Outside and Inside Noise Exposure in Urban and Suburban Areas

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ABSTRACT.—In urban and suburban areas of the United States (away from major airports), the outdoor noise environment usually depends strongly on local vehicular traffic. By relating traffic flow to population density, a model of outdoor noise exposure has been developed for estimating the cumulative 24-hour noise exposure based upon the population density of the area. This noise model has been used to provide first-order estimates of noise exposure in urban areas of this country. The model also can be used to estimate the variation in noise levels in communities and to plan community noise surveys. Field measurements at 100 locations throughout the country have shown good agreement with this model.

THE OUTDOOR NOISE environment in urban and suburban areas in this country is due to many different noise sources of varying frequency content and temporal characteristics. Actual noise levels and noise exposures vary over a considerable dynamic range. However, because of the prevalence of similar major sources of noise, one can expect many similarities in noise exposure and in daily patterns of noise exposure throughout the country. These similarities suggest that there should be good likelihood of developing useful models for predicting the noise environment for different neighborhoods throughout the country.

Because of the well-identified and relatively well-studied impact of jet-aircraft noise and high density freeway traffic noise, rather detailed analytic models have been developed for predicting aircraft and highway noise. These models are quite accurate for locations relatively close to the noise sources. Although aircraft operations and freeway traffic produce some of the noisiest outdoor environments found in this country, only a small proportion of the total population is exposed to these rather intense noise sources. The majority of the population is affected by noise from other sources. A means for defining the noise exposure for this large segment of the population that does not depend upon detailed knowledge of source levels, operating conditions, or identification of specific noise sources is particularly useful for community and land-use planning.

This paper discusses a simple model for estimating the noise exposure in urban and suburban areas not located near airports or major freeways. The paper also discusses measurements made to confirm and verify this model and also provide additional information about typical urban outdoor and indoor noise environments.

An emphasis on the outdoor noise environment sometimes obscures the fact that most of us spend much of our lives indoors, and that actually, our noise exposure is not necessarily predicted well from knowledge of the outdoor noise levels alone. Thus, to provide some perspective, this paper also presents a brief comparison of simultaneous indoor and outdoor measurements made in residential areas.

Before describing the noise model and measurements, we should first define the kind of noise measure that we will use. All measurements will be reported in terms of the A-weighted noise level in decibels. This level incorporates a frequency weighting of the noise signal similar to that of the human ear; it thus provides a reasonably good assessment of the noise in terms of people's subjective response to noise.

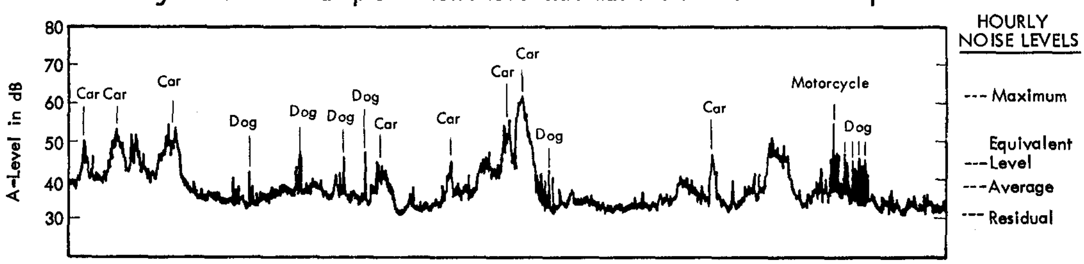
Because of the time-varying nature of the actual noise environment, the temporal aspects of noise must also be considered in selecting a useful scale for measuring the noise environment. Given modern acoustic instrumentation and digital computers, it is now easily possible to develop detailed and exhaustive statistical descriptions of the noise measured over any desired time period, ranging from a few minutes to a few years. However, for many planning purposes, such detail is not needed nor desired. Thus, in this paper the noise environment will be described in terms of the A-weighted *equivalent level* measured over hourly periods or measured during the 24-hour day.

For those not familar with the concept, the *equivalent level* is obtained by "energy" averaging the noise levels occurring over a stated period of time, an hour or day, for example. The equivalent level is equal to the level of a *continuous* noise source that would produce the same energy as contained in the actual fluctuating noise levels occurring over the same time period. Figure 1 shows a graphic level recording of the actual noise levels measured over a short (14-minute) time. The equivalent level noted on the figure may be compared to the maximum level observed during the period and the "arithmetic" average level existing over the period. The equivalent level is much more influenced by the presence of short duration noise intrusions than is the "mean" or "median" noise level.

To describe the noise environment over a 24-hour day, the day-night average level (L_{dn}) measure will be used. The day-night average level extends the equivalent level concept to the entire 24-hour period, but includes a weighting of 10 dB applied to the noise levels measured at night (taken as the period from 10 P.M. to 7 A.M.). This weighting is applied to reflect the greater sensitivity to noise in residential areas during the night.

Other measures of the noise environment are in more or less common use and are described in the literature. For most community noise environments, the correlation of one noise measure with another will generally be quite high. Thus, with the exception of neighborhoods exposed to discrete high-level noise intrusions (such as neighborhoods near jet airports), general conclusions based on day-night levels or hourly equivalent levels will hold for most other noise measures in common use.

