1978 Ontario	Verbal (5)	0.08	0.83	11
	Numeric (11)	0.24	4.88	9
	Considerably	1.54	601.69	16
Western Ontario	Numeric (7)	0.12	3.99	16
French expressway	Verbal (4)	0.06	0.96	15
	Very	2.67	2014.40	17
PART C: RAILWAY SURVEY				
British railway	Verbal (4)	0.03	0.83	32
	Numeric (7)	0.07	3.08	26
	Index (11)	0.11	6.45	23
	Activity	0.42	627.70	60
	Very			

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[a] The studies and annoyance questions have been described in a recent publication (Fields 1985c).

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TABLE II: DESIGN EFFECTS FROM TIME-OF-DAY REGRESSION ANALYSES FOR EIGHT STUDIES[a]

Study	Annoyance scale[a] (number of scale points)	Total Noise Index				Nighttime Noise Variable			
		Regression coefficient B_I	Standard error (Jackknife) σ_{B_I}	Incorrect Std. error (SRS) $\sigma_{B_{I(srs)}}$	Design effect $\sigma_{B_{I(srs)}}$	Regression coefficient (B_n)	Standard error (Jackknife) σ_{B_n}	Incorrect Std. error (srs) $\sigma_{B_{n(srs)}}$	Design effect ($\sigma_{B_n}/\sigma_{B_{n(srs}}$
PART B:	ROAD TRAFFIC SURVEYS								
England traffic	Verbal (4)	0.035	0.003	0.002	1.6	0.566	0.540	0.359	1.5
	Numeric (7)	0.115	0.007	0.005	1.4	0.383	0.340	0.366	0.9
London traffic	Numeric (7)	0.080	0.027	0.011	2.6	0.809	0.810	0.134	6.1
1975 South Ontario	Verbal (5)	0.071	0.009	0.006	1.6	-0.698	1.140	0.413	2.8
1976 South Ontario	Verbal (5)	0.035	0.019	0.008	2.4	0.956	0.170	0.082	2.1
	Numeric (11)	0.062	0.034	0.018	1.8	1.012	0.150	0.016	9.6
1978 Ontario	Verbal (5)	0.080	0.010	0.005	1.9	0.567	0.420	0.237	1.8
	Numeric (11)	0.244	0.026	0.013	1.9	0.103	0.870	0.451	1.9
Western Ontario	Numeric (7)	0.121	0.015	0.009	1.7	1.016	0.110	0.048	2.3
French expressway	Verbal (4)	0.065	0.010	0.007	1.4	1.037	0.078	0.031	2.5
PARC C:	RAILWAY SURVEY								
British railway	Verbal (4)	0.029	0.004	0.002	1.9	0.479	0.510	0.490	1.0
	Numeric (7)	0.067	0.009	0.004	2.1	0.719	0.340	0.226	1.5
	Index (11)	0.111	0.015	0.006	2.3	0.742	0.240	0.184	1.3

[a] All data in this table come from a non-linear regression analysis of annoyance on the noise in two time periods. (See the adjusted energy model in the text.)

TABLE III: FIFTEEN NOISE ENVIRONMENTS ASSUMED TO BE PRESENT IN THE BASELINE STUDY DESIGN

Noise environment identification number	Daytime noise level (dB(A),LEQ)	Difference (Day-Night) (dB(A),LEQ)	Nighttime noise level (dB(A),LEQ)
1	60	8	52
2	65	8	57
3	70	8	62
4	75	8	67
5	80	8	72
6	60	10	50
7	65	10	55
8	70	10	60
9	75	10	65
10	80	10	70
11	60	14	46
12	65	14	51
13	70	14	56
14	75	14	61
15	80	14	66

TABLE IV: 95% CONFIDENCE INTERVALS FOR ESTIMATES OF THE NIGHTTIME WEIGHT (w_n) FOR SIX STUDY DESIGNS AND FOUR SAMPLE SIZES

