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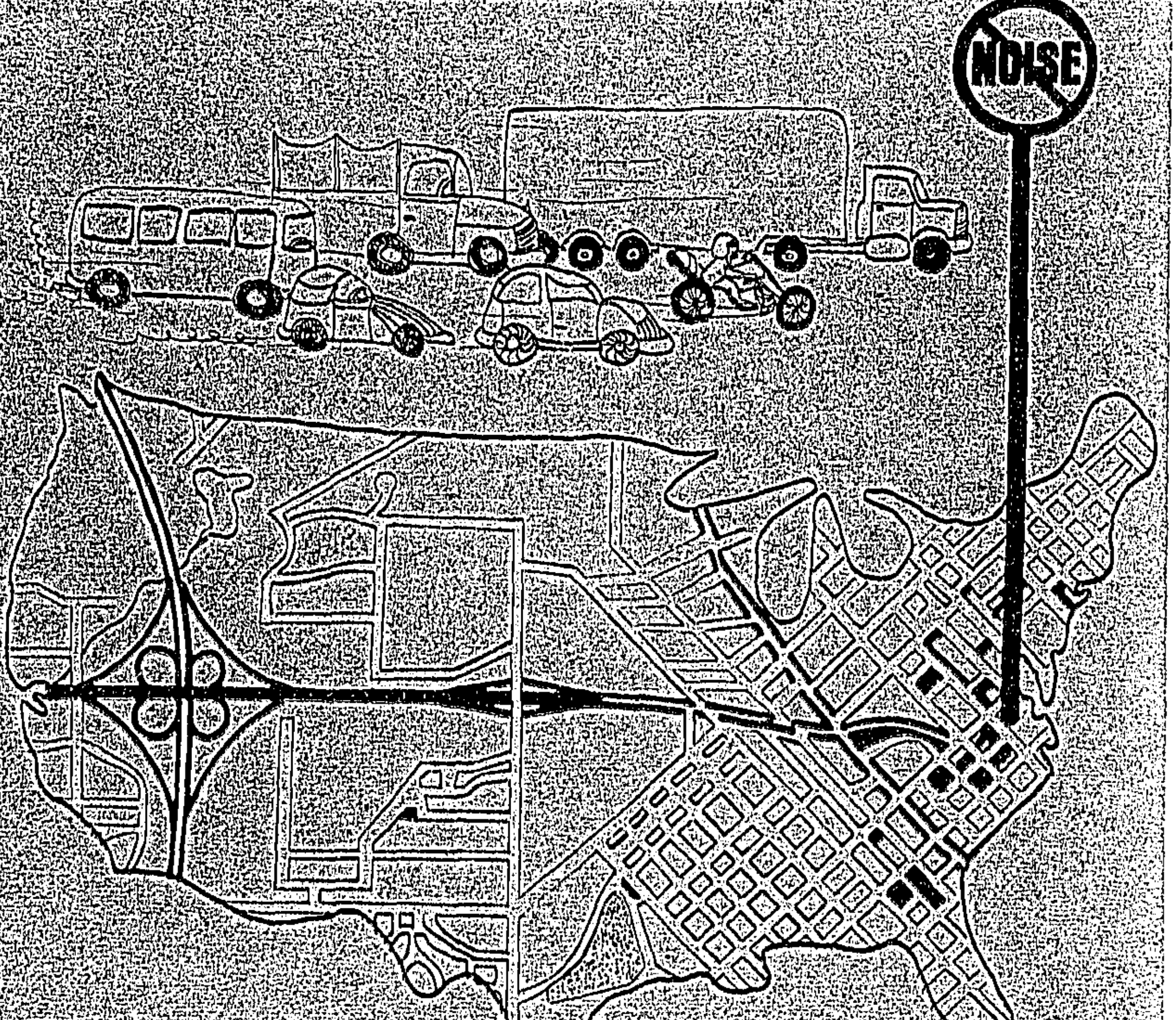
EPA

NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL

Model Description and Data Base



NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL

Prepared By:

Fred Rudder, Jr.
Larry Ronk
Barbara Hutcheson

SCIENCE APPLICATIONS, INC.
Energy Technology and Engineering Group
1651 Old Meadow Road, Suite 600
McLean, VA 22102

Prepared For:

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT AND CONTROL
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ABSTRACT

This report describes the National Roadway Traffic Noise Exposure Model. This Model is a computer simulation of the national roadway network, the noise generated by traffic on the network, and the predicted effects of the noise on the national population. The Model simulates time-varying conditions, using input data, to characterize traffic conditions and population growth from the baseline year (1974) to user-defined future years. To characterize the effects of noise on the national population, the Model is subdivided into two sub-models: the General Adverse Response Model and the Single Event Model. The report describes each sub-model and the common data base used by the sub-models. The structure of the models and the interaction with the various elements of the common data base are described. Example vehicle noise emission standards are presented to illustrate the use of the Model. Predictions resulting from the Model simulation are compared with available empirical data.

Keywords

Traffic Noise Levels
Traffic Noise Exposure
Roadway Traffic Conditions
Population Distribution
Vehicle Operating Characteristics
Noise Exposure Simulation

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1.0 INTRODUCTION

The noise generated by vehicles operating on the national roadway network is the most pervasive noise source impacting the populaton of the United States. Daily, an individual is exposed to a range of noise levels and ambient conditions resulting from roadway traffic operations. This daily noise exposure is a cumulative, life-time experience. Today, community annoyance and concern with roadway traffic-generated noise has resulted in continuing efforts to abate noise exposure, both through highway design and control of vehicle emissions. The development of this model is one element of this continuing effort.

As described in the following sections, the National Roadway Traffic Noise Exposure Model simulates the noise generated by vehicle operations on the 3.586 million miles of national roadway network. The roadway network services the nation's population of 216.7 million people. The population, roadway network, and traffic conditions on the nation's roadways are not static quantities. Population size, roadway characteristics, and traffic conditions on the nation's roadways will vary from year to year. The Model* recognizes these variations in estimating national noise exposure in future years.

The purpose of developing the National Roadway Traffic Noise Exposure Model is to simulate, as closely as possible, the interaction of the parameters describing roadway traffic noise generation and the national impact of roadway traffic noise. The Model* allows the simulation of vehicle noise reduction scenarios based upon this interaction. The Model* is also structured with sufficient flexibility to study the effect of path and receiver noise control measures.

In estimating roadway traffic noise on a national basis, the Model uses over 5600 stored data inputs to characterize the interaction between population, roadway traffic conditions and vehicle noise emissions. These

*"Model" refers to the National Roadway Traffic Noise Exposure Model.

data were developed based on information from the U.S. Bureau of Census, the U.S. Department of Transportation, the U.S. Environmental Protection Agency, and the open technical literature.

The development of this Model was preceded by a review of previous studies related to national exposure to traffic noise. This review encompassed the following technical areas:

- vehicle noise emissions
- vehicle operational characteristics
- roadway and traffic flow descriptions
- population and population density distributions
- traffic noise models
- noise propagation
- national noise exposure models.

It was recognized that available traffic noise prediction models were adequate to describe noise levels adjacent to a roadway segment. The basic objective of this study was to develop a national simulation model with sufficient flexibility to allow sensitivity of real world parameter interactions. Hence, much of the review comprised a search for data upon which to base the Model. The reports and studies reviewed and used in developing this Model are referenced in the text. These references are listed in Section 5.

In order to conduct traffic noise exposure estimates, it is necessary to relate population distribution, roadway configuration, and vehicle characteristics. Figure 1-1 illustrates the relationship among these basic parameters. Each of these parameters are placed at a corner of the outer triangle in Figure 1-1. The inner triangle of Figure 1-1 represents the desired noise exposure estimate. Each leg of the outer triangle indicates the relationship between two of the three basic parameters. To obtain the noise exposure estimate, the three corners must be related using the data indicated in each leg of the outer triangle. The formulation of the Model

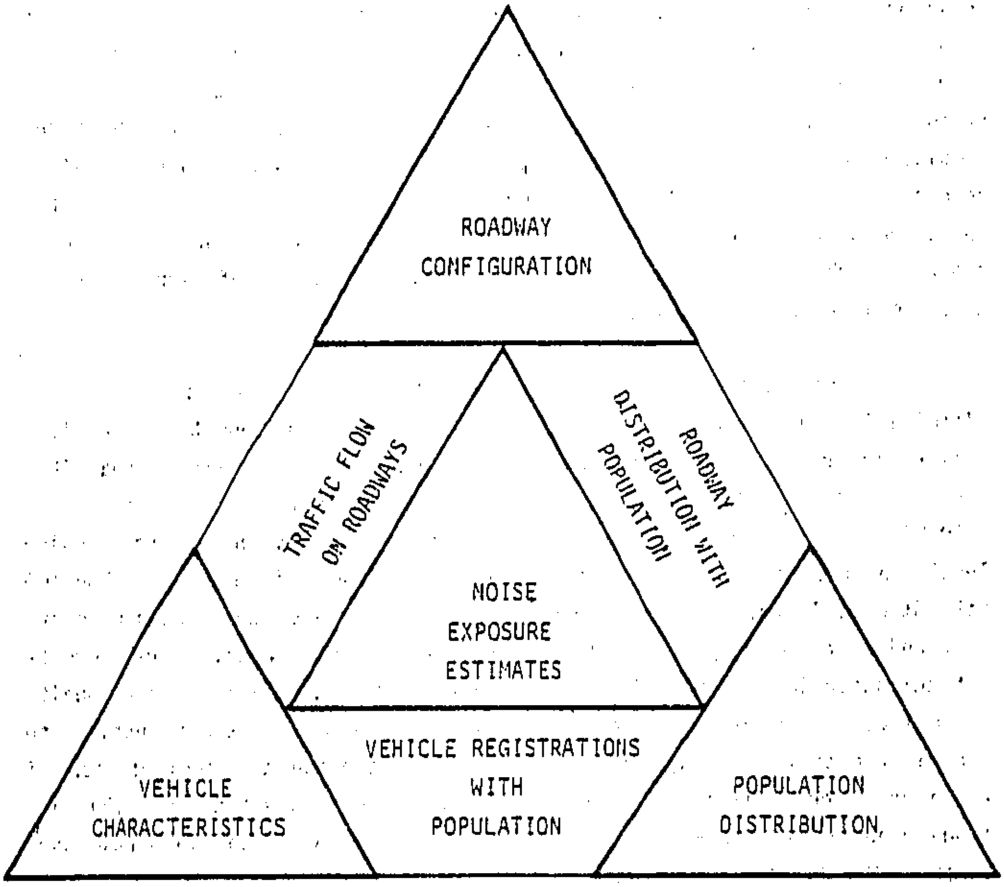

FIGURE 1-1. RELATIONSHIP BETWEEN POPULATION DISTRIBUTION, ROADWAY CONFIGURATION AND VEHICLE CHARACTERISTICS IN DETERMINING NOISE EXPOSURE ESTIMATES

relates population distribution and vehicle characteristics to roadway configurations via the statistics describing traffic flow characteristics. Once these basic parameters are defined, the estimation of the noise exposure is rather simple. The more difficult task faced in developing a national model is the definition of these parameters, in combination, to simulate the national exposure estimates. Based upon the present data base, the Model simulates 4320 combinations of population distribution, roadway traffic conditions, and vehicle characteristics. These simulations are conducted for specified years of a forty-year time stream to estimate national exposure to roadway traffic noise and to evaluate the effectiveness of regulations of motor vehicle noise emissions.

Basic to the literature review was the study entitled: "Population Distribution of the United States as a Function of Outdoor Noise Level."[1] This report described the results of a noise survey of 100 urban area sites across the continental United States, and it is commonly referred to as the "100 Site Study." The 100 Site Study defined empirically the day-night noise level exposure of the nation's population at the place of residence. The 100 Site Study selected sites away from aircraft operations, construction activity, and major highways, in order to represent community noise environments not dominated by a single identifiable noise source. Hence, the community noise levels represent, in general, the ambient sound levels attributable to general community roadway traffic noise. To estimate the contribution of urban and freeway traffic noise to population noise exposure, the 100 Site Study used results from previous research.[2] A review of the data base used in the 100 Site Study is presented in Reference 3.

The results of the 100 Site Study have been used to develop estimates of national roadway traffic noise exposure by scaling specfic scenarios to a national base. It was not an objective of this Model either to scale estimates or to reproduce the empirical basis of the 100 Site Study. However, the 100 Site Study stands as a source of comparison for any national noise exposure model.

Several previous studies have resulted in estimates of the national exposure to roadway traffic noise. To achieve these estimates, these studies took a "scaling" approach, i.e., the noise exposure estimates were conducted for a number of scenarios and scaled or extrapolated to a national base. References 4 and 5 present details of these methods. The present discussion describes the basic methodology and the assumptions used in these studies.

Reference 4 presents the results of a study aimed at estimating the effectiveness of noise regulations for new medium- and heavy-duty trucks. The study of Reference 4 focused upon the noise emissions of vehicles and the mix of vehicle types in the traffic flow. Two basic traffic conditions were considered: urban street traffic (27 mph cruise) and freeway traffic (55 mph cruise). Vehicle mix and operating mode (acceleration and cruise) were considered. The traffic flow noise model used by the Reference 4 study is an L_{eq} formulation for traffic flow mix. Sound level distance attenuation is considered only for the freeway scenario and is assumed to be constant at 9 dB per distance doubling. The salient assumptions used are:

- Total population of urban street traffic is constant on all roadways.
- National noise exposure estimates are obtained by scaling the urban street scenario to match the 100 Site Study results for baseline conditions.
- Freeway noise exposure estimates are based upon a single traffic flow/population density scenario. This result is compared to the 100 Site Study to scale results to the baseline conditions.
- National exposure to roadway noise is the sum of urban street exposure and freeway noise exposure.
- The traffic flow conditions were "typical" of urban conditions.

The Reference 5 study focused upon estimating national exposure to highway traffic noise for the purpose of developing traffic noise regulation strategies. The basic abatement strategies were noise regulation of either existing or new vehicles, vehicle operation, or a combination of those strategies.

The Reference 5 study used an L_{eq} formulation with a constant distance attenuation rate (4.5 dB per distance doubling) to model traffic noise and propagation. A scaling approach was used in that specific combinations of traffic flow conditions and population distribution were modeled and extrapolated to obtain national impact estimates. The scaling approach selected, however, was based upon a statistical sampling of ten cities in the United States, detailed analysis of the traffic flow and population density data for these cities, calculation of noise exposure for these cities, and an extrapolation to national estimates. The traffic noise model considered a state-of-the-art model with a simplified correction for stop and go traffic flow near intersections. Roadways were modeled as single-lane straight segments. Two classes of vehicles were modeled: automobiles and trucks. Low speed traffic flow (35 mph) was used to simulate urban streets and secondary suburban roads. High speed traffic flow (55 mph) was assumed for freeways, rural roads, and major arteries in lightly populated areas. Noise impact estimates were conducted for both urban and rural areas. In each instance, the noise exposure of inhabitants was allocated to a single roadway type. It was recognized by the Reference 5 study that this limitation might affect the urban estimates.

The noise impact estimates presented in Reference 5 were conducted using the model of Reference 6. Hence, the time stream estimates apparently included the growth and attrition of the two vehicle types used in the study. Apparently, the national population was held constant in the noise impact estimates presented.

The formulation of the Model explicitly avoids "scaling" methodology; instead it attempts to simulate the national exposure to roadway traffic noise using a data base aggregated from local statistics. Figure 1-2 illustrates the roadway network through an urbanized area and surrounding rural countryside. The Model defines roadway mileage and travel conditions by the functional classification of roadways comprising the network in this area. On Figure 1-2, closed curves are overlaid on the roadway network to indicate homogeneous population density areas. These areas are indicated by the bold face type and delineate the distribution of population and land areas that comprise the total area. Each of these land areas contains its own allocation of roadways, traffic conditions, and population. The data base for the Model includes the allocation of roadways, traffic conditions, population and land areas so that national conditions are simulated. Using this data base, traffic noise exposure simulation is defined by detailed data inputs and avoids the empiricism inherent with a scaling methodology.

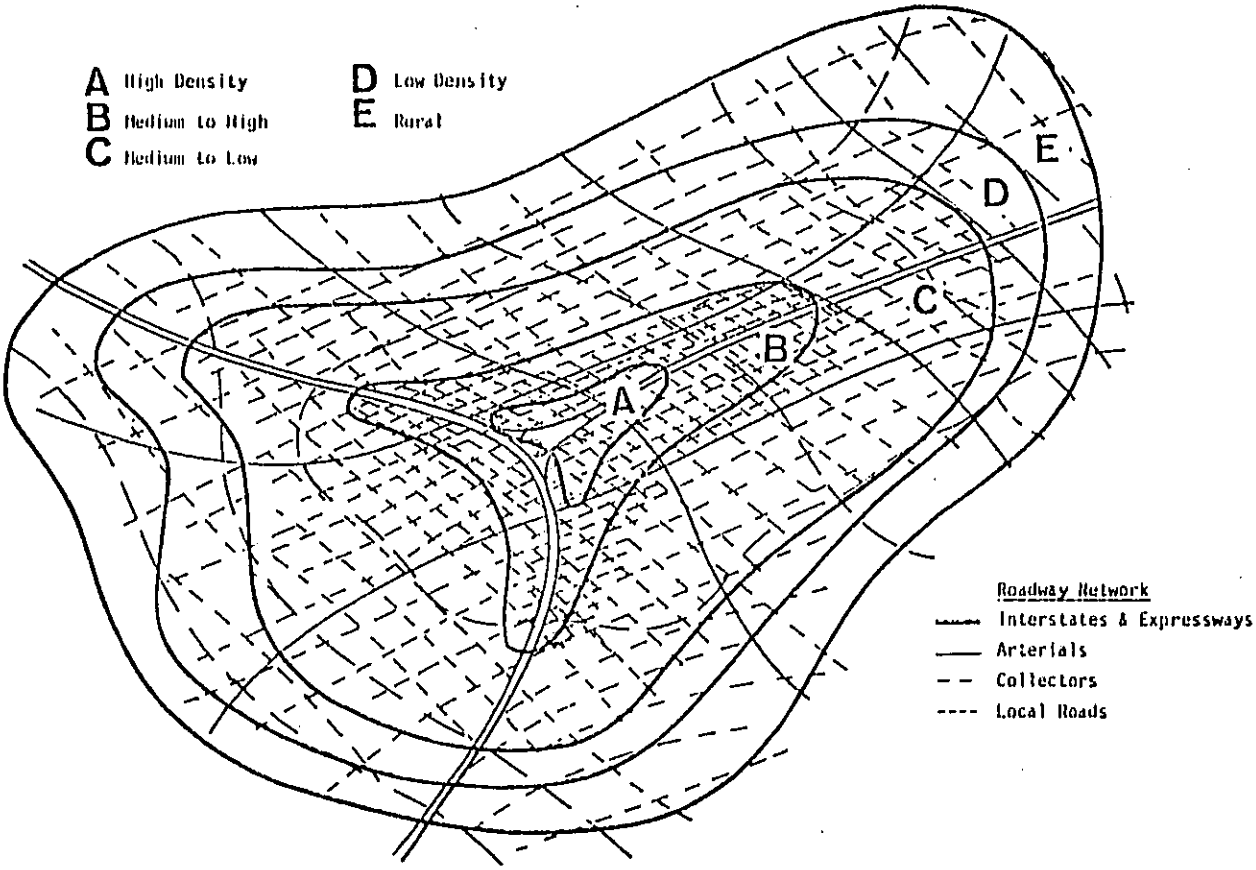

FIGURE 1-2. TYPICAL ROADWAY NETWORK WITH POPULATION DENSITY DISTRIBUTION

2.0 STRUCTURE OF THE IMPACT MODEL

As stated in the Introduction, the National Roadway Traffic Noise Exposure Model was developed based upon a review of previous national noise exposure models. This section of the report describes the formulation of and the methods used by the National Roadway Traffic Noise Exposure Model to estimate noise exposure and traffic noise reduction effectiveness. It is the intent of this report to decribe concepts and typical results rather than extensive detail. The Model, however, is based upon extensive detailed inputs concerning vehicle noise emissions, roadway traffic conditions and distribution of population adjacent to roadways. Appendix A describes the detailed data base. The reader should not allow the level of detail to cloud the Model formulation. The reader should relate detail to Model input data and recognize that input data may be revised based upon the best available information.

2.1 Outline of the Model

The National Roadway Traffic Noise Exposure Model simulates the noise generated by vehicular traffic on the nation's roadway network. The Model does not scale or otherwise "adjust" input data to estimate national noise impact. The Model's estimation procedure is rather direct in that the U.S. population is allocated to roadway traffic conditions surrounding the place of residence. The noise emissions generated by the roadway traffic are then used to estimate the noise exposure of the nation's population.

As with any national simulation model, input data to the Model are statistical in nature. The population in the United States is distributed based upon the Bureau of Census data. The distribution of population relative to roadway traffic conditions is based upon data assembled by the U.S. Department of Transportation's Federal Highway Administration. The noise emission characteristics of vehicles are based upon experimental data collected by the Federal Highway Administration (FHWA), the U.S. Environmental Protection Agency (EPA), and sources in the technical literature.

The Model is a time stream simulation, i.e., the Model uses as input data, factors that alter parameters in time so that the effect of time-varying parameters or otherwise changing projections of a parameter can be simulated. Thus, the Model is a tool both for estimating national exposure to roadway traffic noise and for estimating the sensitivity of specific parameter variation. The need for sensitivity to parameter variations and flexibility in assessing the effect of various source control measures were essentially the reasons for developing the Model, because previous studies had used assumptions and extrapolations to estimate noise exposure. Although the noise exposure estimates of previous studies appeared to be reasonable, it was not possible to evaluate sensitivity to certain parameter variations and look at alternative noise control measures.

The National Roadway Traffic Noise Exposure Model is, in reality, comprised of two separate noise exposure models. These two models are defined as the General Adverse Response Model and the Single Event Model. Both models utilize the same data base to conduct their respective predictions of national exposure to roadway traffic noise. The General Adverse Response Model describes roadway traffic noise in terms of the average 24-hour weighted equivalent noise level, L_{dn}. The day-night sound level, L_{dn}, only considers the average daily sensitivity of the population to noise exposure in that poeple are considered to be "10 dB more sensitive" to noise during nighttime than during the daytime.* Beyond this distinction, the L_{dn} sound level considers the population to be equally sensitive to noise irrespective of their activities when they are exposed to the noise. The Single Event Model attempts to estimate the national population exposure to roadway traffic noise by categories of population activity during the noise exposure. Further, the Single Event Model considers each vehicle type as an independent noise source so that each vehicle's contribution to the overall national population noise exposure may be evaluated. The Single

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* Both models assume the same daytime and nighttime periods as follows:

- Daytime - 7:00 AM to 10:00 PM (0700 to 2200 hours)
- Nighttime - 10:00 PM to 7:00 AM (2200 to 0700 hours)

Event Model considers the specific distribution of the population's activites during the day and during the night and the noise-sensitivity of these activities.

The Single Event Model further estimates the number of noise intrusions imposed upon the national population, the level of these intrusions, and the effect of these intrusions that may be attributed to each vehicle as a noise source. These three elements are combined into a single number using the Fractional Impact Methodology. Basically, the Single Event Model estimates two aspects of noise intrusion: speech interference and sleep interference. The Single Event Model classifies speech interference by location of the national population when the noise intrusion occurs. The Single Event Model classifies sleep interference as to the probability of being either disturbed (but not awakened) or of being awakened by the intruding noise. The calculation scheme used by the Single Event Model does not assign the same person or portion of the population to two different activities simultaneously. Hence, the noise impact estimates are not "double counted."

Together, the General Adverse Response Model and the Single Event Model represent a single method for estimating the various effects of roadway traffic noise on the nation's population. Hence, the two models represent different methodologies required to describe different effects resulting from the same cause.

The following subsections describe the structure of the Model and the interrelationships among the various Model parameters. The reader is encouraged to focus primarily upon the level of detail used by the Model rather than the specific values presented as examples of input data. For each parameter, the formulation of the data base and the interrelationship with other data elements are presented. Appendix A of this report documents the specific values currently used by the Model for each data element.

2.2 Population Model

The Model uses a population model which recognizes the need to allocate people to different traffic conditions. The allocation of the population to roadway traffic conditions is one of the most difficult data assembly tasks associated with creating a national model.

The 1976 National Highway Inventory and Performance Study (NHIPS) conducted by the U.S. Department of Transportation's Federal Highway Administration, provided the basis for allocation of population to roadway traffic conditions.[7,8,9] Reference 7 contains detailed information concerning roadway mileage, travel data, and land areas related to population place size. Further, the data of Reference 7 accumulated on a national basis, the population and land areas allocated to the FHWA functional classification of roadways.

Figure 2-1 presents the percentage allocation of both mileage and travel (Daily Vehicle Miles Traveled, DVMT) by functional roadway classification within each population place size. Two additional subdivisions of this data were required to formulate the data base for the Model. First, the distribution of mileage and travel within each place size and functional roadway classification by average travel speed was required. Second, this allocation of mileage and travel by average travel speed had to be related to the average population density adjacent to the roadway. These two data subdivisons were performed by the staff of the Procedural Development Branch, Program Management Division of the Federal Highway Administration. This task was performed by FHWA at the request of the EPA/ONAC staff and involved a resorting of the NHIPS data by population density groupings and speed range groupings.

The population density groupings described above were based upon gross land areas and populations within these land areas. Hence, the groupings were relative within each place size, in that they covered all place size ranges using four population density groupings (see Appendix A, Sections

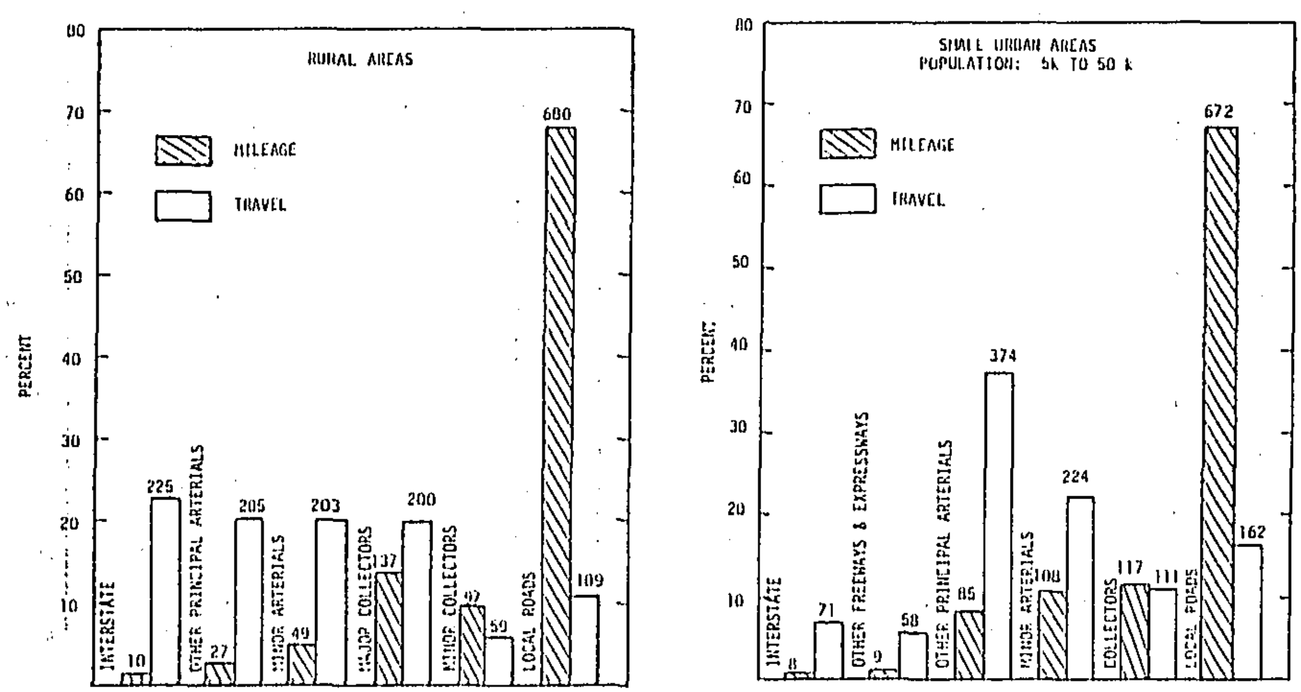


FIGURE 2-1. DISTRIBUTION OF ROADWAY MILEAGE AND TRAVEL BY POPULATION PLACE SIZE

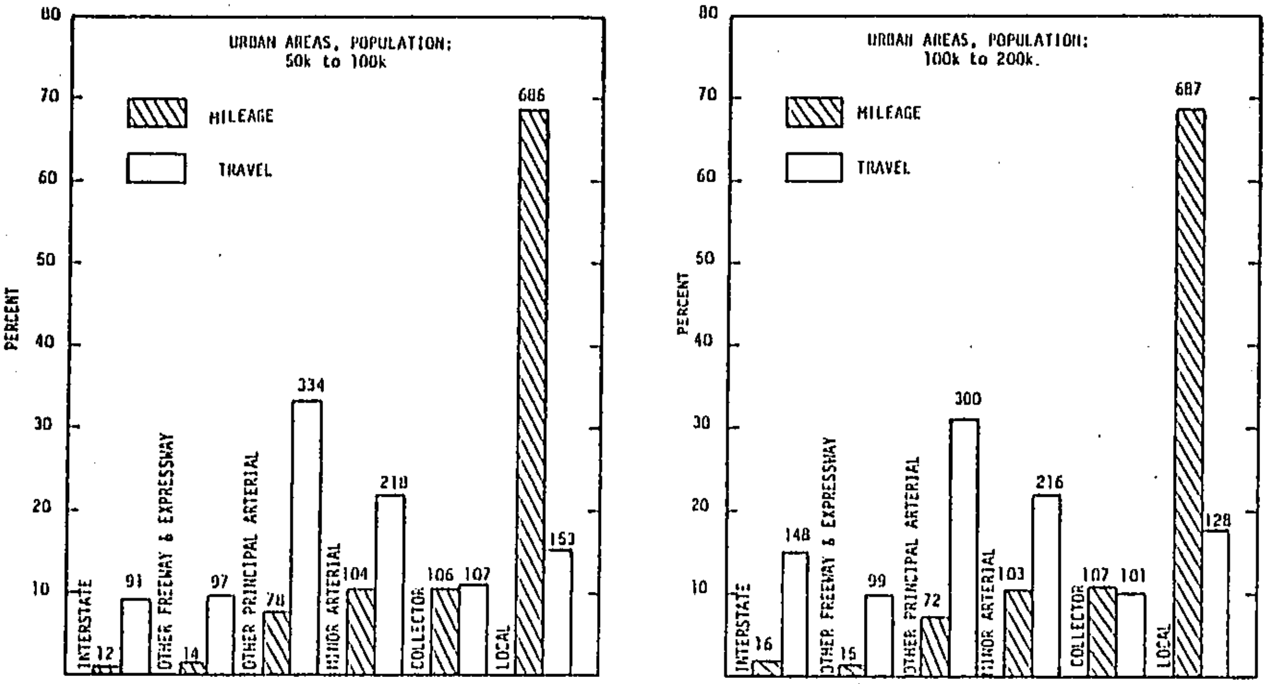


FIGURE 2-1. DISTRIBUTION OF ROADWAY MILEAGE AND TRAVEL BY POPULATION PLACE SIZE (Continued)

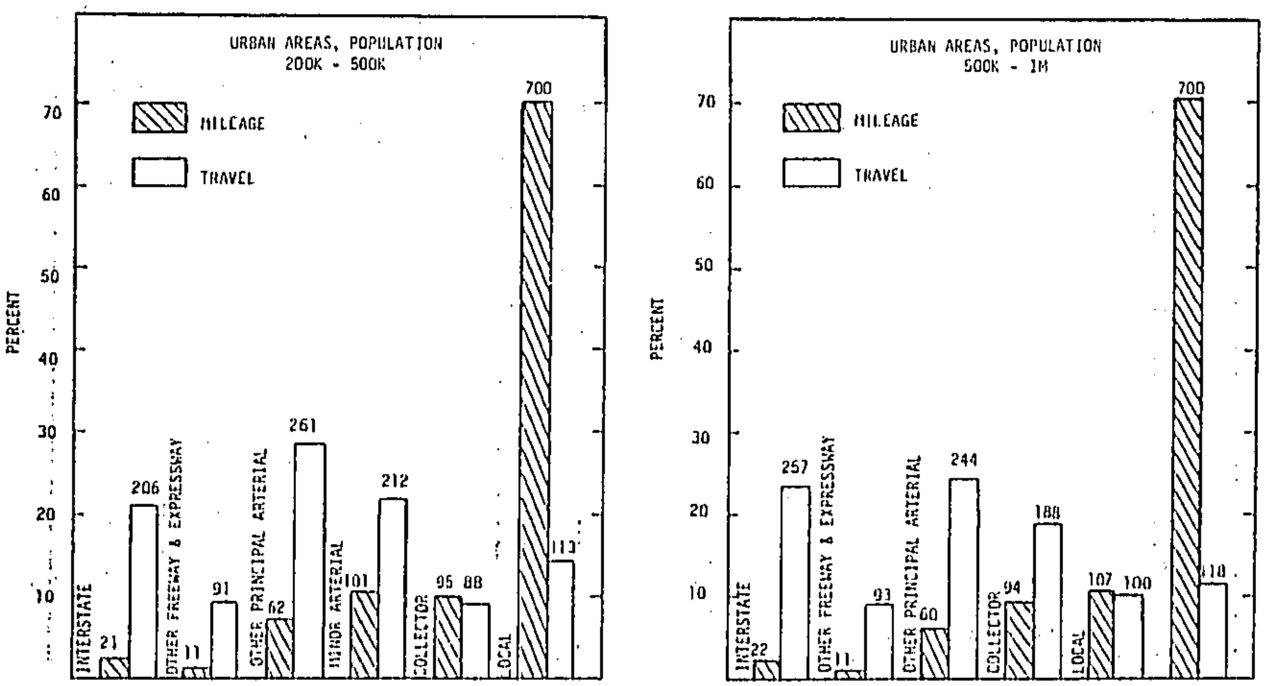


FIGURE 2-1. DISTRIBUTION OF ROADWAY MILEAGE AND TRAVEL BY POPULATION PLACE SIZE (Continued)

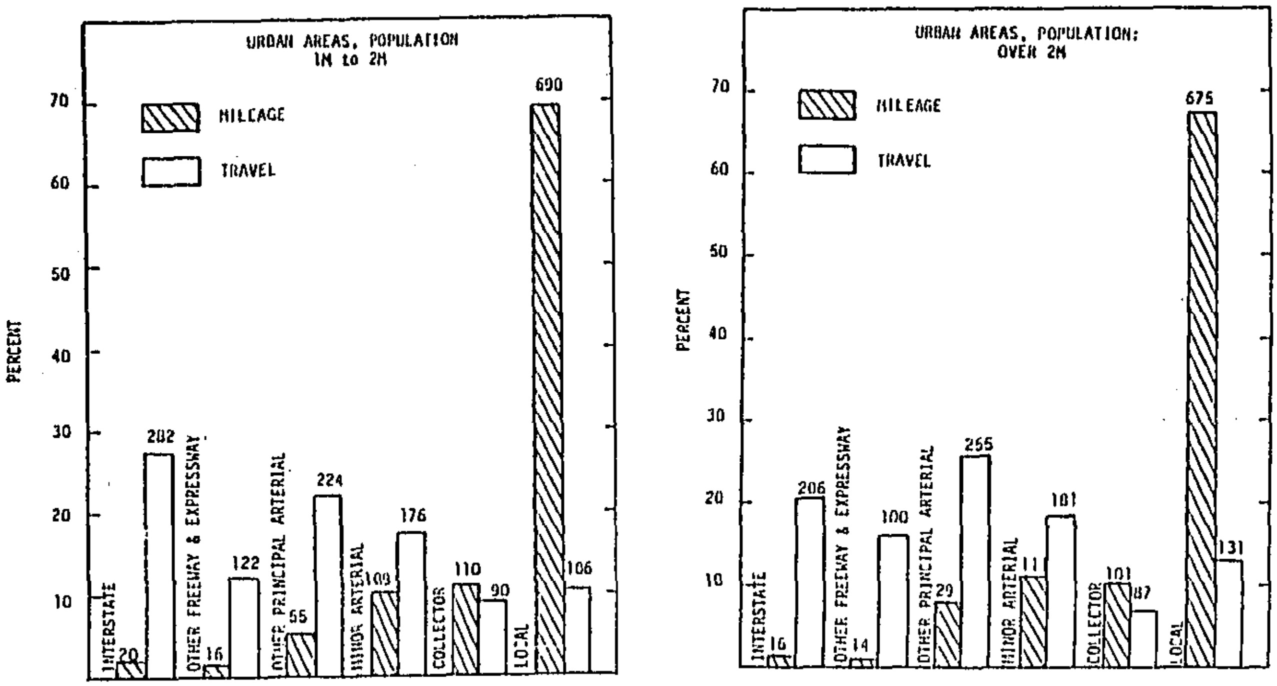


FIGURE 2-1. DISTRIBUTION OF ROADWAY MILEAGE AND TRAVEL BY POPULATION PLACE SIZE (Concluded)

A.2 and A.3). These relative groupings were related to the Bureau of Census' population density ranges by analyzing the distribution of population by population density for each urban place size. Figure 2-2 presents the results for the urban place size metric as defined for the Model. This metric is closely related to the data base of Reference 10, Table 20. These data were analyzed based upon allocation of gross population and land area by place size and the four population density categories within each place size (see Appendix A, Section A.2).

As described in Appendix A, Section A.2, the defniniton of "Urban Place Size", as used by the Model, is slightly different from the various urban place size metrics used by the U.S. Bureau of the Census. The reason for this slight difference is related to differences between data collection and summaries as conducted by the U.S. Bureau of the Census[10] and the Federal Highway Administration.[7] The distribution of population used by the Model is based on FHWA's data base and, as described in Appendix A, Section A.2, is closely related to the Bureau of the Census' "urban area" place size metric (Reference 10, Table 20).

The Model allocates population and land area by eight urban place sizes and one rural area and within each place size the allocation is distributed among four homogenous population density categories. The Model uses as baseline data, the 1974 population and the land area distribution presented in Table 2-1. In each year of the time stream, the Model uses the population and the land area within each population place size and density category to calculate average population densities. The baseline year* population density calculated by te Model is also illustrated in Table 2-1.

The results presented in Table 2-1 represent gross land area and gross population assigned to the land area. It is recognized that urban areas of any size are not totally occupied, i.e., land is used for purposes

*Baseline Year denotes 1974 values.

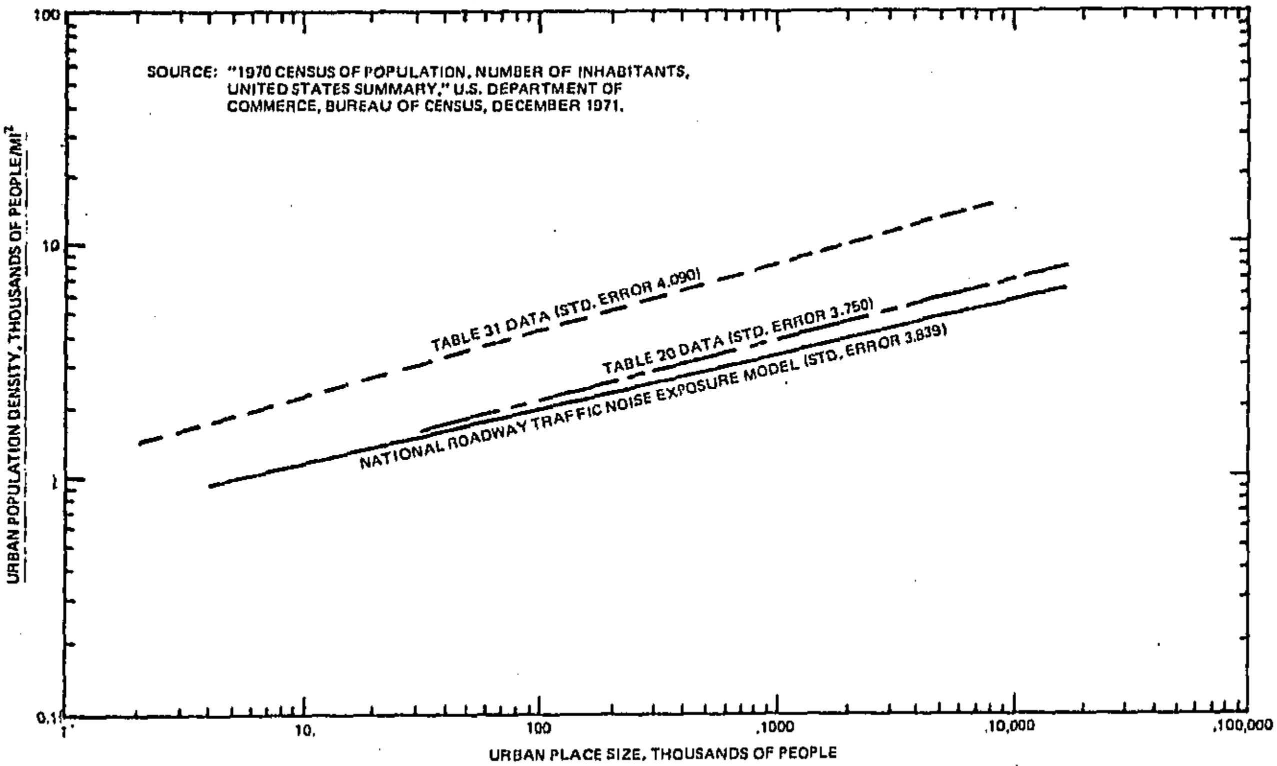


FIGURE 2-2. SUMMARY OF REGRESSION ANALYSIS

TABLE 2-1. POPULATION AND LAND BY PLACE SIZE (J) AND POPULATION DENSITY CLASS (ID)

POPULATION PLACE SIZE--INDEX J

Population Density Area-Index ID	PARAMETER	1 >2M	2 1M -2M	3 500k -1M	4 200k -500k	5 100k -200k	6 50k -100k	7 25k -50k	8 5k -25k	URBAN TOTAL	9 RURAL
1	Population	5.61	2.10	0.36	1.61	1.16	1.07	0.47	1.85	14.23	64.18
	Area	134.2	272	63	215	279	329	58	220	1570.2	3,476,938
	P*	64,711	13,451	9,368	9,368	5,831	4,106	13,091	16,988	-	18.0
2	Population	22.28	4.08	2.04	10.43	2.93	2.12	2.98	4.97	51.83	0.0
	Area	3576	775	488	4558	1305	1115	896	1261	13970.0	0.0
	P*	12,638	9.092	6,967	3697.0	3,384	2,863	8,506	10,681	-	
3	Population	21.59	11.13	8.40	6.75	6.84	4.53	3.51	8.46	71.20	0.0
	Area	8358	5080	4426	5790	5266	4195	2230	4527	39872.0	0.0
	P*	6,107	5,014	3,842	2,264	2,011	1,612.0	4,698	6,271	-	
4	Population	0.0	5.35	5.30	0.0	0.0	0.0	1.92	2.70	15.27	0.0
	Area	0.0	4089	4584	0.0	0.0	0.0	2769	5820	17262.0	0.0
	P*	-	2,505	2,336	-	-	-	2,147	1,673	-	
TOTAL POPULATION		49.48	22.66	16.09	18.78	10.93	7.71	8.88	17.98	152.52	64.18
TOTAL AREA		12064.2	10216.0	9561.0	10563.0	6850.0	5639.0	5953.0	11828.0	72674.2	3476938

Total Population = 216.70 million

Total Land Area = 3,549,612.2 square miles

P* = Population/ (Area) (Area Factor), Adjusted Population Density in People per Square Mile other than residential use. Additionally, as described in the next subsection, the Model allocates a finite amount of land area to the national roadway network, e.g., road length, lane width, and right-of-way distance. Thus, the land areas indicated in Table 2-1 must be adjusted to reflect the unoccupied or unused land area. Based upon the data presented in Reference 11, a regression analysis of total urban area versus percentage of occupied land area for 14 cities was conducted. The results are presented in Figure 2-3 and indicate that the smaller the urban land area, the higher the percentage of inhabited land.