Figure 1.—An example of noise-level fluctuations over a short time period.



HISTORY OF NEIGHBORHOOD NOISE, A 14 MINUTE SEGMENT FROM A ONE HOUR RECORD

BASIC MODEL ASSUMPTIONS

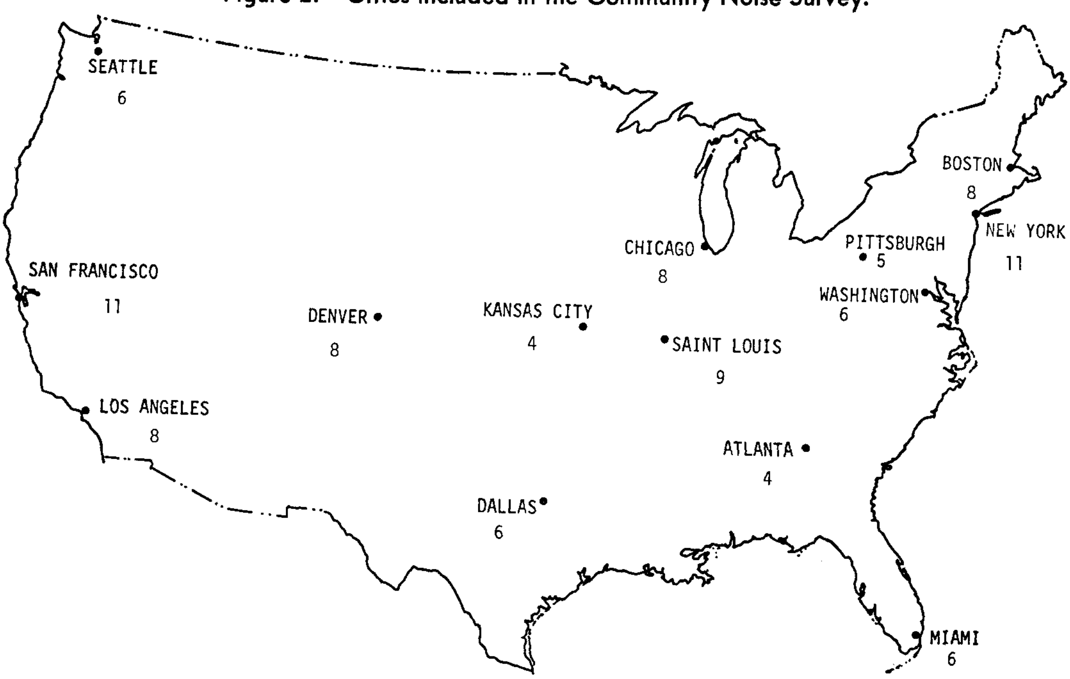
The impetus for developing this noise model arose from the need of the United States Environmental Protection Agency to estimate the outdoor noise exposure for the entire urban and suburban area of the United States. Evidence from community noise surveys pointed out clearly that surface transportation was the most important single contributor to the noise environment. Over a wide range of population densities and of total populations, the number of automobiles per person is almost constant, as is the ratio of trucks in service to automobiles in service. Thus the use of vehicles is directly proportional to population density. If non-freeway traffic is considered, the average speed of motor vehicles in urban areas is essentially constant. Application of existing traffic noise models then suggests that as a first-order estimate, the community noise level should be proportional to 10 times the logarithm of the population density of the community.

This hypothesis was first tested against 30 examples of existing noise data. It was found that the day-night sound level could be correlated with 10 times the logarithm of the density per square mile with an intercept of 32 dB for a population density of 10 people per square mile.

NOISE SURVEY MEASUREMENTS AND ANALYSIS

To obtain more substantiation of this model, a program was set up to measure noise at 100 locations throughout the country. Selection of measurement sites was governed by consideration of the availability of census data, variations in population density, geographic spread of communities, and the need to select sites away from major highways and airports. Figure 2 shows the cities included in the noise survey; the number of sites

Figure 2.—Cities included in the Community Noise Survey.



measured in each city is also shown in the figure.

The central city average density varied among the cities selected from a low of approximately 2,100 in Kansas City to a high of 26,300 in New York City. The field measurements were made in community areas having population densities ranging from slightly over 1,000 per square mile to approximately 90,000 people per square mile.

Measurement sites were restricted to areas not closer than approximately 1,000 feet from major highways and where the estimated noise exposure to aircraft noise was less than an L_{dn} value of 70 dB. At each site, the microphone was located 1.8 meters from the building facade. The microphone was typically located 1.5 meters above the ground for single-story residences. For multi-story residences, the microphone was placed at an elevation comparable to occupant height.

Figure 3-4.—Samples of noise data obtained from a 24-hour site measurement.