Design[a]					Nighttime regression coefficient (assumed)	Predicted accuracy			
Description	Noise levels [dB(A)LEQ]			Sample size		Standard error B_n (σB_n)	95% confidence interval for nighttime weight		
	Daytime range [σLEQ_d]	Day-night levels (LEQ_d-LEQ_n) [σLEQ_d-LEQ_n]	Correlation r_{dn}				Lower limit	Nighttime weight (w_n)	Upper limit
Baseline				1,000		0.12	1		+∞
	60–80	8,10,14	0.94	2,000	0.909	0.08	1	10	+∞
	[7.1]	[2.5]		4,000		0.06	2		+∞
				10,000		0.04	3		+∞
Wider range				1,000		0.12	1		+∞
of noise	50–80	–B–	0.97	2,000	0.909	0.08	1	10	+∞
levels	[10.8]			4,000		0.06	2		+∞
				10,000		0.04	3		+∞
Wider range				1,000		0.06	2		+∞
of differ-	–B–	5,10,20	0.75	2,000	0.909	0.04	3	10	+∞
ences		[6.2]		4,000		0.03	4		+∞
				10,000		0.02	5		63
Assume small				1,000		0.27	–∞		+∞
nighttime	–B–	–B–	–B–	2,000	0.833	0.19	0	5	+∞
weight				4,000		0.13	1		+∞
(w_n=5)				10,000		0.09	1		+∞
Assume large				1,000		0.06	3		+∞
nighttime	–B–	–B–	–B–	2,000	0.9524	0.04	4	20	+∞
weight				4,000		0.03	5		+∞
(w_n=20)				10,000		0.02	7		+∞
Assume large				1,000		0.02	10		+∞
nighttime	–B–	–B–	–B–	2,000	0.9901	0.01	14	100	+∞
weight				4,000		0.01	19		+∞
(w_n=100)				10,000		0.01	27		+∞

[a] B = same as baseline condition

TABLE V: FIFTEEN NOISE ENVIRONMENTS ASSUMED TO BE PRESENT IN THE NO-NIGHTTIME-NOISE BASELINE STUDY DESIGN

Noise environment identification number	Daytime noise level (dB(A),LEQ)	Difference (Day-Night) (dB(A),LEQ)	Nighttime noise level (dB(A),LEQ)
1	60	8	52
2	65	65	0
3	70	8	62
4	75	75	0
5	80	8	72
6	60	60	0
7	65	10	55
8	70	70	0
9	75	10	65
10	80	80	0
11	60	14	46
12	65	65	0
13	70	14	56
14	75	75	0
15	80	14	66

TABLE VI: 95% CONFIDENCE INTERVALS FOR ESTIMATES OF THE NIGHTTIME WEIGHT (w_n) FOR FOUR NO-NIGHTTIME-NOISE STUDY DESIGNS AND FOUR SAMPLE SIZES

Design[a]					Nighttime regression coefficient (assumed)	Predicted accuracy			
Description	Noise levels [dB(A)LEQ]			Sample size		Standard error B_n (σB_n)	95% confidence interval for nighttime weight		
	Daytime range [σLEQ_d]	Day-night levels (LEQ_d-LEQ_n) [σLEQ_d-LEQ_n]	Correlation r_{dn}				Lower limit	Nighttime weight (w_n)	Upper limit
Baseline (No-night-noise environments)	60-80	8,10,14, 60,65,70 75,80 [30.0]	-0.14	1,000	0.909	0.07	2	10	+∞
				2,000		0.05	2		+∞
				4,000		0.04	3		+∞
				10,000		0.02	4		+∞
Wider range of day-night differences	-B-	5,10,20 60,65,70 75,80 [29.7]	-0.14	1,000	0.909	0.06	2	10	+∞
				2,000		0.04	3		+∞
				4,000		0.03	4		+∞
				10,000		0.02	5		48
Small day-night differences	-B-	2,5,8 60,65,70 75,80 [32.8]	-0.13	1,000	0.909	0.05	3	10	+∞
				2,000		0.03	4		+∞
				4,000		0.02	5		1050
				10,000		0.01	6		28
Lower nighttime weight (w_n=8)	-B-	2,5,8 60,65,70 75,80 [32.8]	-0.13	1,000	0.889	0.06	2	8	+∞
				2,000		0.04	3		+∞
				4,000		0.03	3		+∞
				10,000		0.02	4		24

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The relative importance of daytime and nighttime noise of the same noise level is represented by a time-of-day weight in noise annoyance models. The high correlations between daytime and nighttime noise have been regarded as a major reason that previous social surveys of noise annoyance could not accurately estimate the value of the time-of-day weight. This report describes study designs which would reduce the correlation between daytime and nighttime noise. It is concluded that designs based on short-term variations in nighttime noise levels would not be able to provide valid measures of response to nighttime noise. The accuracy of the estimate of the time-of-day weight is predicted for designs which are based on long-term variations in nighttime noise levels. For these designs it is predicted that it is not possible to form satisfactorily precise estimates of the time-of-day weighting.

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