The gross land area presented in Table 2-1 were divided by the number of places in each category to obtain an average gross land area associated with each category. The average gross land area obtained was used to calculate the inhabited land area as a percentage of total land area. This percentage is used by the Model to adjust gross population densities based upon inhabited land area. For the purposes of this study, these percentages are expressed as a fraction and are called 'area factors'. For any place size/population density category combination, the product of gross land area times area factor results in inhabited land area.

The final consideration for characterizing population is the increase in the number of inhabitants in future years. The Model allows for population growth by place size category. The growth in the number of inhabitants is considered by adjusting the baseline population using a "population growth factor" table. The data in this table are based upon the U.S. Bureau of Census' projections. Figure 2-4 presents growth in the number of inhabitants of the U.S. from 1900 to the year 2050[12] and Figure 2-5 presents the gross population growth factor. Table 2-2 presents a summary of the population growth factors in five-year increments, by place size category as simulated by the Bureau of Census Series I population projections (Figure 2-5).

The projection of population increase is based upon various assumptions concerning birth rates, immigration and death rates. The various

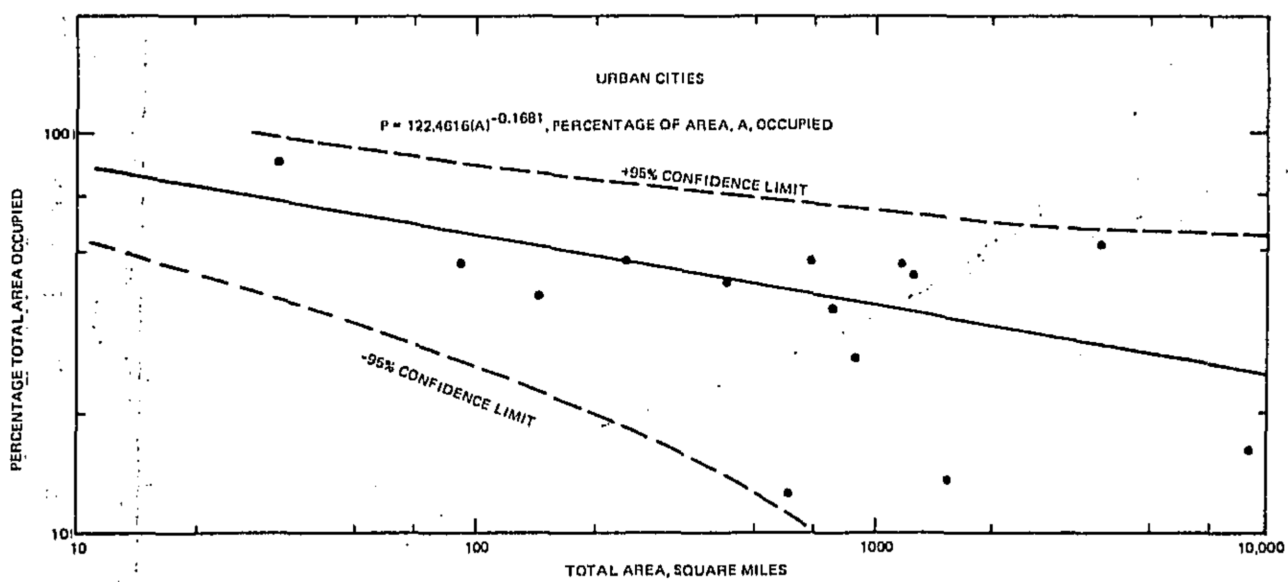


FIGURE 2-3. PERCENTAGE OF TOTAL LAND AREA INHABITED
VERSUS TOTAL LAND AREA: URBAN AREAS

Source: Statistical Abstract of the United States, 1977:
Table No. 5, Page 8.

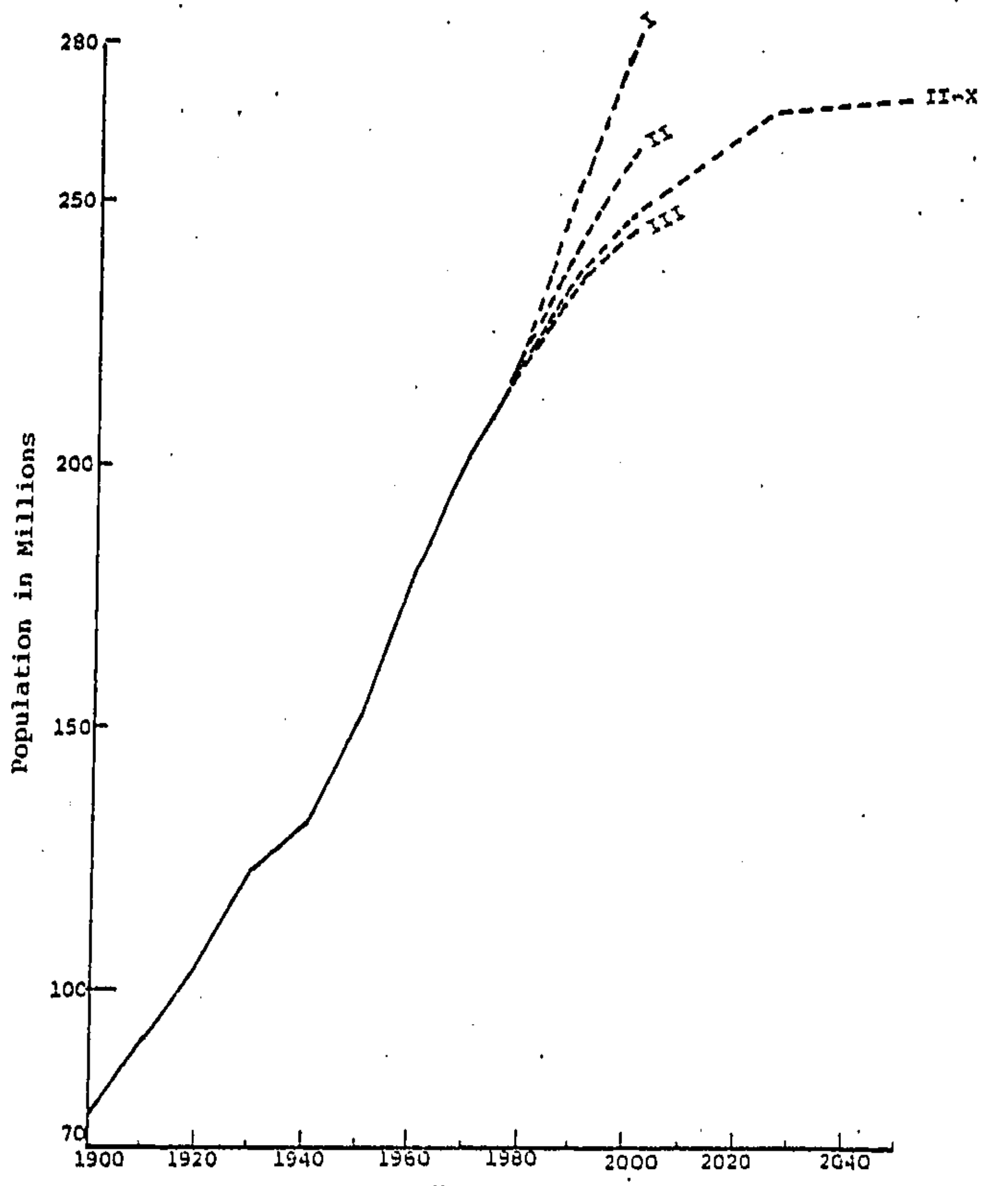


FIGURE 2-4. NATIONAL POPULATION GROWTH: 1900 to 2050

TABLE 2-2. POPULATION GROWTH FACTORS BY PLACE SIZE (J)
FOR EVERY FIVE YEARS IN TIME STREAM

TABLE 11 POPULATION GROWTH FACTOR FOR EACH NET YEAR

		AREA TYPE, J									
		1	2	3	4	5	6	7	8	9	ALL J
PLACE SIZE, THOUSANDS		OVER 2000	1000-2000	500-1000	200-500	100-200	50-100	25-50	5-25	RURAL	
YEAR	VARIABLE	POP(YEAR)/POP(BASELINE)									
1974		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1980		1.08	1.07	1.07	1.02	1.02	1.02	1.02	1.02	1.12	
1986		1.17	1.16	1.16	1.04	1.04	1.04	1.04	1.04	1.23	
1988		1.19	1.19	1.19	1.05	1.05	1.05	1.05	1.05	1.27	
1990		1.22	1.22	1.22	1.05	1.05	1.05	1.05	1.05	1.31	
1995		1.29	1.29	1.29	1.07	1.07	1.07	1.07	1.07	1.39	
2000		1.36	1.36	1.36	1.08	1.08	1.09	1.09	1.09	1.48	
2005		1.43	1.44	1.44	1.10	1.10	1.10	1.10	1.10	1.57	
2010		1.50	1.51	1.51	1.12	1.12	1.12	1.12	1.12	1.65	

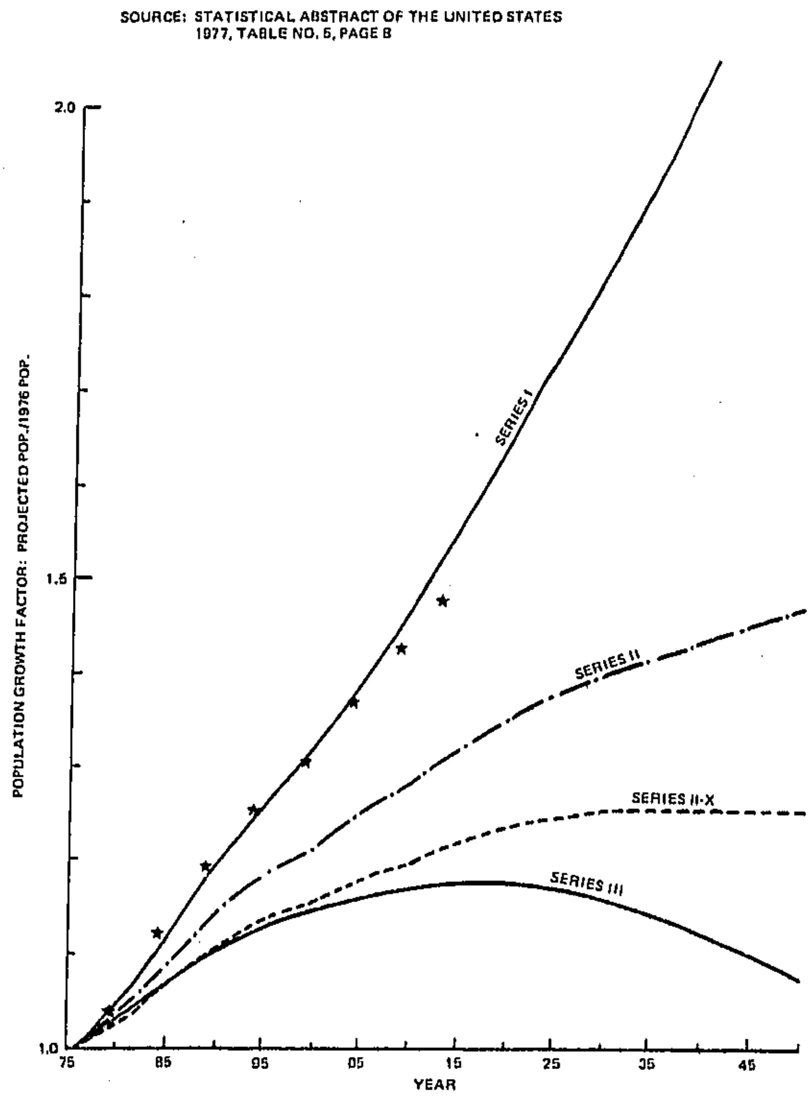


FIGURE 2-5. PROJECTED POPULATION GROWTH FACTORS: (1975 to 2050)

projections indicated in Figures 2-4 and 2-5 are labeled with Roman numerals indicating the Bureau of Census projection series.[12] Series I, II and III each assume a slight improvement in the mortality rate and a constant immigration rate. Each of these series differs in that Series I assumes an immigration and fertility rate based upon historical trends. Series II differs from Series I in that the fertility rate assumed represents a 'replacement level', i.e., the population would exactly replace itself in the absence of net immigration. Series III represents a lower fertility rate as compared to both Series I and II. Series II-X is identical to Series II except that zero net immigration is assumed. In Figures 2-5, the asterisks denote the population growth factors currently used by the Model. These data approximate the Bureau of Census Series I projections.

2.2.1 Summary of Population Model

The Model simulates the distribution of the nation's population by categorizing it into nine place size classes. The place size classes are denoted in the Model by an Index "J" and are:

Place Size Class	Index J
Population over 2M	1
Population 1M to 2M	2
Population 500k to 1M	3
Population 200k to 500k	4
Population 100k to 200k	5
Population 50k to 100k	6
Population 25k to 50k	7
Population 5k to 25k	8
Rural Areas	9

The Model further subdivides each place size class into four homogeneous population density categories. These population density categories are denoted in the Model by an Index "ID" and are:

Population Density Class*	Index, ID
High Density	1
High to Medium Density	2
Medium to Low Density	3
Low Density	4

The Model allocates population and land area based upon the nine classes of place size and the four population density classes. Hence, the four population density classes are relative for each of the nine classes of place size. As indicated in Table 2-1, rural areas (J=9) are defined by a single characteristic population density and this value is assigned the "high density" index (ID=1). The development of these data are described in Appendix A, Section A.2.

The urban areas, the gross land area is adjusted to obtain inhabited land area. Based upon Bureau of the Census data, the Model allows the user to simulate population projections in future years. Currently, the Bureau of Census Series I population projections are used.

2.2.2 Population Activity Model

The Single Event Model considers the population's activity during an average 24 hour day. This is necessary since the Single Event Model must estimate the effect of traffic noise intrusions for sleep and speech activities. Hence, the population must be distributed by its activity. This activity distribution is relative to the population's place of residence.

The Single Event Model divides the average 24 hour day into two time periods: daytime and nighttime. These time periods are denoted in the model by the Index "IDAY" and are defined as follows:

*The four population density classes are relative for each urban place size (see Table 2-1).

DAILY TIME PERIOD	INDEX, IDAY
Daytime: 0700 to 2200 hours	1
Nighttime: 2200 to 0700 hours	2

This Index "IDAY" is used also to denote the number of vehicle operations on a roadway by the daytime and nighttime periods. The General Adverse Response Model also uses the above definition of day and night to estimate the population's noise exposure. However, the population's sensitivity to noise is included by adding 10 dB to traffic noise generated during the nighttime period and by assuming traffic to be allocated between daytime and nighttime periods (Appendix D, page D-15).

The Single Event Model, however, accounts for a vehicle's noise intrusiveness by daytime and by nighttime. This consideration is necessary since both population activity and vehicle operations depend upon time of day. The Single Event Model uses a distribution of population activity that is based upon statistical averages. Details of the methodology used to develop this distribution are presented in Appendix B of this report.

Figure 2-6 presents the population activity distribution used by the Single Event Model. The vertical axis in Figure 2-6 is the cumulative percentage of the population. That is, during any hour of the day the Model assigns 100 percent of the population to an activity. The horizontal axis in Figure 2-6 is the hour of the day based upon a 24 hour clock. The extreme left hand side of the figure is 2200 hours or the beginning of the Model's nighttime. Midnight is denoted by 0000 hours and the daytime is denoted by time span between 0700 hours and 2200 hours (extreme right side of the figure). For the daytime period and the nighttime period, individual activities are denoted by the percentage of the population engaged in that activity. The percentages are denoted by the numbers of parenthesis in the figure.

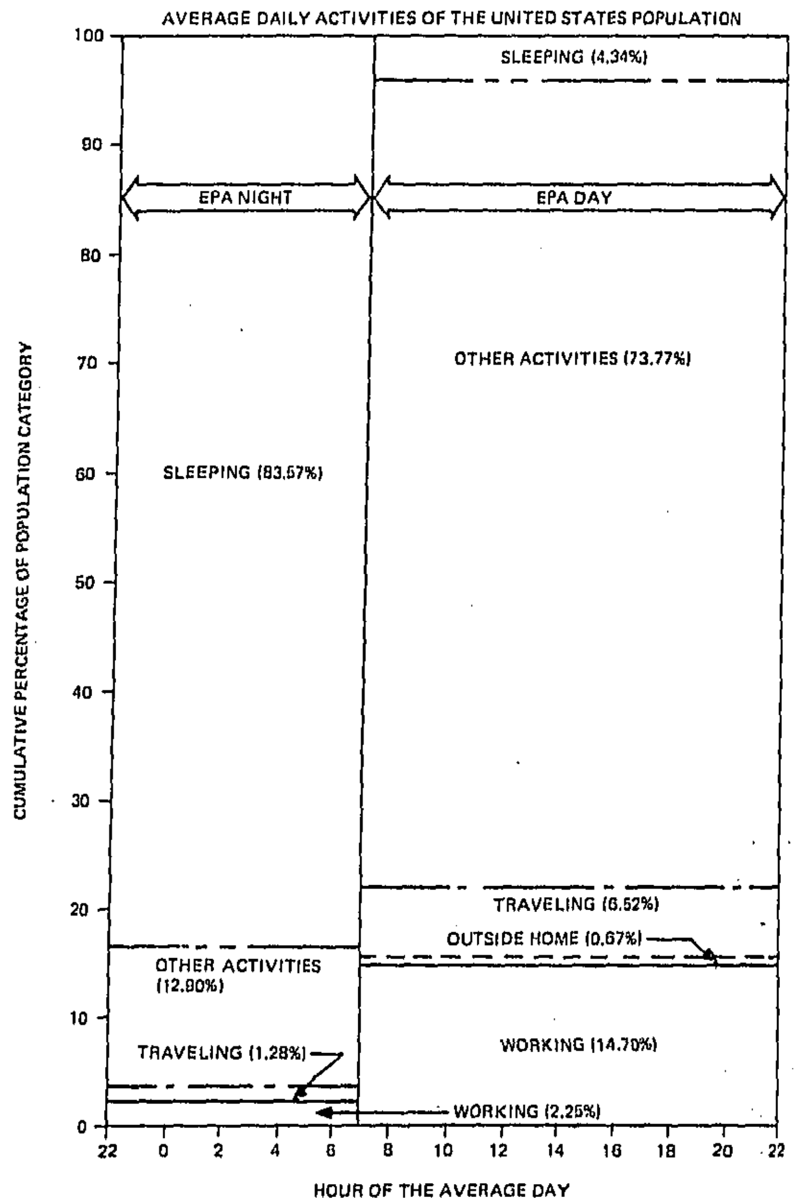


FIGURE 2-6. AVERAGE DAILY ACTIVITIES OF THE UNITED STATES' POPULATION

The interpretation of Figure 2-6 is rather simple in that it describes - on the average - what the population is doing on a daily basis. During any hour, one individual may change his activity from "sleeping" to "other activities" and, on the average, another individual will simultaneously change his activity from "other activities" to "sleeping" so that the distributions are adequately described by constants during the daytime and during the nighttime.

As described in Appendix B, the activity distributions presented in Figure 2-6 are esitmated on the basis of weighted averages to include such diverse segments of the population as employed males and housewives. The weighting is conducted so that person-hours of activity are conserved for each segment of the population.

For example, Figure 2-6 indicates that "on the average" 14.7 percent of the population is working during the 15 hour daytime period and that 2.25 percent is working during the 9 hour nighttime period. For the 1974 national population of 216.7 M people, the average person-hours of work per day are estimated to be:

$$[15(0.147) + 9(0.0225)](216.7) = 521.7 \text{ M, person-hours.}$$

As described in Appendix B, the 1974 working population is estimated to be 88.216 M persons comprising 50.668 M employed males and 37.548 M employed females. Hence, one would estimate the average daily hours worked per employed person to be: 521.7/88.216 = 5.91 person-hours per day. The U.S. Bureau of Census[12] reports that the average hours worked per week in 1974 was 36.6 person-hours. For a seven day week, the census' estimate is 5.23 person-hours per day.

The Single Event Model assumes that the activity distribution presented in Figure 2-6 applies to the entire national population irrespective of the assignment of the population to either place size or population density area. For example, Table 2-1 indicates that 5.61 M people reside in high density urban areas with over 2 M total population. The activity percentages indicated in Figure 2-6 would estimate that (0.8357)(5.61) = 4.69 M people in this area are asleep during any hour of the nighttime and that (0.0434)(5.61) = 0.24 M people are asleep during any hour of the daytime. For rural areas, the sleeping population would be estimated to be 2.79 M during any hour of the daytime and 53.64 M during any hour of the nighttime.

2.3 Roadway Traffic Model

The Model simulates roadway traffic conditions for the purpose of calculating traffic-generated noise. The Model uses the number of miles of roadway and travel (DVMT)* categorized by functional class, as the basic metrics to describe roadway traffic conditions. This basic description is illustrated in Figure 2-1. Based upon data furnished by FHWA,[7] roadway mileage and travel are allocated by functional roadway class to each population place size and population density area used by the Model.

The Model uses the FHWA functional classifications for roadway mileage and travel. These classifications are denoted in the Model by an Index "K" and are:

Functional Roadway Classification	Index, K
Interstate Highways	1
Freeways and Expressways	2
Major Arterials	3
Minor Arterials	4
Collectors	5
Local Roads and Streets	6

*Daily Vehicle Miles Traveled

The roadway mileage and travel (DVMT or ADT*) used for baseline year conditions by the Model are presented in Table 2-3. The Model allocates 3.586 million miles of roadway to population places sizes representing a total of 216.7 million people and 2.549 million square miles of land area (see also Table 2-1).

Furthermore, the Model distributes mileage and travel by each roadway functional classification into five average travel speed ranges from 20 mph to 60 mph. This distribution is at the level of each population place size and population density range. The detailed roadway mileage distribution by place size (Index J), population density area (Index ID), roadway functional clas (Index K), and average travel speed (Index L) are described in Appendix A, Section A.3. In the present version of the Model, this formulation defines 1080 distinct combinations of roadway traffic condtions and population densities adjacent to the roadways.

For a given roadway classification in a given place size and population density area, ADT is held constant for all travel speeds. Assigning specific ADT values for each speed range would, at a minimum, increase the number of basic traffic conditions recognized by the Model to 5400 distinct combinations of traffic conditions and poulation densities. The Model is structured so that this feature may be implemented without an appreciable increase in computing time.

In the population distribution used by the Model, unoccupied or unused land area is recognized in adjusting population densities. Based upon the land use classifications adjacent to roadways, as developed by the FHWA, mileage and travel data for urban roadways through this vacant land were estimated. These roadway mileage and travel data were deleted from the Model input data at the level of population place size, roadway classification, and speed range. Thus, the Model only considers roadway mileage and travel by speed range through inhabited urban land areas. Rural areas are treated as a single area of homogenous population density.

*Average Daily Traffic

TABLE 2-3. DISTRIBUTION OF ROADWAYS MILEAGE, AVERAGE DAILY TRAFFIC (ADT) AND DAILY VEHICLE MILES TRAVELED (DVMT) BY PLACE SIZE (J) AND ROADWAY TYPE (K)

PLACE SIZE			ROADWAY TYPE: INTERSTATE	OTHER F'WAY & EXP'WAY	MAJOR ARTERIALS	MINOR ARTERIALS	COLLECTORS	LOCAL
	>2M	Miles	1,998	1,749	9,861	14,103	12,854	84,247
		ADT	74,866	66,470	18,760	9,315	3,783	1,129
		DVMT	149,582,268	116,256,030	185,071,240	131,369,445	48,626,682	95,114,863
	1M to 2M	Miles	1,869	1,527	5,156	10,219	10,308	64,678
		ADT	60,228	32,548	17,397	6,898	3,496	656
		DVMT	112,566,132	49,700,796	89,698,932	70,490,662	36,036,768	42,428,760
	500k to 1M	Miles	1,477	739	4,034	6,320	7,190	47,466
		ADT	46,997	34,036	16,359	8,045	3,760	672
		DVMT	69,414,569	25,152,604	65,992,206	50,844,400	27,034,400	31,897,152
	200k to 500k	Miles	1,743	1,076	5,566	8,569	7,897	58,252
		ADT	40,367	28,812	16,039	8,478	3,812	839
		DVMT	70,359,681	31,001,712	89,317,414	75,579,430	30,103,164	48,873,428
	100k to 200k	Miles	854	803	3,851	5,502	5,714	36,697
		ADT	32,190	22,984	14,904	7,301	3,287	649
		DVMT	27,490,260	18,456,152	57,352,943	40,170,102	18,781,918	23,816,353
	50k to 100k	Miles	512	600	3,335	4,445	4,534	29,284
		ADT	21,913	19,971	12,376	6,057	2,917	645
		DVMT	11,219,456	11,982,600	41,273,960	26,923,365	13,225,678	18,888,180
	25k to 50k	Miles	397	447	4,202	5,177	5,828	33,454
		ADT	23,251	16,875	11,104	5,430	2,484	631
		DVMT	9,230,647	7,543,125	40,746,290	29,197,110	14,476,752	21,109,479
	5k to 25k	Miles	899	1,099	9,652	13,124	13,130	75,431
		ADT	18,206	13,244	8,922	4,255	1,946	495
		DVMT	16,367,144	13,343,016	86,115,144	61,587,620	25,550,980	37,338,345
	Rural	Miles	31,744	85,716	155,547	435,517	307,917	1,942,733
		ADT	13,700	4,623	2,523	899	370	98
		DVMT	434,892,800	396,265,068	392,445,081	387,174,613	113,929,290	190,387,834

NOTE: ADT=DVMT/MILES IS THE DERIVED QUANTITY

The Model increases travel on each defined mile of roadway for future years by considering the increase in the number of vehicles as projected by the input data, i.e., vehicle sales and attrition. This formulation was adopted since projections of national roadway travel for more than a few years into the future are, at best, guesses. Trends in vehicular sales, particularly as related to vehicle engineering characteristics, are perhaps more realistic and are, therefore, used by the Model.

In each population place size and population density area, the Model assigns the number of lanes, lane width, and clear zone distance for each functional roadway classification. That is, the Model considers multilane traffic flow and recognizes that a clear zone (area clear of inhabitants) exists adjacent to each roadway type. The DVMT or ADT values assigned to a roadway type are uniformly distributed across all travel lanes. Additionally, the Model considers, using lane widths, that noise exposure adjacent to the roadway is contributed by traffic flows from lanes at different distances from the observer. As an independent audit of the input data, the land area allocated to roadways (pavement and clear zone) was compared to the vacant land area obtained using the area factors described above. The result was that for each population place size and population density area, the land area allocated to roadways was less than the total estimated vacant land area and appeared to be representative of values published in the literature.[11] Also, the paved roadway network described by the current Model input data set represents 0.62 percent of the U.S. land area of 3,549,612 square miles. Including areas allocated to clear zones, the total land area occupied by the roadway network is approximately 3.4 percent of the total U.S. land area.

In summary, the Model simulates roadway traffic conditions by miles of roadway with a specified value of Average Daily Traffic and average travel speed. Roadway mileage is categorized according to the Federal Highway Administration functional classification system and is distributed over population space sizes and population density areas. The present version of the Model uses 1080 distinct traffic flow conditions in simulating national exposure to roadway traffic noise. Roadways are modeled by the number of lanes, average lane widths, and a clear zone adjacent to each roadway. The Model recognizes roadway mileage and travel by speed range only through inhabited urban land areas. Rural areas are treated as a single area of constant population density. Travel on roadways is increased in future years proportional to projected vehicular sales and survival rate.

2.4 Vehicle Model

The Model recognizes four classes of vehicles: light vehicles, trucks, buses, and motorcycles. The light vehicle class is subdivided into seven vehicle types; the truck class into two vehicle types; the bus class into three vehicle types; and the motorcycle class into two vehicle types. Thus, the Model recognizes 14 vehicle types, and each type is described by distinct engineering characteristics as indicated in Table 2-4. These classifications of vehicle types are denoted in the Model by an Index "I".

The number of vehicles by vehicle type is defined for the baseline year (1974) as input data, and includes a mixture of vehicles from previous model years.[13,14,15,16] In each subsequent year of the time stream calculation, the number of vehicles by each type is estimated based upon sales and survivability data stored in the Model's data base. Details of the vehicle sales and survivability calculations are presented in Appendix C. Table 2-5 presents the net vehicle type distribution estimates used by the Model. Figure 2-7 indicates the trend in total number of vehicle registrations since 1940 and the projections from Table 2-5.

In conducting noise exposure estimates, the estimated number of vehicles is used in two ways: to adjust traffic flow mix and to adjust Average Daily Traffic values for roadway traffic conditions. For the baseline year, the Model uses a specified traffic mix by vehicle type, distributed as indicated in Table 2-6.[17] In any future year, the traffic mix of vehicle types is adjusted on a percentage basis to reflect the net change in the number of each vehicle type. Also, based upon the net changes in total

TABLE 2-4

CLASSIFICATION OF VEHICLE TYPES USED
BY THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL

Index, I	Vehicle Type	Engineering Characteristics
1	Passenger Car	8 cyl. Gasoline Engine Automatic Transmission
2	Passenger Car	6 cyl. Gasoline Engine Automatic Transmission
3	Passenger Car	6 & 8 cyl. Gasoline Engine Manual Transmission
4	Passenger Car and Light Truck	4 cyl. Gasoline Engine Automatic Transmission
5	Passenger Car and Light Truck	4 cyl. Gasoline Engine Manual Transmission
6	Light Truck	6 & 8 cyl. Gasoline Engine
7	Passenger Car and Light Truck	Diesel Engine
8	Medium Truck	Two Axle (GVWR > 10,000 lb)
9	Heavy Truck	Three or more Axles (GVWR > 26,000 lb)
10	Intercity Buses	
11	Transit Buses	
12	School Buses	
13	Unmodified Motorcycle	
14	Modified Motorcycle	

TABLE 2-5. NUMBER OF VEHICLES IN TIME STREAM

TABLE 5 VEHICLE POPULATION BY TYPE. BUS NUMBERS ARE IN HUNDREDS OF THOUSANDS.

TYPE>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	ALL TYPES
CYLINDERS	8	8	6&8	4	4	6&8									
ENGINE	GAS	GAS	GAS	GAS	GAS	GAS	DIESEL								
TRANS-MISSION	AUTO-MATIC	AUTO-MATIC	MAN-UAL	AUTO-MATIC	MAN-UAL	----	----	----	----	----	----	----	----	----	
VEH. TYPE>	PC	PC	PC	PC&LT	PC&LT	LT TRK	PC&LT	MED TRK	HVY TRK	IC BUS	TR BUS	SCH BUS	LP MTCY	HI MTCY	
UNIT	MILLIONS									THOUSANDS X 0.01			MILLIONS		
YEAR															
1974	58.68	17.83	2.10	7.76	20.13	19.01	0.06	2.41	1.51	0.21	0.69	3.57	4.36	1.59	134.89
1980	63.60	21.21	2.66	11.16	22.63	26.26	2.59	2.87	1.80	0.14	1.[illegible]7	5.00	5.01	1.68	1[illegible]1.09
1986	42.58	28.02	3.70	26.15	25.53	28.28	19.47	3.47	2.17	0.15	1.22	7.16	5.49	1.78	186.69
1988	33.35	30.63	4.07	32.17	26.69	27.69	26.36	3.63	2.27	0.15	1.21	7.60	5.91	1.81	1[illegible]4.49
1990	24.66	33.12	4.41	37.59	27.93	27.11	32.50	3.78	2.37	0.15	1.18	8.17	6.15	1.84	2[illegible]2.42
1995	16.15	38.33	5.11	47.13	31.17	27.43	42.80	4.18	2.62	0.15	1.14	9.36	6.80	1.93	223.[illegible]7
2000	16.10	42.56	5.67	52.82	34.46	29.87	48.23	4.61	2.89	0.15	1.15	10.55	7.51	1.02	246.93
2005	17.75	46.98	6.26	58.31	38.03	32.96	53.24	5.09	3.19	0.15	1.15	11.72	8.26	1.13	272.53
2010	19.59	51.86	6.91	64.37	41.98	36.38	58.77	5.62	3.52	0.15	1.15	12.91	9.14	1.25	3[illegible]0.80

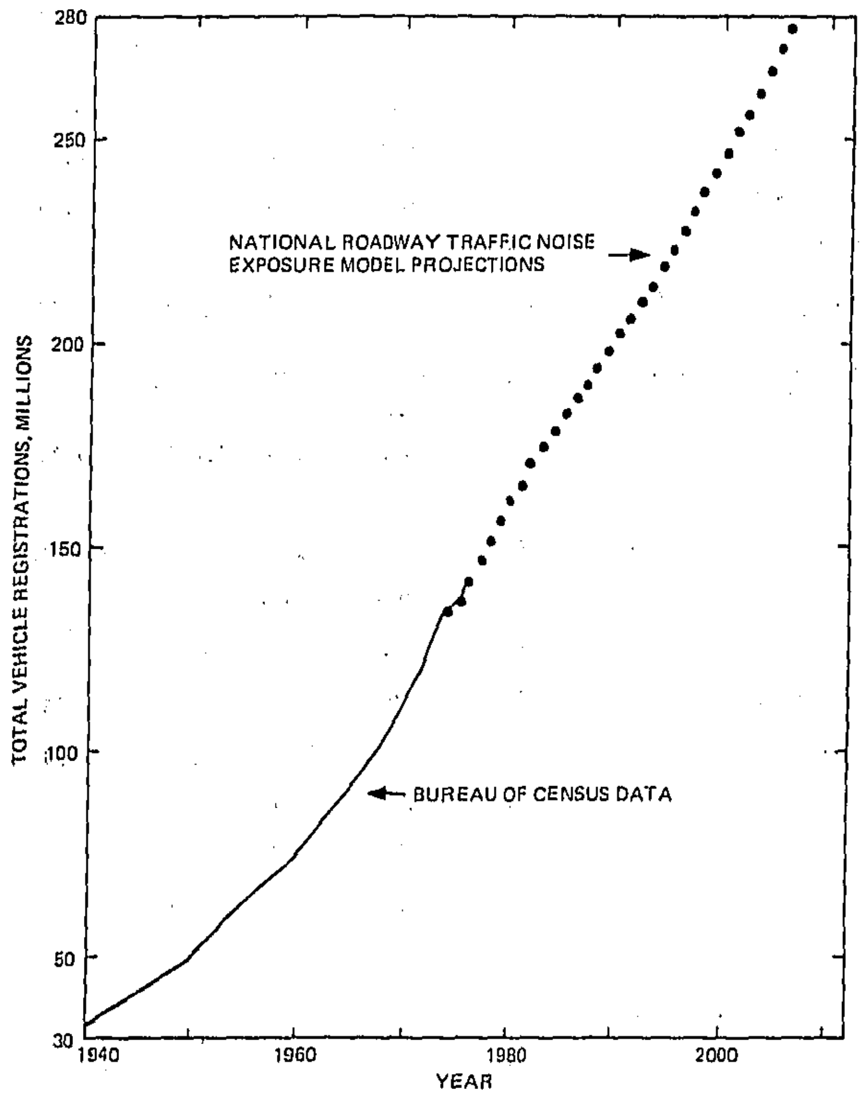


FIGURE 2-7. TRENDS AND PROJECTIONS OF TOTAL U.S. VEHICLE REGISTRATIONS

TABLE 2-6 PERCENTAGE VEHICLE MIX IN TRAFFIC FLOW BY PLACE SIZE AND FUNCTIONAL ROADWAY CLASSIFICATION; BASELINE CONDITIONS

URBAN PLACE SIZES: Over 2M; 1M-2M; 500k-1M

VEHICLE TYPE	ROADWAY TYPE (INDEX K)					
	1	2	3	4	5	6
Light Vehicles	87.62	87.62	91.82	90.52	90.51	95.76
Medium Trucks	2.11	2.11	3.05	4.31	3.61	1.16
Heavy Trucks	9.17	9.17	4.03	3.11	3.82	0.99
Intercity Buses	0.03	0.03	0.03	0.00	0.00	0.00
Transit Buses	0.08	0.08	0.08	0.54	0.54	0.54
School Buses	0.00	0.00	0.00	0.02	0.02	0.02
Modified Motorcycles	0.88	0.88	0.88	1.32	1.32	1.32
Unmodified Motorcycles	0.12	0.12	0.12	1.18	1.18	1.18
	100.00	100.00	100.00	100.00	100.00	100.00

URBAN PLACE SIZES: 200k-500k; 100k-200k; 50k-100k

VEHICLE TYPE	ROADWAY TYPE (INDEX K)					
	1	2	3	4	5	6
Light Vehicles	87.64	87.64	91.84	90.71	90.70	95.98
Medium Trucks	2.11	2.11	3.05	4.31	3.61	1.16
Heavy Trucks	9.17	9.17	4.03	3.11	3.82	0.99
Intercity Buses	0.04	0.04	0.04	0.01	0.01	0.01
Transit Buses	0.04	0.04	0.04	0.30	0.30	0.30
School Buses	0.00	0.00	0.00	0.08	0.08	0.08
Modified Motorcycles	0.88	0.88	0.88	1.32	1.32	1.32
Unmodified Motorcycles	0.12	0.12	0.12	1.18	1.18	1.18
	100.00	100.00	100.00	100.00	100.00	100.00

NOTE: Some columns do not add up to exactly 100 because of rounding.

TABLE 2-6 PERCENTAGE VEHICLE MIX IN TRAFFIC FLOW BY PLACE SIZE AND FUNCTIONAL ROADWAY CLASSIFICATION; BASELINE CONDITIONS (Continued)

URBAN PLACE SIZES: 25k-50k; 5k-25k

VEHICLE TYPE	ROADWAY TYPE (INDEX K) 1	2	3	4	5	6
Light Vehicles	87.67	87.67	91.87	90.34	90.33	95.61
Medium Trucks	2.11	2.11	3.05	4.31	3.61	1.16
Heavy Trucks	9.17	9.17	4.03	3.11	3.82	0.99
Intercity Buses	0.03	0.03	0.03	0.00	0.00	0.00
Transit Buses	0.05	0.05	0.05	0.21	0.21	0.21
School Buses	0.00	0.00	0.00	0.52	0.52	0.52
Modified Motorcycles	0.88	0.88	0.88	1.32	1.32	1.32
Unmodified Motorcycles	0.12	0.12	0.12	1.18	1.18	1.18
	100.00	100.00	100.00	100.00	100.00	100.00

RURAL AREAS

VEHICLE TYPE	ROADWAY TYPE (INDEX K) 1	2	3	4	5	6
Light Vehicles	79.67	79.67	85.78	88.27	93.33	96.74
Medium Trucks	2.74	2.74	3.80	4.39	0.56	0.41
Heavy Trucks	16.16	16.16	8.99	5.14	3.91	0.65
Intercity Buses	0.24	0.24	0.24	0.00	0.00	0.00
Transit Buses	0.00	0.00	0.00	0.00	0.00	0.00
School Buses	0.19	0.19	0.19	0.70	0.70	0.70
Modified Motorcycles	0.88	0.88	0.88	1.32	1.32	1.32
Unmodified Motorcycles	0.12	0.12	0.12	1.18	1.18	1.18
	100.00	100.00	100.00	100.00	100.00	100.00

NOTE: Some columns do not add up to exactly 100 because of rounding.

number of vehicles, the Model adjusts the values of ADT to reflect increased or decreased vehicle usage. This adjustment is applied uniformly over all roadway categories in each population place size and population density area.

Since the Single Event Model considers each vehicle type as an independent noise source, the data base is used differently from the methodology used by the General Adverse Response Model. The Single Event Model uses the vehicle data to estimate the number of individual noise events occurring on each mile of roadway for the type of vehicle being considered.

The operation of each vehicle type on each mile of roadway is defined by the percentage of time that the vehicle type operates in one of four distinct modes. The operational modes considered by the Model are: idle, acceleration, cruise, and deceleration. This percentage time factor is currently characterized by vehicle type, roadway category, and average cruise speed. This input is based upon the best available data.[18,19] For the General Adverse Response Model, the percentage operating time is used to characterize the vehicle type contribution to the total traffic flow noise emissions. For the Single Event Model the percentage operating time is used to estimate the number of operations, by vehicle type, occurring at the noise level characteristic of each mode.

In summary, the Model uses 14 distinct vehicle types to simulate the vehicle mix in a traffic flow. Vehicle mix is specified by input data in the baseline year by roadway type and population areas. In future years, the traffic flow mix is adjusted by vehicle type based upon vehicle sales trends and vehicle survivability rates. Total traffic flow on the roadways is adjusted yearly based upon changes in the estimated number of vehicles in use. The percentage of time that each vehicle type spends in each of four operating modes is specified to the level of vehicle type, roadway category and average travel speed on the roadway.

2.5 Roadway Noise Generation and Propogation

2.5.1 General Adverse Response Model

2.5.1.1 Generation of Noise From Roadways

The basic element of the General Adverse Response Model is the noise generated by traffic operations on a roadway. The pupose of the traffic flow noise model is to estimate the average day-night sound level at a location along the roadway. Traffic, roadway, and adjacent land use characteristics are combined to estimate noise exposure from complex traffic conditions. Details of the development of the traffic flow noise model are presented in Appendix D.