SITE # 1303

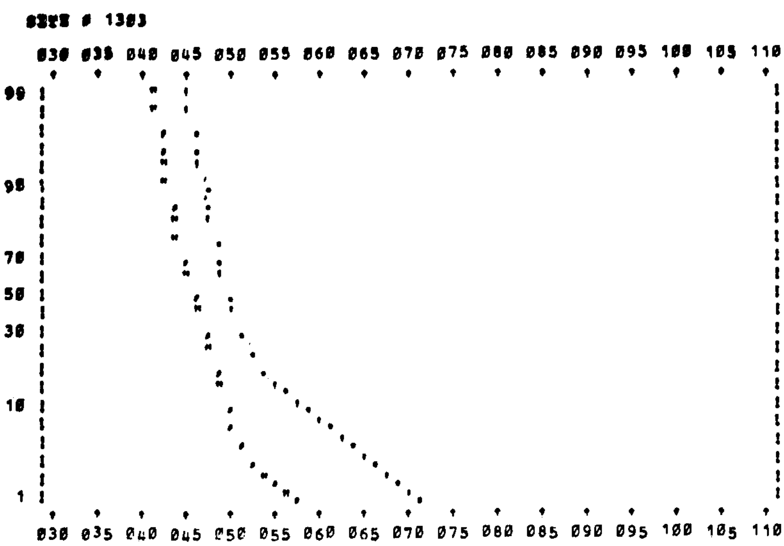
HR	MAX	MIN	NPL	SIG	LEQ	TNI	L1	L3	L5	L10	L20
1	68.8	42.5	55.0	2.4	48.9	29.4	58.0	54.8	52.2	48.9	48.3
2	68.8	42.5	50.5	1.6	46.4	26.3	51.2	48.4	47.5	47.2	46.4
3	71.3	41.3	54.8	2.8	47.7	28.5	60.6	51.4	48.4	46.8	45.9
4	62.5	40.0	50.0	1.8	45.3	26.9	52.8	48.2	47.0	46.1	45.6
5	76.3	40.0	54.0	2.7	47.0	25.9	58.7	49.6	46.6	45.3	44.6
6	68.8	40.0	54.0	2.8	46.8	34.3	56.9	51.1	49.6	47.7	46.0
7	76.3	42.5	62.3	3.7	52.9	37.0	65.6	58.6	53.5	50.6	48.7
8	70.0	42.5	56.7	2.7	49.9	37.1	59.7	55.2	53.3	51.2	49.7
9	71.3	42.5	57.8	2.8	50.6	36.1	60.8	56.2	54.0	51.3	49.8
10	81.3	45.0	67.5	4.2	56.9	40.8	70.0	64.9	59.7	53.7	51.3
11	70.0	43.8	56.7	2.4	50.7	33.0	60.9	53.6	52.0	50.9	49.9
12	83.8	43.8	63.5	3.5	54.6	46.3	63.8	58.8	56.9	54.9	53.4
13	82.5	43.8	65.5	3.9	55.6	40.1	65.4	59.4	55.9	51.7	49.9
14	77.5	45.0	63.3	3.7	53.9	43.2	66.1	62.0	58.7	54.1	50.7
15	76.3	43.8	57.8	2.6	51.0	36.1	58.6	52.4	51.4	50.8	49.9
16	75.0	43.8	60.0	2.9	52.5	34.2	64.0	58.7	55.3	51.9	50.4
17	81.3	43.8	60.9	3.2	52.7	39.6	63.2	57.0	54.3	52.2	50.9
18	86.3	47.5	70.1	4.4	58.9	51.6	70.8	65.5	62.3	57.4	53.6
19	98.8	45.0	84.5	7.0	66.6	84.9	77.6	72.4	69.6	65.3	60.3
20	92.5	46.3	79.0	5.9	63.9	72.3	75.9	69.4	66.3	62.5	58.6
21	93.8	46.3	86.0	7.2	67.6	92.2	79.5	75.4	73.0	69.0	64.6
22	90.0	46.3	66.6	3.7	57.2	43.5	68.3	62.2	59.2	55.2	52.4
23	65.0	46.3	53.7	1.4	50.1	29.1	55.9	53.8	52.6	51.1	50.1
24	67.5	43.8	52.8	1.6	48.7	28.9	55.6	51.5	50.4	49.7	48.9

HR	L30	L40	L50	L60	L70	L80	L90	L95	L97	L99
1	47.9	47.5	47.2	46.9	46.6	46.3	45.3	44.6	44.3	43.9
2	46.1	45.8	45.5	45.3	45.0	44.5	44.1	43.9	43.8	43.0
3	45.4	45.0	44.5	44.1	43.7	43.3	42.8	42.6	42.5	41.8
4	45.0	44.8	44.5	44.2	44.0	43.6	42.5	41.9	41.6	41.4
5	44.1	43.6	43.3	43.0	42.7	42.3	41.7	41.4	41.3	40.7
6	45.0	44.5	43.9	43.5	43.1	42.8	42.2	41.7	41.5	41.3
7	48.0	47.4	47.0	46.6	46.2	45.7	45.2	44.6	44.2	43.9
8	48.7	48.3	47.8	47.4	47.0	46.6	45.9	45.4	45.1	44.4
9	49.1	48.6	48.2	47.8	47.4	46.9	46.3	45.6	45.3	44.6
10	50.7	50.1	49.7	49.4	49.0	48.7	48.0	47.7	47.6	46.8
11	49.5	49.1	48.7	48.3	48.0	47.6	46.9	46.5	46.3	45.5
12	52.3	51.0	49.9	49.2	48.6	48.2	47.7	47.5	46.9	46.3
13	49.1	48.5	48.0	47.6	46.9	46.2	45.6	45.2	45.1	44.7
14	49.8	49.5	49.1	48.8	48.5	48.1	47.8	47.6	47.6	47.2
15	49.2	48.5	47.6	47.1	46.7	46.3	45.7	45.3	45.2	45.0
16	49.8	49.6	49.3	49.0	48.8	48.3	47.8	47.5	46.8	45.6
17	50.0	49.4	48.8	48.1	47.4	46.9	46.4	45.8	45.5	45.1
18	52.4	51.8	51.2	50.8	50.4	50.0	49.4	49.0	48.9	48.8
19	57.1	54.6	52.7	51.3	50.3	49.5	48.8	48.0	47.6	46.8
20	56.1	54.3	52.9	51.7	50.8	50.0	49.2	48.8	48.4	47.8
21	61.1	58.6	56.5	54.9	53.5	52.3	51.3	50.3	49.8	48.9
22	51.8	51.2	50.8	50.4	50.0	49.5	49.1	48.8	48.7	47.9
23	49.8	49.6	49.4	49.2	49.1	48.9	48.4	47.9	47.8	47.6
24	48.5	48.3	48.0	47.8	47.5	47.0	46.6	46.4	46.3	45.7