The traffic parameters used by the General Adverse Response Model are the percentage mix of vehicle types on the roadway, the fraction of time each vehicle type operates in a given mode (idle, acceleration, cruise, and deceleration), the average daily traffic (ADT) count for the roadway, and the average travel or cruise speed for the traffic flow. The roadway parameters are the number of lanes, the lane widths, and the roadway clear zone distance. The roadway clear zone is specified by the distance from the center line of the outside lane to a line parallel to the roadway. The land area within the clear zone is uninhabited.

Each population place size is subdivided into four population density areas and miles of roadway are allocated to each area according to the functional classification of roadways used by the Federal Highway Administration. Each functional class or type of roadway is further subdivided into five cruise speed groups. Each speed group covers a 10 mile per hour range, with the traffic flow assigned an average cruise speed at the center of the range. The average traffic cruise speeds used by the Model are: 20, 30, 40, 50 and 60 miles per hour. Considering the above description of the roadway system of the United States, the Model uses 1080 distinct traffic flow conditions allocated to a total of 3.586 million miles of roadway to estimate noise exposure from roadway traffic.

Several assumptions are made in the traffic flow noise model. These assumptions are:

- Traffic is uniformly distributed over all lanes of roadway
- The cruise speed is constant for all lanes of roadway
- The headway or vehicle spacing remains constant
- Each mile of roadway may be considered as an infinite straight roadway relative to a receiver
- Traffic is split 87 percent for daytime (0700 to 2200 hour) and 13 percent for nighttime (2200 to 0700 hours)
- Traffic conditions are constant for each day of the year.

These assumptions result in the following algorithm for estimating the day-night sound level (L_{dn}) metric along the roadway at the specified clear zone distance:

$$L_{dn} = L_o^{eq} + 10 \log(\bar{N}/S) + 10 \log \left\{ \frac{1}{n} \sum_r D_r^{-C_1/10} \right\} + C_2 \qquad (2\text{-}1)$$

where: $L_o^{eq} = 10 \log \left\{ \sum_i \eta_i \sum_j f_{ij} \, 10^{L_{oij}^{eq}/10} \right\}$

is the reference equivalent sound level at a distance of 50 ft. from a given lane

$\bar{N}$ is the ADT for the roadway system

S is the cruise speed for the roadway system, mph

n is the number of lanes of width W for the roadway system

D_r is the distance, in feet, from each lane to the edge of the roadway clear zone (a function of lane width)

C_1 and C_2 are constants (See Appendix D)

η_i is the fraction of vehicles of type i of the total traffic count

f_{ij} is the fraction of time that the i^{th} vehicle operates in the j^{th} mode

L^{eq}_{oij} is the equivalent A-weighted sound level for the i^{th} vehicle type of the j^{th} operational mode at a distance of 50 ft. from the vehicle line of travel for any model year.

Subscript "i" denotes one of 14 vehicle types recognized by the model

Subscript "j" denotes one of 4 operational modes

Subscript "r" denotes one of the lanes of traffic

Subscript "o" denotes a reference quantity evaluated at a constant distance of 50 ft. from the traffic lane.

The constants C_1 and C_2 represent a variable excess distance attenuation function that is specified for each roadway type and population density area, and conversion units, respectively. The excess distance attenuation rate is to propagate noise generated by each lane of travel to the edge of the clear zone (see Appendix D).

The vehicle noise levels used in the noise impact calculations are the mean reference noise emission level and a standard deviation of the level for each operating mode and speed combination. The value of the equivalent reference noise emission level is then calculated as:

$$L^{eq}_{oij} = \overline{L^{eq}_{oij}} + 0.115\sigma^2_{oij} \qquad (2\text{-}2)$$

where: $\overline{L^{eq}_{oij}}$ is the mean sound level.

X σ_{oij} is the standard ~~devision~~ deviation of levels.

This relation, of course, assumes that the test data points are normally distributed in level. Using this input data format, it is quite direct to introduce the value of L^{eq}_{oij} as obtained by integration of skewed histogram data.[20] The values given in Table 2-7 are the results of the calculations using Equation (2-2), which were developed as indicated in Appendix A. For each of the 14 vechicle types, Table 2-8 presents the representative acceleration noise level for each of the calendar years shown in Table 2-7. The data presented in Table 2-8 are obtained from the data in Table 2-7 using the methodology described in Appendix A, Section A.5.2. This methodology allows one to develop data in the form of Table 2-7 using "regulation levels" for each vehicle type.

The General Adverse Response Model uses as stored input data, noise emission levels for each vehicle type, each vehicle operating mode, and each cruise speed range. Additionally, for each vehicle type and the above conditions, up to four future year noise emission schedules may be defined. Future year noise emissions, as specified by the input data, allow the simulation of implementing a staged noise emission regulation (See Table 2-7).

TABLE 2-7
VEHICLE REFERENCE NOISE EMISSION LEVELS BY VEHICLE TYPE,
OPERATING MODE, AND AVERAGE CRUISE SPEED

TABLE 4.1 REGULATION LEVELS, IN DBA

VEHICLE TYPE 1

ACCELERATION MODE					
YEARS>	1974	1983			
0-20 MPH	59.30	59.30			
0-30	61.30	61.30			
0-40	63.00	63.00			
0-50	64.80	64.80			
0-60	66.70	66.70			
DECELERATION MODE					
YEARS>	1974	1983			
20-0 MPH	50.50	50.50			
30-0	56.10	56.10			
40-0	60.10	60.10			
50-0	63.20	63.20			
60-0	65.80	65.80			
CRUISE MODE					
YEARS>	1974	1983			
<25 MPH	59.80	59.80			
25-34	62.40	62.40			
35-44	66.40	66.40			
45-54	69.50	69.50			
>55	72.00	72.00			
IDLE MODE					
YEARS>	1974	1983			
	46.00	46.00			

VEHICLE TYPE 2

ACCELERATION MODE					
YEARS>	1974	1983			
0-20 MPH	60.50	60.50			
0-30	62.20	62.20			
0-40	63.70	63.70			
0-50	65.30	65.30			
0-60	67.30	67.30			
DECELERATION MODE					
YEARS>	1974	1983			
20-0 MPH	50.50	50.50			
30-0	56.10	56.10			
40-0	60.10	60.10			
50-0	63.20	63.20			
60-0	65.80	65.40			
CRUISE MODE					
YEARS>	1974	1983			
<25 MPH	59.80	59.80			
25-34	62.40	62.40			
35-44	66.40	66.40			
45-54	69.50	69.50			
>55	72.00	72.00			
IDLE MODE					
YEARS>	1974	1983			
	46.00	46.00			

TABLE 2-7

VEHICLE REFERENCE NOISE EMISSION LEVELS BY VEHICLE TYPE, OPERATING MODE, AND AVERAGE CRUISE SPEED (Continued)

TABLE 4. 2 REGULATION LEVELS, IN DBA

VEHICLE TYPE 3

ACCELERATION MODE					
YEARS>	1974	1983			
0-20 MPH	60.20	59.50			
0-30	62.40	61.80			
0-40	63.90	63.50			
0-50	65.50	65.20			
0-60	67.20	67.00			
DECELERATION MODE					
YEARS>	1974	1983			
20-0 MPH	50.50	50.20			
30-0	56.10	55.90			
40-0	60.10	60.00			
50-0	63.20	63.10			
60-0	65.80	65.70			
CRUISE MODE					
YEARS>	1974	1983			
<25 MPH	59.80	59.60			
25-34	62.40	62.20			
35-44	66.40	66.20			
45-54	69.50	69.40			
>55	72.00	71.90			
IDLE MODE					
YEARS>	1974	1983			
	46.00	46.00			

VEHICLE TYPE 4

ACCELERATION MODE					
YEARS>	1974	1983			
0-20 MPH	62.50	62.10			
0-30	64.00	63.60			
0-40	65.10	64.80			
0-50	66.40	66.10			
0-60	67.80	67.60			
DECELERATION MODE					
YEARS>	1974	1983			
20-0 MPH	50.50	50.30			
30-0	56.10	56.00			
40-0	60.10	60.00			
50-0	63.20	63.10			
60-0	65.80	65.70			
CRUISE MODE					
YEARS>	1974	1983			
<25 MPH	59.80	59.70			
25-34	62.40	62.30			
35-44	66.40	66.30			
45-54	69.50	69.40			
>55	72.00	72.00			
IDLE MODE					
YEARS>	1974	1983			
	46.00	46.00			

TABLE 2-7

VEHICLE REFERENCE NOISE EMISSION LEVELS BY VEHICLE TYPE, OPERATING MODE, AND AVERAGE CRUISE SPEED (Continued)

TABLE 4. 1 REGULATION LEVELS, IN DBA

VEHICLE TYPE 5

ACCELERATION MODE					
YEARS>	1974	1983			
0-20 MPH	62.20	59.50			
0-30	64.30	62.00			
0-40	65.60	63.90			
0-50	67.00	65.80			
0-60	68.60	67.70			
DECELERATION MODE					
YEARS>	1974	1983			
20-0 MPH	51.70	50.80			
30-0	57.30	56.60			
40-0	61.30	60.70			
50-0	64.40	63.90			
60-0	67.00	66.60			
CRUISE MODE					
YEARS>	1974	1983			
<25 MPH	61.00	60.20			
25-34	63.80	62.90			
35-44	67.60	67.10			
45-54	70.70	70.30			
>55	73.20	72.40			
IDLE MODE					
YEARS>	1974	1983			
	46.00	46.00			

VEHICLE TYPE 6

ACCELERATION MODE					
YEARS>	1974	1983			
0-20 MPH	62.50	62.10			
0-30	64.40	64.10			
0-40	66.00	65.80			
0-50	67.80	67.70			
0-60	69.70	69.50			
DECELERATION MODE					
YEARS>	1974	1983			
20-0 MPH	53.40	53.20			
30-0	59.30	58.90			
40-0	63.00	62.90			
50-0	66.10	66.00			
60-0	68.70	68.60			
CRUISE MODE					
YEARS>	1974	1983			
<25 MPH	62.70	62.60			
25-34	65.30	65.20			
35-44	69.30	69.20			
45-54	72.40	72.30			
>55	74.90	74.90			
IDLE MODE					
YEARS>	1974	1983			
	46.00	46.00			

TABLE 2-7

VEHICLE REFERENCE NOISE EMISSION LEVELS BY VEHICLE TYPE, OPERATING MODE, AND AVERAGE CRUISE SPEED (Continued)

TABLE 4. 4 REGULATION LEVELS, IN DBA

VEHICLE TYPE 7

ACCELERATION MODE					
YEARS>	1974	1983			
0-20 MPH	55.20	61.20			
0-30	66.60	63.00			
0-40	67.50	64.30			
0-50	66.30	65.80			
0-60	69.30	67.40			

DECELERATION MODE					
YEARS>	1974	1983			
20-0 MPH	52.30	50.40			
30-0	57.50	56.20			
40-0	61.90	60.40			
50-0	65.00	63.60			
60-0	67.60	66.20			

CRUISE MODE					
YEARS>	1974	1983			
<25 MPH	61.60	59.60			
25-34	64.20	62.60			
35-44	68.20	66.70			
45-54	71.30	70.00			
>55	73.80	72.60			

IDLE MODE					
YEARS>	1974	1983			
	46.00	46.00			

VEHICLE TYPE 8

ACCELERATION MODE					
YEARS>	1974	1978	1982		
0-20 MPH	75.10	75.10	74.80		
0-30	75.70	75.70	75.40		
0-40	76.50	76.50	76.20		
0-50	77.50	77.50	77.30		
0-60	78.70	78.70	78.60		

DECELERATION MODE					
YEARS>	1974	1978	1982		
20-0 MPH	65.70	65.70	65.60		
30-0	65.70	65.70	65.60		
40-0	69.90	69.90	69.80		
50-0	73.20	73.20	73.10		
60-0	75.90	75.90	75.80		

CRUISE MODE					
YEARS>	1974	1978	1982		
<25 MPH	74.40	74.40	74.20		
25-34	74.40	74.40	74.20		
35-44	76.40	76.40	76.30		
45-54	79.70	79.70	79.60		
>55	82.30	82.30	82.30		

IDLE MODE					
YEARS>	1974	1978	1982		
	54.30	54.30	54.30		

TABLE 2-7

VEHICLE REFERENCE NOISE EMISSION LEVELS BY VEHICLE TYPE, OPERATING MODE, AND AVERAGE CRUISE SPEED (Continued)

TABLE 4. 5 REGULATION LEVELS, IN DBA

VEHICLE TYPE 9

ACCELERATION MODE					
YEARS>	1974	1978	1982		
0-20 MPH	82.70	78.90	75.50		
0-30	82.80	79.00	76.00		
0-40	82.80	79.10	76.40		
0-50	83.00	79.40	76.90		
0-60	83.20	79.90	77.70		
DECELERATION MODE					
YEARS>	1974	1978	1982		
20-0 MPH	73.70	70.10	67.60		
30-0	73.70	70.10	67.60		
40-0	76.70	73.40	71.00		
50-0	79.10	75.90	73.70		
60-0	81.10	78.10	76.10		
CRUISE MODE					
YEARS>	1974	1978	1982		
<25 MPH	80.70	77.20	74.60		
25-34	80.70	77.20	74.60		
35-44	82.10	78.90	76.80		
45-54	84.50	81.50	79.60		
>55	86.50	83.70	82.10		
IDLE MODE					
YEARS>	1974	1978	1982		
	63.00	60.00	57.00		

VEHICLE TYPE 10

ACCELERATION MODE					
YEARS>	1974	1979	1982	1985	
0-20 MPH	81.60	77.80	74.80	71.80	
0-30	82.00	78.30	75.30	72.40	
0-40	82.30	78.60	75.80	73.20	
0-50	82.60	79.00	76.50	74.30	
0-60	82.80	79.60	77.40	75.60	
DECELERATION MODE					
YEARS>	1974	1979	1982	1985	
20-0 MPH	71.40	68.10	65.70	53.80	
30-0	71.40	68.10	65.70	63.80	
40-0	73.80	70.80	68.90	67.40	
50-0	75.60	73.00	71.50	70.50	
60-0	77.10	75.00	73.90	73.20	
CRUISE MODE					
YEARS>	1974	1979	1982	1985	
<25 MPH	76.00	73.00	71.00	69.60	
25-34	76.00	73.00	71.00	69.60	
35-44	78.40	75.90	74.50	73.50	
45-54	80.20	78.30	77.40	74.80	
>55	81.70	80.50	80.00	79.70	
IDLE MODE					
YEARS>	1974	1979	1982	1985	
	62.00	58.00	56.00	53.00	

TABLE 2-7

VEHICLE REFERENCE NOISE EMISSION LEVELS BY VEHICLE TYPE, OPERATING MODE, AND AVERAGE CRUISE SPEED (Continued)

TABLE 4.6 REGULATION LEVELS, IN DBA

VEHICLE TYPE 11

ACCELERATION MODE					
YEARS>	1974	1979	1982	1985	
0-20 MPH	81.00	81.00	78.20	75.20	
0-30	81.00	81.00	78.20	75.30	
0-40	81.10	81.10	78.40	75.60	
0-50	81.20	81.20	78.70	76.20	
0-60	81.50	81.50	79.20	77.10	
DECELERATION MODE					
YEARS>	1974	1979	1982	1985	
20-0 MPH	63.70	63.70	61.30	58.90	
30-0	67.80	67.80	65.60	63.80	
40-0	71.60	70.60	68.90	67.50	
50-0	72.90	72.90	71.50	70.50	
60-0	74.70	74.70	73.70	73.10	
CRUISE MODE					
YEARS>	1974	1979	1982	1985	
<25 MPH	73.00	73.00	71.10	69.60	
25-34	73.00	73.00	71.10	69.60	
35-44	75.80	75.80	74.50	73.60	
45-54	78.10	78.10	77.30	76.80	
>55	79.90	79.90	79.60	79.50	
IDLE MODE					
YEARS>	1974	1979	1982	1985	
	58.00	58.00	55.00	53.00	

VEHICLE TYPE 12

ACCELERATION MODE					
YEARS>	1974	1979	1982	1985	
0-20 MPH	77.60	77.60	74.80	71.80	
0-30	78.10	76.10	75.30	72.40	
0-40	78.40	78.40	75.80	73.20	
0-50	78.90	78.90	76.50	74.30	
0-60	79.40	79.40	77.40	75.60	
DECELERATION MODE					
YEARS>	1974	1979	1982	1985	
20-0 MPH	63.70	63.70	61.30	58.90	
30-0	67.80	67.80	65.60	63.80	
40-0	70.60	70.60	68.90	67.50	
50-0	72.90	72.90	71.50	70.50	
60-0	74.70	74.70	73.70	73.10	
CRUISE MODE					
YEARS>	1974	1979	1982	1985	
<25 MPH	73.00	73.00	71.10	69.60	
25-34	73.00	73.00	71.10	69.60	
35-44	75.80	75.40	74.50	73.60	
45-54	76.10	78.10	77.30	76.80	
>55	74.90	79.90	79.60	79.50	
IDLE MODE					
YEARS>	1974	1979	1982	1985	
	58.00	58.00	55.00	53.00	

TABLE 2-7

VEHICLE REFERENCE NOISE EMISSION LEVELS BY VEHICLE TYPE, OPERATING MODE, AND AVERAGE CRUISE SPEED (Continued)

TABLE 4. 7 REGULATION LEVELS, IN DBA

VEHICLE TYPE 13

ACCELERATION MODE					
YEARS>	1974	1980	1982	1985	
0-20 MPH	73.30	73.30	71.50	69.50	
0-30	74.50	74.90	73.10	71.10	
0-40	75.40	75.40	73.60	71.60	
0-50	75.70	75.70	73.90	71.90	
0-60	75.90	75.90	74.10	72.10	
DECELERATION MODE					
YEARS>	1974	1980	1982	1985	
20-0 MPH	61.50	61.50	59.70	57.70	
30-0	65.90	65.90	64.10	62.10	
40-0	69.00	69.00	67.20	65.20	
50-0	71.40	71.40	69.60	67.60	
60-0	73.40	73.40	71.60	69.60	
CRUISE MODE					
YEARS>	1974	1980	1982	1985	
<25 MPH	71.30	71.30	69.50	67.50	
25-34	71.30	71.30	69.50	67.50	
35-44	74.40	74.40	72.60	70.60	
45-54	76.90	76.90	75.10	73.10	
>55	78.90	78.90	77.10	75.10	
IDLE MODE					
YEARS>	1974	1980	1982	1985	
	[illegible]	60.00	59.00	57.00	

VEHICLE TYPE 14

ACCELERATION MODE					
YEARS>	1974	1980	1982	1985	
0-20 MPH	87.50	87.50	87.50	87.50	
0-30	89.10	89.10	89.10	89.10	
0-40	89.60	89.60	89.60	89.60	
0-50	89.90	89.90	89.90	89.90	
0-60	90.10	90.10	90.10	90.10	
DECELERATION MODE					
YEARS>	1974	1980	1982	1985	
20-0 MPH	75.70	75.70	75.70	75.70	
30-0	80.10	80.10	80.10	80.10	
40-0	83.20	83.20	83.20	83.20	
50-0	85.60	85.60	85.60	85.60	
60-0	87.60	87.60	87.60	87.60	
CRUISE MODE					
YEARS>	1974	1980	1982	1985	
<25 MPH	85.50	85.50	85.50	85.50	
25-34	85.50	85.50	85.50	85.50	
35-44	88.60	88.60	88.60	88.60	
45-54	91.10	91.10	91.10	91.10	
>55	93.10	93.10	93.10	93.10	
IDLE MODE					
YEARS>	1974	1980	1982	1985	
	72.00	72.00	72.00	72.00	

Table 2-8. REPRESENTATIVE ACCELERATION NOISE LEVELS BY CALENDAR YEAR FOR EACH VEHICLE TYPE

(See Appendix A, Section A.5.2)

Vehicle Type, I	Representative Acceleration Noise Levels by Calendar Year							
	1974	1978	1981	1982	1983	1984	1985	1987
1	63.4				63.4		63.4	62.0
2	64.6				64.6		64.0	62.0
3	66.9				66.0		64.0	62.0
4	66.6				66.0		64.0	62.0
5	68.9				66.0		64.0	62.0
6	66.6				66.0		64.0	62.0
7	70.2				66.0		64.0	62.0
8	78.5	78.5		78.0			73.0	
9	85.0	81.0		78.0			73.0	
10	85.0				81.0			
11	81.0				81.0			
12	81.0				81.0			
13	79.0		78.0			75.0		
14	94.2		94.2			94.2		

Vehicle source noise emission levels, L^{eq}_{oij}, are defined relative to the cruise speed of the vehicle. That is, the equivalent A-weighted sound level describing the acceleration mode is for an acceleration past the observer from idling to the cruise speed. The cruise mode sound level is one which is recorded at an observer's position during a constant speed pass-by test at the indicated cruise speed. Similarly, the deceleration sound level is for a vehicle coming to rest from the specified cruise speed. The vehicle idle mode noise emission is, of course, for the vehicle at rest. All vehicle source noise emissions are referenced to an observer distance of 50 feet. In total, the present version of the General Adverse Response Model may use a maximum of 1120 distinct vehicle noise emission levels for all vehicle types, operation modes and future year noise emissions.

For a given year, the vehicle types produced are assigned the noise emission characteristics appropriate to that year. For example, if noise emission levels are defined in the years of 1974 (baseline year), 1980, and 1983, vehicles produced and surviving between 1974 and 1980 are assigned the 1974 levels; vehicles produced and surviving between 1980 and 1983 are assigned 1980 are assigned 1980 levels; and vehicles produced beyond 1983 are assigned 1983 levels. Each vehicle type may be assigned noise emission characteristics in any year in the time stream up to a maximum of four "regulatory" years. Currently, noise exposure estimates are computed for a user-specified sequence of years out to 40-years beyond the baseline year (1974).

2.5.1.2 Progagation of Noise From Roadway

The General Adverse Response Model considers a line source attenuation of traffic noise in populated areas. Figure 2-8 presents the line source attenuation curves used to estimate propagation in urban areas characterized by the average population density. These curves were developed from data and analyses presented in Reference 15 and 22 through 24. As indicated in Figure 2-8, the curves are further defined by the clear zone distance in that the zero attenuation value corresponds to the clear zone distance. Hence, the appropriate attenuation curve is selected based upon the population place size (Index J), population density category (Index ID), and the roadway type (Index K).

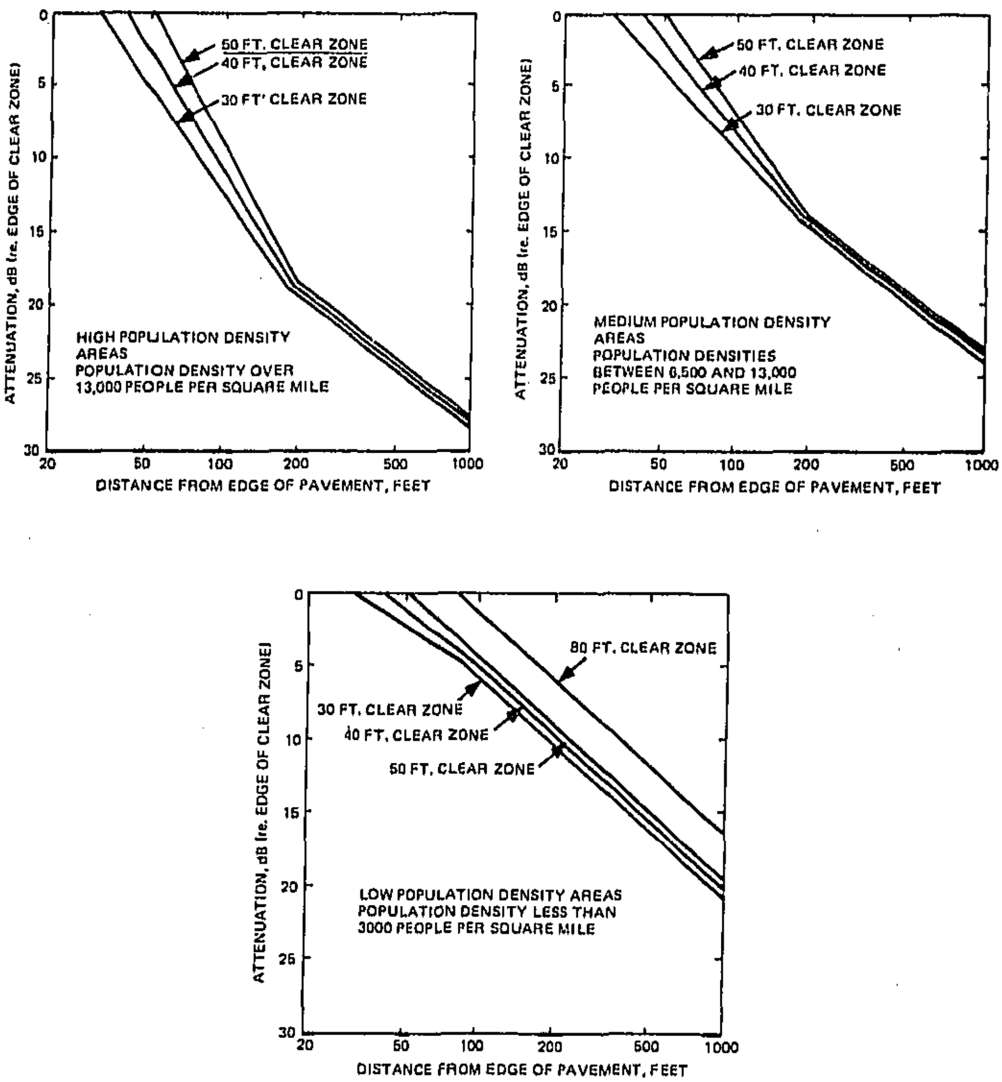


FIGURE 2-8. SOUND LEVEL ATTENUATION CURVES: LINE SOURCE

2.5.2 Single Event Model

2.5.2.1 Generation of Noise From Roadways

To estimate the sound exposure of a receiver resulting from a discrete noise event, one requires the determination of the total acoustic intensity received from the source during a defined time period. The definition of the time period usually depends upon the characteristics of the source. For example, solid waste compactor (i.e., garbage truck) noise may be estimated, on a single event basis, using the noise emissions generated during the compaction cycle time. For a discrete event such as characterized by the passage of an aircraft, a railway train, or a roadway vehicle, the "10 dB down duration" is used to characterize the vehicle's noise signature.[25] That is, the time required for the sound level to rise from 10 dB below the maximum level to the maximum level and then to decay to 10 dB below the maximum level is commonly used.

For a single discrete noise intrusion, the total acoustic intensity received during the defined time period is used to define appropriate sound levels. One level, called the Sound Exposure Level or SEL, is simply a measure of the total received acoustic intensity for the duration of the event. Another level, called the Equivalent Sound Level or L_{eqT} is a time average of the total received acoustic intensity. The equivalent sound level is a measure of the average acoustic intensity received during any instant of the event's duration.

The requirement for estimating two sound levels to describe a single event is based upon the expected effects of this noise on the population.[26] The Sound Exposure Level or SEL is used to estimate the population's sleep interference. The equivalent sound level, L_{eqT} is used to estimate the population's speech interference. Since the Single Event Model assigns one segment of the population to sleeping activities and another segment of the population to non-sleeping activities, the two sound levels are applied only to the appropriate segment of the population to estimate the effect of the single event noise intrusion.

For a time varying sound level, $L(t)$, of duration of T, the Sound Exposure Level, SEL, and the single event equivalent sound level, L_{eqT}, are defined as:

$$SEL = 10 \cdot \log \left\{ \int_0^t 10^{L(t)/10} dt \right\} \qquad (2\text{-}3)$$

$$L_{eqT} = 10 \cdot \log \left\{ \frac{1}{T} \int_0^t 10^{L(t)/10} dt \right\} \qquad (2\text{-}4)$$

From the definitions given above, the Sound Exposure Level is related to the single event equivalent sound level by the relationship:

$$SEL = L_{eqT} + 10 \cdot \log(T) \qquad (2\text{-}5)$$

As indicated in Appendix E, the single event exposure duration may be easily estimated for a discrete vehicle pass-by. For a vehicle moving at a constant speed, V, and a receiver located at a distance, D, from the roadway the single event " ΔL_{dB} down duration" is expressed as:

$$T = 2(D/V) \left[10^{\Delta L/5(2+\gamma)} - 1\right]^{1/2} \qquad (2\text{-}6)$$

where γ is a site constant describing the acoustic propagation from the lane centerline to the edge of the clear zone. For the "10 dB down duration", Equation (2-6) estimates the single event exposure time to be:

$$T = 6(D/V) \text{ for acoustically hard } (\gamma = 0) \qquad (2\text{-}7a)$$

$$T = 4.61(D/V) \text{ for acoustically soft } (\gamma = 0.5) \text{ sites} \qquad (2\text{-}7b)$$

The important aspects of the above results is that both the SEL and the L_{eqT} levels depend explicitly upon the absolute distance between the source and the receiver and upon the vehicle speed. Hence, the Single Event Model must calculate the noise exposure of the population adjacent to a multilane roadway on a lane-by-lane basis. Additionally, for a single vehicle type, it is necessary to conduct the calculations separately for each group of vehicles having the same noise emission characteristics. Hence, the Single Event Model requires approximately 80 times the number of calculations as the General Adverse Response Model to conduct an estimate for each year in the time stream.

As indicated in Appendix E, the "SEL propagation" is different from the "L_{eqT} propagation" due to the fact that the exposure duration is a function of distance from the lane. The propagation model is consistent, however, since at any receiver distance, the relationship between SEL and L_{eqT} given by Equation (2-5) is maintained.

The Sound Exposure Level and the equivalent single event level are used to quantify a vehicle's noise emission for a single vehicle pass by. The Single Event Model, however, estimates the effect of an average day's exposure to vehicle noise. To conduct this daily exposure estimate, it is assumed that each single noise exposure may be estimated and the effect accumulated for an entire day. Hence, it is necessary to estimate the number of vehicle operations on a daily basis. To conduct this estimation, traffic data and vehicle operational data are used. Except as noted below, both the General Adverse Response Model and the Single Event Model use an identitical data base for traffic conditions and vehicle operations.

To estimate the number of single noise events for each type of vehicle operating on each mile roadway, the Average Daily Traffic (ADT) assigned to the roadway is used. Currently, the data base specifies values for ADT by population place size (Index J) and by roadway type (Index K). To estimate the number of daily operations for the Ith vehicle type, the specific ADT value for the roadway is multiplied by the fraction of the total traffic comprising the Ith vehicle's mix. The data base specifies percentage mix of vehicles, by vehicle type, for categories of population place size (Index J) and roadway type (Index K).

Hence, the number of operations of the Type I vehicle, on the Type K roadway, in the Jth category of population place size is given by:

$$N_{IKJ} = P_{IKJ} \times ADT_{KJ} \qquad (2\text{-}8)$$

where P_{IKJ} is the fraction of the traffic mix

ADT_{KJ} is the Average Daily Traffic

Subscript I denotes vehicle type

Subscript K denotes roadway type

Subscript J denotes population place size.

Since the population's activity varies with the time of day (see Figure 2-6), it is necessary to estimate the number of daytime and nighttime vehicle operations in order to conduct the single event analysis. Hence, it is necessary to estimate the fraction of daily vehicle operations that occur during the daytime and the nighttime. The General Response Model assumes that all traffic is uniformly distributed, on a national basis, into daytime and into nighttime operations. Currently, it is assumed that 87 percent of vehicle operations occur during the daytime (0700 to 2200) and 13 percent occur during the nighttime (2200 to 0700 hours). For the Single Event Model, however, the user may define, by vehicle type (Index I), the fraction of daytime and nighttime operations independent of the above assumed values.

From Equation (2-8), the number of vehicle operations for daytime and for nighttime are estimated using:

$$(N_{IKJ})_D = F_{DI} \times N_{IKJ} = F_{DI} \times P_{IKJ} \times ADT_{KJ} \qquad (2\text{-}9a)$$

$$(N_{IKJ})_N = F_{NI} \times N_{IKJ} = (1-F_{DI}) \times N_{IKJ} \qquad (2\text{-}9b)$$

where F_{DI} is the fraction of daytime operations
F_{NI} is the fraction of nighttime operations

Subscript D denoted daytime
Subscript N denotes nighttime

For the General Adverse Response Model, $F_{DI} = 0.87$ and $F_{NI} = 0.13$ for all roadway and vehicle types. These fractions are, however, specified by vehicle type for the Single Event Model.

Since the receiver sound level depends upon the absolute distance from a traffic lane on a roadway to the receiver, it is necessary to distribute the number of vehicle operations over each lane of roadway. For both the General Adverse Response Model and the Single Event Model, it is assumed that traffic is uniformly distributed over all lanes. Hence, the number of daytime operations of each vehicle type on each lane of roadway is obtained by dividing the Equation (2-9a) estimate by the number of lanes defined for the roadway. The number of nighttime operations on each lane are obtained by dividing the Equation (2-9b) estimate by the number of lanes.

The number of operations obtained in this manner must further be refined, for each vehicle type, to consider the noise emissions peculiar to the mode of operation and time stream simulation of "quiet" vehicles entering the traffic flow in future years. These aspects of the operational counting scheme used by the Single Event Model are presented in following sections.

2.5.2.2 Propagation of Noise From Roadways

The Single Event Model considers a point source attenuation of traffic noise in populated areas. Figure 2-9 presents the point source attentuation curves used to estimate propagation in urban areas. The specialized nature of the single event propagation model is described in Appendix E. The curves in Figure 2-9 were developed from data and analyses presented in References 15 and 23.

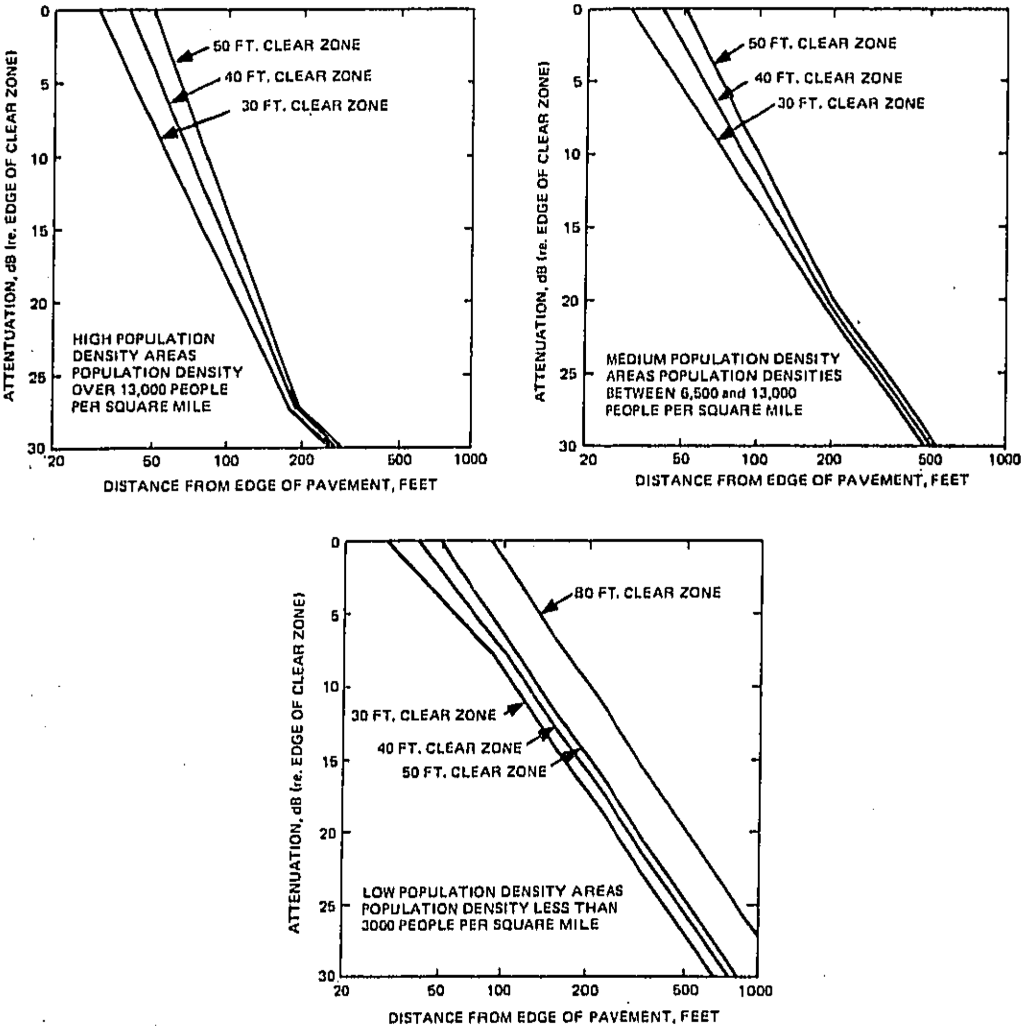


FIGURE 2-9. SOUND LEVEL ATTENUATION: POINT SOURCE

2.6 Noise Impact Descriptors

2.6.1 General Adverse Response Descriptors

The basic output descriptor of the General Adverse Response Model is the Level Weighted Population, LWP, defined as:[26,27]

$$LWP_i = \frac{P_i}{20} (L_i - 55) \qquad L_i \geq 55 \text{ dB} \qquad (2\text{-}10)$$

where P_i is the population exposed to the sound level L_i.

All estimates are performed using a defined sound level interval and assigns the center of the level interval as the exposure level, L_i. The population exposed to this level interval is accumulated by year, for each population place size, roadway type (by primary exposure allocations) and national totals. Based upon the population exposed to sound levels in an interval, Equation (2-10) is used to calculate the Level Weighted Population.

The specific information and format of the output data are presented in Section 3.

2.6.2 Single Event Descriptors

The Single Event Model provides the user with five noise impact estimates related to a vehicle's operation on the national roadway network. These noise impact estimates are each related to the various activities assigned to the population. The Model assigns an activity using the Index, IPACT. The relationship between the activity and the activity index is as follows:

Activity	Index, IPACT
Indoor Speech Interference	1
Outdoor Speech Interference	2
Pedestrian Speech Interference	3
Sleep Interference	4

As described in Section 2.2.2, the population's daily activity is categorized as to daytime and nighttime activity. The Single Event Model denotes the daily activity using the Index IDAY as follows:

Daily Time Period	Index, IDAY
Daytime: 0700 to 2200 hours	1
Nighttime: 2200 to 0700 hours	2

To evaluate the impact of a single event noise exposure, the Fractional Impact (FI) methodology is used. The Sound Exposure Level, SEL, is used to estimate sleep interference and the single event equivalent sound level, L_{eqT}, is used to estimate speech interference. The Single Event Model estimates the number of people-exposures in dB bands considering both the population's activity and location. For segments of the population assigned to indoor activities, the exposure levels are reduced by the building exterior skin noise reduction.

Figure 2-10 presents a graphical representation of the relationship between vehicle noise generation, population activity, and Fractional Impact of the noise exposure. This figure presents the "layered" aspect of the National Roadway Traffic Noise Exposure Model as considered by the Single Event Model. As illustrated in Figure 2-10, the first level of detail corresponds to the General Adverse Response Model with subsequent detail being the the considerations necessary for the Single Event Model estimates. Also,

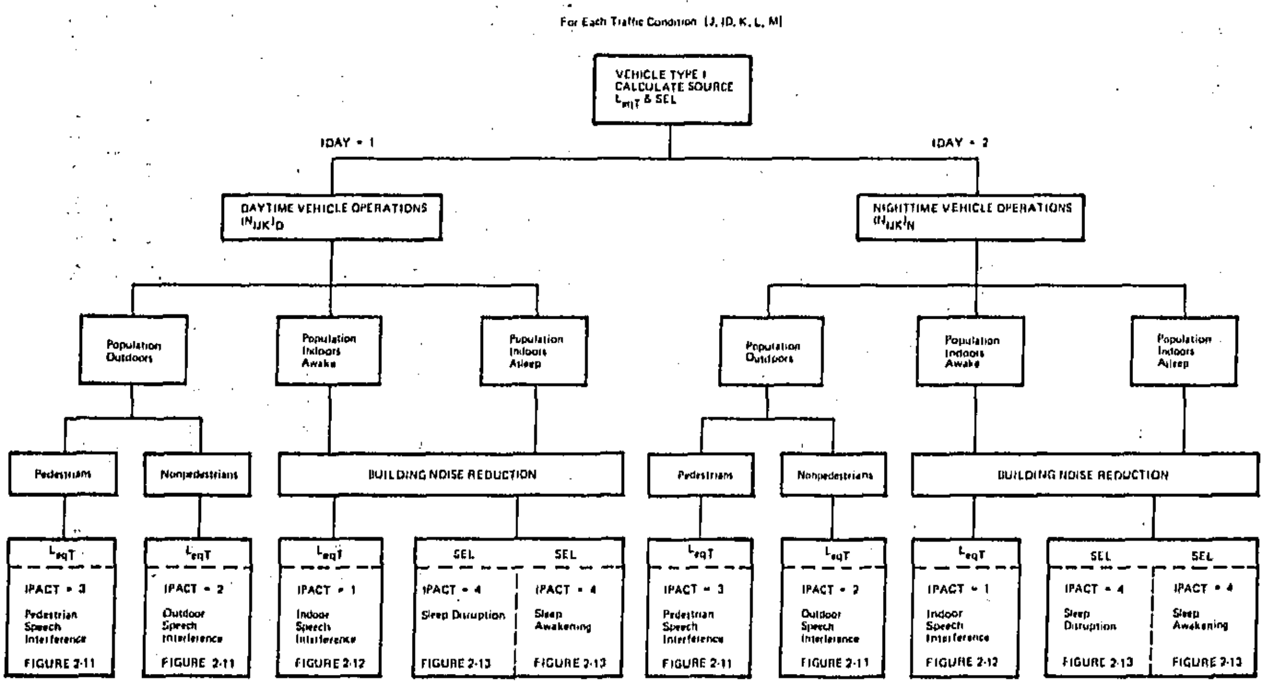


FIGURE 2-10. SINGLE EVENT MODEL: CATEGORIZATION OF POPULATION ACTIVITIES AND NOISE EXPOSURE IMPACT ESTIMATES

the reader should recognize that the population segments assigned to speech activities are district sets in so far as noise impact is concerned. For sleep interference, however, one population set (people indoors and asleep) is used to estimate two noise impacts: sleep disruption and sleep awakening. Each of the single event noise impacts estimated by the Single Event Model are discussed in the following subsections.

2.6.2.1 Population Outdoors

The Single Event Model considers two categories of population located outdoors: pedestrians and people outside their residences. Both pedestrians and outdoor residential population comprise a definite fraction of the total population assigned to a roadway. Pedestrians are assumed to be located adjacent to the roadway in order to calculate their noise exposure levels. Outdoor residential population, however, is assumed to be uniformly distributed over the inhabited area adjacent to the roadways. Hence, the outdoor residential population is exposed to single event sound levels determined by the distance attenuation function applicable to the area being considered.

Outdoor speech interference is used to estimate the single event noise exposure effect for population outdoors. For speech interference, the single event equivalent sound level, L_{eqT}, is used. For pedestrians, only the primary exposure is used since noise from the roadway is expected to predominate the exposure estimate (see Appendix F).

Figure 2-11 presents the Fractional Impact array currently used to estimate the Level Weighted Population for single event outdoor speech interference.[28] Figure 2-11 indicates that the Fractional Impact for outdoor speech interference is not a simple function of the single event level. Further, the discrete steps indicated in Figure 2-11 illustrate the "look-up table" method used by the Single Event Model to estimate the Level Weighted Population. That is, the Model estimates the exposure level and then "looks up" the Fractional Impact value from a data array. The

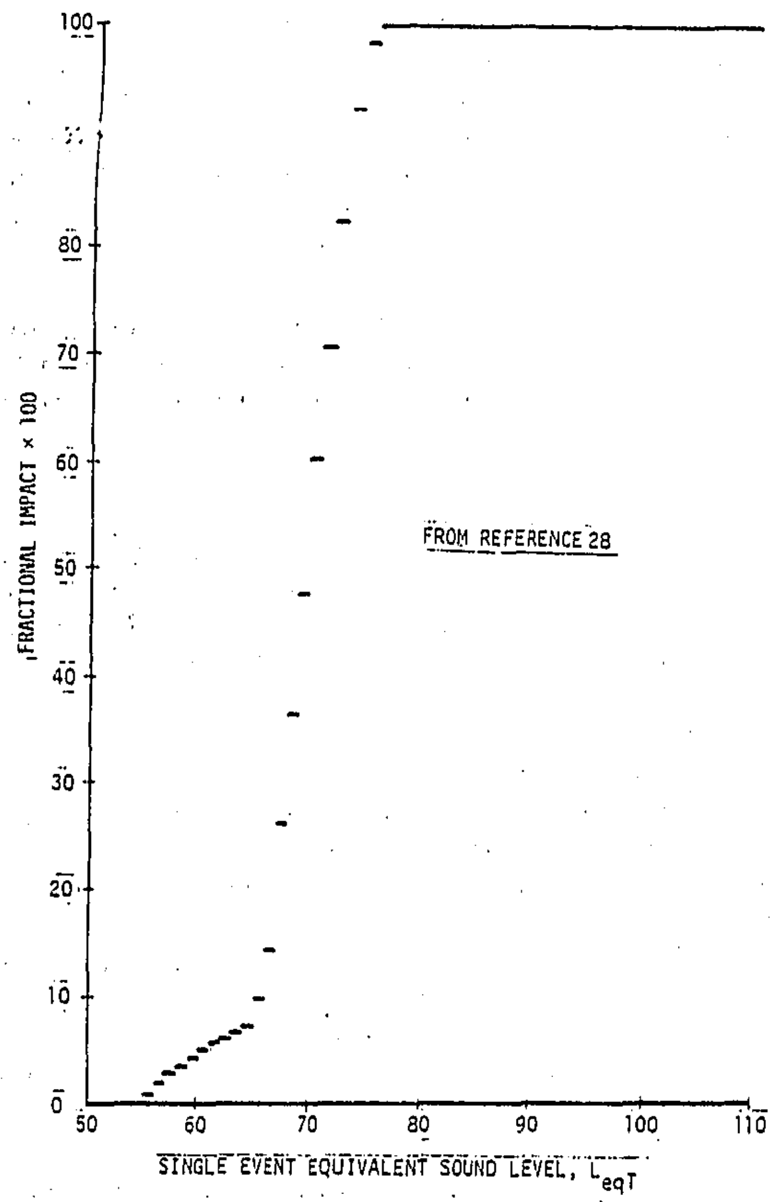


FIGURE 2-11. FRACTIONAL IMPACT FOR OUTDOOR SPEECH INTERFERENCE

data array assumes that the Fractional Impact is constant over a one dB band that represents the average value for that band. This method is used so that complicated functional relationships, such as indicated in Figure 2-11, may be accurately estimated with computational efficiency. For example, if the exposure level were estimated to be L_{eqT} = 69.8 dB, the Fractional Impact would be estimated to be 0.475, whereas, if the level was 70.1 dB the Fractional Impact would be estimated to be 0.600.

As used by the Single Event Model, the exposure level estimated for the "local" dB bands is used to select the appropriate Fractional Impact value prior to sorting the resultant calculation into the "global" dB band arrays.

For single event equivalent sound levels below 55 dB, the Fractional Impact values for outdoor speech interference are zero (i.e., there is no impact). For single event equivalent sound levels above 75 dB, the Fractional Impact values for outdoor speech interference are assumed to be one (i.e., the impact is 100 percent) irrespective of the exposure level.

2.6.2.2 Population Indoors

The Single Event Model considers two categories of population located indoors: population awake and population asleep. During the average day, the vast majority of the United States' population spends their time indoors (see Figure 2-6). The indoor population considered by the Single Event Model comprises only the segment expected to remain at their residential location during the day. To estimate the single event noise exposure effects for population indoors, indoor speech interference criteria are applied to the population awake and sleep interference criteria are applied to the population asleep.

Figure 2-12 presents the Fractional Impact criteria for indoor speech interference currently used by the Single Event Model. The "look up table" characteristic of the data in Figure 2-12 emphasizes the technique

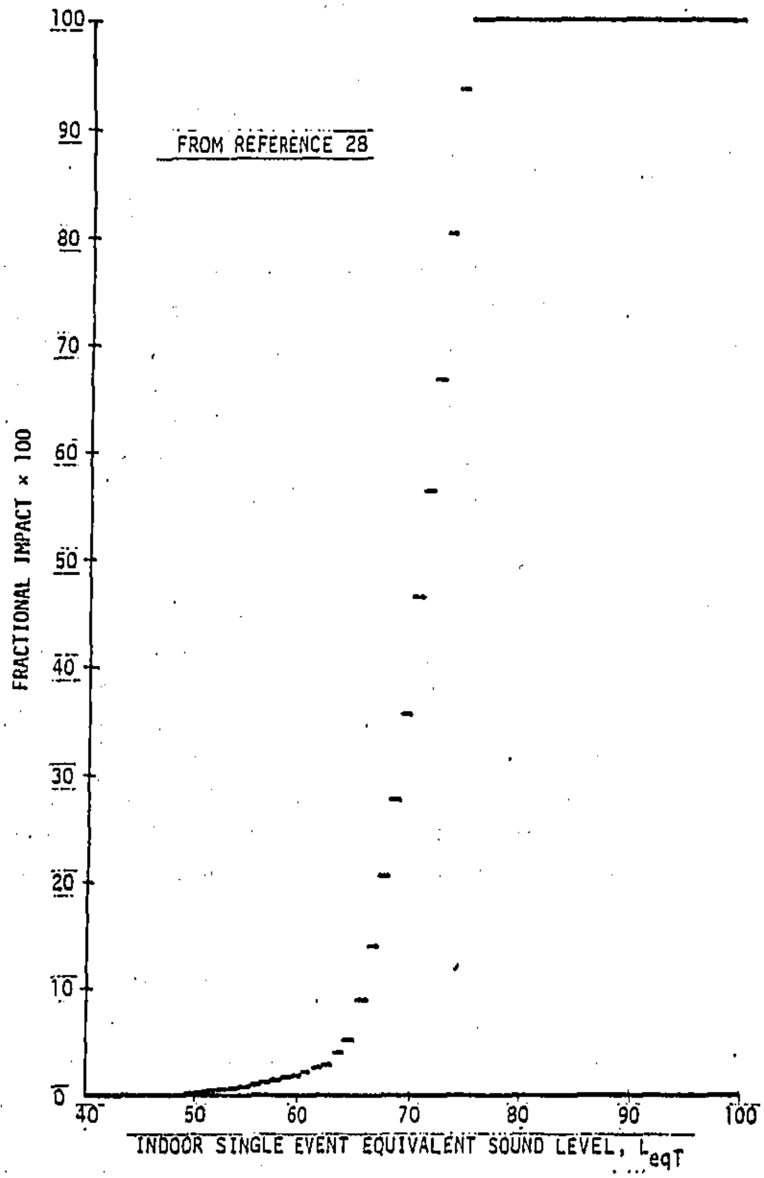


FIGURE 2-12. FRACTIONAL IMPACT FOR INDOOR SPEECH INTERFERENCE

used to estimate the indoor speech interference. The single event equivalent sound level, L_{eqT}, is used to evaluate the noise exposure. As indicated in Figure 2-12, the Fractional Impact for indoor speech interference is taken as zero below 45 dB and is set to one above 75 dB. Of course, the indoor single event equivalent sound level is attenuated from the outdoor level to simulate the building exterior skin noise reduction. The current values of building noise reduction used by the Single Event Model are presented in Table 2-9.

Figure 2-13 presents the Fractional Impact criteria for sleep interference. The Single Event Model considers all sleeping population to be located indoors. The indoor Sound Exposure Level, SEL, is used to estimate the intrusiveness of a vehicle's noise emission on sleep. For each sleeping individual, two values of Fractional Impact are estimated: sleep disruption and sleep awakening. Hence, a single noise exposure of a single individual will result in two categories of sleep interference being estimated.

As indicated in Figure 2-13, both sleep disruption and sleep awakening Fractional Impacts may be estimated as a linear function of the indoor Sound Exposure Level. However, the Single Event Model uses a "look up table" to evaluate the Fractional Impacts since this approach is computationally more efficient than conducting the specific calculations. The Fractional Impact is set to zero for indoor Sound Exposure Levels below 37 dB in the case of sleep disruption and below 45 dB in the case of sleep awakening. The Fractional Impact is set to one for indoor Sound Exposure Levels above 111 dB in the case of sleep disruption and above 135 dB in the case of sleep awakening.

To estimate the value of the indoor SEL that must be exceeded to result in a combined Fractional Impact for sleep disruption and sleep awakening above 1.0, the results of Figure 2-13 may be used. By adding the two expressions for the Fractional Impacts, setting the result equal to 1.0, and solving for the value of SEL, it is estimated that the indoor SEL must exceed 81.4 dB. Hence, by using the Level Weighted Population

TABLE 2-9
BUILDING EXTERIOR SKIN NOISE REDUCTION, dB
BY PLACE SIZE (INDEX J) AND POPULATION DENSITY AREA (INDEX ID)
(See Table 2-1)

Population Density Area Index, ID	Population Place Size, Index J								
	1	2	3	4	5	6	7	8	9
	Over 2M	1M-2M	500K-1M	200K-500K	100K-200K	50K-100K	25K-50K	5K-25K	Rural Areas
1 High Density	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
2 Medium to High Density	20.0	20.0	20.0	15.0	15.0	15.0	20.0	20.0	15.0
3 Medium to Low Density	20.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
4 Low Density	20.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0

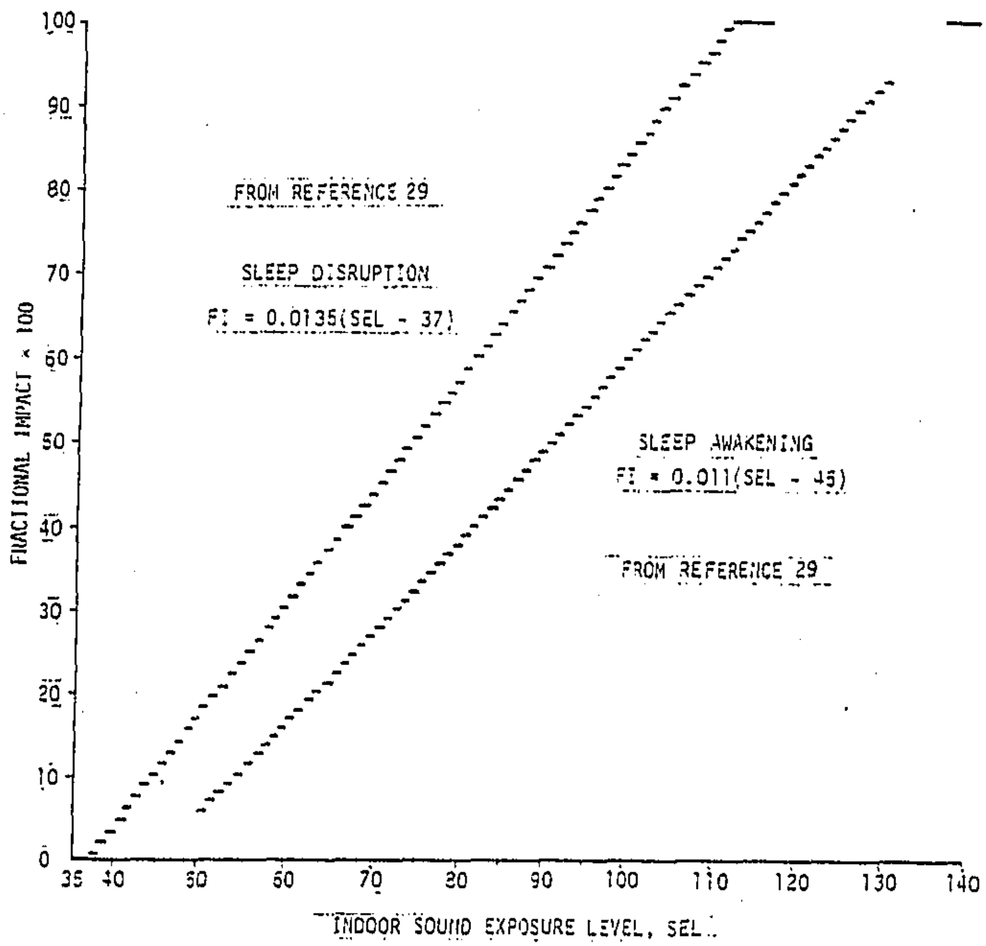


FIGURE 2-13. FRACTIONAL IMPACT FOR SLEEP DISRUPTION AND SLEEP AWAKENING INTERFERENCE

estimates presented in dB bands by the Single Event Model, sleep disruption and sleep awakening estimates for bands above SEL = 80 dB represent an effective multiple counting of the noise impact.

2.6.2.3 Ambient Sound Levels and Cut-Off Criteria

The lower limits on the Fractional Impact Criteria presented in Figures 2-11 through 2-13 are generally below ambient sound levels in and around a person's residence. Of course, these ambient levels are generally attributable to all noise sources. In particular, general roadway traffic may mask or obsure a single event noise intrusion from a specific vehicle source. However, as used by the Single Event Model, the only roadway noise source considered is the vehicle type used in the particular scenario. Hence, in the context used by the Single Event Model, an ambient sound level is attributable to local nonroadway noise sources. For example, building interior ambient sound levels may result from HVAC operation, appliances, etc. Ambient exterior sound levels may result from activities in and around buildings, HVAC system noise, etc.

To accommodate physical conditions that would result in the ambient sound level "masking" an intruding single event vehicle noise, the Single Event Model uses a "Cut-Off Criterion" for each Fractional Impact function defined for the Model. The Cut-Off Criterion is a total receiver sound level - that is user defined - below which it is assumed that the single event noise intrusion is effectively masked by the ambient sound level.

For example, Figure 2-13 indicates that sleep disruption begins at an indoor SEL value of 37 dB. This level is several dB below interior ambient sound levels of even quiet buildings. Hence, if it is considered that the receiver's ambient level is acceptable to the receiver and that the ambient level is greater than the lower limits on the Fractional Impact functions, single event noise intrusions masked by the ambient level should be discounted in the noise effects analysis.

To establish rational Cut-Off Criteria limits applicable to single event noise intrusions, the Single Event Model assumes that the ambient sound level effectively masks the intruding noise if the maximum instantaneous level of the intruding noise is equal to or less than the ambient level. The receiver's total noise exposure (SEL and L_{eqT}) resulting from the combined ambient and time varying single event intrusion is used to define the Cut-Off Criterion. In this manner, the Single Event Model allows the user to include an ambient sound level in the noise effect analysis. The details of this consideration are illustrated in Figure 2-14 and presented in Appendix E, Section E.7.

For speech interference, the receiver's noise exposure is excluded if the vehicle's maximum intruding noise level is equal to or less than the equivalent sound level of the ambient noise. For sleep interference, the Sound Exposure Level, SEL, is evaluated for the receiver considering the maximum intruding level to be equal to the equivalent sound level of the ambient noise. For single event noise exposures equal to or less than this SEL value, the receiver's noise exposure is excluded. For both the SEL and L_{eqT} levels, the receiver's total single event noise exposure will be 5.3 dB above the level without ambient using this procedure.

From the analysis in Appendix E and the assumption that the maximum level equals the equivalent sound level of the ambient, the following expressions for estimating the Cut-Off Criterion are obtained:

$$(L_{eqT})COC = (L_{eq})_{ambient} + 10\cdot\log\,[1+I] \qquad (2\text{-}11)$$

and

$$(SEL)_{COC} = (L_{eqT})COC + 10\cdot\log(T) \qquad (2\text{-}12)$$

where $I = (D/VT)\int_{-\phi}^{+\phi} \cos^{\gamma}(\phi)d\phi$

$\phi = TAN^{-1}\,(VT/2D)$

T is the exposure duration given by Equation (2-6)
D is the distance of the receiver from the roadway

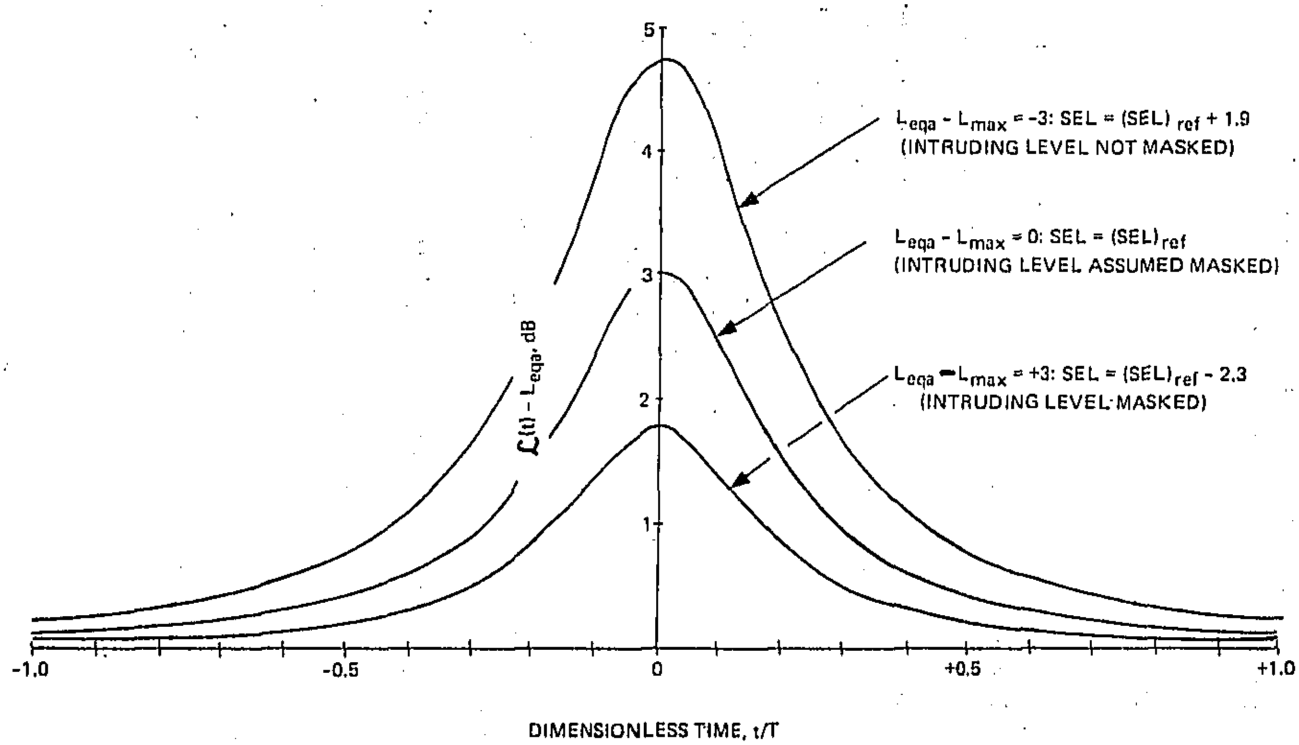


FIGURE 2-14. COMBINATION OF SINGLE EVENT INTRUSION WITH AMBIENT SOUND

Using the results of Equation (2-7), the expressions for the Cut-Off Criterion may be simplified to obtain:

$$(L_{eqT})_{COC} = (L_{eq})_{ambient} + \begin{cases} 1.51 \text{ (hard sites)} \\ 1.52 \text{ (soft sites)} \end{cases} \quad (2\text{-}13)$$

$$(SEL)_{COC} = (L_{eq})_{ambient} + 10 \cdot \log(D/V) + \begin{cases} 9.29 \text{ (hard sites)} \\ 8.16 \text{ (soft sites)} \end{cases} \quad (2\text{-}14)$$

These results simply state that for the single event equivalent sound level, the Cut-Off Criterion is 1.5 dB above the assumed ambient. The Cut-Off Criterion for the Sound Exposure Level is about 9 dB above the ambient plus a correction for duration given by the (D/V) term. For example, with a receiver at 100 feet from a vehicle pass by at 35 mph (51.33 ft/sec), the duration correction in Equation (2-14) would be 2.9 dB. In this example, the Cut-Off Criterion for the Sound Exposure Level would be 2.9 + 9.3 = 12.2 db above the ambient for hard sites and 2.9 + 8.2 = 11.1 dB above the ambient for soft sites.

Currently, the Cut-Off Criteria used by the Single Event Model are defined as:

Fractional Impact Criteria	Ambient*	Cut-Off Criterion
Pedestrian Speech Interference	55.0 dB	56.5 dB, L_{eqT}
Outdoor Speech Interference	55.0 dB	56.5 dB, L_{eqT}
Indoor Speech Interference	45.0 dB	46.5 dB, L_{eqT}
Sleep Disruption	45.0 dB	56.1 dB, SEL
Sleep Awakening	45.0 dB	56.1 dB, SEL

* Equivalent Level

2.7 Noise Exposure Estimates

2.7.1 Noise Exposure Calculation Scheme

2.7.1.1 General Adverse Response Model

Several metrics are used to quantify the noise impact in terms of the general adverse response to roadway traffic noise. These metrics are all based upon the Fractional Impact (FI) methodology and relate population noise exposure to the magnitude of the impact.[26] Below a lower limit criterion of L_{dn} = 55 dB, it is assumed that traffic noise will have no adverse effect (impact) on the population. No "ambient" noise level is used or assumed in the noise impact calculations since the ambient noise is primarily generated by roadway traffic.

In order to appreciate the noise impact methodology used by the General Adverse Response Model, it must be remembered that the basic requirement for the simulation is the allocation of population to roadways. The nation's population and land area are distributed into 36 categories of homogeneous population density. In each land area of constant population density, roadway mileage and traffic conditions are defined. Since only roadways within an inhabited land area are considered in the data base, the total land area is prorated among the roadway mileage defined for the area. Based upon the roadway mileage and the allocated land area, a maximum width* is calculated for the strip of land adjacent to each roadway which is allowed to contain the population. Hence, a fraction of the total population and the total land area is assigned to each mile of roadway by roadway type and traffic condition. The allocation scheme places the total population adjacent to the total roadway mileage. The maximum width or distance away from the roadway is called the "cut-off" distance for purposes of discussion. The

* This calculation is performed in the baseline year and remains constant throughout the time stream.

cut-off distance represents the limit in the noise exposure calculation scheme to ensure that the estimates do not represent a "double-counting" of the exposed population.

Everyone is aware that in a typical urban situation, a receiver at a given location is potentially exposed to several distinct roadway noise sources during a typical day. That is, a receiver may be living on a local street a few blocks from an interstate highway and although the maximum sound levels to which he is exposed may result from traffic on the local street, most of the long-term noise exposure may result from traffic on the interstate. To account for this situation, the roadway traffic noise exposure is divided into two exposure categories, primary exposure and secondary exposure. Primary Noise Exposure is the noise exposure of the population assigned to a roadway generated by the traffic on that roadway. Secondary Noise Exposure is the noise exposure of the population assigned to a roadway generated by traffic on other roadways defined for the same population density land area.

The Primary Noise Exposure calculation is a deterministic scheme in that all parameters required for the calculation are defined for each mile of roadway. The Secondary Noise Exposure calculation is a probabilistic scheme since the relative alignment of all roadways in a land area (and hence the noise propagation distances) can only be defined in a random sense. By calculating cut-off distances to be used with the noise distance attenuation curves (Figure 2-8), it is assured that the Primary Noise Exposure calculation will not result in noise propagation beyond the assigned land area and that the Secondary Noise Exposure levels are not greater than the levels at the cut-off distance for the secondary roadway.

The noise exposure of inhabitants is estimated by accumulating the population exposed to roadway traffic noise within discrete sound level intervals (dB bands). The population so exposed is assigned the sound level at the center of the band. Three-dB bands are used for the purpose of accumulating population noise exposure. However, the coded format allows other sound level intervals to be specified. For the primary exposure estimates, population noise exposure below the criteria limit of 55 dB is accumulated. The secondary noise exposure level for each dB band is estimated and the total noise exposure for the population in that band is calculated by adding the primary and the secondary levels on an intensity basis.

2.7.1.2 Single Event Model

The Single Event Model estimates the population's noise exposure and the resulting effect due to a single vehicle type operating on the nation's roadway network. As indicated in Appendix E, both the SEL and L_{eqT} sound levels are based upon the vehicle reference sound level, L_0. Noise emission tests of identical vehicles result in a set of maximum pass-by levels for each mode of operation. These sets of data define a distribution of reference levels for the type of vehicle tested. Since the Single Event Model estimates the effect of noise on the nation's population due to one event (i.e., one value of L_0) and accumulates the total effect due to all similar events, the model should, properly, include the distribution of the reference levels. That is, the Single Event Model is basically a counting scheme of distinct events.

However, to strictly use a distribution of reference sound levels for the Single Event Model, it would be necessary to conduct extensive testing to insure that the distribution of levels represented the noise emission characteristics of the vehicle fleet. When additional data were introduced, the distribution of reference levels would be altered and the counting of the single events would be altered. The average emission level used by the General Adverse Response Model is obtained by assuming that the test data are normally distributed. That is, the reference levels follow a Gaussian distribution. This assumption could be extended explicitly to the Single Event Model by assuming that the number of occurrences of a single reference level followed a Gaussian distribution. However, to do this would be prohibitive from a computing standpoint since the program would have to consider approximately 12 reference levels for each mode of operation on each lane of roadway for the vehicle type. Hence, it is assumed that an average reference emission level can be used for the Single Event Model in the form defined for the General Adverse Response Model (see Table 2-7 in Section 2.5.1).

The number of operations estimated by Equation (2-9) must be further distributed by the specific vehicle reference emission levels. That is, the number of occurrences of each level in Table 2-7 must be estimated for the vehicle type being considered. As described in Appendix E, definition of the SEL or L_{eqT} levels requires the average vehicle speed. The data base distributes roadway mileage by average cruise speed. This average cruise speed is used to estimate the single event duration, T, of a vehicle's noise intrusion - irrespective of the mode of operation. That is, the duration of a single event noise exposure - as used by the Single Event Model - is not estimated explicitly for each mode of operation. This approach is consistent for the cruise mode and is an approximation for the acceleration and deceleration modes. Further, the single event noise exposure resulting from the idle mode of operation is not currently estimated by the Single Event Model since the source-receiver distance cannot be adequately defined (in a statistical sense) with the present model formulation.

The above approximations, however, are not believed to be too serious. First, the reference emission levels are equivalent levels defined for each mode relative to a receiver moving with the vehicle (see Appendix A, Section A.5, pages A-75 through A-91). Second, the idle mode is the lowest noise emission level of each vehicle type. Hence, ignoring the idle mode of operation may be expected to have a smaller effect on the noise impact estimate that the higher levels associated with acceleration, deceleration, and cruise.

To obtain the estimate of the number of vehicle operations in a given mode, the percent of time in each operating mode is used. The data base explicitly defines this time fraction for each vehicle type (Index I) and by roadway type (Index K). By assuming that an operating mode can occur at any location along a roadway with uniform probability, then an observer at a location next to the roadway would observe a number of vehicle operations in a given mode in the same ratio to the total operations as the fraction of time the vehicle operates in that mode compared to the total time. Hence, to estimate the number of single events related to a mode of operation, the Single Event Model multiplies the estimates obtained from Equation (2-9) by the fraction of time that the vehicle operates in the mode for the roadway type being considered.

The Single Event Model estimates, in a future year, the population of a vehicle type by the noise emissions defined by a scenario (see Table 2-7). Hence, in any future year, the total population of a single vehicle type is distributed among groups of that vehicle type exhibiting identical noise emissions. This distribution is assumed to apply uniformly to all roadways in the year for which calculations are conducted.

The distribution of a vehicle's population by noise emission groups is dependent upon the user-defined noise emission schedules, the vehicle sales projects and the vehicle survival curve defined for a particular scenario. Both the General Adverse Response Model and the Single Event Model use identical methods for distributing the vehicle's total population by noise emission characteristics.

Since the General Adverse Response Model considers only the average noise emissions of a vehicle type, an equivalent sound level for the vehicle type is calculated based upon a weighted intensity summation of the vehicle's noise emissions. The weighting factors are the fractions of the total vehicle population corresponding to the defined noise emission level. For the Single Event Model, however, each noise level category of each vehicle type must be considered individually. The reason for this distinction is that the Sound Exposure Level, SEL, and the single event equivalent sound level, L_{eqT}, both depend upon the reference level, L_o, and the absolute distance from the traffic lane to the receiver.

To calculate the single event noise exposure efficiently, the Single Event Model uses a "dB Band Sorting Scheme" to accumulate the number of exposures of the population to a given level of SEL and L_{eqT}. This sorting scheme is used at the highest level of detail within the Single Event Model. Table 2.10 presents a comparison between the General Adverse Response Model and the Single Event Model for the level of detail required to estimate the population's noise exposure. The "dB Band Sorting Scheme" is used to avoid repetitious calculations that are identical. That is, for a noise level group of a given vehicle type, the population's noise exposure is sorted into dB bands depending upon the sound level attenuation from the lane to the receiver's location and multiplied by the number of events.

First, the population's noise exposure is calculated using a "local" set of dB bands. The dB bandwidth is a constant ΔdB attenuation from the level (SEL or L_{eqT}) calculated at the edge of the clear zone. The population's distribution with noise exposure level is then multiplied by the number of events corresponding to that category of vehicle noise level. Hence, each "local" set of dB bands contains the product of the population times the number of events. The "local" set of dB band noise exposures is then sorted into a "global" set of dB band noise exposures. The "global" set of dB bands is an absolute set of band limits ΔdB wide. The "global" set of dB bands are used to accumulate noise exposures calculated for each "local" set of dB bands. For example, suppose that the SEL at the edge of the clear zone was estimated to be 97 dB. For a 5 dB band width, the "local" dB band noise exposure would be the product of the number of events times the population for the bands 97 to 92 dB; 92 to 87 dB, etc. For the "local" exposure in the 97 to 92 dB band, the estimates would be sorted such that the 97 to 95 "local" dB estimate would be sorted into the 100 to 95 "global" dB band and the 95 to 92 "local" estimate would be sorted into the 95 to 90 "global" dB band, etc.

The above procedure is continued for each noise group category of the vehicle type for each lane of the roadway. Using this method, the distribution of the product of number of exposures of the population to various noise levels resulting from the operation of a single vehicle type is accumulated.

TABLE 2-10 COMPARISON OF LEVEL OF DETAIL FOR NOISE EXPOSURE CALCULATIONS
(Single Vehicle Type, Single Vehicle Noise Group, Single Traffic Lane)

GENERAL ADVERSE RESPONSE MODEL	PHYSICAL PARAMETERS REQUIRED	SINGLE EVENT MODEL
Required	Population Place Size (J)	Required
Required	Population Density (ID)	Required
Required	Roadway Type (K)	Required
Required	Average Cruise Speed (L)	Required
Required	Mode of Operation (M)	Required
Indirectly Required	Time of Day (IDAY)	Required
Not Required	Population Activity (IPACT)	Required
4,320	Parameter Combinations*	34,560

* (J) (ID) (K) (L) (M) (IDAY) (IMPACT)

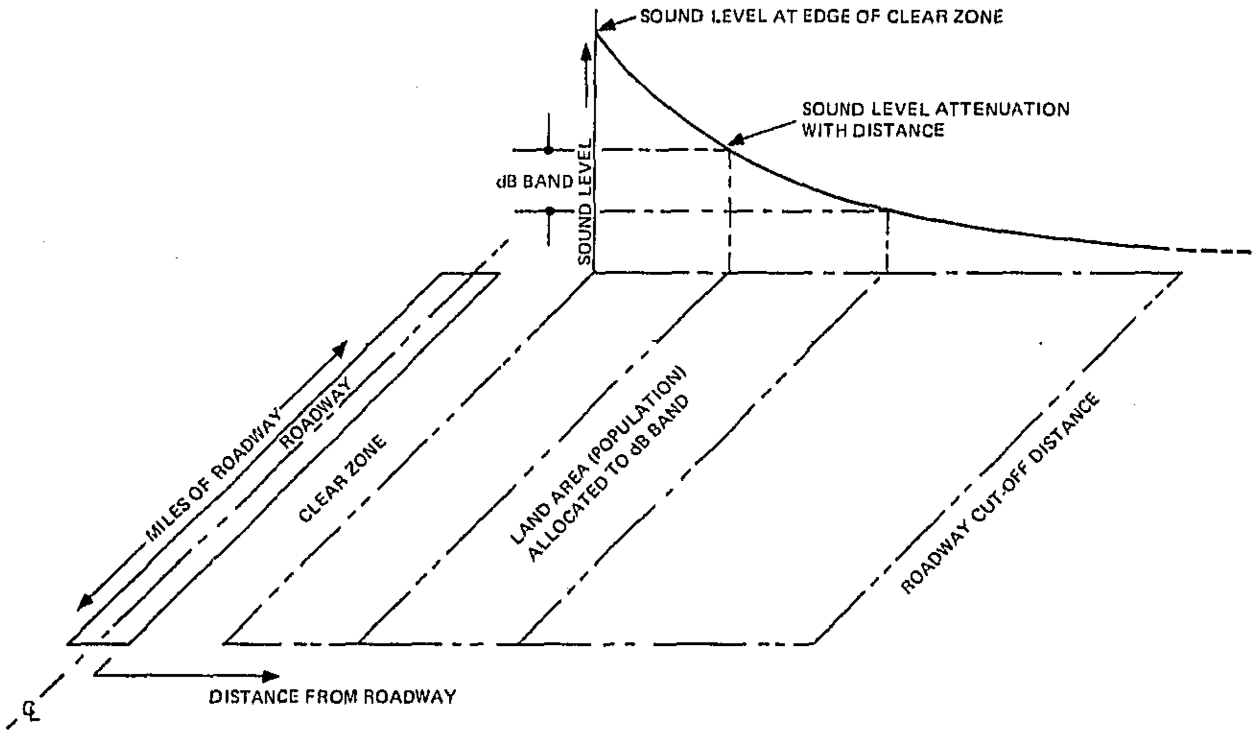
Since the Single Event Model considers the population's activities and location when they are exposed to an intruding noise level, it is necessary to attenuate the noise levels for population assigned to indoor activities. As described in Section 2.6.2, sleep interference and indoor speech interference are the quantitative descriptors of single event noise impact for indoor activities. Hence, the "local" dB band levels are uniformly decreased by the building exterior skin noise reductions defined for the problem prior to accumulating these results into the "global" set of dB band estimates. Currently, building exterior skin noise reduction is considered to be predominately related to population density by considering the general type of building construction in a given area (see Table 2-9). Hence, the present version of the Single Model allows building exterior skin noise reduction to be specified by the place size (Index J) and the population density area (Index ID). Building exterior skin noise reduction, of course, is not required for the General Adverse Response Model.

2.7.2 Primary Noise Exposure

The Nation's population and land area are distributed into 36 categories of constant population density.* For each land are of constant population density, the roadway mileage, traffic conditions, and noise attenuation with distance (Figures 2-8 and 2-9) are defined. As described in preceding sections, a "cut off" distance away from the roadway defines the absolute limit for the land area and/or the population assigned to the roadway. Figure 2-15 illustrates the basic relationship between the roadway noise source, the noise distance attenuation and the population surrounding the roadway. Since population density is constant at this level of detail within the Model, the terms land area and population are synonymous. As indicated in Figure 2-15, the land area (population)

---

* Population and land area are used to derive population density.



NOTE: LAND AREA AND POPULATION IS UNIFORMLY DISTRIBUTED ON BOTH SIDES OF THE ROADWAY.

FIGURE 2-15. ROADWAY TRAFFIC NOISE EXPOSURE OF LAND AREA enclosed between the clear zone adjacent to the roadway and outer limit for the noise propagation is divided into dB bands. The land area (population) defined by the width of the dB band and the roadway mileage define the exposure to the sound level at the center of the band. This estimate is termed the Primary Exposure.

The primary traffic noise exposure calculation does not recognize the criteria limit of 55 dB. That is, land area (population) is sorted into dB bands out to the cut-off distance. Depending upon the noise level at the edge of the clear zone and the distance attenuation function defining the noise propagation, the noise level at the cut-off distance may or may not exceed 55 dB. This procedure is used to properly combine the primary and secondary noise exposure estimates to obtain total exposure.

For each population density area, the primary noise exposure calculation is repeated and the results are stored for each roadway before proceeding with the secondary noise exposure calculations.

2.7.3 Secondary Noise Exposure

The General Adverse Response Model recognizes that population noise exposure in urban areas is a combination of noise generated on, perhaps, several roadways. Since population is assigned to each roadway, it is necessary to estimate the population's noise exposure contributed by contiguous roadways assigned to each place size and population density area. The noise exposure resulting from roadway other than the roadway to which the population is assigned is termed the secondary noise exposure.

The Single Event Model estimates secondary noise exposure in an identical manner to the methodology used by the General Adverse Response Model with one important difference. The General Adverse Response Model must combine levels of primary noise exposure and secondary noise exposure to estimate total noise exposure. The Single Event Model considers each roadway to be an independent noise source so that an individual will be exposed to primary levels independently of the secondary levels. Hence, the Single Event Model combines an individual's primary and secondary noise exposure by accumulating the number of noise events from each roadway at the appropriate exposure levels.

For example, the General Adverse Response Model may estimate a primary exposure level of L_{dn} = 63 dB and a secondary exposure level of 58 dB so that the total exposure level is L_{dn} = 64.2 dB. The Single Event Model, however, would accumulate the number of exposures at the primary exposure level and the secondary exposure level. For a primary exposure level of SEL = 73 dB occurring 10 times and a secondary exposure level of SEL = 62 dB occurring 20 times, the individual's total single event noise exposure would be accumulated as ten events at 73 dB and twenty events at 62 dB. Hence, the Single Event Model estimates the distribution of an individual's noise exposure by estimating the number of exposures at the various exposure levels. These exposure estimates are the result of vehicles operating on all roadways surrounding the individual's residence. Appendix F presents the detailed description of the secondary noise exposure calculation used by the General Adverse Response Model and the Single Event Model. Except for the distinction of combining primary and secondary exposure levels to obtain the total level, both the General Adverse Response Model and the Single Event Model use the same basic methodology for calculating secondary noise exposure.

2.7.4 Examples of Primary and Secondary Exposure

2.7.4.1 General Adverse Response Model

To provide the reader with an appreciation of the noise exposure calculation scheme and the significance of the secondary noise exposure calculation, two examples are presented. These examples result from execution of the model using the calculation options provided to the user. All results are presented as percentages or ratios so that the illustrations emphasize relative estimates rather than absolute results tied to a specific scenario.

The first example considers the effect of secondary noise exposure. The model was executed considering all population distribution to all roadways; however, traffic noise was calculated only for traffic on interstate highways. As described in Section 3, the model provides estimates of the traffic noise impact by the functional classification of roadways (e.g., interstates, arterials, etc.). Hence, the resulting estimates of population exposed above 55 dB represent total noise exposure for the population assigned to interstates with all exposure estimates for other roadways resulting from secondary noise exposure due to the traffic noise generated by interstate highways. Figure 2-16 presents the result of this example as a percentage of the national population exposed above 55 dB from only interstate traffic noise. The percentage estimates given in Figure 2-16 indicate, for example, that only 29.2 percent of the national population exposed to interstate traffic noise above 55 dB live along interstates.

As a second example, the model was executed so that only the primary noise exposure estimates were conducted for each roadway type. For each roadway type, the ratio of the total population (primary plus secondary) noise exposure estimate to the population using only the primary noise exposure estimate was calculated. These results are presented in Figure 2-17.

Figure 2-17 indicates that for interstates, the total noise exposure of the population adjacent to interstates is dominated by noise from the adjacent interstates. At the other extreme, the total noise exposure of people living along local roads and streets is dominated by noise generated on other roadways (including other local streets) since the total exposure estimate is over two and one-half times the primary exposure estimates.

The result given in Figure 2-17 is presented for all roadway types to indicate the relative significance of noise emissions from one roadway type resulting in noise exposure of population living adjacent to other roadways.