Sample Output Listing

A-weighted noise levels were monitored continuously for a full 24-hour period at each site, using portable unmanned monitoring systems we had developed. These systems sampled the noise environment at a rate of 8 times per second. For each sample, the noise signal was A-weighted, converted to a decibel format, and distributed into 1 of 64 bins, each 1.25 dB wide spanning a sound level range from 30 to 110 dB. Once each hour, the contents of the 64 bins as well as the time of day were recorded on a digital tape.

The data tapes were later processed by computer to yield various noise-level statistics and measures for each hour as well as for daytime and nighttime periods. Figures 3 and 4 show a sample output listing for one of the sites. Various statistics describing the cumulative distribution of noise levels occuring for each hour and for the daytime and nighttime periods are tabulated. Also tabulated are the maximum and minimum noise levels, as well as other noise measures, including the equivalent level and the day-night level. Cumulative distribution curves of the daytime and nighttime noise levels are also plotted.



CUMULATIVE DISTRIBUTION

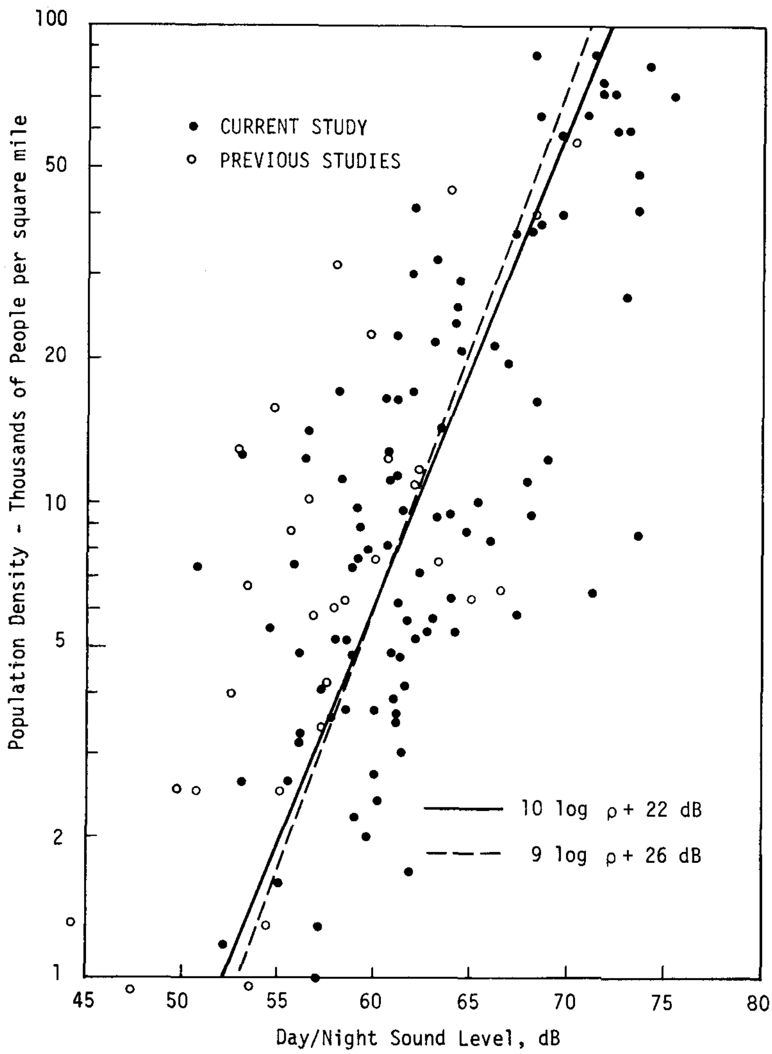
	DAY '.'.	NIGHT ",".	WEIGHTING	WEIGHTED L_{eq}
MAX	98.8	76.3	0.	58.7
MIN	42.5	40.0	8.	59.5
NPL	74.0	56.7	10.	60.0
SIG	5.2	3.1	12.	60.7
LEQ	60.6	48.8		
TNI	60.4	39.6		
L1	71.9	57.6		
L3	66.0	52.5		
L5	62.7	50.8		
L10	57.8	49.6		
L20	53.3	48.5		
L30	51.4	47.6		
L40	50.5	46.7		
L50	49.7	46.0		
L60	49.2	45.2		
L70	48.6	44.5		
L80	47.9	43.9		
L90	46.9	42.9		
L95	46.2	42.4		
L97	45.7	41.9		
L99	45.2	41.4		