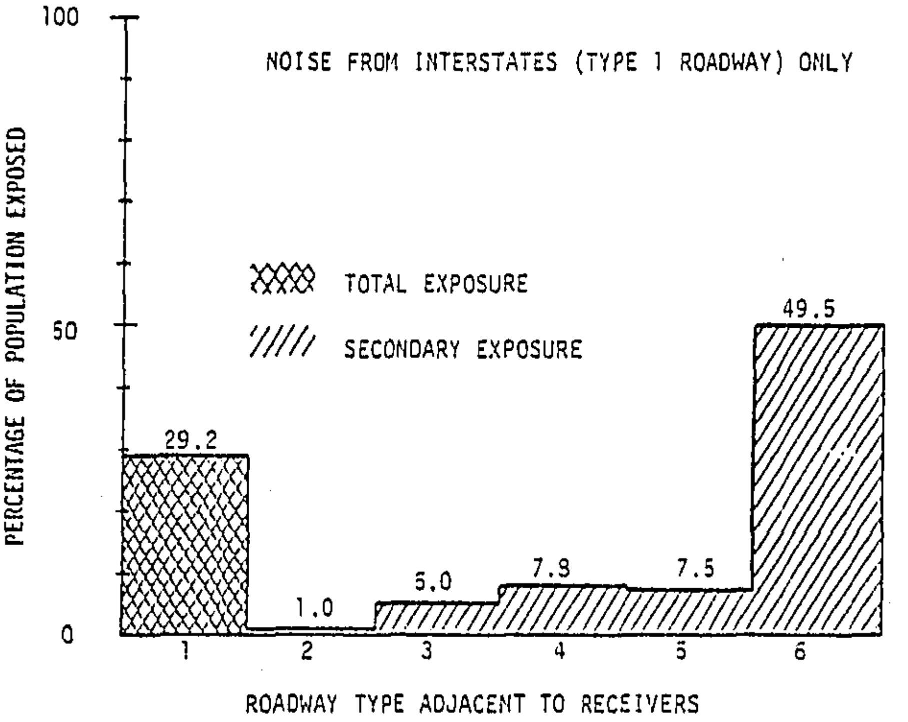


FIGURE 2-16. PERCENTAGE OF POPULATION EXPOSED ABOVE 55 dB DUE TO INTERSTATE TRAFFIC NOISE BY ROADWAY TYPE ADJACENT TO POPULATION

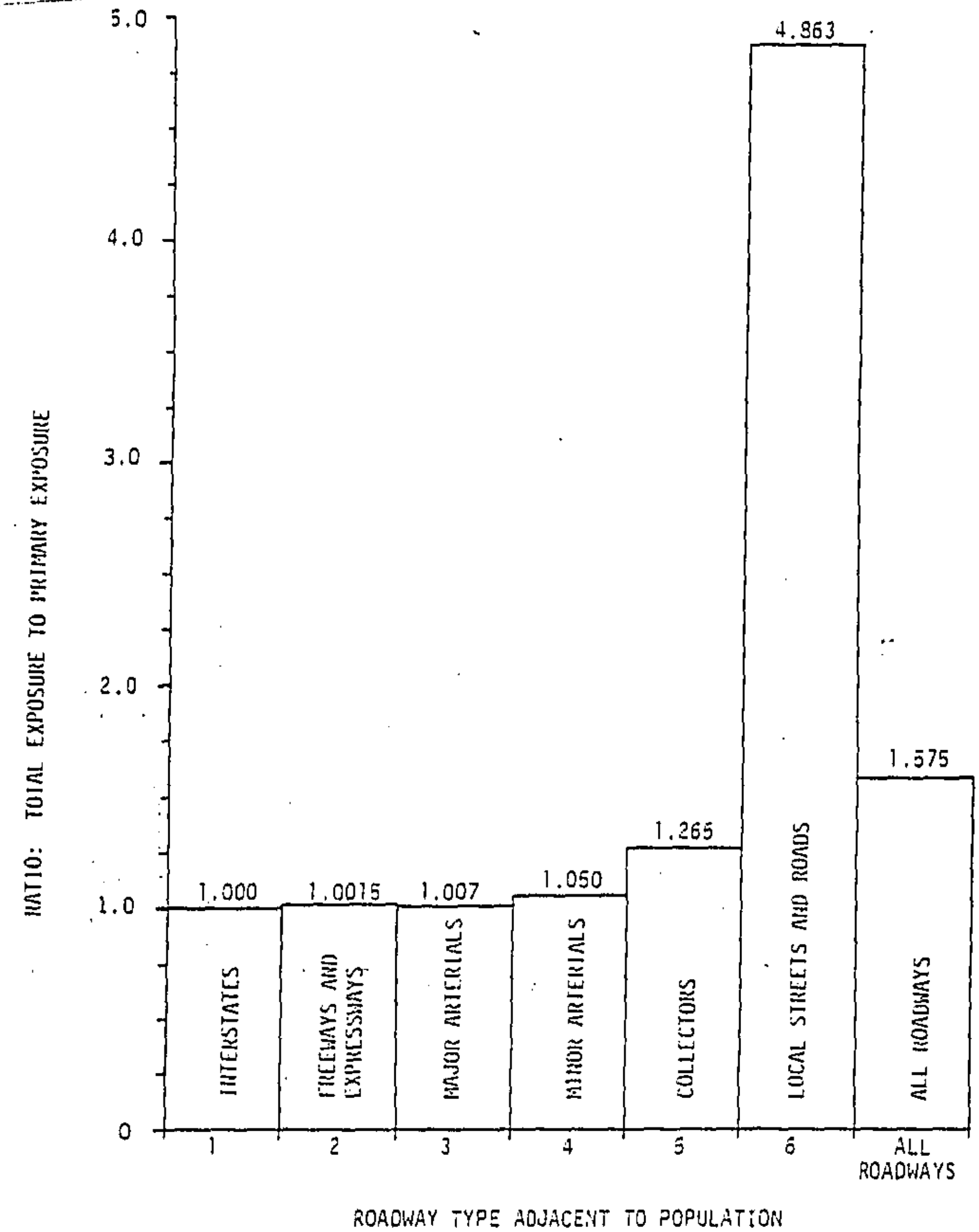


FIGURE 2-17. POPULATION EXPOSED ABOVE 55 dB BY ROADWAY TYPE ADJACENT TO POPULATION: RATIO OF TOTAL EXPOSURE ESTIMATE TO PRIMARY EXPOSURE ESTIMATE

2.7.4.2 Single Event Model

This section presents examples to illustrate the significance of primary and secondary noise exposure for the various single event metrics and to illustrate the Single Event Model's sensitivity to specific vehicle operational characteristics.

As described in Section 2.6.2, two of the single event metrics quantify sleep disruption and indoor speech interference. These metrics use the Fractional Impact (FI) methodology to determine the Level Weighted Population (LWP) associated with each metric. Further, the Single Event Model provides estimates for the Level Weighted Population in terms of "dB bands" of single event noise exposure level. The "dB band" estimates are used to present the illustrations of primary and secondary exposure.

Figure 2-18 presents distribution of the single event Level Weighted Population (LWP) for the 24 hour sleep disruption effect estimated for transit bus operations (Type 11 vehicles). The distributions are normalized to the total LWP estimate for all bands. As indicated in Figure 2-18, primary noise exposure contributes 78.51 percent of the total LWP and secondary exposure contributes 21.49 percent of the total LWP. Hence, it appears that for sleep disruption due to transit buses, people living along bus routes are the most disturbed. Further, the distributions presented in Figure 2-18 indicate that the primary exposure is at higher levels of Sound Exposure Level than the secondary exposure. The primary exposure distribution is "humped" in shape, whereas, the secondary exposure distribution is continuously decreasing from low levels to higher levels. These results are consistent with one's intuition concerning an individual's proximity to a noise source i.e., the levels are higher as one is closer to the source.

Figure 2-19 presents the distribution of the single event LWP for the 24 hour indoor speech interference effect estimated for transit bus operations. This result is somewhat surprising in that the secondary

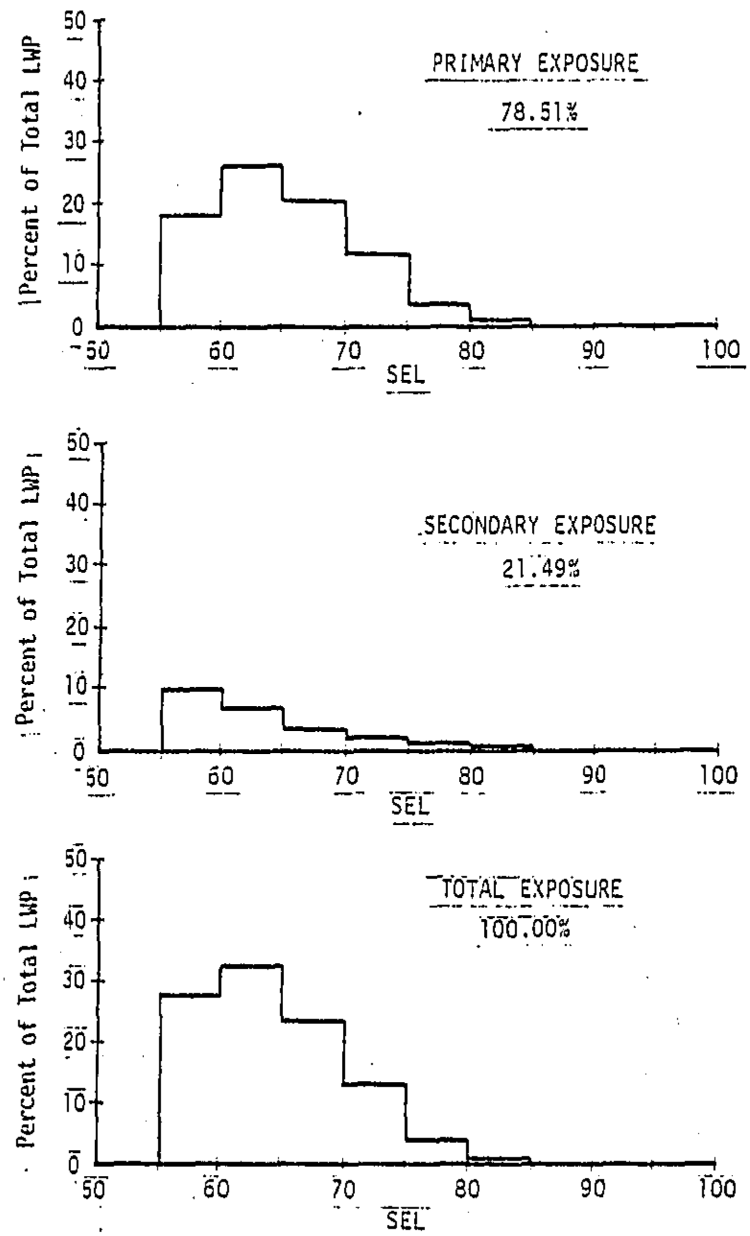


FIGURE 2-18. EXAMPLE OF PRIMARY AND SECONDARY NOISE EXPOSURE: SLEEP DISRUPTION DUE TO TRANSIT BUSES

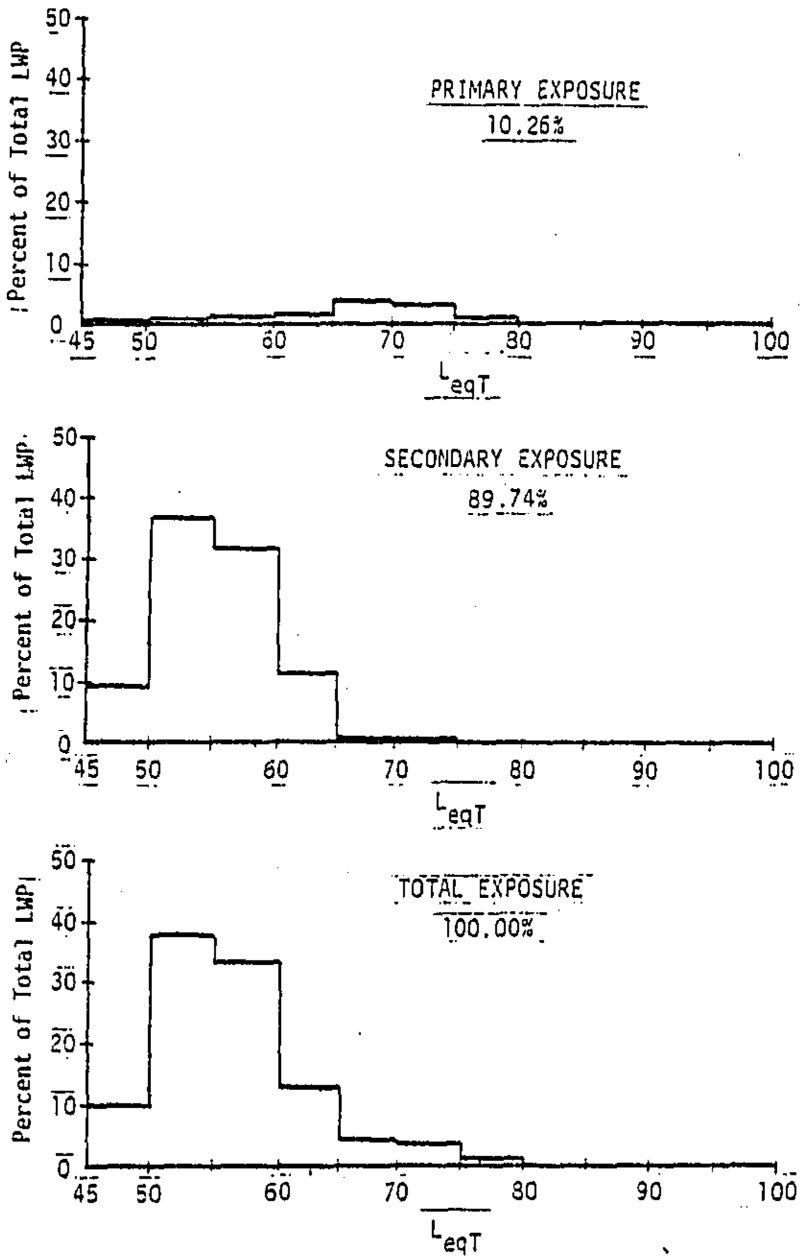


FIGURE 2-19. EXAMPLE OF PRIMARY AND SECONDARY NOISE EXPOSURE: INDOOR SPEECH INTERFERENCE DUE TO TRANSIT BUSES

exposure dominates the total exposure for indoor speech interference. However, one sees in Figure 2-19 that the secondary exposure distribution is at much lower exposure levels than the primary exposure distribution. Further, the result of Figure 2-19 is not so surprising when one recognizes that transit buses are not assigned to all roadways. Hence, during the estimation of the primary exposure LWP, the population assigned to roadways on which transit buses do not operate are not considered. For the secondary exposure calculation, however, the Model considers all population using only those roadways on which the transit buses are assigned as noise sources.

Figure 2-20 presents the distribution of the single event LWP for the 24 hour outdoor speech interference effect estimated for transit bus operations. The result is similar to the indoor speech distributions in that the secondary noise exposure dominates the total exposure.

Figure 2-21 presents the distribution of the single event LWP for the 24 hour indoor speech interference effect estimated for 8 cylinder gasoline engine automobiles (Type 1 vehicles). These distributions are considerably different from the corresponding transit bus distributions presented in Figure 2-19. For Type 1 vehicles (which operate on all roadways), the primary exposure estimate is greater than the secondary exposure estimate, as one might expect.

Figure 2-22 presents the distribution of the single event LWP for the 24 hour outdoor speech interference estimated for Type 1 vehicles. For the outdoor speech interference, it is seen that the secondary exposure is the major contribution, however, the primary exposure is a significant component of the total exposure. The interesting aspect of Figure 2-22 is that the total distribution of LWP with the single event equivalent sound level is distinctly bimodal in character.

The results of Figures 2-19 through 2-22 were obtained using standard execution options and data for the baseline (1974) year conditions defined for the Single Event Model.

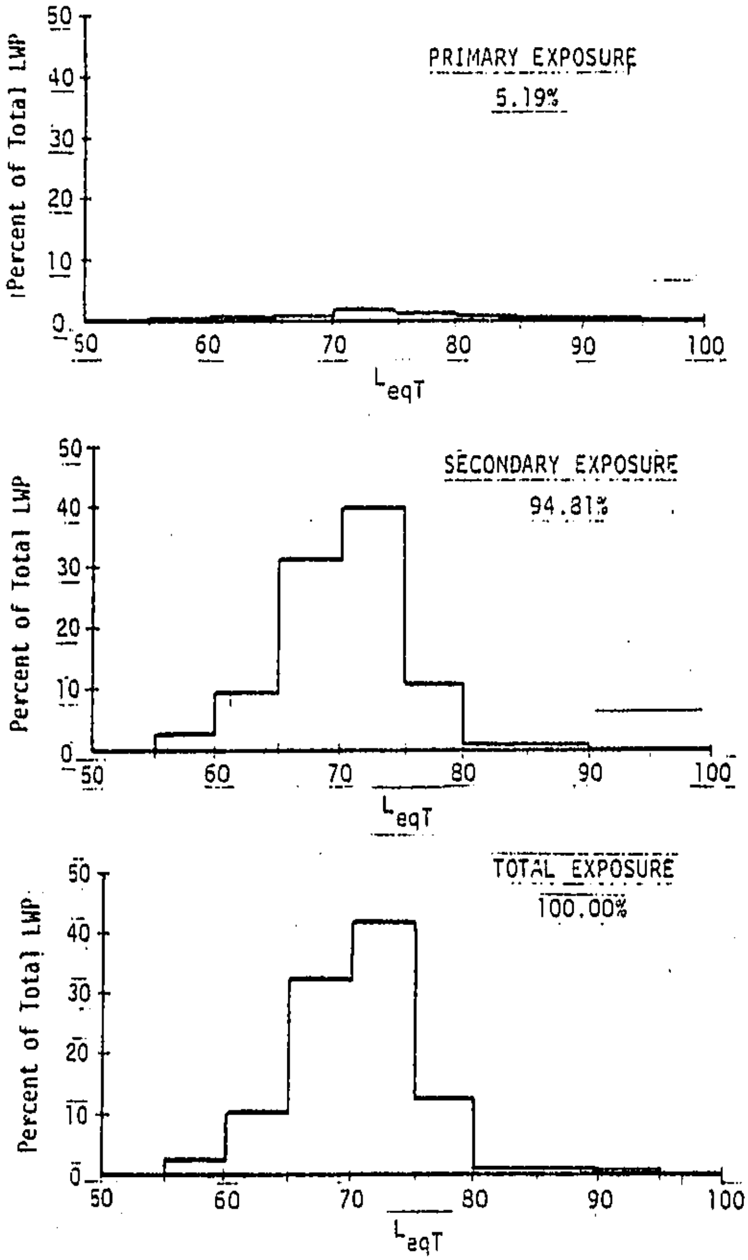


FIGURE 2-20. EXAMPLE OF PRIMARY AND SECONDARY NOISE EXPOSURE: OUTDOOR SPEECH INTERFERENCE DUE TO TRANSIT BUSES

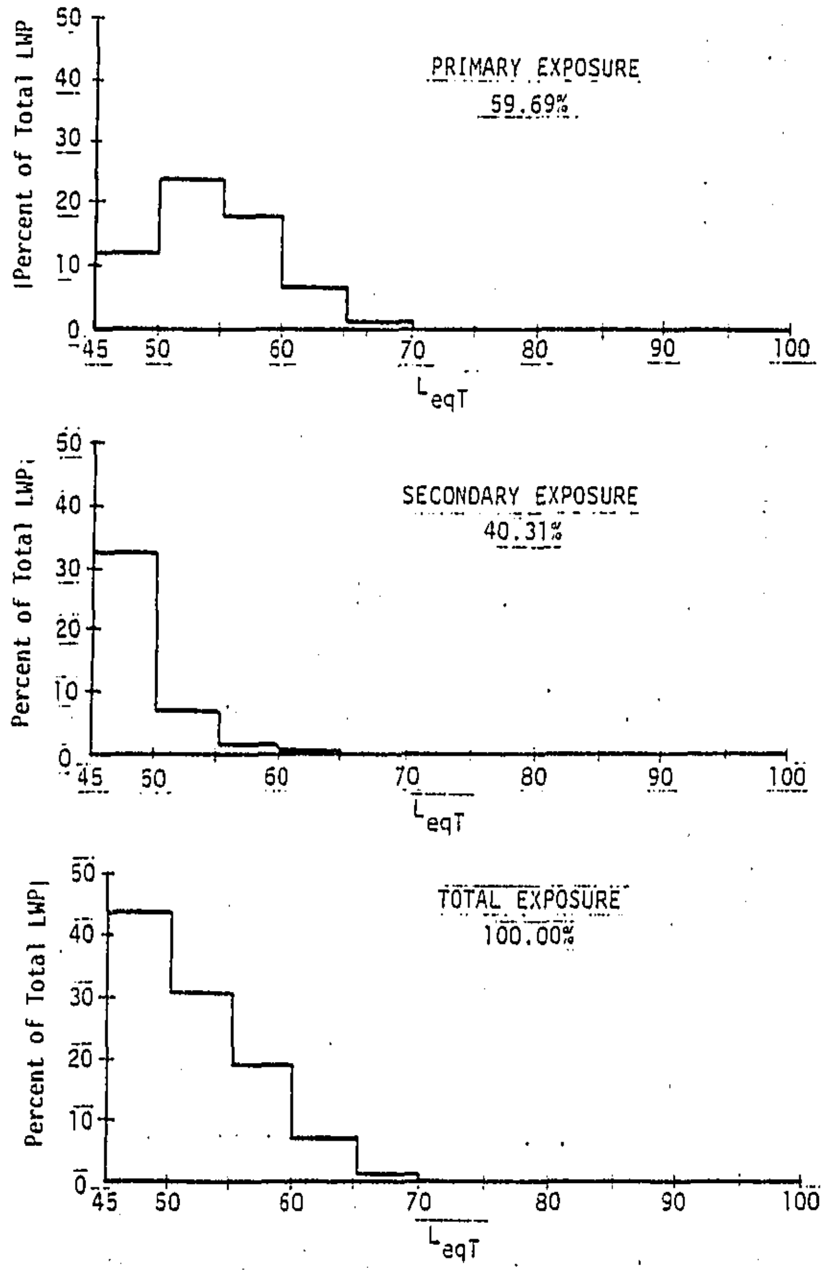


FIGURE 2-21. EXAMPLE OF PRIMARY AND SECONDARY NOISE EXPOSURE: INDOOR SPEECH INTERFERENCE DUE TO 8 CYL. AUTOMOBILES

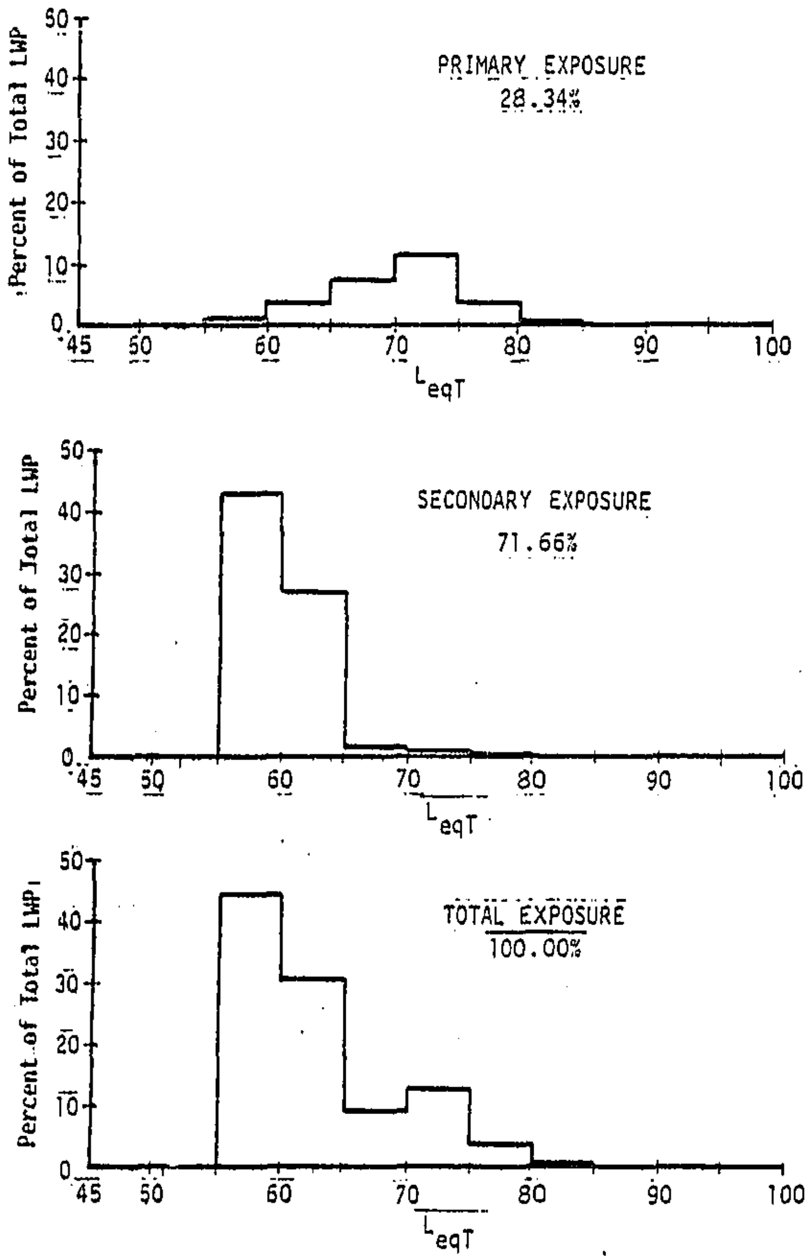


FIGURE 2-22. EXAMPLE OF PRIMARY AND SECONDARY NOISE EXPOSURE: OUTDOOR SPEECH INTERFERENCE DUE TO 8 CYL. AUTOMOBILES

3.0 PREDICTIONS OF ROADWAY TRAFFIC NOISE IMPACT

3.1 General Adverse Response Model

This section presents predicted results for a typical scenario representative of a staged noise regulation for various vehicle types. Alteration or modification of any of the data will change the predicted results, which is the main feature of the General Adverse Response Model -- sensitivity to details of the input data. Documentation of the data base is presented in Appendix A.

Both tabulated and plotted (line printer) output data are provided. The format used for the output data is suitable for direct inclusion in a report using only photo reduction of the printed results. The tabulated output describes elements of the input data and the predicted results. The plotted data present the time variation of population and various general impact summaries for the defined time stream simulation.

The specific outputs are presented below. The example scenario assumes noise regulation of medium- and heavy-duty trucks, buses, and motorcycles. Light vehicles are, however, unregulated in this scenario. The population of the United States is assumed to follow the U.S. Bureau of Census Series I projections (see Figure 2-5). For continuity of presentation, all tables and figures are presented at the end of this section in the sequence printed during output.

3.1.1 Tabulated Output

Since any estimates of national roadway traffic noise exposure using the General Adverse Response Model depends upon the data base used, output tabulations are printed to document the data used to conduct the estimates. The basic tabulations of input data are printed as output so that the user can clearly define the scenario used.

3.1.2 Documentation of Scenario Input Data

Five basic output tabulations are provided to document the input data that define the scenario. This documentation covers population, vehicle and roadway parameters.

A title page and a scenario summary tabulation are printed for each execution, but these listings are not presented in this discussion since they are more directly related to user implementation. These tabulations are described in the User's Manual for the National Roadway Traffic Noise Exposure Model.

The term 'baseline condition' as used in this report means the year year 1974, when there were no vehicle noise regulations for either new sources or in-use vehicles, i.e., a 'no-regulation' condition. 'Present condition' means the existing status under the promulgated noise regulation for new medium- and heavy-duty trucks (including the in-use and new truck regulation). 'Future condition' means the projected and proposed regulations which include the 75 dB level for medium- and heavy-duty trucks, as well as regulated noise levels for buses and motorcycles, but no regulations for light vehicles.

Population Parameters: The population parameters comprise baseline year population densities, baseline population, and population growth factors used for a given scenario.

Table 2.1* presents the baseline year population density by population place size (Index J) and by population density class (Index ID). These population densities are computed from the baseline population (Table 2.2) and land areas allocated to each place size and population density class.

*Table numbers refer to the computer-printed table numbers. All of the output is listed sequentially at the end of this section, as Table 3-1.

Table 2.2 presents the baseline year population by place size (Index J) and by population density class (Index ID). This table totals population distribution both by place size (Index J) and population density class (Index ID). It should be noted that the total population assigned to the Index ID = 1 includes the rural population. That is, for the scenario presented, the urban population assigned to the high population density class is 14.23 M out of a total urban population of 152.52 M people.

The population growth factors used as input data to simulate the annual variation of population by population place size (Index J), summarized for each five years of the time stream, are presented in Table 11 (see Figure 2-5). The scenario presented simulates the U.S. Bureau of Census' Series I population growth projections.

Roadway Parameters: The documentation of input data related to roadway parameters is summarized in Table 3 as the gross mileage of roadway type (Index K) assigned to each population place size (Index J).

The tabulated roadway mileage is summarized from the stored data by summing over the mileage assigned to each of the five speed ranges for each roadway class. Table 3 totals roadway mileage by functional class and by population place size. The detailed roadway data are presented in Appendix A.

Vehicle Parameters: The documentation of vehicle parameters comprises the vehicle noise emission schedules defined for the scenario and the net number of vehicles by year used to conduct the noise impact estimates.

Table 4 comprises seven pages of tabulations documenting the noise emission characteristics of each of the 14 vehicle types considered in the noise impact analyses. Each page tabulates the input data for two vehicle types. As indicated in Table 4, sound level data are specified by operational mode, speed range and year. The year denotes the point in the time stream at which the specified vehicle type exhibits the tabulated noise emission characteristics. Noise emission levels, by operating mode and speed range, must be specified for each vehicle type in the baseline year. The noise emission characteristics should be specified as typical noise levels at 50 feet in terms of the mean level and the standard deviation.

In addition to the baseline year noise emissions, the user may specify up to a maximum of four future year noise emission schedules. These schedules may be introduced for each vehicle type, any year of the time stream, and any operating mode as related to cruise speed.

The data presented in Tables 4.1 through 4.7 comprise the noise emission characteristics used to estimate the noise exposure from roadway traffic operations presented in the following sections.

Table 5 presents the net number of vehicles by vehicle type (engineering characteristics) for each year of the time stream. This table reflects both the vehicle sales projections and the vehicle's survival data used as input parameters. These data are used to alter vehicle mix (by type and age) and the ADT values assigned to each roadway traffic condition in each year of the time stream simulation (see Figure 2-6).

3.1.3 Noise Impact Estimates

Five tables are presented to describe the noise impact of traffic situations. The tables are all interrelated and represent cross tabulations and/or summaries, as indicated.

Noise Impact by Year: Table 6 presents the noise impact, by year, for the nation's population. This impact is accumulated from the estimates of population noise exposure at the highest level of detail used by the General Adverse Response Model, i.e., a roadway traffic condition in an area of homogeneous population density. For each specified year of the time stream, the following national estimates of noise impact are printed:

- Total U.S. Population (Estimated from baseline population) (Table 2.2) and projected population growth Table 11).

- Total U.S. Population Exposed to Day-Night Sound Levels from roadway traffic above 55 dB (see Tables 7, 8, and 10).

- Relative Population Exposed to Day-Night Sound Levels from roadway traffic above 55 dB. This is the percentage of the U.S. Population in each year exposed above the 55 dB criteria.

- Population Impacted. This is the tabulation of the population exposed above L_{dn} = 55 dB that is used for noise impact estimates. For the scenario presented, the total U.S. population exposed above 55 dB is used for the impact calculations (See Tables 7 and 8).

- Level Weighted Population. This metric was formerly denoted as P_{eq} or ENI (see Tables 7, 8, and 9).

- Noise Impact Index. This is the ratio of the LWP to the total population expressed as a percentage. (The LWP and total population must correspond to the defined land area.)

- Change in Level Weighted Population. This column is the increase (negative number) or decrease (positive number) in Level Weighted Population relative to the baseline year value of Level Weighted Population.

- Relative Change in Level Weighted Population. This column is the percentage change of the Level Weighted Population in each year relative to the baseline year.

Noise Impact by Population Area: Table 7 presents the following noise impact estimates: the population exposed above L_{dn} = 55 dB, the Noise Impact Index (NII) for the area and the Level Weighted Population by population place size. The accumulation of results presented is over all roadway types and population density areas defined within each place size. The NII is relative to the total population assigned to each area in the given year.

Noise Impact by Highway Type: Table 8 presents the following estimates of noise impact: the population exposed above L_{dn} = 55 dB, the population used for impact calculation, and the Level Weighted Population by functional highway classification. It must be reemphasized that this accumulation is relative to the allocation of population to a roadway type and does not necessarily indicate the ranking of roadway types as noise sources. The accumulation of results is over all population areas containing the indicated roadway type.

Yearly Impact; LWP in dB Bands: Table 9 presents the values of Level Weighted Population for each specified year of the time stream in 3 dB bands beginning at 55 dB and ending at 91 dB. This result is accumulated from the population exposure estimates in dB bands at the highest level of detail, i.e., roadway traffic condition in an area of homogeneous population density. The LWP estimates presented in Table 9 are obtained from the population exposure using Equation (2-10) and the sound level at the center of each dB band.

Yearly Impact; Population Exposed above 55 dB in dB Bands: Table 10 presents the values of population exposed for each specified year of the time stream in 3 dB bands beginning at 55 dB and ending at 91 dB. This result is accumulated in 3 dB bands at the highest level of detail, i.e., roadway traffic condition in an area of homogeneous population density. The 3 dB level intervals and the associated population are a result of considering both primary exposure and secondary exposure, as described in Section 2.7.

3.1.4 Plotted Output

As directed by the user, plotted output is provided in addition to the tabulations described in the previous subsection. Using a line printer, the predictions tabulated in Table 6, National Noise Impact by Year, are plotted.

The plots are executed after the termination of the main program. The data plotted versus year are:

- Total U.S. Population (Frame 1)
- Total U.S. Population Exposed above L_{dn} = 55 dB (Frame 2)
- Percentage of U.S. Population Exposed above L_{dn} = 55 dB (Frame 3)
- Total Level Weighted Population (Frame 4)
- Noise Impact Index (Frame 5)
- Change in Level Weighted Population (Frame 6)
- Relative Change in Impact (Frame 7)

Typical line printer plots are presented following the tables at the end of this section. These plots correspond to the data of Table 6 on page 3-22. (To obtain plots, the user must specify sufficient points in the time stream to define the curves. The plotting package interpolates points between calculated values).

Two features of the plotting package should be mentioned: first, the user supplies a 16-digit alphanumeric title that is printed following each title on each plot, which allows the user to identify plotted data with the corresponding tabulated scenario data. This feature was added since the two jobs are executed independently and could be separated between output and delivery. The second feature is that the vertical axis on each plot will always be shifted, if necessary, an integral number of divisions as indicated on each plot to ensure that the minimum or maximum value, as appropriate, will be plotted. This is done so that plotted results from different scenarios can be directly aligned and compared without being concerned with scaled divisions assigned by the computer.

3.1.5 Summary of Output

The user is provided with both tabulated output and plotted output. The tabulated output is in a format with titles so that it may be included directly in a report. The line printer plots allow the user to present graphic trends without recourse to other plotting methods. The output generated, documents the data base defining the scenario and the resulting estimates of national exposure to roadway traffic noise.

3.2 Single Event Model

As described in Section 2, the Single Event Model conducts a detailed estimate of the noise interference effects attributable to a single vehicle's noise emissions on the national roadway network. This section presents estimates of single event noise intrusion for two vehicle types: medium trucks and heavy trucks. These two examples are based upon the existing status under the promulgated noise regulation for new medium- and heavy-duty trucks (including the in-use and new truck regulation). This scenario is also used to illustrate typical outputs of the General Adverse Response Model. As presented here, the Single Event Model's estimates are compared for the two vehicle types. These estimates, however, are not presented to illustrate the effectiveness of noise regulations. To do this, it is necessary to conduct baseline estimates for a "no regulation" scenario for each vehicle and to compare the results over the time stream from 1974 to 2013.

Hence, this section illustrates and discusses typical outputs of the Single Event Model within the context of specific scenarios rather than comparing alternate scenarios. In particular, the discussion focuses upon similarities and differences between the two vehicle types considered. So that the discussion in the text is not interrupted by presenting the tabulated and plotted output generated by the Single Event Model, all outputs are presented at the end of this section.

3.2.1 Tabulated Output

Since any estimate of national roadway traffic noise exposure using the Single Event Model depends upon the data base used, output tabulations are printed to document the data used to conduct the estimates. The basic tabulations of input data are printed as output so that the user can clearly define the scenario used. As described in the User's Manual, optional printout of all data used is available at the user's request.

3.2.2 Documentation of Scenario Input Data

The Single Event Model provides five basic output tabulations documenting the input data that define the scenario. This documentation covers population, vehicle and roadway parameters.

A title page and a scenario summary tabulation are printed for each execution. These listings are not presented here since they are mostly related to user implementation and are therefore described in the User's Manual. The term 'baseline condition' as used in this section means the year 1974, when there were no vehicle noise regulations for either new or in-use vehicles.

<u>Population, Roadway and Vehicle Parameters:</u> The population, roadway and vehicle input data parameters used in the Single Event Model are identical to those used in the General Adverse Response Model. However, since the Single Event Model is used to quantify the noise impact of eacn vehicle type separately, noise emissions from all vehicle types, other than the vehicle being studied, are set to zero. Hence, the Single Event Model only presents output tabulations of noise emissions for the vehicle(s) being studied. All other vehicle types are ignored in conducting noise impact estimates. Even though the Single Event Model considers only one vehicle type in conducting the noise exposure estimates, it is necessary to conduct the complete vehicle population projection. The reason for this is that the National Roadway Traffic Noise Exposure Model assumes that the Average Daily Traffic (ADT) on the nation's roadways grows proportional to the total traffic population.

As described in Section 2, the number of events for any particular vehicle is obtained from the ADT estimate for the roadway and the percentage mix of that vehicle type.

3.2.3 Noise Impact Estimates

Tables 3-2 and 3-3 presented at the end of this section, list the noise impact estimates printed by the Single Event Model as standard documentation of a scenario.

In particular, the interpretation of any scenario requires the user to always consider the interrelationship among population growth, noise emissions, and net vehicle population to understand the Single Event Model's estimate of noise effects on man. A detailed discussion of the output format is presented in Section 4.

3.2.4 Plotted Output

As directed by the user, the tabulated output data may be plotted using a line printer. Details of the plotting package are discussed in Section 3.1.4.

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL

		AREA TYPE, J									
		1	2	3	4	5	6	7	8	9	ALL J
PLACE SIZE, THOUSANDS		OVER 2000	1000-2000	500-1000	200-500	100-200	50-100	25-50	5-25	RURAL	
ID	VARIABLE	POPULATION DENSITY, IN THOUSANDS PER SQ.MI.									
1		41.83	7.72	5.67	7.47	4.16	3.24	8.05	8.41	.02	
2		6.24	5.26	4.17	2.29	2.25	1.90	3.33	3.94	0.0	
3		2.58	2.19	1.90	1.17	1.30	1.08	1.57	1.87	0.0	
4		0.0	1.31	1.16	0.0	0.0	0.0	0.69	3.46	0.0	

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

		AREA TYPE, J									
		1	2	3	4	5	6	7	8	9	ALL J
PLACE SIZE, THOUSANDS		OVER 2000	1000-2000	500-1000	200-500	100-200	50-100	25-50	5-25	RURAL	
ID	VARIABLE	POPULATION, MILLIONS									TOTAL
1		5.61	2.10	0.36	1.61	1.15	1.07	0.47	1.85	64.18	78.41
2		22.28	4.08	2.04	10.43	2.93	2.12	2.98	4.97	0.0	51.83
3		21.59	11.13	8.40	6.75	6.84	4.53	3.51	8.46	0.0	71.20
4		0.0	5.35	5.30	0.0	0.0	0.0	1.92	2.7	0.0	15.27
	TOTAL	49.48	22.66	16.09	18.78	10.93	7.71	8.88	17.98	64.18	216.70

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

		AREA TYPE, J									
		1	2	3	4	5	6	7	8	9	ALL J
PLACE SIZE, THOUSANDS		OVER 2000	1000-2000	500-1000	250-500	100-200	50-100	25-50	5-25	RURAL	
K		MILES OF ROADWAY									
1		1998	1869	1477	1743	854	517	397	899	31744	41493
2		1749	1527	739	1076	803	600	447	1009	85716	93666
3		9861	5156	4034	5566	3851	3335	4282	9652	155547	201284
4		14103	10219	6320	8569	5502	4445	5377	12124	435517	502176
5		12854	10308	7190	7897	5714	4534	5828	13130	307917	375372
6		84247	64678	47466	58252	36697	29284	33454	75431	1942733	2372242
	TOTAL	124812	93757	67226	83103	53421	42710	49785	117245	2959174	3506233

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

TYPE 1

ACCELERATION MODE					
YEARS>	1974				
0-20 MPH	59.30				
0-30	61.30				
0-40	63.00				
0-50	64.80				
0-60	66.70				

DECELERATION MODE					
YEARS>	1974				
20-0 MPH	50.50				
30-0	56.10				
40-0	60.10				
50-0	63.20				
60-0	65.80				

CRUISE MODE					
YEARS>	1974				
<25 MPH	59.80				
25-34	62.40				
35-44	66.40				
45-54	69.50				
>55	72.00				

IDLE MODE					
YEARS>	1974				
	46.00				

TYPE 2

ACCELERATION MODE					
YEARS>	1974				
0-20 MPH	60.50				
0-30	62.20				
0-40	63.70				
0-50	65.30				
0-60	67.00				

DECELERATION MODE					
YEARS>	1974				
20-0 MPH	[illegible]				
30-0	56.10				
40-0	60.10				
50-0	63.20				
60-0	65.80				

CRUISE MODE					
YEARS>	1974				
<25 MPH	59.80				
25-34	62.40				
35-44	65.40				
45-54	69.50				
>55	72.00				

IDLE MODE					
YEARS>	1974				
	45.00				

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

TYPE 3

ACCELERATION MODE					
YEARS>	1974				
0-20 MPH	60.20				
0-30	62.40				
0-40	63.90				
0-50	65.50				
0-60	67.20				
DECELERATION MODE					
YEARS>	1974				
20-0 MPH	56.50				
30-0	56.10				
40-0	60.10				
50-0	63.20				
60-0	65.80				
CRUISE MODE					
YEARS>	1974				
<25 MPH	59.80				
25-34	62.40				
35-44	66.40				
45-54	69.50				
>55	72.00				
IDLE MODE					
YEARS>	1974				
	46.60				

TYPE 4

ACCELERATION MODE					
YEARS>	1974				
0-20 MPH	[illegible]				
0-30	64.[illegible]0				
0-40	65.[illegible]				
0-50	65.4[illegible]				
0-60	67.8[illegible]				
DECELERATION MODE					
YEARS>	1974				
20-0 MPH	53.50				
30-0	55.1[illegible]				
40-0	6[illegible].1[illegible]				
50-0	63.2[illegible]				
60-0	65.[illegible]				
CRUISE MODE					
YEARS>	1974				
<25 MPH	59.[illegible]				
25-34	62.4[illegible]				
35-44	65.4[illegible]				
45-54	69.[illegible]				
>55	72.[illegible]0				
IDLE MODE					
YEARS>	1974				
	46.[illegible]0				

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

TYPE 5

ACCELERATION MODE					
YEARS>	1974				
0-20 MPH	62.20				
0-30	64.30				
0-40	65.60				
0-50	67.00				
0-60	66.60				
DECELERATION MODE					
YEARS>	1974				
20-0 MPH	51.70				
30-0	57.30				
40-0	61.30				
50-0	64.40				
60-0	67.00				
CRUISE MODE					
YEARS>	1974				
<25 MPH	61.30				
25-34	63.60				
35-44	67.60				
45-54	70.70				
>55	73.20				
IDLE MODE					
YEARS>	1974				
	46.00				

TYPE 6

ACCELERATION MODE					
YEARS>	1974				
0-20 MPH	62.[illegible]				
0-30	64.4[illegible]				
0-40	65.[illegible]				
0-50	67.[illegible]				
0-60	69.7[illegible]				
DECELERATION MODE					
YEARS>	1974				
20-0 MPH	53.4[illegible]				
30-0	59.[illegible]				
40-0	63.[illegible]				
50-0	65.1				
60-0	65.7				
CRUISE MODE					
YEARS>	1974				
<25 MPH	67.7				
25-34	65.3[illegible]				
35-44	69.3[illegible]				
45-54	72.4				
>55	74.9[illegible]				
IDLE MODE					
YEARS>	1974				
	46.10				

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

TYPE 7

ACCELERATION MODE					
YEARS>	1974				
0-20 MPH	65.20				
0-30	66.60				
0-40	67.50				
0-50	68.30				
0-60	69.30				
DECELERATION MODE					
YEARS>	1974				
20-0 MPH	52.30				
30-0	57.90				
40-0	61.90				
50-0	65.00				
60-0	67.60				
CRUISE MODE					
YEARS>	1974				
<25 MPH	61.60				
25-34	64.20				
35-44	68.20				
45-54	71.30				
>55	73.80				
IDLE MODE					
YEARS>	1974				
	46.00				

TYPE 8

ACCELERATION MODE					
YEARS>	1974	1978	1982		
0-20 MPH	75.10	75.10	74.80		
-30	75.70	75.70	75.40		
0-40	76.50	76.50	76.20		
0-50	77.50	77.50	77.30		
0-60	78.70	78.70	78.60		
DECELERATION MODE					
YEARS>	1974	1978	1982		
20-0 MPH	65.70	65.70	65.[illegible]		
30-0	65.70	65.70	65.60		
40-0	69.90	69.90	69.80		
50-0	73.20	73.20	73.10		
60-0	75.90	75.90	75.80		
CRUISE MODE					
YEARS>	1974	1978	1982		
<25 MPH	74.40	74.40	74.20		
25-34	74.40	74.40	74.20		
35-44	75.40	76.40	76.30		
45-54	79.70	79.70	79.60		
>55	82.30	82.30	82.30		
IDLE MODE					
YEARS>	1974	1978	1982		
	54.00	54.[illegible]0	54.10		

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

TYPE 9

ACCELERATION MODE					
YEARS>	1974	1978	1982		
0-20 MPH	82.70	78.90	75.90		
0-30	82.80	79.00	76.30		
0-40	82.80	79.10	76.40		
0-50	83.00	79.40	76.90		
0-60	83.20	79.90	77.70		
DECELERATION MODE					
YEARS>	1974	1978	1982		
20-0 MPH	73.70	70.10	67.60		
30-0	73.70	70.10	67.60		
40-0	76.70	73.40	71.00		
50-0	79.10	75.90	73.70		
60-0	81.10	78.60	76.10		
CRUISE MODE					
YEARS>	1974	1978	1982		
<25 MPH	80.70	77.20	74.60		
25-34	80.70	77.20	74.60		
35-44	82.10	78.90	76.80		
45-54	84.50	81.50	79.60		
>55	86.50	83.70	82.10		
IDLE MODE					
YEARS>	1974	1978	1982		
	63.00	60.00	57.00		

TYPE 1[illegible]

ACCELERATION MODE					
YEARS>	1974	1981	1985		
0-20 MPH	[illegible]	77.8[illegible]	74.[illegible]		
0-30	[illegible]	78.3	75.[illegible]		
0-40	[illegible]	78.6[illegible]	75.[illegible]		
0-50	[illegible]	79.[illegible]	76.5[illegible]		
0-60	[illegible]	79.6	77.[illegible]		
DECELERATION MODE					
YEARS>	1974	1981	1985		
20-0 MPH	71.4[illegible]	[illegible]	65.[illegible]		
25-0	71.4	68.1[illegible]	65.7[illegible]		
40-0	73.[illegible]	[illegible]	68.9[illegible]		
50-0	75.[illegible]	[illegible]	71.5[illegible]		
60-0	77.3	[illegible]	73.[illegible]		
CRUISE MODE					
YEARS>	1974	1981	1985		
<25 MPH	76.[illegible]	73.[illegible]	71.[illegible]		
25-34	76.[illegible]	73.[illegible]	71.[illegible]		
35-44	78.40	75.9[illegible]	74.5[illegible]		
45-54	[illegible]	78.3	77.4[illegible]		
>55	[illegible]	80.5[illegible]	80.[illegible]		
IDLE MODE					
YEARS>	1974	1981	1985		
	62.[illegible]	[illegible]	56.[illegible]		

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL
ROADWAY TRAFFIC NOISE EXPOSURE MODEL
(Continued)

TYPE 11

ACCELERATION MODE					
YEARS>	1974	1981	1985		
0-20 MPH	81.00	81.00	78.20		
0-30	81.00	81.00	78.20		
0-40	81.10	81.10	78.40		
0-50	81.20	81.20	78.70		
0-60	81.50	81.50	79.20		
DECELERATION MODE					
YEARS>	1974	1981	1985		
20-0 MPH	63.70	63.70	61.30		
30-0	67.80	67.80	65.60		
40-0	70.60	70.60	68.90		
50-0	72.90	72.90	71.50		
60-0	74.70	74.70	73.70		
CRUISE MODE					
YEARS>	1974	1981	1985		
<25 MPH	73.00	73.00	71.10		
25-34	73.00	73.00	71.10		
35-44	75.80	75.80	74.50		
45-54	78.10	78.10	77.30		
>55	79.90	79.90	79.60		
IDLE MODE					
YEARS>	1974	1981	1985		
	58.00	58.00	55.00		

TYPE 12

ACCELERATION MODE					
YEARS>	1974	1981	1985		
0-20 MPH	77.6	77.6	74.[illegible]		
0-30	78.1	78.1	75.3		
0-40	78.4	78.40	75.[illegible]		
0-50	78.9	78.9	76.5		
0-60	79.4	79.4	77.40		
DECELERATION MODE					
YEARS>	1974	1981	1985		
20-0 MPH	63.7	63.7	61.30		
30-0	67.8	67.8	65.60		
40-0	70.6	70.60	68.90		
50-0	72.9	72.90	71.50		
60-0	74.7	74.70	73.70		
CRUISE MODE					
YEARS>	1974	1981	1985		
<25 MPH	73.00	73.00	71.10		
25-34	73.00	73.00	71.10		
35-44	75.80	75.80	74.50		
45-54	78.1	78.1	77.30		
>55	79.9	79.9	79.60		
IDLE MODE					
YEARS>	1974	1981	1985		
	58.00	58.00	55.00		

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

TYPE 13

ACCELERATION MODE					
YEARS>	1974	1980	1982	1985	
0-20 MPH	73.30	73.30	71.50	69.50	
0-30	74.90	74.90	73.10	71.10	
0-40	75.40	75.40	73.60	71.60	
0-50	75.70	75.70	73.90	71.90	
0-60	75.90	75.90	74.10	72.10	
DECELERATION MODE					
YEARS>	1974	1980	1982	1985	
20-0 MPH	61.50	61.50	59.70	57.70	
30-0	65.90	65.90	64.10	62.10	
40-0	69.00	69.00	67.20	65.20	
50-0	71.40	71.40	69.60	67.60	
60-0	73.40	73.40	71.60	69.60	
CRUISE MODE					
YEARS>	1974	1980	1982	1985	
<25 MPH	71.30	71.30	69.50	67.50	
25-34	71.30	71.30	69.50	67.50	
35-44	74.40	74.40	72.60	70.60	
45-54	76.90	76.90	75.10	73.10	
>55	78.90	78.90	77.10	75.10	
IDLE MODE					
YEARS>	1974	1980	1982	1985	
	60.00	60.00	59.00	57.00	

TYPE 14

ACCELERATION MODE					
YEARS>	1974				
0-20 MPH	87.5				
0-30	89.1				
0-40	87.6				
0-50	89.9				
0-60	9[illegible].1				
DECELERATION MODE					
YEARS>	1974				
20-0 MPH	75.7[illegible]				
30-0	83.1[illegible]				
40-0	83.2[illegible]				
50-0	85.6[illegible]				
60-0	87.6[illegible]				
CRUISE MODE					
YEARS>	1974				
<25 MPH	85.50				
25-34	85.5[illegible]				
35-44	88.6[illegible]				
45-54	91.1[illegible]				
>55	93.1				
IDLE MODE					
YEARS>	1974				
	77.[illegible]0				

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

TYPE>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	ALL TYPES
CYLINDERS	8	6	6&8	4	4	6&8									
ENGINE	GAS	GAS	GAS	GAS	GAS	GAS	DIESEL								
TRANS-MISSION	AUTO-MATIC	AUTO-MATIC	MAN-UAL	AUTO-MATIC	MAN-UAL	----	----	----	----	----	----	----	----	----	
VEH. TYPE>	PC	PC	PC	PC&LT	PC&LT	LT TRK	PC&LT	MED TRK	HVY TRK	IC BUS	TR BUS	SCH BUS	LT MCY	HV MCY	
UNIT	MILLIONS									THOUSANDS X .01			MILLIONS		
YEAR															
1975	58.68	17.83	2.10	7.76	20.13	19.01	0.06	2.41	1.51	0.21	0.69	3.57	4.36	0.59	1 4.69
1980	63.69	21.21	2.66	11.14	22.63	26.26	2.19	2.87	1.60	0.14	1.07	5.10	5.11	0.68	1 1.09
1986	52.58	26.02	3.70	26.15	25.53	28.28	19.47	3.47	2.17	0.15	1.22	7.16	5.65	0.78	176.69
1988	33.35	36.13	4.57	32.17	26.69	27.69	26.36	3.63	2.27	0.15	1.21	7.68	5.91	0.81	1 4.49
1990	25.66	35.12	4.41	37.59	27.93	27.11	32.50	3.78	2.37	0.15	1.16	6.17	6.15	0.84	2 2.42
1995	16.15	38.33	5.11	47.13	31.17	27.49	42.80	4.18	2.72	0.14	1.14	9.36	6.80	0.93	2 3.67
2000	16.10	42.56	5.57	52.82	34.46	29.87	48.23	4.61	2.89	0.15	1.15	10.55	7.51	1.02	2 6.93
2005	17.75	46.98	6.26	58.31	38.03	32.96	53.24	5.09	3.19	0.15	1.15	11.72	8.21	1.13	272.53
2010	19.59	51.86	6.91	64.37	41.98	36.38	58.77	5.67	3.52	0.15	1.15	12.91	9.14	1.25	306.80

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

	TOTAL US POPULATION	POPULATION EXPOSED >55DB, PEXP	RELATIVE EXPOSURE PEXP/TOPOP	POPULATION IMPACTED POPIMP	LEVEL-WEIGHTED POPULATION LWP	NOISE IMPACT INDEX, NII= LWP/TOPOP	CHANGE IN LWP DLWP= LWPO-LWP	RELATIVE CHANGE IN IN LWP RCI= DLWP/LWPO
UNIT>	MILLIONS	MILLIONS	PERCENT	MILLIONS	MILLIONS	PERCENT	MILLIONS	PERCENT
YEAR								
1974	216.70	93.96	43.36	93.96	28.30	13.06	0.0	0.0
1980	232.80	103.80	44.59	103.80	31.33	13.46	-3.03	-10.71
1985	248.74	104.53	42.02	104.53	30.39	12.22	-2.08	-7.36
1988	254.35	104.33	41.07	104.33	29.89	11.77	-1.59	-5.61
1990	259.37	104.93	40.46	104.93	29.74	11.47	-1.44	-5.08
1995	272.24	111.73	41.04	111.73	31.59	11.60	-3.28	-11.60
2000	285.11	123.11	43.18	123.11	35.40	12.42	-7.10	-25.08
2005	297.99	135.79	45.57	135.79	39.80	13.36	-11.50	-40.64
2010	310.86	149.33	48.04	149.33	44.63	14.36	-16.33	-57.69

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

		AREA TYPE,J									
		1	2	3	4	5	6	7	8	9	ALL J
PLACE SIZE, THOUSANDS		OVER 2000	1000-2000	500-1000	200-500	100-200	50-100	25-50	5-25	RURAL	
YEAR	VARIABLE	POPS AND LWP IN MILLIONS, NII IN PERCENT.									
1978	EXPOSED>	30.17	12.97	8.06	9.62	5.11	3.10	3.62	2.15	1.79	81.79
	NII, % >	18.09	18.67	15.84	16.97	14.90	12.69	12.21	11.94	0.61	15.80
	LWP >	9.15	4.21	2.55	1.19	1.61	9.98	1.00	2.15	0.40	25.56
1980	EXPOSED>	34.40	14.64	9.09	10.26	5.41	3.51	3.90	2.67	2.17	91.05
	NII, % >	19.97	19.68	16.71	17.77	15.60	11.32	12.05	12.56	0.69	12.25
	LWP >	10.70	4.77	2.00	1.41	1.25	1.05	1.11	2.31	0.49	29.52
1985	EXPOSED>	35.97	15.45	9.57	10.09	5.31	3.42	3.90	2.66	2.31	93.69
	NII, % >	19.27	19.02	16.12	17.02	14.91	12.61	12.20	11.97	0.69	11.70
	LWP >	10.99	4.91	2.97	1.11	1.69	1.01	1.11	2.21	0.51	20.00
1990	EXPOSED>	37.24	16.11	9.96	9.04	5.10	3.31	3.85	2.59	2.47	95.55
	NII, % >	10.44	10.24	15.94	16.19	14.12	11.86	11.65	11.31	0.67	11.10
	LWP >	11.16	5.01	1.01	1.20	1.62	9.96	1.09	2.14	0.57	20.00
1995	EXPOSED>	42.44	17.56	10.84	10.16	5.39	3.42	4.06	7.91	2.76	102.00
	NII, % >	18.95	18.71	15.84	16.52	14.40	12.11	11.96	11.62	0.77	11.15
	LWP >	12.12	5.47	1.29	1.12	1.60	1.00	1.14	2.21	0.64	18.09
2000	EXPOSED>	45.11	19.60	12.11	10.47	5.69	3.66	4.10	8.55	3.17	111.17
	NII, % >	20.29	19.90	16.93	17.56	15.16	12.97	12.96	12.49	0.70	12.10
	LWP >	11.69	6.10	1.72	1.50	1.03	1.09	1.29	2.44	0.74	34.49
2005	EXPOSED>	50.43	21.04	11.57	11.60	6.09	3.95	4.75	9.31	3.65	125.20
	NII, % >	21.02	21.41	18.16	18.76	16.99	11.97	13.41	13.49	0.85	12.95
	LWP >	15.49	6.98	4.20	1.00	1.90	1.19	1.16	2.67	0.86	18.60
2010	EXPOSED>	56.01	24.20	15.01	12.56	6.57	4.25	5.14	10.09	4.17	137.97
	NII, % >	21.49	12.91	19.48	20.04	17.58	15.09	15.01	14.55	0.99	13.86
	LWP >	17.46	7.85	4.74	4.20	2.15	1.10	1.99	2.91	0.97	41.09
2011	EXPOSED>	59.61	25.69	15.95	11.10	6.79	4.49	5.10	10.50	4.51	146.97
	NII, % >	24.47	13.47	20.31	20.05	18.10	13.71	15.72	15.71	0.99	14.44
	LWP >	18.71	8.41	5.08	4.41	2.25	1.37	1.57	1.09	1.08	45.99

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

YEAR	VARIABLE	ROADWAY TYPE, k						TOTAL ALL TYPES
		1	2	3	4	5	6	
1974	EXPOSED>	2.41	2.02	11.51	15.99	14.37	35.45	81.79
	IMPACTED>	2.41	2.02	11.53	15.99	14.37	35.45	81.79
	LWP >	1.03	1.40	6.04	5.44	1.67	7.10	23.56
1980	EXPOSED>	2.69	2.10	12.19	17.02	15.50	41.57	91.05
	IMPACTED>	2.63	2.10	12.19	17.02	15.50	41.57	91.05
	LWP >	1.99	1.50	6.50	6.01	4.09	8.10	28.52
1985	EXPOSED>	2.79	2.29	12.73	17.71	15.72	42.50	93.69
	IMPACTED>	2.79	2.29	12.73	17.71	15.72	42.50	93.69
	LWP >	2.13	1.52	6.69	6.06	4.09	8.40	28.89
1990	EXPOSED>	2.89	2.39	13.26	18.35	15.79	42.80	95.55
	IMPACTED>	2.89	2.39	13.26	18.35	15.79	42.80	95.55
	LWP >	2.19	1.52	6.71	6.05	4.06	8.47	29.00
1995	EXPOSED>	3.03	2.52	13.84	19.21	16.61	47.27	102.48
	IMPACTED>	3.03	2.52	13.84	19.21	16.61	47.27	102.48
	LWP >	2.14	1.59	7.08	6.41	4.11	9.34	30.89
2000	EXPOSED>	3.19	2.67	14.45	20.21	17.95	54.69	113.17
	IMPACTED>	3.19	2.67	14.45	20.21	17.95	54.69	113.17
	LWP >	2.51	1.72	7.65	7.10	4.61	10.07	33.69
2005	EXPOSED>	3.35	2.83	15.07	21.22	19.32	63.40	125.20
	IMPACTED>	3.35	2.83	15.07	21.22	19.32	63.40	125.20
	LWP >	2.63	1.85	7.27	7.83	5.24	12.71	38.60
2010	EXPOSED>	3.51	2.99	15.69	22.22	20.59	72.94	137.97
	IMPACTED>	3.51	2.99	15.69	22.22	20.59	72.94	137.97
	LWP >	2.84	2.00	8.92	8.60	5.89	14.81	43.09
2011	EXPOSED>	3.65	3.10	16.06	22.81	21.12	79.39	146.07
	IMPACTED>	3.65	3.10	16.06	22.81	21.12	79.39	146.07
	LWP >	2.99	2.00	9.32	9.08	6.39	16.21	45.99

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

LDN	DNL RANGE, dB												TOTAL
	2	3	4	5	6	7	8	9	10	11	12	13	
DNL RANGE	91.-88.	88.-85.	85.-82.	82.-79.	79.-76.	76.-73.	73.-70.	70.-67.	67.-64.	64.-61.	61.-58.	58.-55.	
YEAR	MILLIONS OF LEVEL-WEIGHTED PEOPLE												
1978	0.0	0.00	0.00	0.18	0.53	1.25	2.05	3.88	5.21	5.88	4.55	2.02	25.56
1980	0.0	0.00	0.00	0.24	0.63	1.45	2.76	4.33	5.77	5.99	5.09	2.25	28.52
1985	0.0	0.00	0.00	0.23	0.63	1.48	2.69	4.28	5.78	6.14	5.10	2.30	28.80
1990	0.0	0.00	0.03	0.22	0.62	1.35	2.59	4.17	5.66	6.22	5.48	2.49	28.80
1995	0.0	0.00	0.01	0.26	0.70	1.49	2.79	4.95	6.02	6.61	5.89	2.67	30.89
2000	0.0	0.00	0.03	0.33	0.83	1.76	3.19	5.30	6.69	7.25	6.49	2.92	34.49
2005	0.0	0.00	0.06	0.42	0.90	2.09	3.66	5.44	7.44	7.97	7.17	3.18	38.60
2010	0.0	0.00	0.10	0.52	1.16	2.44	4.20	6.34	8.23	8.75	7.92	3.44	43.09
2011	0.00	0.00	0.11	0.59	1.28	2.68	4.55	6.78	8.72	9.27	8.40	3.60	45.99

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

PEXP	LDN RANGE, DB												TOTAL
	2	3	4	5	6	7	8	9	10	11	12	13	
LDN RANGE	91.-88.	88.-85.	85.-82.	82.-79.	79.-76.	76.-73.	73.-70.	70.-67.	67.-64.	64.-61.	61.-58.	58.-55.	
YEAR	MILLIONS OF PEOPLE												
1970	0.0	0.00	0.00	0.15	0.48	1.29	2.98	5.76	9.94	14.55	20.19	26.46	81.78
1980	0.0	0.00	0.00	0.19	0.56	1.50	3.36	6.43	10.99	15.09	22.57	29.54	91.04
1985	0.0	0.00	0.00	0.18	0.56	1.45	3.27	6.16	10.95	16.31	23.51	31.10	93.60
1990	0.0	0.00	0.00	0.17	0.56	1.39	3.15	6.19	10.80	16.55	24.27	32.46	95.54
1995	0.0	0.00	0.01	0.20	0.62	1.53	3.39	6.50	11.48	17.60	26.12	34.92	102.47
2000	0.0	0.00	0.02	0.26	0.74	1.82	3.80	7.41	12.74	19.10	28.79	38.20	111.16
2005	0.0	0.00	0.04	0.33	0.87	2.15	4.45	8.16	14.17	21.22	31.81	41.70	125.19
2010	0.0	0.00	0.07	0.41	1.04	2.51	5.10	9.40	15.66	23.10	35.14	45.33	137.96
2015	0.00	0.00	0.09	0.46	1.15	2.76	5.54	10.36	16.58	24.66	37.24	47.51	146.06

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL (Continued)

		AREA TYPE,J									
		1	2	3	4	5	6	7	8	9	ALL J
PLACE SIZE, THOUSANDS		OVER 2000	1000-2000	500-1000	200-500	100-200	50-100	25-50	5-25	RURAL	
YEAR	VARIABLE	POP(YEAR)/POP(BASELINE)									
1974		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1980		1.08	1.07	1.07	1.02	1.02	1.02	1.02	1.02	1.12	
1985		1.15	1.14	1.14	1.04	1.04	1.04	1.04	1.04	1.22	
1990		1.22	1.22	1.22	1.05	1.05	1.05	1.05	1.05	1.31	
1995		1.29	1.29	1.29	1.07	1.07	1.07	1.07	1.07	1.39	
2000		1.36	1.36	1.36	1.08	1.08	1.09	1.09	1.09	1.48	
2005		1.43	1.44	1.44	1.10	1.10	1.10	1.10	1.10	1.57	
2010		1.50	1.51	1.51	1.12	1.12	1.12	1.12	1.12	1.65	
2013		1.55	1.56	1.56	1.13	1.13	1.13	1.13	1.13	1.70	

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL
ROADWAY TRAFFIC NOISE EXPOSURE MODEL
(Continued)

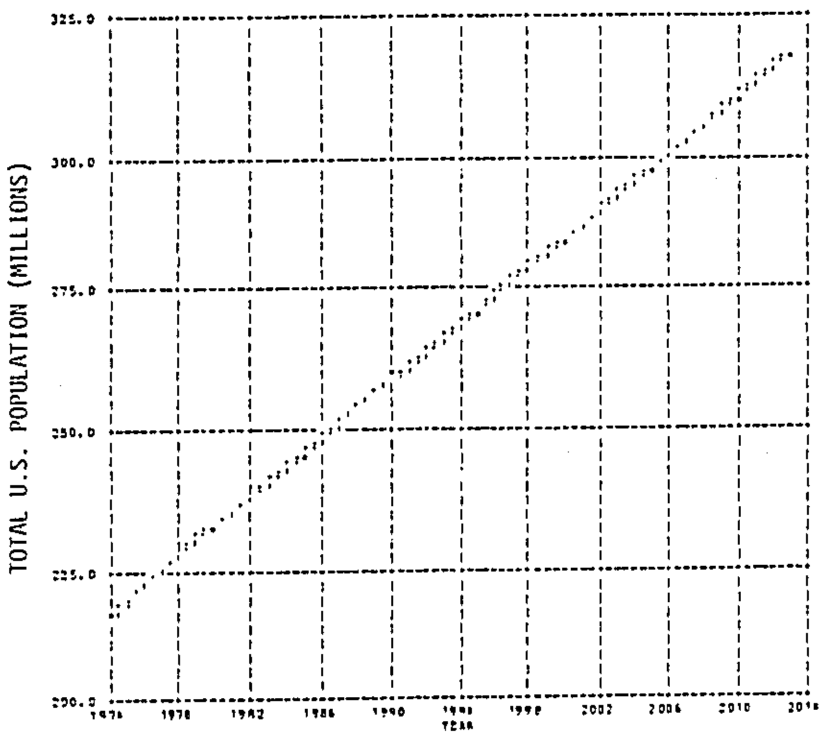
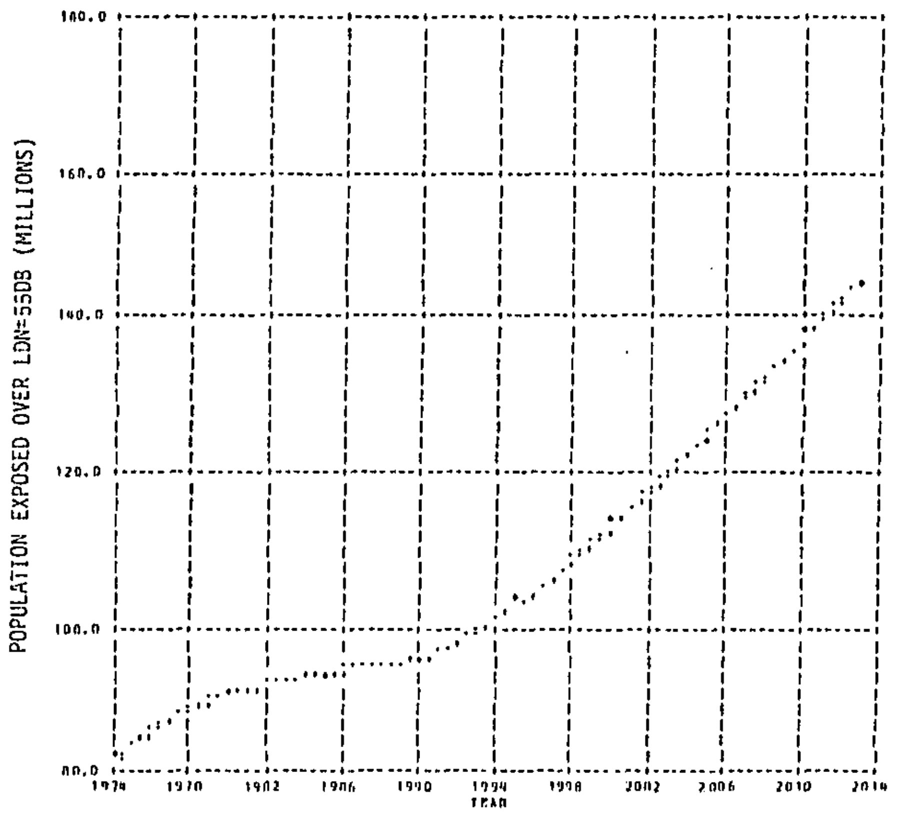


TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL
ROADWAY TRAFFIC NOISE EXPOSURE MODEL
(Continued)



3-29

TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL
ROADWAY TRAFFIC NOISE EXPOSURE MODEL
(Continued)

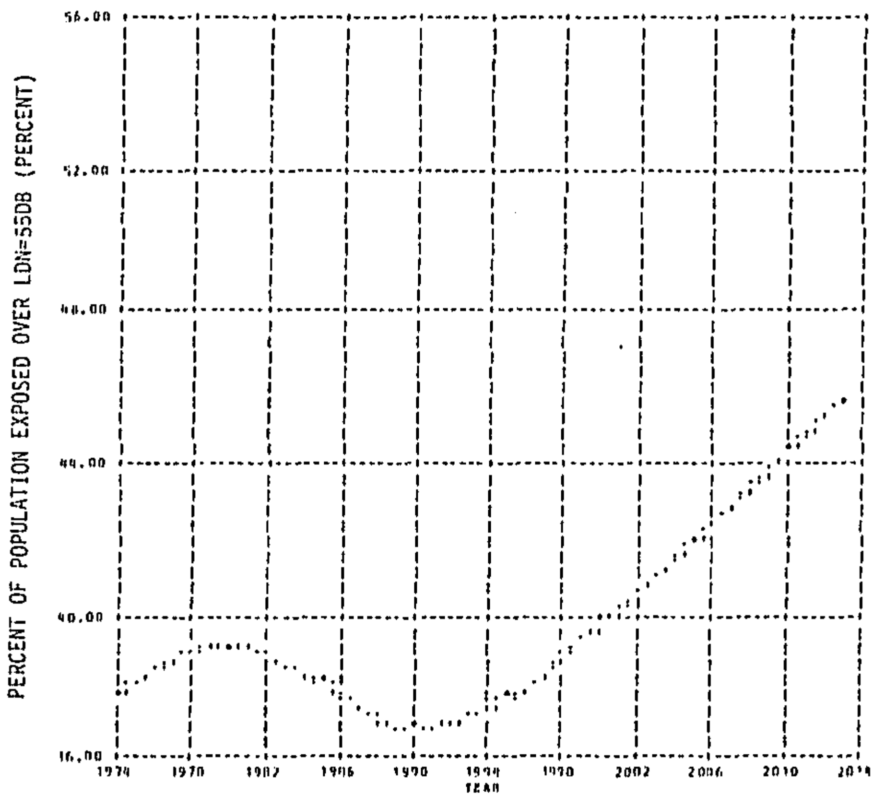


TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL
ROADWAY TRAFFIC NOISE EXPOSURE MODEL
(Continued)

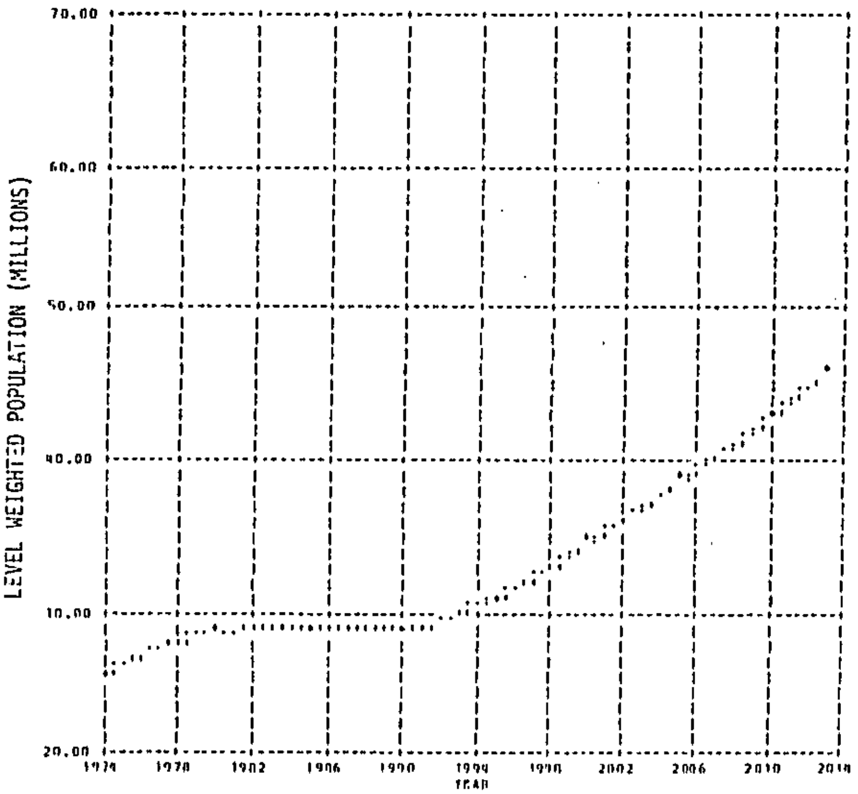


TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL
ROADWAY TRAFFIC NOISE EXPOSURE MODEL
(Continued)

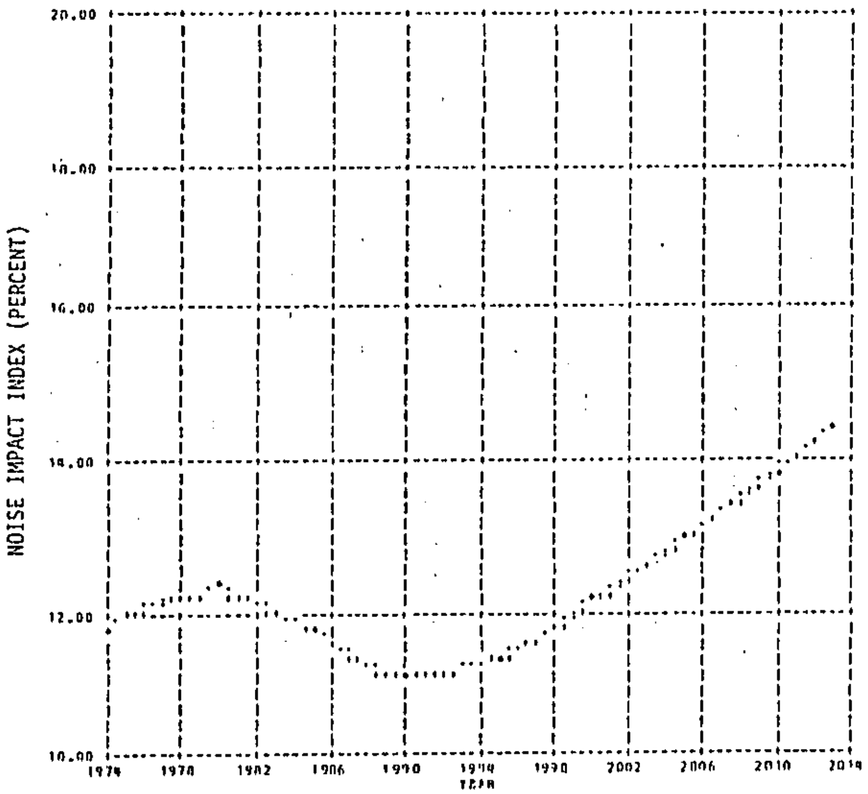


TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL
ROADWAY TRAFFIC NOISE EXPOSURE MODEL
(Continued)

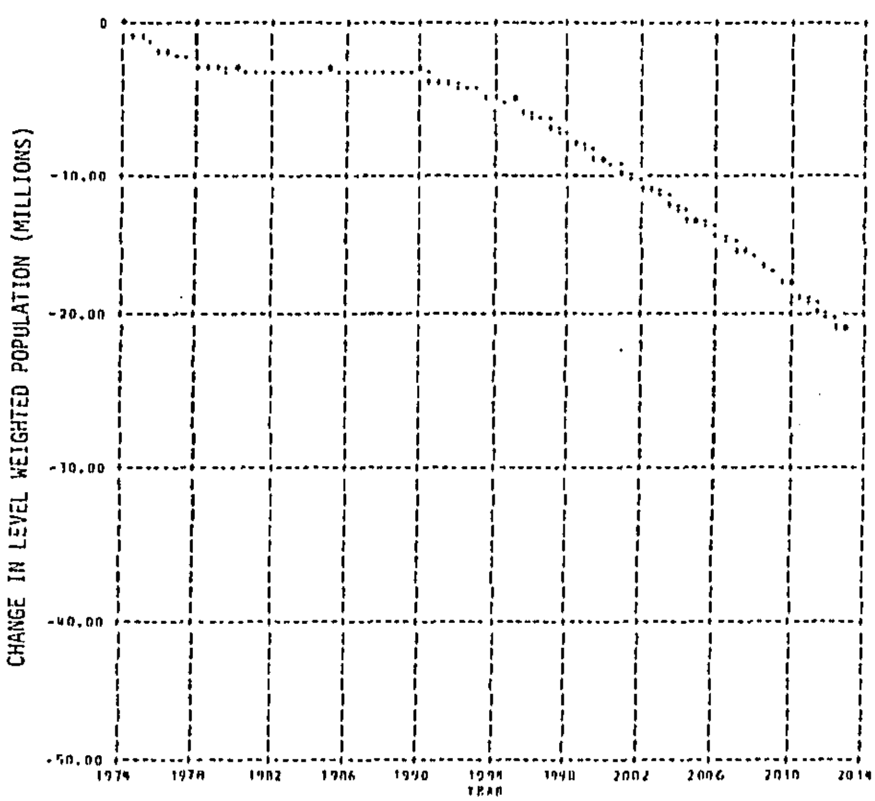


TABLE 3-1

TYPICAL PREDICTION OUTPUTS OF THE NATIONAL
ROADWAY TRAFFIC NOISE EXPOSURE MODEL
(Continued)

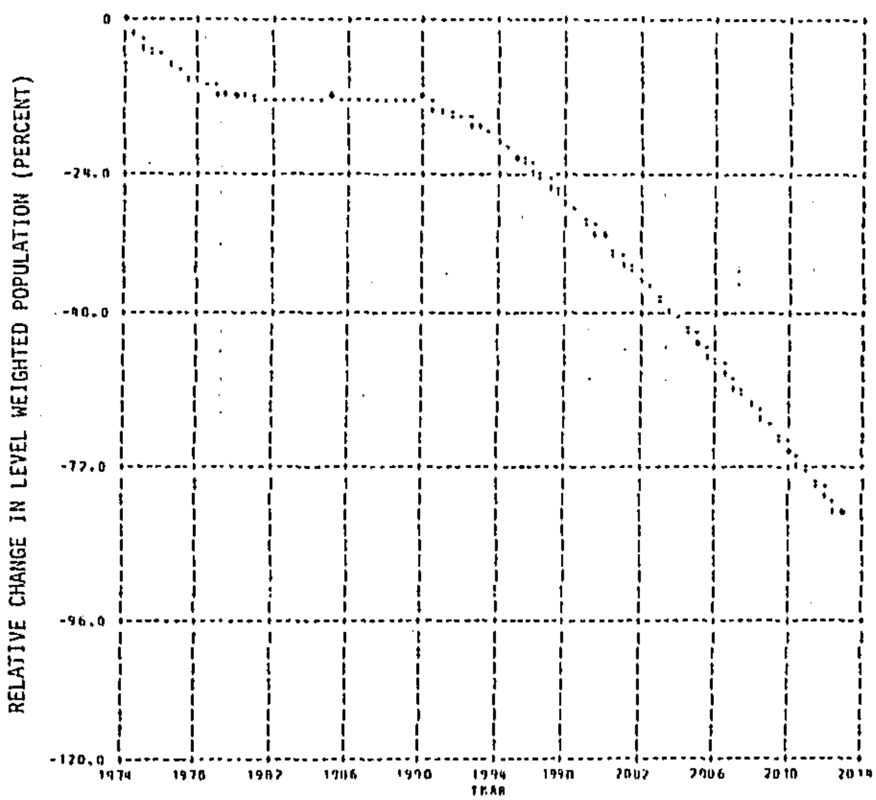


TABLE 3-2

SINGLE EVENT NOISE ANALYSIS FOR MEDIUM-DUTY TRUCKS

YEAR	DAY			NIGHT			TOTAL		
	LWP	DLWP	RCI	LWP	DLWP	RCI	LWP	DLWP	RCI
1974	1.529E 08	0.0	0.0	4.409E 08	0.0	0.0	5.937E 08	0.0	0.0
1980	1.911E 08	-3.824E 07	-25.01	5.493E 08	-1.085E 08	-24.60	7.404E 08	-1.467E 08	-24.71
1985	2.116E 08	-7.871E 07	-51.48	6.631E 08	-2.222E 08	-50.41	8.947E 08	-3.009E 08	-50.68
1990	2.665E 08	-1.136E 08	-74.29	7.625E 08	-3.217E 08	-72.97	1.029E 09	-4.352E 08	-73.31
1995	3.057E 08	-1.524E 08	-99.69	8.742E 08	-4.334E 08	-98.30	1.180E 09	-5.858E 08	-98.66
2000	3.509E 08	-1.980E 08	-129.51	1.005E 09	-5.646E 08	-128.07	1.356E 09	-7.626E 08	-128.44
2005	4.027E 08	-2.498E 08	-163.30	1.154E 09	-7.130E 08	-161.73	1.557E 09	-9.628E 08	-162.16
2010	4.613E 08	-3.084E 08	-201.71	1.322E 09	-8.812E 08	-199.89	1.783E 09	-1.190E 09	-200.36
2011	4.994E 08	-3.466E 08	-226.68	1.434E 09	-9.931E 08	-225.27	1.933E 09	-1.340E 09	-225.63

SLEEP DISRUPTION

TABLE 3-2

(Continued)

YEAR	DAY LWP	DAY DLWP	DAY RCI	NIGHT LWP	NIGHT DLWP	NIGHT RCI	TOTAL LWP	TOTAL DLWP	TOTAL RCI
1978	7.980E 07	0.0	0.0	2.303E 08	0.0	0.0	3.101E 08	0.0	0.0
1980	9.961E 07	-1.982E 07	-24.81	2.880E 08	-5.769E 07	-25.05	3.876E 08	-7.751E 07	-25.00
1985	1.205E 08	-4.067E 07	-50.96	3.488E 08	-1.186E 08	-51.49	4.693E 08	-1.592E 08	-51.35
1990	1.386E 08	-5.883E 07	-73.72	4.009E 08	-1.707E 08	-74.12	5.396E 08	-2.295E 08	-74.02
1995	1.590E 08	-7.922E 07	-99.28	4.590E 08	-2.287E 08	-99.32	6.180E 08	-3.079E 08	-99.31
2000	1.829E 08	-1.031E 08	-129.25	5.265E 08	-2.962E 08	-128.65	7.094E 08	-3.994E 08	-128.80
2005	2.100E 08	-1.286E 08	-161.10	6.031E 08	-3.728E 08	-161.90	8.130E 08	-5.030E 08	-162.21
2010	2.406E 08	-1.608E 08	-201.48	6.906E 08	-4.604E 08	-199.93	9.312E 08	-6.211E 08	-200.32
2013	2.609E 08	-1.811E 08	-226.97	7.486E 08	-5.183E 08	-225.09	1.009E 09	-6.994E 08	-225.57

SLEEP AWAKENING

TABLE 3-2

(Continued)