Sample Output Listing

The day-night levels observed over the 100 sites range from approximately 50 to 75 dB. Figure 5 shows the measured day-night levels plotted vs. the logarithm of the population density. The computed least squares regression line yields an equation showing that L_{dn} is equal to 9 times the logarithm of the population density plus 26 dB. The regression line has a correlation coefficient of 0.72 and a standard error of the estimate of about 4 dB.

If we assume that the noise level varies with 10 times the logarithm of the population density, the model indicates an intercept of 32 for a population density of 10. At the 5-percent level of significance, this regression line with a slope of 10 is statistically insignificant from the least square regression line. Thus, the equation showing L_{dn} equal to 10 log population density plus 22 provides a useful first-order estimate of outdoor levels in urban residential areas in this country.

Figure 5.—Correlation of day-night levels with population density.



Day/Night Sound Level as a Function of Population Density

MODEL APPLICATIONS

If one assumes that at each level of population density, the L_{dn} values are normally distributed about the average level (given by the model equation) with a standard deviation of the same order as the standard error of the regression line (4 dB), one can then estimate the noise exposure for the country, given the population density distribution of the urban population in the United States. This was done, using population-density information for census tracts, obtained from the 1970 census. Some results are given in table I (more detailed results are given in Galloway 1973).

Table I.—Estimated community noise exposure in the United States*

L_{dn} in dB	Number of people exposed to specified L_{dn} or greater
	Millions
55	93.4
60	59.0
65	24.3
70	6.9
75	1.3
80	.1

*Excluding freeway and airport noise.

This analysis indicates that more than 90 million people live in areas with day-night levels in excess of 55 dB, and 1.3 million people live in areas with day-night levels in excess of 75 dB.

The population-density model also provides a basis for estimating the variation of noise levels throughout a community and as a basis for planning detailed community noise surveys. In this approach, noise levels derived from estimates of the population density can be viewed as setting a "plateau" noise level for community areas that are not located near strong localized noise sources. Then, to this plateau, one can add the "ridges" and "mountains" contributed by the noise of strong sources (major highways, railroads, and industrial noise sources as well as aircraft).

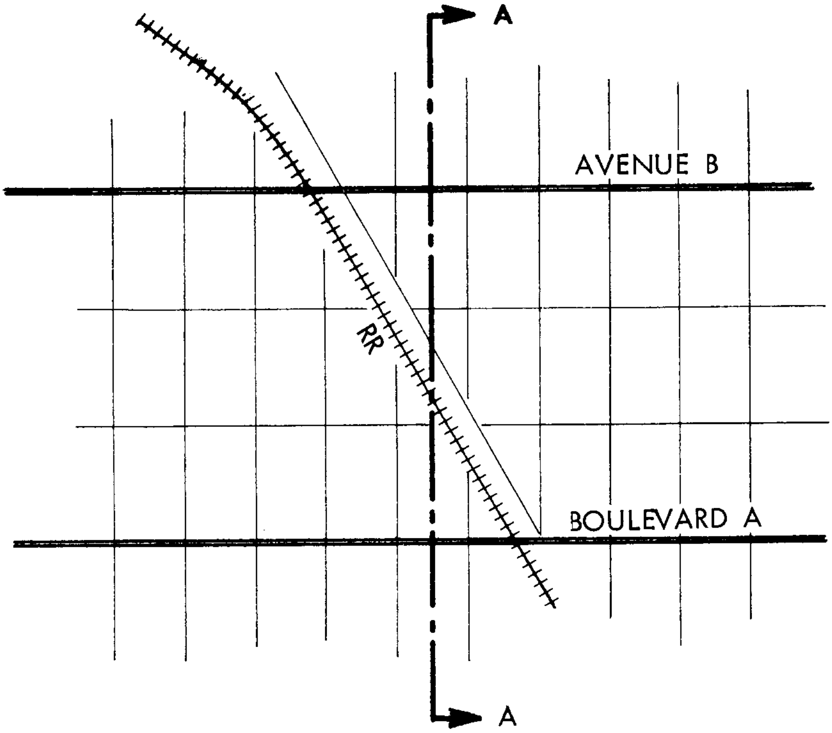
Figure 6 shows this application to a hypothetical community area. The community area of interest is bordered by two major roadways and is intersected by a railroad. The lower portion of the figure shows an estimate of the noise levels throughout Section AA. The plateau noise level given by the population density is shown as is the contribution by the surface traffic sources. This profile may be used to provide first-order estimates of the differing noise exposure through the cross-section. It also provides a basis for initially locating noise-measurement positions for a detailed field-noise survey.