YEAR	DAY			NIGHT			TOTAL		
	LWP	DLWP	NCI	LWP	DLWP	NCI	LWP	DLWP	NCI
1974	2.796E 07	0.0	0.0	7.291E 05	0.0	0.0	2.869E 07	0.0	0.0
1980	3.510E 07	-7.146E 06	-25.56	9.147E 05	-1.856E 05	-25.45	3.602E 07	-7.332E 06	-25.56
1985	4.206E 07	-1.410E 07	-50.43	1.100E 06	-3.709E 05	-50.79	4.316E 07	-1.447E 07	-50.44
1990	4.792E 07	-1.996E 07	-71.40	1.255E 06	-5.254E 05	-72.05	4.917E 07	-2.049E 07	-71.41
1995	5.477E 07	-2.681E 07	-95.91	1.434E 06	-7.046E 05	-96.63	5.621E 07	-2.752E 07	-95.93
2000	6.100E 07	-3.512E 07	-125.62	1.651E 06	-9.219E 05	-126.44	6.471E 07	-3.604E 07	-125.64
2005	7.250E 07	-4.454E 07	-159.32	1.899E 06	-1.170E 06	-160.50	7.440E 07	-4.571E 07	-159.35
2010	8.317E 07	-5.521E 07	-197.49	2.181E 06	-1.452E 06	-199.11	8.535E 07	-5.667E 07	-197.53
2013	9.031E 07	-6.235E 07	-221.01	2.366E 06	-1.617E 06	-224.53	9.267E 07	-6.399E 07	-221.05

INDOOR SPEECH INTERFERENCE

TABLE 3-2

(Continued)

YEAR	DAY LWP	DAY DLWP	DAY RCI	NIGHT LWP	NIGHT DLWP	NIGHT RCI	TOTAL LWP	TOTAL DLWP	TOTAL RCI
1974	1.805E 07	0.0	0.0	0.0	0.0	0.0	1.805E 07	0.0	0.0
1980	2.283E 07	-4.782E 06	-26.49	0.0	0.0	0.0	2.283E 07	-4.782E 06	-26.49
1985	2.761E 07	-9.579E 06	-51.07	0.0	0.0	0.0	2.761E 07	-9.579E 06	-51.07
1990	3.174E 07	-1.369E 07	-75.07	0.0	0.0	0.0	3.174E 07	-1.369E 07	-75.07
1995	3.649E 07	-1.848E 07	-102.15	0.0	0.0	0.0	3.649E 07	-1.848E 07	-102.15
2000	4.219E 07	-2.414E 07	-133.76	0.0	0.0	0.0	4.219E 07	-2.414E 07	-133.76
2005	4.866E 07	-3.061E 07	-169.61	0.0	0.0	0.0	4.866E 07	-3.061E 07	-169.61
2010	5.594E 07	-3.789E 07	-209.91	0.0	0.0	0.0	5.594E 07	-3.789E 07	-209.91
2011	6.081E 07	-4.279E 07	-217.05	0.0	0.0	0.0	6.081E 07	-4.279E 07	-217.05

OUTDOOR SPEECH INTERFERENCE

TABLE 3-2

(Continued)

YEAR	DAY			NIGHT			TOTAL		
	LWP	DLWP	NCI	LWP	DLWP	NCI	LWP	DLWP	NCI
1974	4.889E 07	0.0	0.0	1.064E 06	0.0	0.0	5.076E 07	0.0	0.0
1980	6.196E 07	-1.307E 07	-26.71	2.362E 06	-4.978E 05	-26.71	6.432E 07	-1.357E 07	-26.71
1985	7.579E 07	-2.689E 07	-55.00	2.880E 06	-1.024E 06	-54.94	7.868E 07	-2.792E 07	-55.00
1990	8.775E 07	-1.006E 07	-79.48	3.394E 06	-1.480E 06	-79.41	9.110E 07	-4.034E 07	-79.47
1995	1.010E 08	-5.214E 07	-106.70	3.051E 06	-1.907E 06	-106.50	1.049E 08	-5.413E 07	-106.64
2000	1.167E 08	-6.770E 07	-138.62	4.447E 06	-2.501E 06	-138.50	1.211E 08	-7.016E 07	-138.62
2005	1.346E 08	-8.567E 07	-175.21	5.129E 06	-3.265E 06	-175.10	1.397E 08	-8.891E 07	-175.21
2010	1.549E 08	-1.060E 08	-216.80	5.905E 06	-4.041E 06	-216.77	1.608E 08	-1.100E 08	-216.80
2013	1.684E 08	-1.195E 08	-244.40	6.421E 06	-4.557E 06	-244.46	1.749E 08	-1.241E 08	-244.40

PEDESTRIAN SPEECH INTERFERENCE

TABLE 3-2

(Continued)

BAND	6	7	8	9	10	11	12	13	14	15
LEVEL, IN DBA>	105.-100.	100.- 95.	95.- 90.	90.- 85.	85.- 80.	80.- 75.	75.- 70.	70.- 65.	65.- 60.	60.- 55.
YEAR										
1974	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.120E 07	2.222E 08	3.303E 08
1980	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.355E 07	2.775E 08	4.214E 08
1985	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.823E 07	3.315E 08	5.129E 08
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.294E 07	3.796E 08	5.964E 08
1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.920E 07	4.117E 08	6.805E 08
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.801E 07	4.953E 08	7.911E 08
2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.825E 07	5.670E 08	9.105E 08
2010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.988E 07	6.500E 08	1.044E 09
2013	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.761E 07	7.047E 08	1.133E 09

SLEEP DISRUPTION

TABLE 3-2

(Continued)

BAND	6	7	8	9	10	11	12	13	14	15
LEVEL, IN DBA>	105.-100.	100.- 95.	95.- 90.	90.- 85.	85.- 80.	80.- 75.	75.- 70.	70.- 65.	65.- 60.	60.- 55.
YEAR										
1974	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.959E 07	1.225E 08	1.680E 08
1980	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.451E 07	1.520E 08	2.102E 08
1985	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.844E 07	1.816E 08	2.573E 08
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.120E 07	2.091E 08	2.991E 08
1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.491E 07	2.186E 08	3.445E 08
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.009E 07	2.730E 08	3.955E 08
2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.612E 07	3.140E 08	4.529E 08
2010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.290E 07	3.595E 08	5.107E 08
2013	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.754E 07	3.895E 08	5.625E 08

SLEEP AWAKENING

TABLE 3-2

(Continued)

BAND	8	9	10	11	12	13	14	15	16	17
LEVEL, IN DBA	95.- 90.	90.- 85.	85.- 80.	80.- 75.	75.- 70.	70.- 65.	65.- 60.	60.- 55.	55.- 50.	50.- 45.
YEAR										
1976	0.0	0.0	0.0	0.0	0.0	2.124E 04	8.555E 05	6.672E 06	1.304E 07	7.790E 06
1980	0.0	0.0	0.0	0.0	0.0	2.705E 04	1.001E 06	8.101E 06	1.736E 07	9.166E 06
1985	0.0	0.0	0.0	0.0	0.0	1.227E 04	1.265E 06	9.910E 06	2.002E 07	1.110E 07
1990	0.0	0.0	0.0	0.0	0.0	3.611E 04	1.395E 06	1.116E 07	2.382E 07	1.276E 07
1995	0.0	0.0	0.0	0.0	0.0	4.110E 04	1.570E 06	1.264E 07	2.732E 07	1.463E 07
2000	0.0	0.0	0.0	0.0	0.0	4.805E 04	1.814E 06	1.455E 07	3.147E 07	1.685E 07
2005	0.0	0.0	0.0	0.0	0.0	5.509E 04	2.101E 06	1.676E 07	3.617E 07	1.931E 07
2010	0.0	0.0	0.0	0.0	0.0	6.483E 04	2.429E 06	1.924E 07	4.151E 07	2.210E 07
2011	0.0	0.0	0.0	0.0	0.0	7.000E 04	2.648E 06	2.090E 07	4.507E 07	2.390E 07

INDOOR SPEECH INTERFERENCE

TABLE 3-2

(Continued)

BAND	6	7	8	9	10	11	12	13	14	15
LEVEL, IN DNA	105.-100.	100.- 95.	95.- 90.	90.- 85.	85.- 80.	80.- 75.	75.- 70.	70.- 65.	65.- 60.	60.- 55.
YEAR										
1978	0.0	0.0	0.0	0.0	7.666E 03	9.260E 05	6.907E 06	6.256E 06	2.526E 06	1.347E 06
1980	0.0	0.0	0.0	0.0	9.094E 03	1.105E 06	8.009E 06	7.098E 06	3.171E 06	1.603E 06
1985	0.0	0.0	0.0	0.0	1.170E 04	1.409E 06	1.069E 07	9.584E 06	3.803E 06	2.047E 06
1990	0.0	0.0	0.0	0.0	1.331E 04	1.503E 06	1.219E 07	1.104E 07	4.531E 06	2.386E 06
1995	0.0	0.0	0.0	0.0	1.494E 04	1.802E 06	1.396E 07	1.269E 07	5.252E 06	2.771E 06
2000	0.0	0.0	0.0	0.0	1.733E 04	2.009E 06	1.615E 07	1.466E 07	6.072E 06	3.207E 06
2005	0.0	0.0	0.0	0.0	2.013E 04	2.424E 06	1.864E 07	1.689E 07	6.991E 06	3.693E 06
2010	0.0	0.0	0.0	0.0	2.333E 04	2.805E 06	2.149E 07	1.934E 07	8.039E 06	4.244E 06
2013	0.0	0.0	0.0	0.0	2.566E 04	3.060E 06	2.180E 07	2.103E 07	8.734E 06	4.613E 06

OUTDOOR SPEECH INTERFERENCE

TABLE 3-2

(Continued)

BAND	6	7	8	9	10	11	12	13	14	15
LEVEL, IN DBA>	105.-100.	100.- 95.	95.- 90.	90.- 85.	85.- 80.	80.- 75.	75.- 70.	70.- 65.	65.- 60.	60.- 55.
YEAR										
1974	0.0	0.0	0.0	0.0	2.439E 05	1.201E 07	3.257E 07	5.501E 06	3.201E 05	2.719E 04
1980	0.0	0.0	0.0	0.0	3.132E 05	1.514E 07	4.127E 07	6.956E 06	4.094E 05	3.429E 04
1985	0.0	0.0	0.0	0.0	3.934E 05	1.821E 07	4.946E 07	1.006E 07	5.097E 05	4.003E 04
1990	0.0	0.0	0.0	0.0	4.670E 05	2.045E 07	5.604E 07	1.350E 07	6.001E 05	4.610E 04
1995	0.0	0.0	0.0	0.0	5.461E 05	2.320E 07	6.377E 07	1.654E 07	6.962E 05	5.229E 04
2000	0.0	0.0	0.0	0.0	6.364E 05	2.699E 07	7.344E 07	1.919E 07	8.050E 05	5.998E 04
2005	0.0	0.0	0.0	0.0	7.392E 05	3.132E 07	8.461E 07	2.202E 07	9.208E 05	6.807E 04
2010	0.0	0.0	0.0	0.0	8.566E 05	3.626E 07	9.731E 07	2.522E 07	1.070E 06	7.895E 04
2011	0.0	0.0	0.0	0.0	9.348E 05	3.956E 07	1.050E 08	2.735E 07	1.163E 06	8.565E 04

PEDESTRIAN SPEECH INTERFERENCE

TABLE 3-2

(Continued)

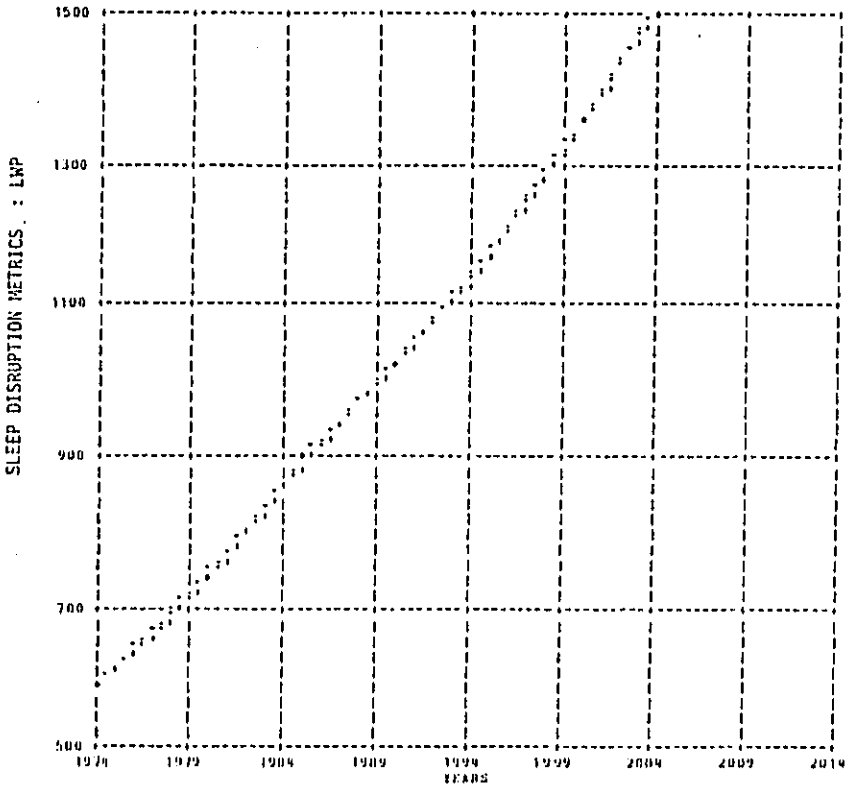


TABLE 3-2

(Continued)

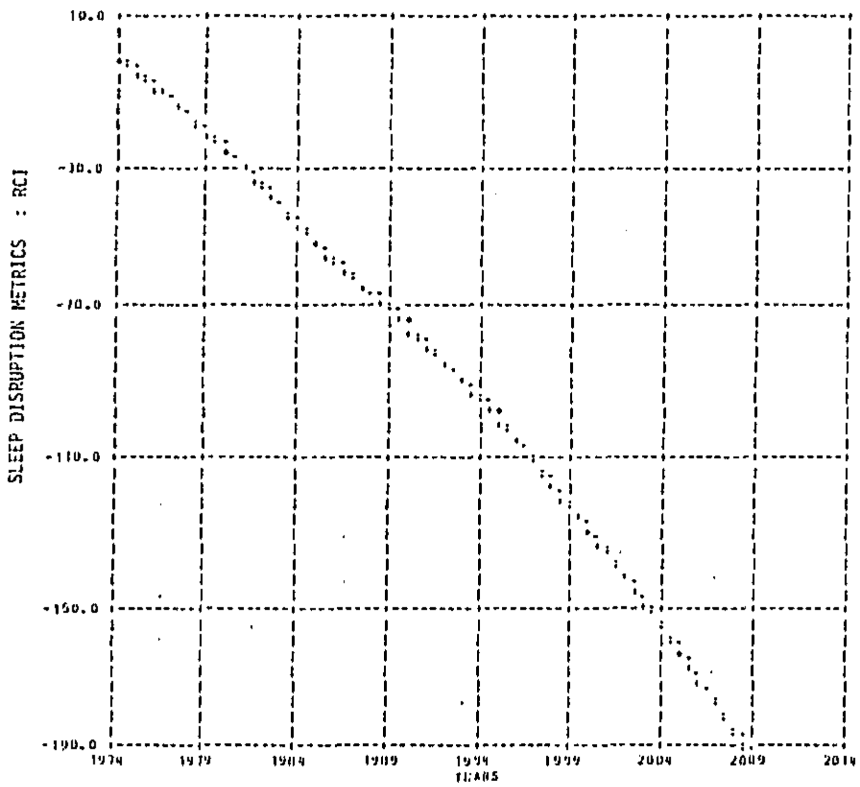


TABLE 3-2

(Continued)

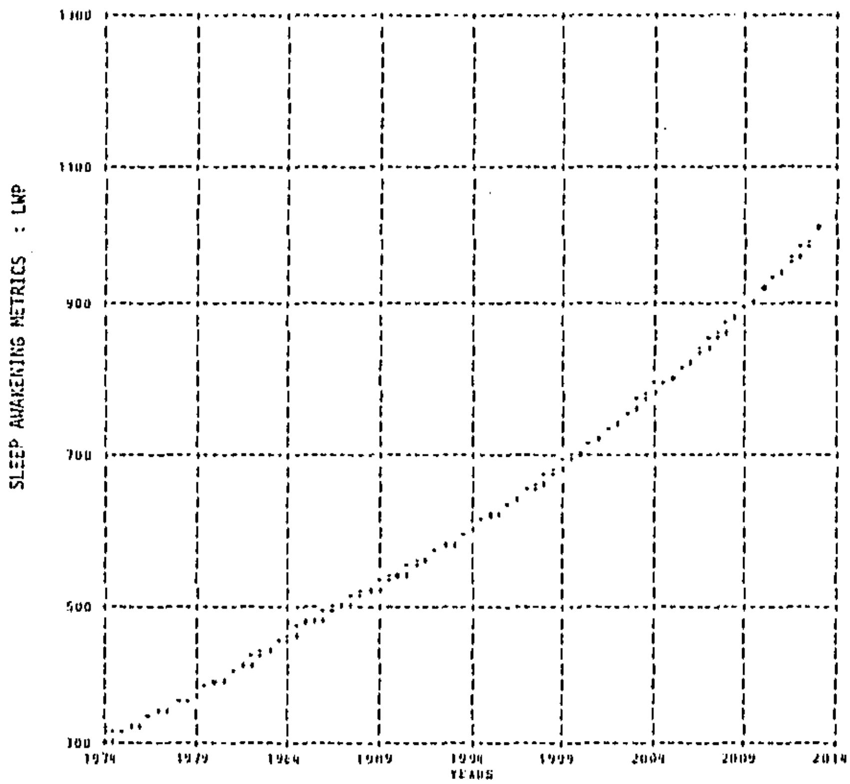


TABLE 3-2

(Continued)

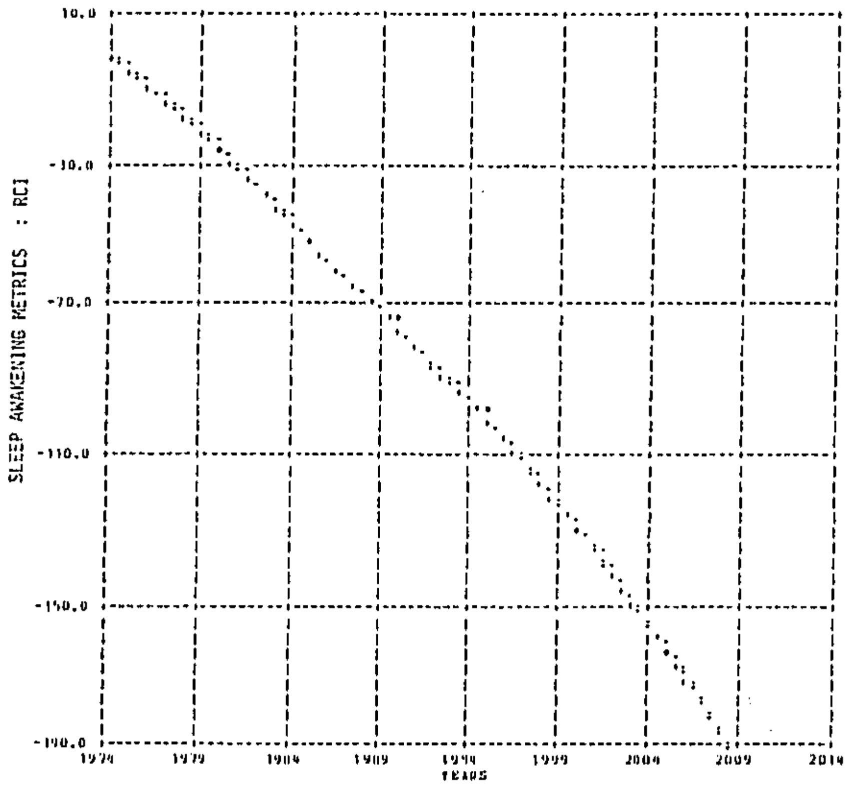


TABLE 3-2

(Continued)

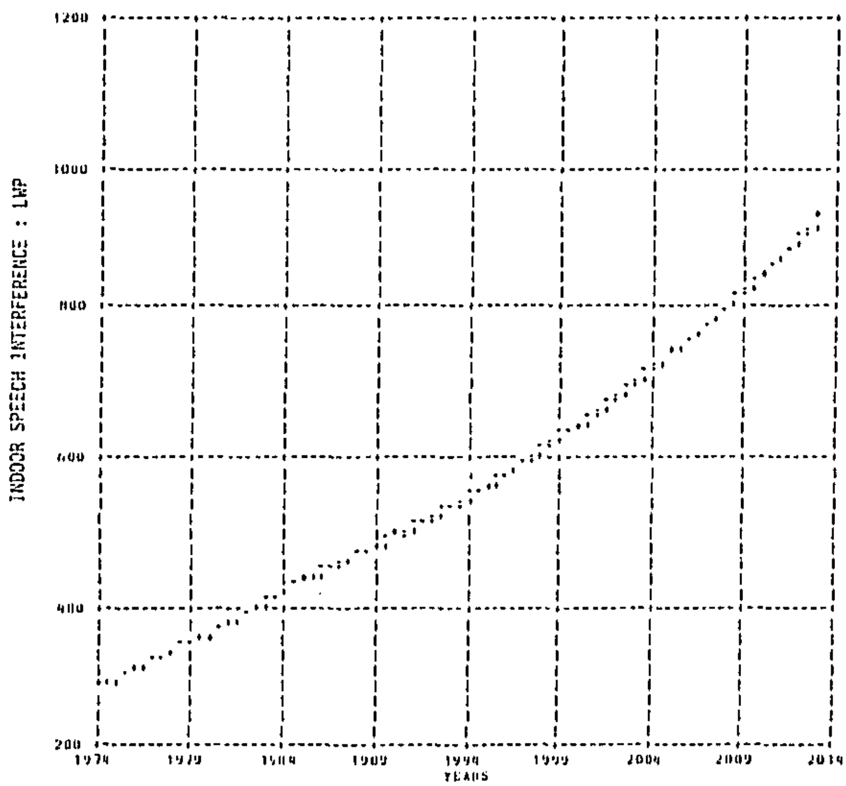


TABLE 3-2

(Continued)

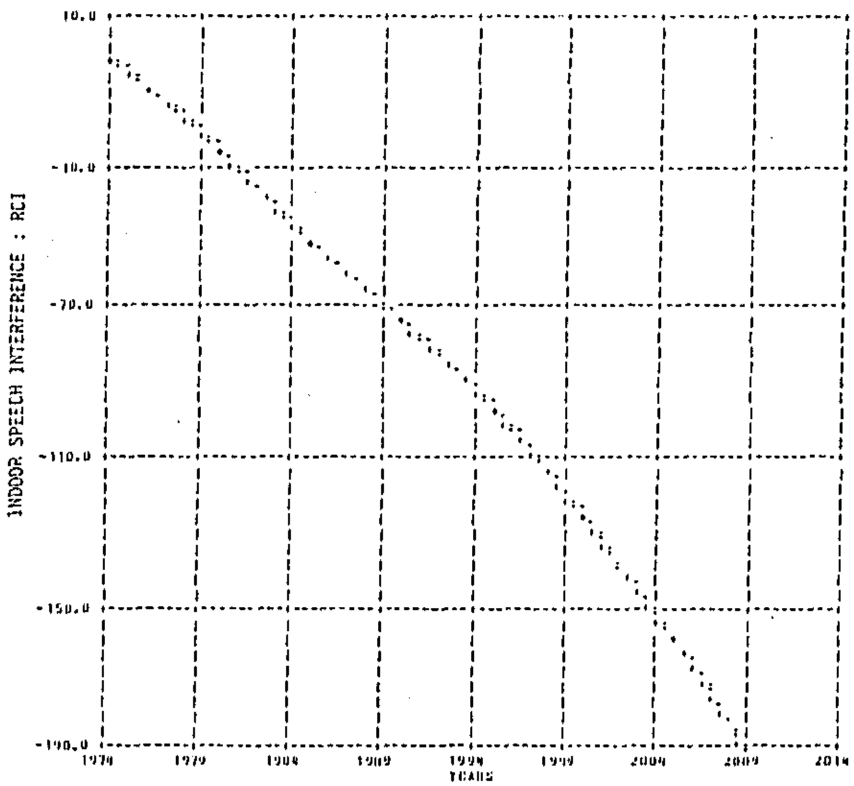


TABLE 3-2

(Continued)

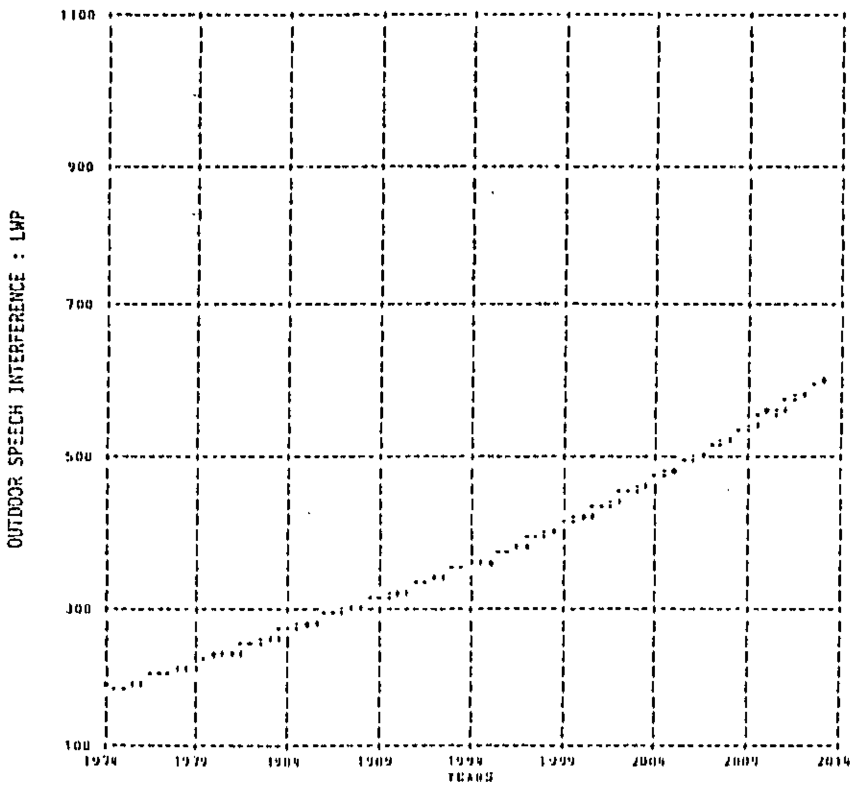


TABLE 3-2

(Continued)

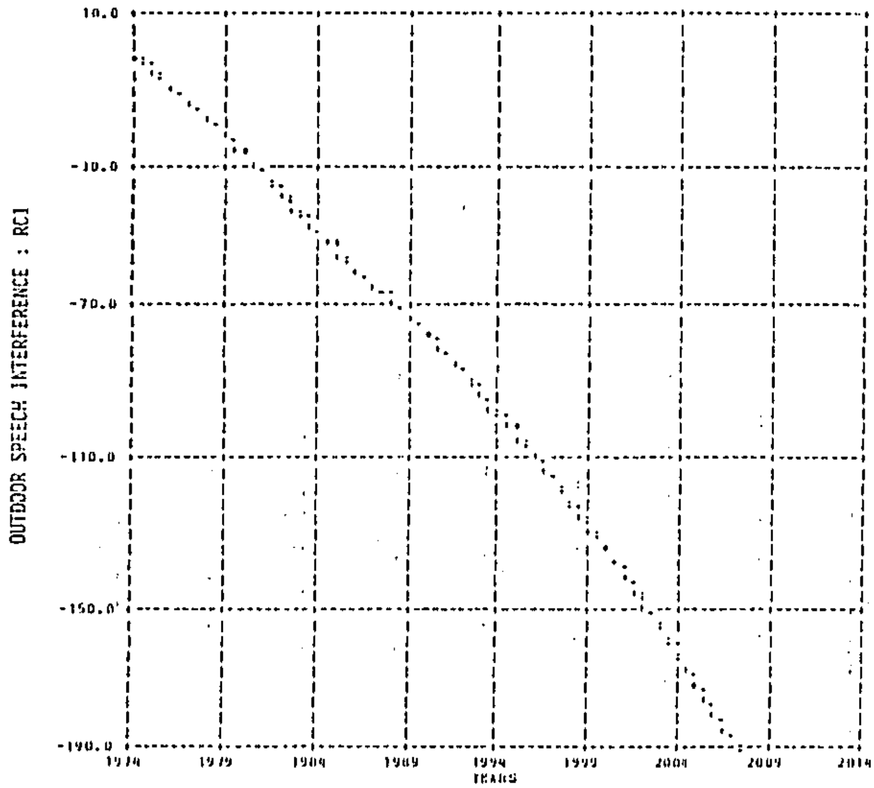


TABLE 3-2

(Continued)

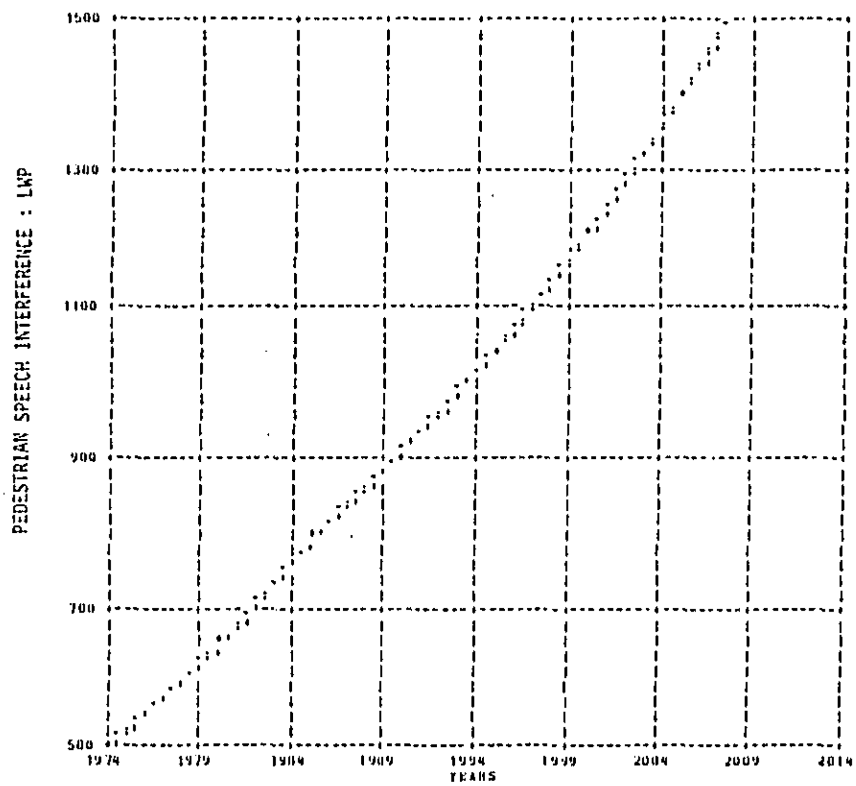


TABLE 3-2

(Continued)

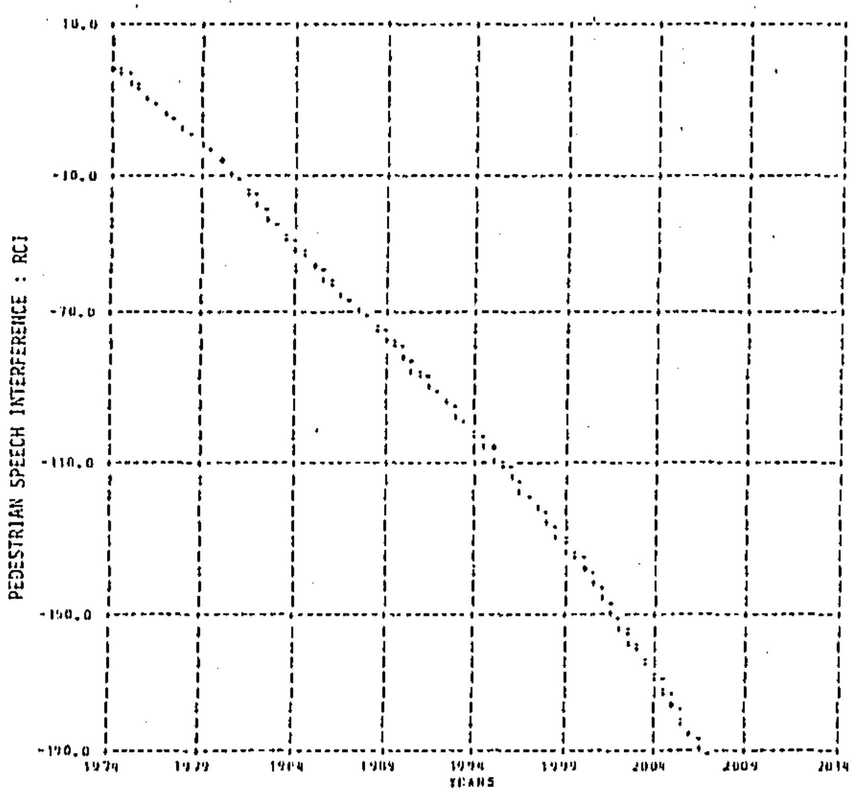


TABLE 3-3

SINGLE EVENT NOISE ANALYSIS FOR HEAVY-DUTY TRUCKS

YEAR	DAY LWP	DAY DLWP	DAY RCI	NIGHT LWP	NIGHT DLWP	NIGHT RCI	TOTAL LWP	TOTAL DLWP	TOTAL RCI
1979	6.092E 08	0.0	0.0	1.971E 09	0.0	0.0	2.661E 09	0.0	0.0
1980	7.027E 08	-9.350E 07	-13.57	2.245E 09	-2.740E 08	-11.90	3.028E 09	-3.675E 08	-13.81
1985	7.705E 08	-8.925E 07	-12.95	2.241E 09	-2.700E 08	-11.70	3.020E 09	-3.591E 08	-11.50
1990	7.671E 08	-7.006E 07	-11.11	2.214E 09	-2.621E 08	-12.20	2.981E 09	-3.201E 08	-12.01
1995	8.114E 08	-1.442E 08	-20.92	2.405E 09	-4.117E 08	-22.00	3.219E 09	-5.779E 08	-21.72
2000	9.565E 08	-2.673E 08	-18.78	2.763E 09	-7.031E 08	-40.04	3.717E 09	-1.057E 09	-39.71
2005	1.101E 09	-4.117E 08	-59.76	3.179E 09	-1.207E 09	-64.21	4.279E 09	-1.619E 09	-60.84
2010	1.265E 09	-5.762E 08	-81.60	3.651E 09	-1.682E 09	-85.31	4.919E 09	-2.250E 09	-84.87
2011	1.375E 09	-6.857E 08	-99.49	3.969E 09	-1.998E 09	-101.12	5.344E 09	-2.681E 09	-100.85

SLEEP DISRUPTION

TABLE 3-3

(Continued)

YEAR	DAY			NIGHT			TOTAL		
	LWP	DLWP	PCI	LWP	DLWP	PCI	LWP	DLWP	PCI
1974	1.767E 08	0.0	0.0	1.079E 09	0.0	0.0	1.056E 09	0.0	0.0
1980	4.201E 08	-5.110E 07	-11.64	1.222E 09	-1.426E 08	-11.21	1.650E 09	-1.919E 08	-11.32
1985	4.235E 08	-4.671E 07	-12.40	1.209E 09	-1.249E 08	-11.57	1.628E 09	-1.716E 08	-11.70
1990	4.129E 08	-3.617E 07	-5.60	1.176E 09	-9.667E 07	-8.99	1.589E 09	-1.326E 08	-9.11
1995	4.457E 08	-6.900E 07	-10.32	1.274E 09	-1.997E 08	-10.08	1.720E 09	-2.617E 08	-10.11
2000	5.108E 08	-1.301E 08	-15.60	1.463E 09	-1.018E 08	-15.56	1.974E 09	-5.179E 08	-15.57
2005	5.888E 08	-2.111E 08	-56.00	1.605E 09	-6.051E 08	-56.00	2.271E 09	-8.166E 08	-56.00
2010	6.735E 08	-2.968E 08	-78.79	1.937E 09	-8.571E 08	-79.02	2.610E 09	-1.154E 09	-79.26
2013	7.105E 08	-3.517E 08	-91.90	2.106E 09	-1.025E 09	-94.96	2.815E 09	-1.379E 09	-94.68

SLEEP AWAKENING

TABLE 3-3

(Continued)

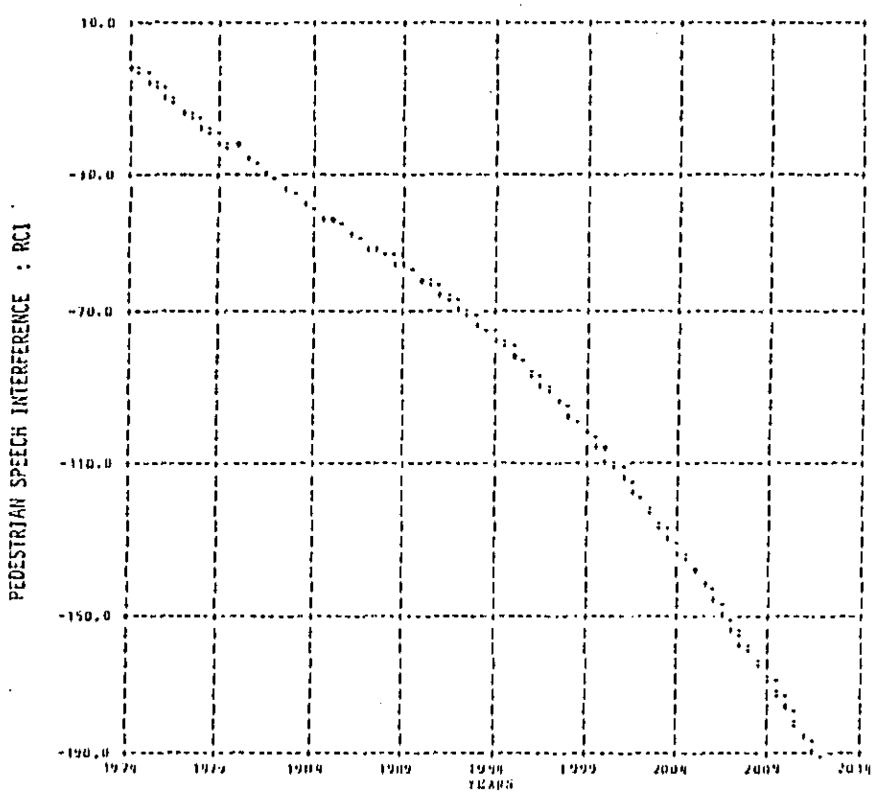


TABLE 3-3

(Continued)

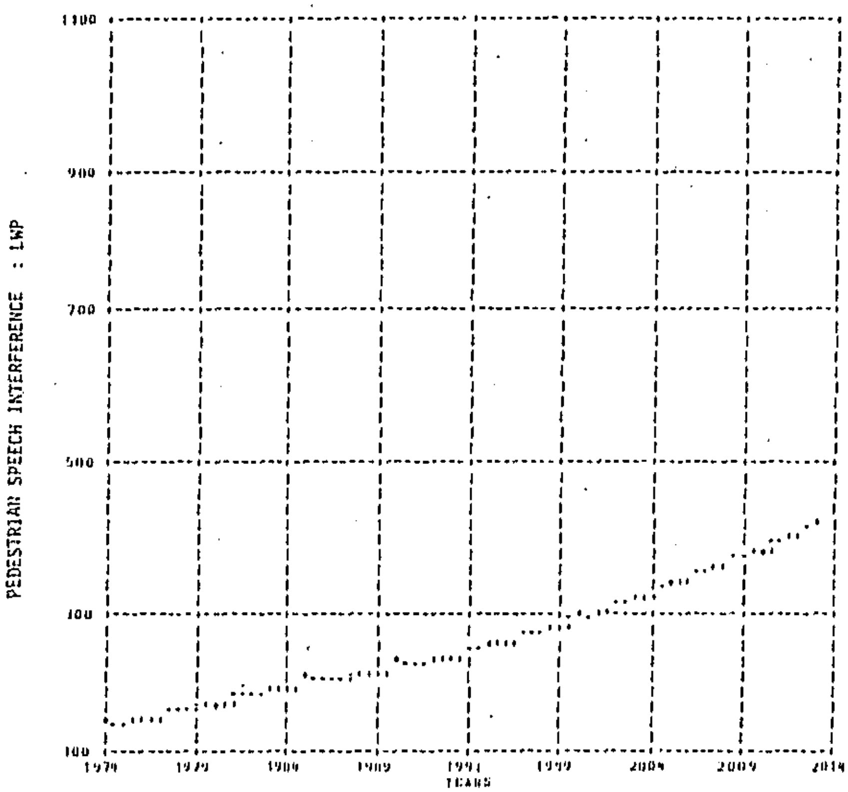


TABLE 3-3

(Continued)

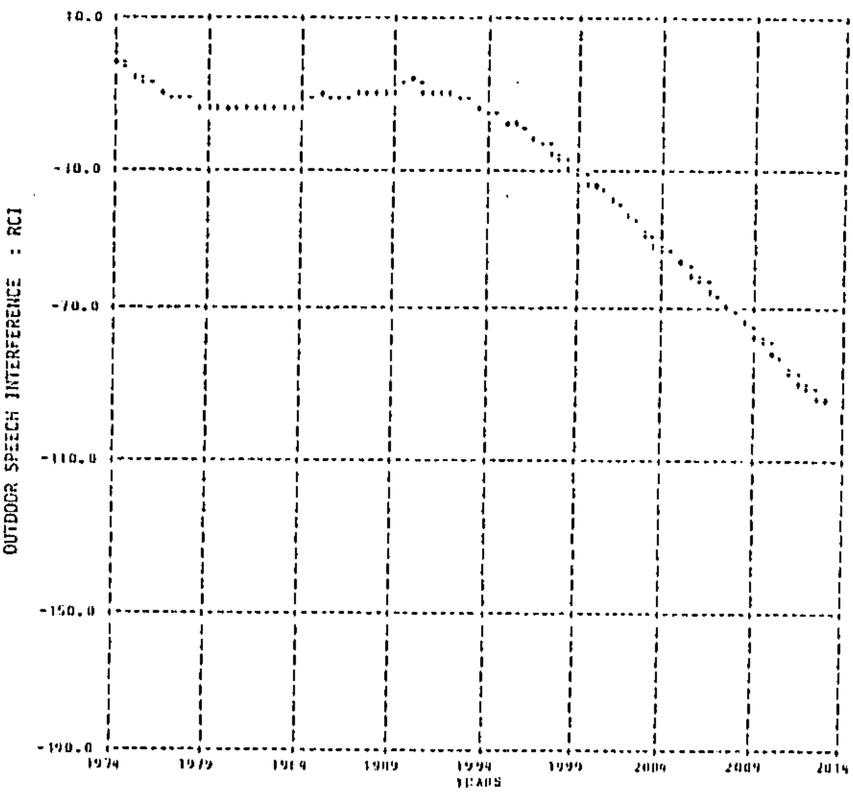


TABLE 3-3

(Continued)