DAILY NOISE-LEVEL TIME PATTERNS

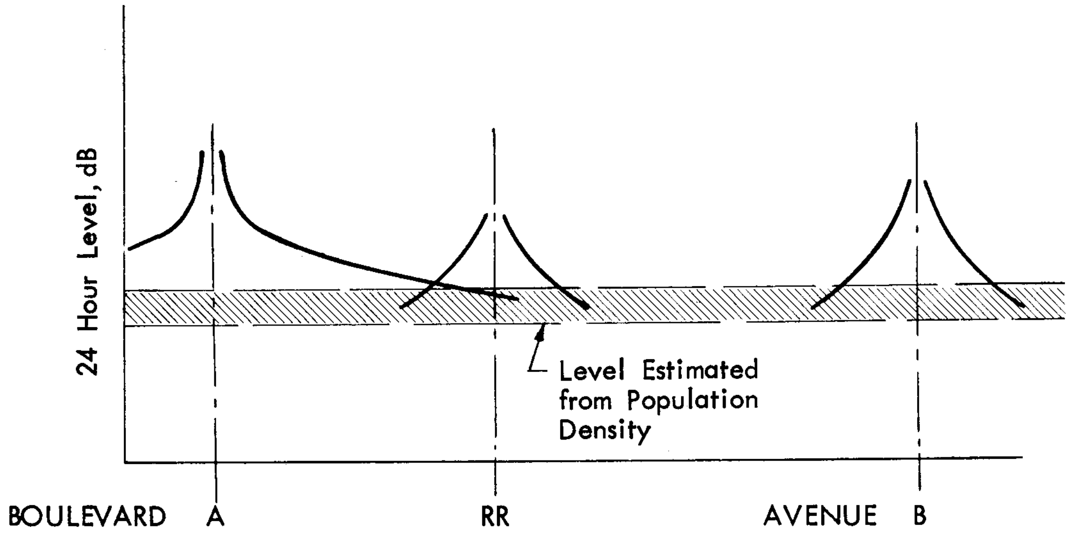
The information collected at the 100 sites throughout the country provided much information in addition to the 24-hour L_{dn} data. The data, for example, provide some insight into the typical variations in noise levels during different times of the day. Figure 7 shows the composite daily noise pattern where the average equivalent level for each hour of the day (across the 100 sites) is plotted as a function of time of day. At each site, the hourly values have been referenced to the day-night level for that site. Thus, the figure shows the difference between the 24-hour day-night average level and the equivalent level for each hour of the day.

Since the difference between the equivalent level at any one hour and the day-night level generally differs from site to site, one can obtain a measure of a variability in relative noise levels with time of day by computing the standard deviation for those differences for each hour of the day. This information may be useful, for example, in determining the best time of day in which to take measurements, i.e. in determining which hourly measures would provide the most reliable estimates of the

Figure 6.—Using the population density model to predict noise-level variations in a community area.

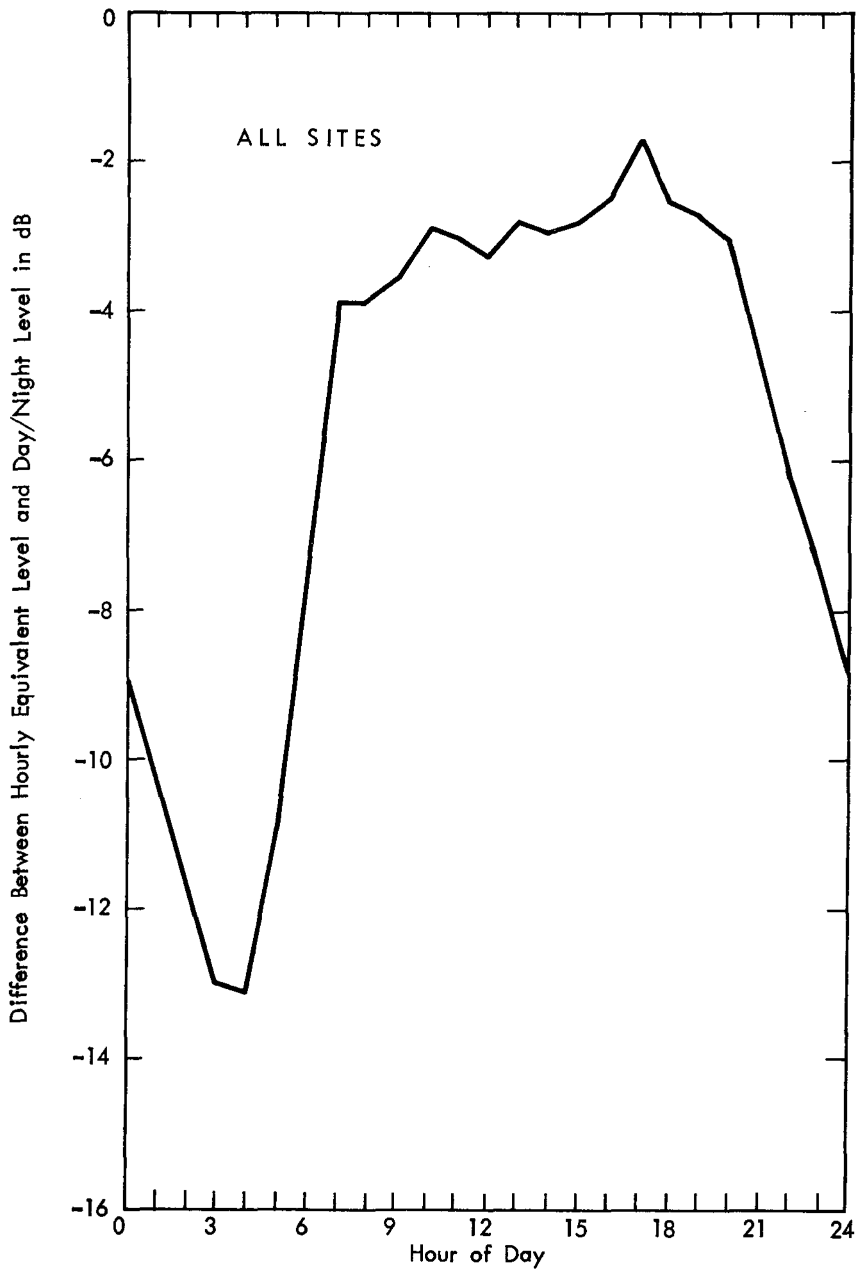


A. MAP OF NOISE SURVEY AREA



B. NOISE LEVEL PROFILE THROUGH SECTION A-A

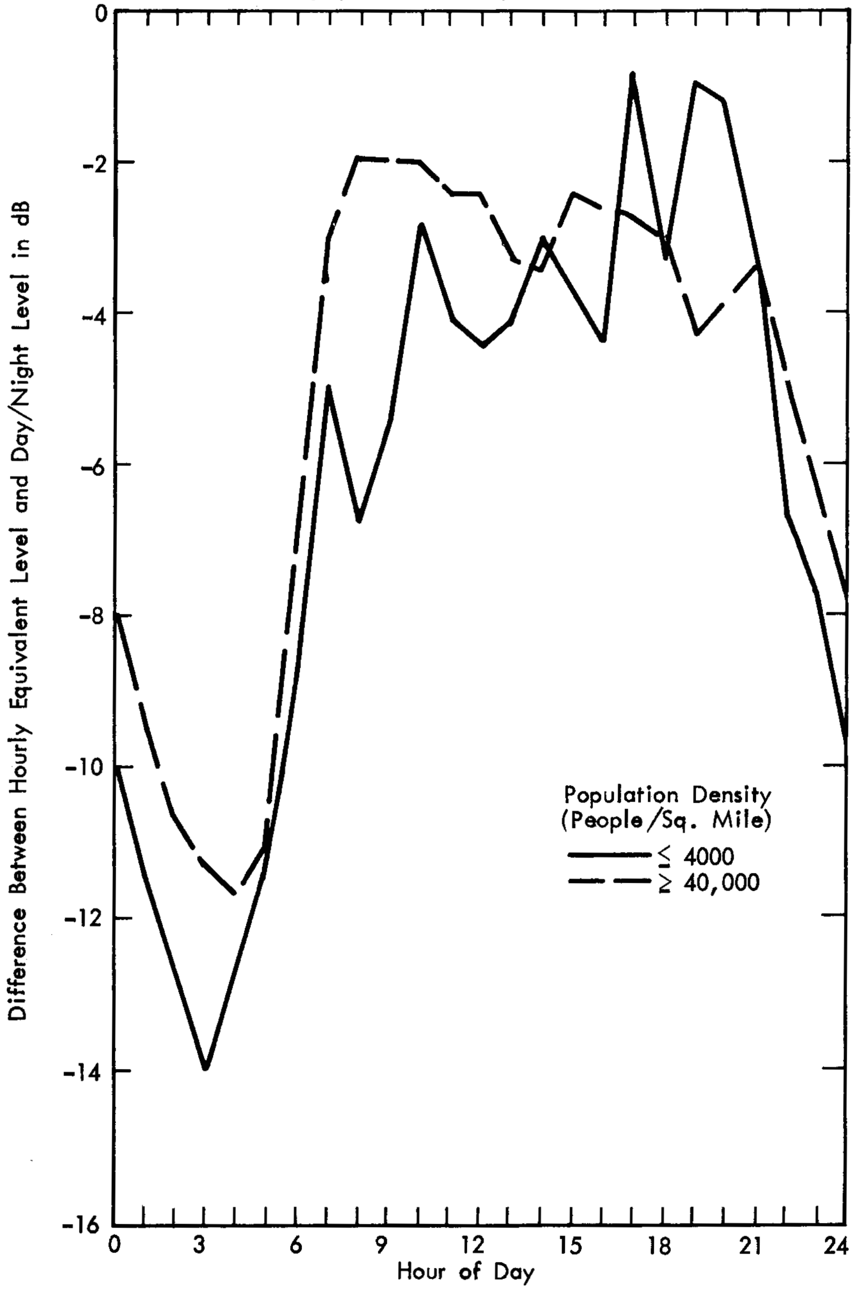
Figure 7.—Average hourly time patterns of noise levels (100-site survey).



24-hour noise exposure. For the data shown in figure 7, the standard deviations of the hourly averages range from about 4 dB in the early morning hours, generally decreasing through the day to about 2.5 dB in the late evening.

One can examine these daily patterns for sites having different population densities to check if there are differences in patterns for areas having greatly different densities. Some can be anticipated, since the daily traffic flow patterns may differ between high and low density urban areas. As an example, figure 8 shows the variation in hourly noise levels for sites with: (a) popula-

Figure 8.—Hourly time patterns of noise levels for sites of widely different population density.



tion densities of 4,000 persons per square mile or less; and (b) population densities of 40,000 people per square mile or greater.

Several interesting trends can be noted in the comparison. For the lower density sites the range in noise levels from minimum nighttime levels to maximum daytime levels is greater—approximately 13 dB compared to 10 dB for the higher density areas. This confirms earlier measurements showing smaller variations in levels for areas exposed to heavier volumes of daily traffic *(Bishop and Simpson 1973)*.

Another interesting finding is that, in the high-density areas, the noise levels show less variation during the day, with levels reaching a maximum early in the morning and decreasing slightly during the day. In the low-density neighborhoods, more typical of suburban residential areas, the pattern shows a general rise in the noise levels during the day, with a maximum occurring between the hours of 5 and 9 P.M.

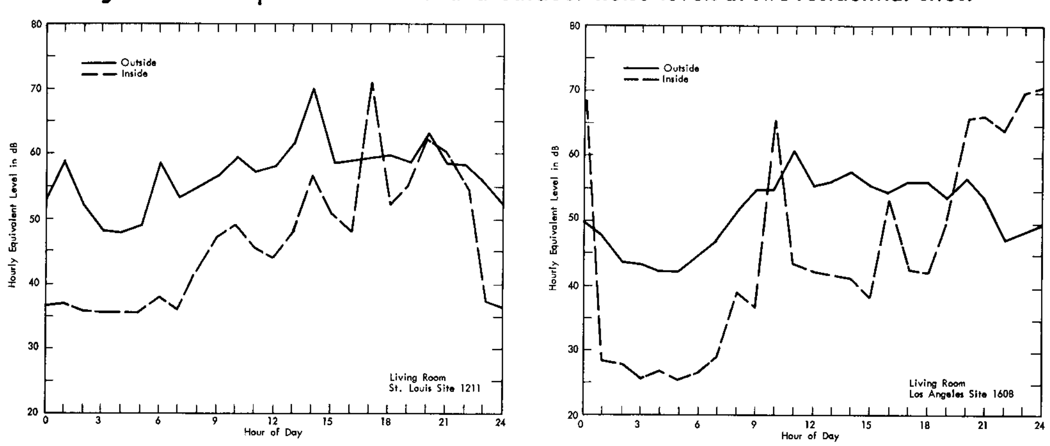
COMPARISON OF INSIDE AND OUTSIDE NOISE LEVELS

Thus far we have concentrated on descriptions of the outdoor noise environment; but most of our time is spent inside buildings, and the noise environment inside a building can bear little relationship to the environment measured outdoors. Thus, it is important to have some knowledge of the correlation of inside and outside noise environments. Sometimes too much importance may be placed on the control of exterior noise if one neglects the noise that is generated by people activity inside a building and the noise resulting from use of appliances, tools, radios, and televisions. Of course, we must remember that much of the noise generated inside a building may be wanted noise and even essential. In contrast, most noise intrusions from the outside are generally undesired.

Typically, in moderately quiet neighborhoods, we would expect the indoor noise environment to be controlled primarily by internally generated noise sources. It is only in relatively noisy outdoor environments that the noise leaking in from the outside contributes measurably to the indoor noise environment. There are extremely wide variations in the noise patterns found in different rooms of a building, depending, obviously, on the degree and kinds of activities.

Figure 9 shows the inside and outside measurements made in two different living rooms. The patterns here show some fairly predictable patterns. In both living rooms, the noise levels during late night hours (from midnight until about 6 or 7 in the morning) fall well below the outdoor noise levels. It is during this night period that exterior noise events most noticeably influence the indoor noise patterns. During the day, both indoor and outdoor noise levels increase, with a marked increase of indoor noise

Figure 9.—Comparison of indoor and outdoor noise levels at two residential sites.



to a maximum during the evening hours when the living room is either occupied or activities are occurring in adjacent areas of the house.

SUMMARY

Field noise measurements consisting of sets of 24-hour measurements made at 100 residential sites scattered across the country confirm a simple model for estimating the community noise environment based on knowledge of the site population density. This model has been used to provide a first-order estimate of the noise exposure in urban areas of this country. The model also can be used in estimating the variation in noise levels in community areas and in planning detailed community noise surveys. Data obtained from the 100-site field study have also yielded considerable information on the time pattern of noise levels occurring during the 24-hour day. Simultaneous inside and outside measurements in residences confirm the general lack of correlation between inside and outside noise levels, which result from the noise generated by people's indoor activities.

REFERENCES

W. J. Galloway, K. McK. Eldred, and M. A. Simpson.
1974. POPULATION DISTRIBUTION OF THE UNITED STATES AS A FUNCTION OF OUTDOOR NOISE LEVEL. EPA Rep. 550/9-74-009.

D. E. Bishop and M. A. Simpson.
1973. CORRELATIONS BETWEEN DIFFERENT COMMUNITY NOISE MEASURES. Noise Control Engin. 1: 74-78.