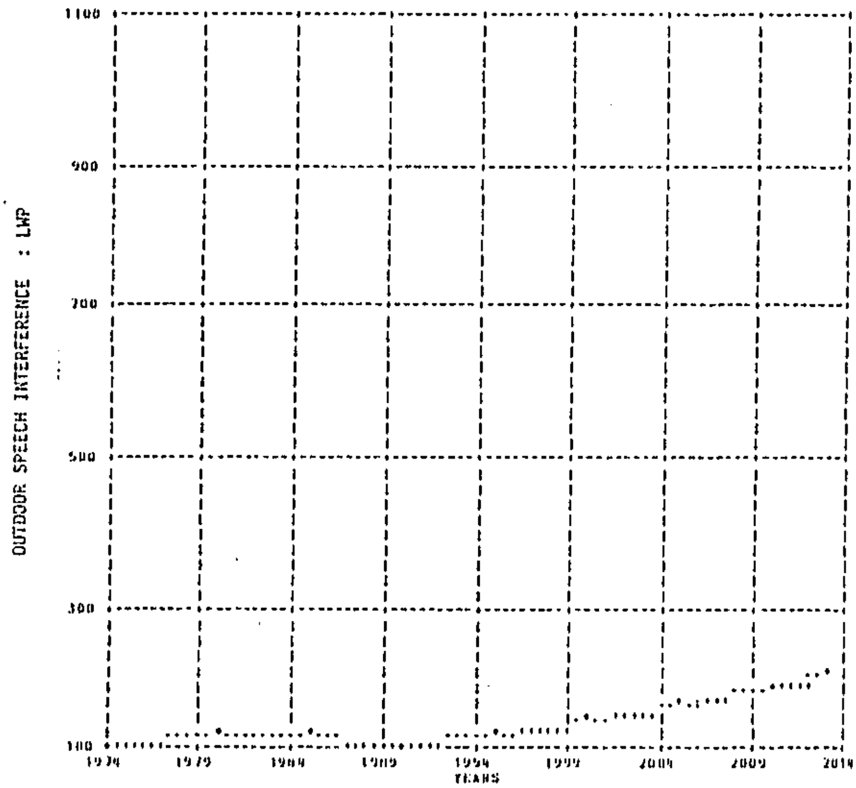


TABLE 3-3

(Continued)

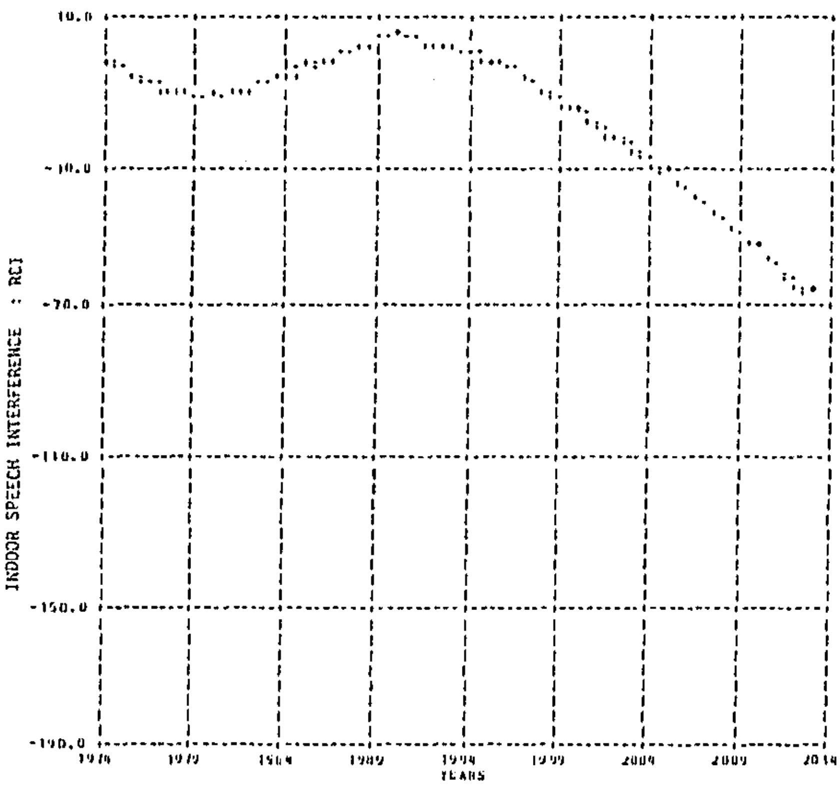


TABLE 3-3

(Continued)

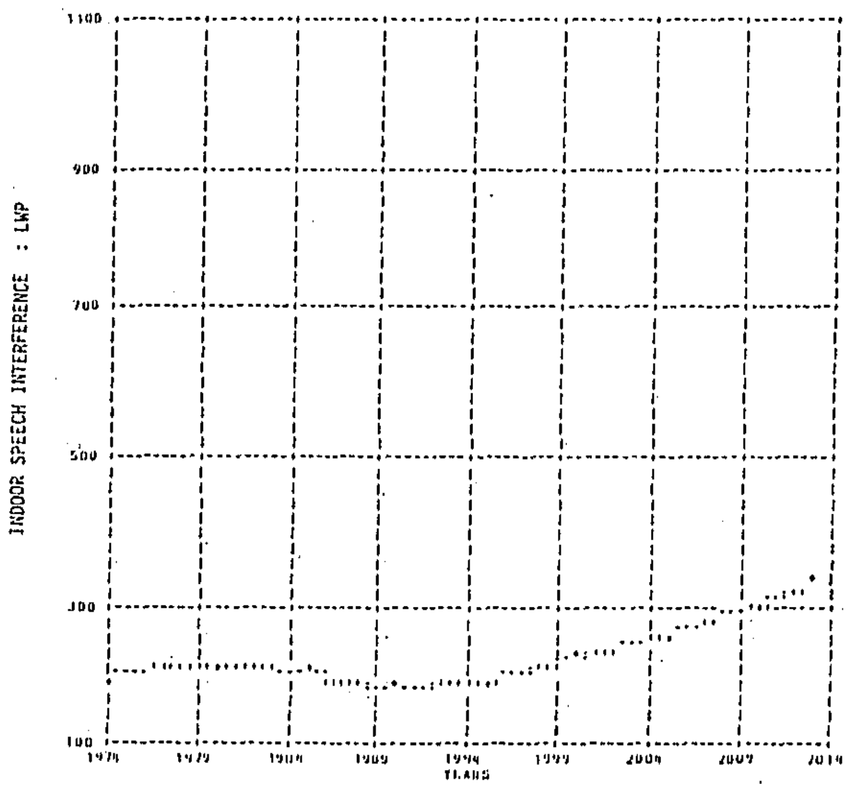


TABLE 3-3

(Continued)

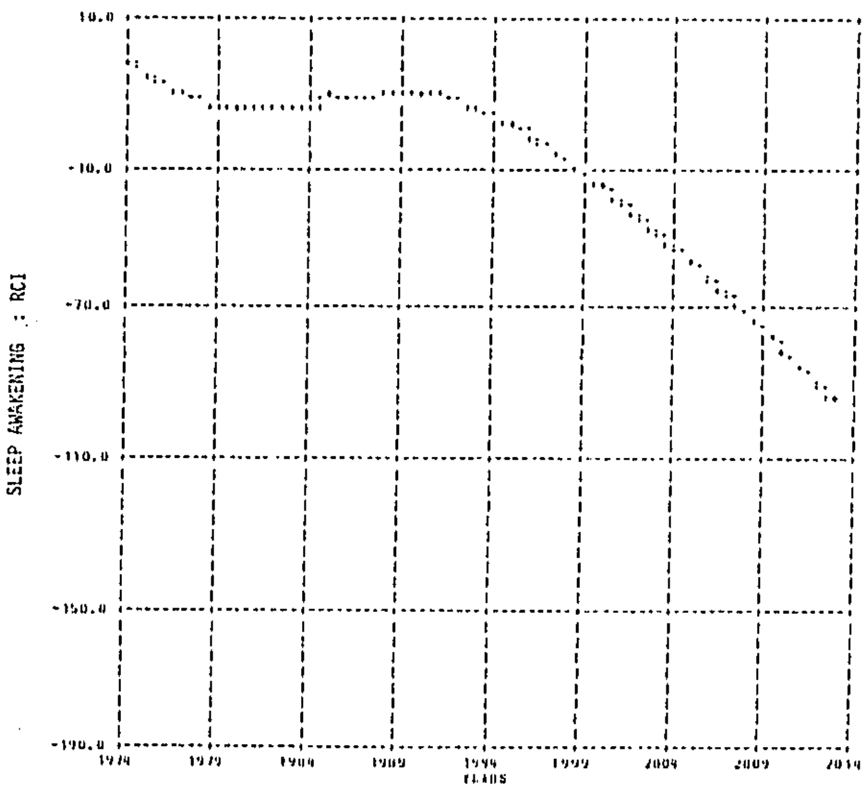


TABLE 3-3

(Continued)

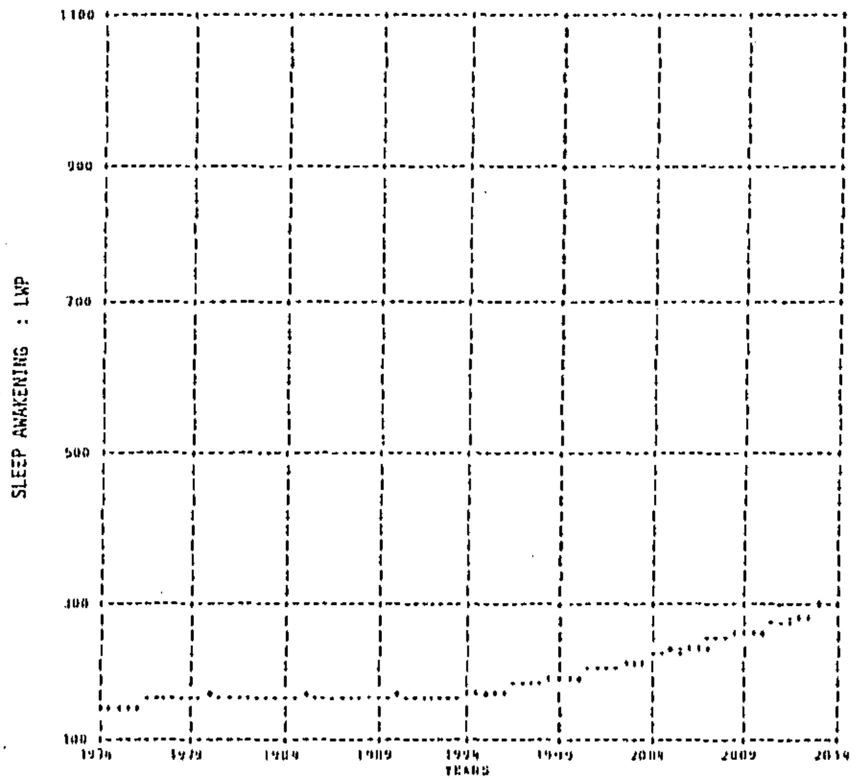


TABLE 3-3

(Continued)

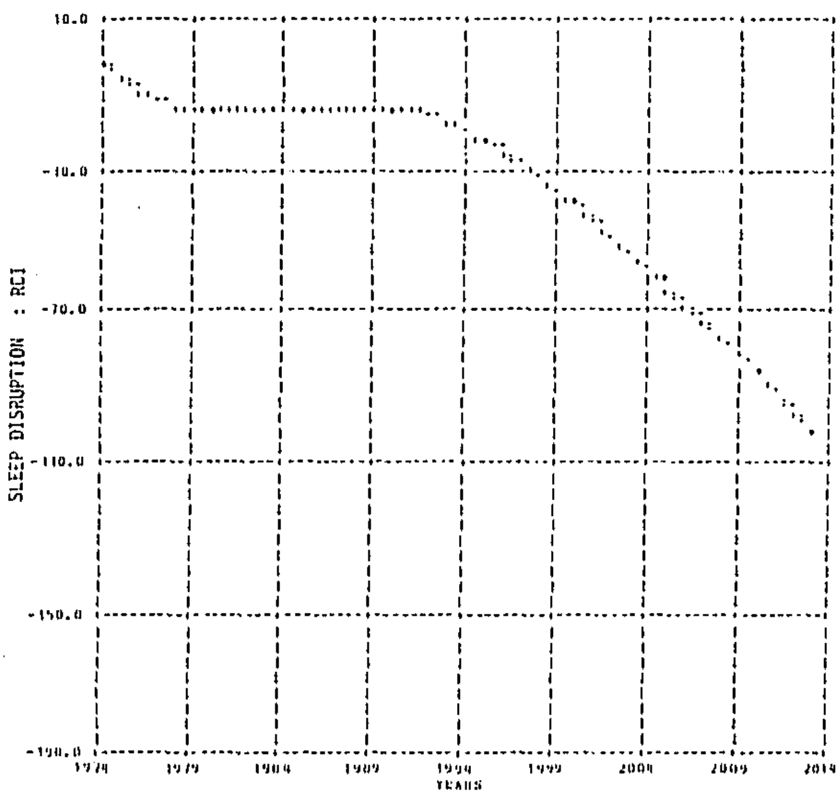


TABLE 3-3

(Continued)

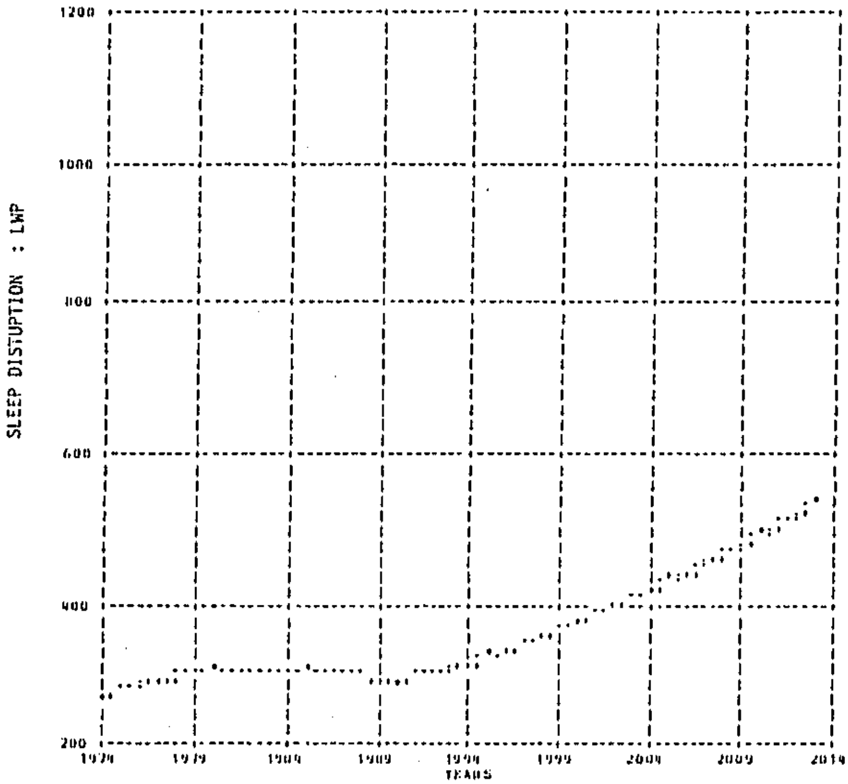


TABLE 3-3

(Continued)

BAND	6	7	8	9	10	11	12	13	14	15
LEVEL, IN DBA>	105.-100.	100.- 95.	95.- 90.	90.- 85.	85.- 80.	80.- 75.	75.- 70.	70.- 65.	65.- 60.	60.- 55.
YEAR										
1978	0.0	0.0	0.0	4.505E 05	2.002E 07	8.750E 07	2.077E 07	1.110E 06	8.711E 03	1.105E 02
1980	0.0	0.0	0.0	1.901E 05	2.966E 07	1.005E 08	1.920E 07	2.576E 06	4.917E 04	5.509E 02
1985	0.0	0.0	0.0	1.974E 05	2.002E 07	9.017E 07	7.126E 07	6.944E 06	2.100E 05	1.395E 04
1990	0.0	0.0	0.0	4.104E 04	9.924E 06	9.176E 07	1.041E 08	1.166E 07	4.320E 05	1.090E 04
1995	0.0	0.0	0.0	6.170E 02	6.045E 06	1.001E 08	1.270E 08	1.511E 07	5.790E 05	4.153E 04
2000	0.0	0.0	0.0	0.0	6.120E 06	1.151E 08	1.475E 08	1.761E 07	6.024E 05	5.130E 04
2005	0.0	0.0	0.0	0.0	7.110E 06	1.311E 08	1.701E 08	2.021E 07	7.860E 05	5.802E 04
2010	0.0	0.0	0.0	0.0	8.499E 06	1.541E 08	1.959E 08	2.310E 07	9.055E 05	6.729E 04
2011	0.0	0.0	0.0	0.0	9.266E 06	1.679E 08	2.110E 08	2.510E 07	9.845E 05	7.291E 04

PEDESTRIAN SPEECH INTERFERENCE

TABLE 3-3

(Continued)

BAND	6	7	8	9	10	11	12	13	14	15
LEVEL, IN dB(A)	105.-100.	100.- 95.	95.- 90.	90.- 85.	85.- 80.	80.- 75.	75.- 70.	70.- 65.	65.- 60.	60.- 55.
YEAR										
1978	0.0	0.0	0.0	1.679E 04	2.027E 06	2.495E 07	4.725E 07	2.151E 07	6.025E 06	2.500E 06
1980	0.0	0.0	0.0	1.450E 04	2.696E 06	2.617E 07	5.010E 07	2.554E 07	7.517E 06	3.240E 06
1985	0.0	0.0	0.0	7.210E 01	1.677E 06	2.091E 07	5.361E 07	2.771E 07	8.919E 06	4.021E 06
1990	0.0	0.0	0.0	1.577E 01	7.945E 05	1.607E 07	5.190E 07	2.952E 07	1.012E 07	4.745E 06
1995	0.0	0.0	0.0	2.311E 01	5.370E 05	1.551E 07	5.595E 07	3.317E 07	1.150E 07	5.532E 06
2000	0.0	0.0	0.0	0.0	5.949E 05	1.767E 07	6.419E 07	3.813E 07	1.337E 07	6.411E 06
2005	0.0	0.0	0.0	0.0	6.901E 05	2.040E 07	7.449E 07	4.420E 07	1.541E 07	7.392E 06
2010	0.0	0.0	0.0	0.0	7.991E 05	2.371E 07	8.590E 07	5.104E 07	1.769E 07	8.507E 06
2011	0.0	0.0	0.0	0.0	8.717E 05	2.585E 07	9.361E 07	5.555E 07	1.914E 07	9.240E 06

OUTDOOR SPEECH INTERFERENCE

TABLE 3-3

(Continued)

BAND	8	9	10	11	12	13	14	15	16	17
LEVEL, IN DBA	95.- 90.	90.- 85.	85.- 80.	80.- 75.	75.- 70.	70.- 65.	65.- 60.	60.- 55.	55.- 50.	50.- 45.
YEAR										
1974	0.0	0.0	0.0	0.0	2.122E 05	1.192E 07	1.674E 07	7.021E 07	5.760E 07	1.995E 07
1980	0.0	0.0	0.0	0.0	1.827E 05	1.116E 07	1.647E 07	7.606E 07	6.701E 07	2.426E 07
1985	0.0	0.0	0.0	0.0	9.087E 04	6.013E 06	2.656E 07	6.909E 07	7.146E 07	2.754E 07
1990	0.0	0.0	0.0	0.0	1.987E 04	1.106E 06	1.707E 07	6.082E 07	7.366E 07	3.033E 07
1995	0.0	0.0	0.0	0.0	2.996E 02	2.022E 06	1.620E 07	6.280E 07	8.135E 07	3.443E 07
2000	0.0	0.0	0.0	0.0	0.0	2.231E 06	1.817E 07	7.177E 07	9.162E 07	3.976E 07
2005	0.0	0.0	0.0	0.0	0.0	2.580E 06	2.126E 07	8.277E 07	1.079E 08	4.502E 07
2010	0.0	0.0	0.0	0.0	0.0	2.996E 06	2.456E 07	9.520E 07	1.207E 08	5.271E 07
2015	0.0	0.0	0.0	0.0	0.0	1.260E 06	2.676E 07	1.016E 08	1.350E 08	5.730E 07

INDOOR SPEECH INTERFERENCE

TABLE 3-3

(Continued)

BAND	6	7	8	9	10	11	12	13	14	15
LEVEL, IN DBA	105.-100.	100.- 95.	95.- 90.	90.- 85.	85.- 80.	80.- 75.	75.- 70.	70.- 65.	65.- 60.	60.- 55.
YEAR										
1974	0.0	0.0	0.0	0.0	0.0	4.577E 05	6.421E 07	3.652E 08	5.553E 08	4.710E 08
1980	0.0	0.0	0.0	0.0	0.0	3.913E 05	5.702E 07	3.792E 08	6.524E 08	5.603E 08
1985	0.0	0.0	0.0	0.0	0.0	1.951E 05	1.219E 07	2.979E 08	6.715E 08	6.260E 08
1990	0.0	0.0	0.0	0.0	0.0	4.268E 04	1.109E 07	2.100E 08	6.726E 08	6.871E 08
1995	0.0	0.0	0.0	0.0	0.0	6.112E 02	4.661E 06	2.031E 08	7.309E 08	7.811E 08
2000	0.0	0.0	0.0	0.0	0.0	0.0	4.803E 06	2.294E 08	8.377E 08	9.071E 08
2005	0.0	0.0	0.0	0.0	0.0	0.0	5.659E 06	2.645E 08	9.643E 08	1.030E 09
2010	0.0	0.0	0.0	0.0	0.0	0.0	6.547E 06	3.048E 08	1.100E 09	1.192E 09
201[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	7.139E 06	3.109E 08	1.203E 09	1.294E 09

SLEEP AWAKENING

TABLE 3-3

(Continued)

BAND	6	7	8	9	10	11	12	13	14	15
LEVEL, IN DBA>	105.-100.	100.- 95.	95.- 90.	90.- 85.	85.- 80.	80.- 75.	75.- 70.	70.- 65.	65.- 60.	60.- 55.
YEAR										
1978	0.0	0.0	0.0	0.0	0.0	7.105E 05	1.029E 08	6.109E 08	9.990E 08	9.472E 08
1980	0.0	0.0	0.0	0.0	0.0	6.105E 05	9.260E 07	6.341E 08	1.173E 09	1.120E 09
1985	0.0	0.0	0.0	0.0	0.0	1.031E 05	5.164E 07	4.985E 08	1.211E 09	1.255E 09
1990	0.0	0.0	0.0	0.0	0.0	6.619E 04	1.781E 07	3.675E 08	1.216E 09	1.380E 09
1995	0.0	0.0	0.0	0.0	0.0	9.790E 02	7.519E 06	3.411E 08	1.320E 09	1.560E 09
2000	0.0	0.0	0.0	0.0	0.0	0.0	7.076E 06	3.869E 08	1.513E 09	1.809E 09
2005	0.0	0.0	0.0	0.0	0.0	0.0	9.129E 06	4.457E 08	1.742E 09	2.083E 09
2010	0.0	0.0	0.0	0.0	0.0	0.0	1.056E 07	5.129E 08	2.001E 09	2.394E 09
2015	0.0	0.0	0.0	0.0	0.0	0.0	1.152E 07	5.975E 08	2.174E 09	2.601E 09

SLEEP DISRUPTION

TABLE 3-3

(Continued)

YEAR	DAY			NIGHT			TOTAL		
	LWP	DLWP	NCI	LWP	DLWP	NCI	LWP	DLWP	NCI
1974	1.339E 08	0.0	0.0	5.102E 06	0.0	0.0	1.390E 08	0.0	0.0
1980	1.660E 08	-3.210E 07	-24.04	6.330E 06	-1.227E 06	-24.06	1.724E 08	-3.333E 07	-24.04
1985	1.915E 08	-5.767E 07	-41.00	7.290E 06	-2.196E 06	-41.04	1.988E 08	-5.986E 07	-41.00
1990	2.119E 08	-7.799E 07	-58.26	8.072E 06	-2.970E 06	-58.21	2.199E 08	-8.096E 07	-58.26
1995	2.318E 08	-1.059E 08	-79.11	9.110E 06	-4.016E 06	-79.11	2.409E 08	-1.100E 08	-79.11
2000	2.767E 08	-1.429E 08	-106.72	1.055E 07	-5.445E 06	-106.72	2.873E 08	-1.483E 08	-106.72
2005	3.197E 08	-1.858E 08	-138.02	1.219E 07	-7.001E 06	-138.02	3.319E 08	-1.929E 08	-138.02
2010	3.606E 08	-2.347E 08	-175.31	1.405E 07	-8.946E 06	-175.14	3.746E 08	-2.436E 08	-175.13
2013	4.011E 08	-2.672E 08	-199.64	1.529E 07	-1.019E 07	-199.65	4.164E 08	-2.774E 08	-199.64

PEDESTRIAN SPEECH INTERFERENCE

TABLE 3-3

(Continued)

YEAR	DAY			NIGHT			TOTAL		
	LWP	DLWP	NCI	LWP	DLWP	NCI	LWP	DLWP	NCI
1978	1.052E 08	0.0	0.0	0.0	0.0	0.0	1.052E 08	0.0	0.0
1980	1.199E 08	-1.420E 07	-11.57	0.0	0.0	0.0	1.199E 08	-1.420E 07	-11.57
1985	1.169E 08	-1.170E 07	-11.11	0.0	0.0	0.0	1.169E 08	-1.170E 07	-11.11
1990	1.111E 08	-7.975E 06	-7.50	0.0	0.0	0.0	1.111E 08	-7.975E 06	-7.50
1995	1.223E 08	-1.710E 07	-16.26	0.0	0.0	0.0	1.223E 08	-1.710E 07	-16.26
2000	1.400E 08	-3.560E 07	-33.05	0.0	0.0	0.0	1.400E 08	-3.560E 07	-33.05
2005	1.627E 08	-5.757E 07	-54.76	0.0	0.0	0.0	1.627E 08	-5.757E 07	-54.76
2010	1.877E 08	-8.255E 07	-78.49	0.0	0.0	0.0	1.877E 08	-8.255E 07	-78.49
2013	2.043E 08	-9.911E 07	-94.24	0.0	0.0	0.0	2.043E 08	-9.911E 07	-94.24

OUTDOOR SPEECH INTERFERENCE

TABLE 3-3

(Continued)

YEAR	DAY			NIGHT			TOTAL		
	LWP	DLWP	NCI	LWP	DLWP	NCI	LWP	DLWP	NCI
1974	1.916E 08	0.0	0.0	5.009E 06	0.0	0.0	1.966E 08	0.0	0.0
1980	2.112E 08	-1.962E 07	-10.24	5.510E 06	-5.061E 05	-10.11	2.168E 08	-2.013E 07	-10.24
1985	1.964E 08	-4.826E 06	-2.52	5.121E 06	-1.095E 05	-2.19	2.016E 08	-4.966E 06	-2.52
1990	1.811E 08	1.051E 07	5.50	4.729E 06	2.751E 05	5.50	1.858E 08	1.081E 07	5.50
1995	1.910E 08	-1.790E 05	-0.09	5.007E 06	-3.176E 03	-0.06	1.968E 08	-1.830E 05	-0.09
2000	2.200E 08	-2.838E 07	-14.81	5.745E 06	-7.014E 05	-14.02	2.257E 08	-2.912E 07	-14.81
2005	2.537E 08	-6.212E 07	-32.42	6.620E 06	-1.617E 06	-32.31	2.604E 08	-6.371E 07	-32.41
2010	2.921E 08	-1.005E 08	-52.44	7.610E 06	-2.614E 06	-52.24	2.997E 08	-1.031E 08	-52.44
2011	3.177E 08	-1.260E 08	-65.78	8.289E 06	-3.280E 06	-65.55	3.259E 08	-1.291E 08	-65.77

INDOOR SPEECH INTERFERENCE

4.0 INTERPRETATION AND COMPARISON OF RESULTS

4.1 General Adverse Response Model

Section 3 of this report presented noise impact estimates for a specific scenario using the General Adverse Response Model. The user must always interpret the estimates considering all aspects of each scenario data base. This section considers the interpretation of three scenarios: (1) no regulation, (2) new medium- and heavy-duty truck regulations, and (3) a "future scenario". Additionally, prediction estimates for the baseline year are compared to the empirical results of the 100 Site Study.[1]

4.1.1 Interpretation of a Regulation Scenario

The results in Section 3 defined a noise regulation scenario for medium- and heavy-duty trucks, buses, and motorcycles. This regulation scenario is defined by the noise emission schedules presented in Tables 4.1 through 4.7* (pages 3-14 through 3-20). These schedules are used to define three scenarios representative of alternative noise emission regulations.

The "Baseline Scenario" assumes that no vehicle noise emission regulations are implemented. That is, all vehicle types are assigned the 1974 noise emission schedules presented in Tables 4.1 through 4.7 (pages 3-14 through 3-20). These noise emission schedules remain constant throughout the time stream.

The "Present Scenario" simulates the existing status under the promulgated noise regulation for new medium- and heavy-duty trucks (Including the in-use and new truck regulation). That is, all vehicle types except Types 8 and 9 exhibit noise emissions as defined for 1974 in Tables 4.1 through 4.7. Type 8 and 9 vehicles are assumed to follow the 1974, 1978,

*Table numbers refer to the numerical sequence used by the Model in presenting output data.

and 1982 noise schedules of Tables 4.4 abd 4.5*, respectively. Beyond 1982, however, the medium- and heavy-duty truck noise emission schedules remain at the 1982 values.

The "Future Scenario" comprises the noise regulation schedules presented in Tables 4.1 through 4.7 (pages 3-14 through 3-20). For this scenario, noise regulation of medium- and heavy-duty trucks, buses, and motorcycles is simulated.

The Model was executed for each of the above scenarios. Only the plotted output is presented and compared. The output of these three scenarios is superimposed to show the comparison.

Figure 4-1 presents the projected population growth of the United States from the baseline year (1974) to the end of the time stream (2013). This population growth applies to all scenarios described, and is based on the U.S. Bureau of Census Series I population projections.

Figure 4-2 presents a plot of the population exposed above L_{dn} = 55 dB for each of the scenarios for the 40-year time stream. This comparison indicates that population growth, as projected in Figure 4-1, will eventually result in an increasingly larger population noise exposure in future years relative to the baseline noise exposure. However, both the "Present" and the "Future" scenarios provide definite reductions in population exposure throughout the time stream relative to the "Baseline" scenario. As might be expected, fewer people are exposed above 55 dB for the "Present Scenario" relative to "Baseline" and still fewer people are exposed for the "Future Scenario".

Figure 4-3 presents the population exposure to roadway traffic noise above 55 dB as a percentage of the U.S. population in each year. Here it is seen that the "Baseline" Scenario results in an ever-increasing percentage of population exposure. Both the "Present" and the "Future" Scenarios, however, indicate that the percentage exposure may be expected

*See tabulations at the end of Section 3.

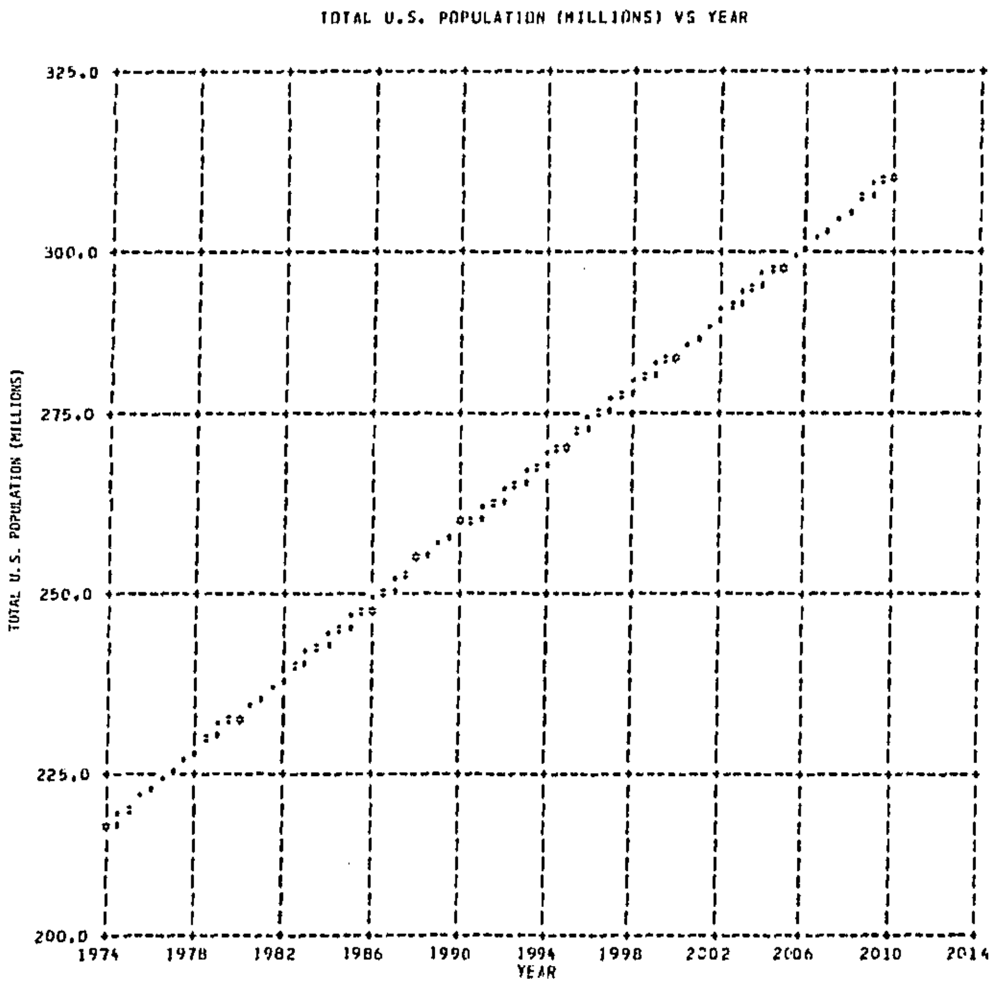


FIGURE 4-1 PROJECTED POPULATION GROWTH FOR COMPARISON SCENARIOS

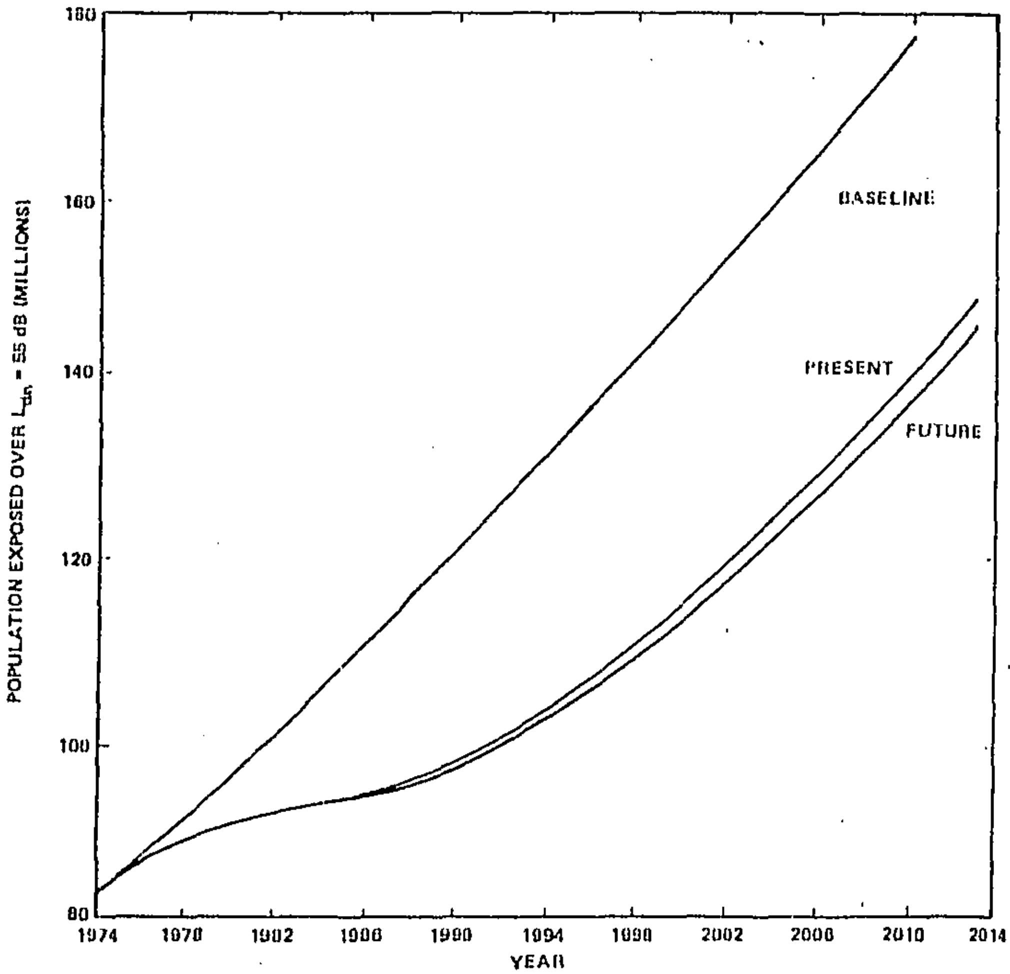


FIGURE 4-2 POPULATION EXPOSED ABOVE L_{dn} = 55 dB VERSUS YEARS OF THE TIME STREAM: COMPARISON SCENARIO

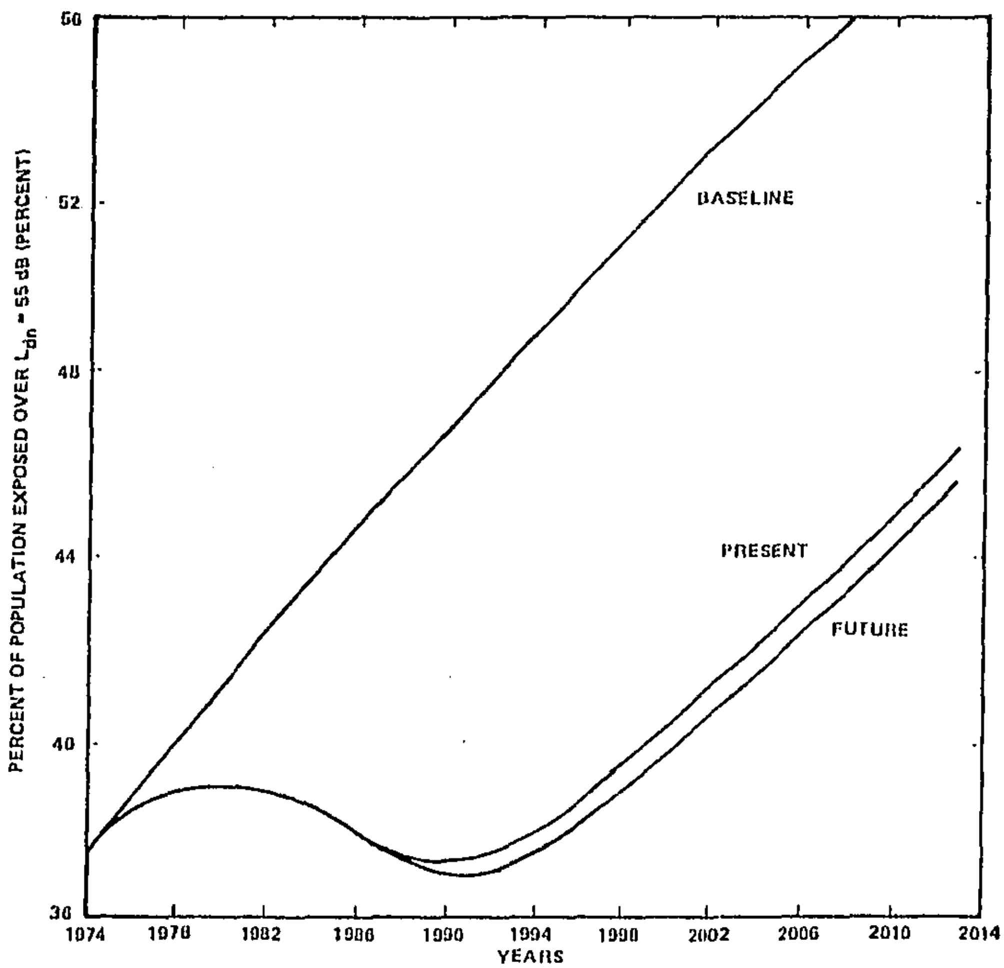


FIGURE 4-3 PERCENT OF U.S. POPULATION EXPOSED ABOVE L_{dn} = 55 dB VERSUS YEARS OF THE TIME STREAM: COMPARISON SCENARIO

to decrease from 1980, to reach a minimum about 1990 and then begin to increase. This result is, of course, dependent upon the regulation level, vehicle sales and attrition, and the allocation of truck traffic to the roadways (see Table 2-6, pages 2-30, 31; and Table 5, page 3-21).

Figure 4-4 compares the growth of Level Weighted Population (LWP) for the three time stream scenarios, as expected, it is similar in shape to Figure 4-2.

Figure 4-5 is a comparison of the Noise Impact Index (NII) for the three time stream scenarios. Being a percentage metric it is similar to Figure 4-3. This figure indicates that the "Future Scenario" would minimize the Level Weighted Population at about 11.1 percent of the 1990 projected population of the United States of 259 million people (see Table 6, page 3-22).

Figure 4-6 is a comparison of the change in Level Weighted Population (LWP) for the three time stream scenarios. The negative numbers indicate an ever-increasing value of the Level Weighted Population (LWP) relative to the baseline year of 1974. This figure is essentially a reflection about the time axis of Figure 4-4 with a zero value in 1974. The "Future" scenario indicates an absolute reduction in LWP of about 3.2 million people in 1990 (see Table 6, pages 3-22).

Figure 4-7 is a comparison of the Relative Change in Impact (RCI) for the three time stream scenarios. This is a percentage metric based upon Figure 4-6.

The results presented in Figures 4-2 through 4-7 indicate the noise exposure trends based upon the input data simulation for the three scenarios. In both absolute and relative terms, the population growth projection of Figure 4-1 eventually dominates the trends. Apparently, the noise regulation scenarios postulated can result in an improvement of population exposure to roadway traffic noise. As an additional consideration, it is necessary to

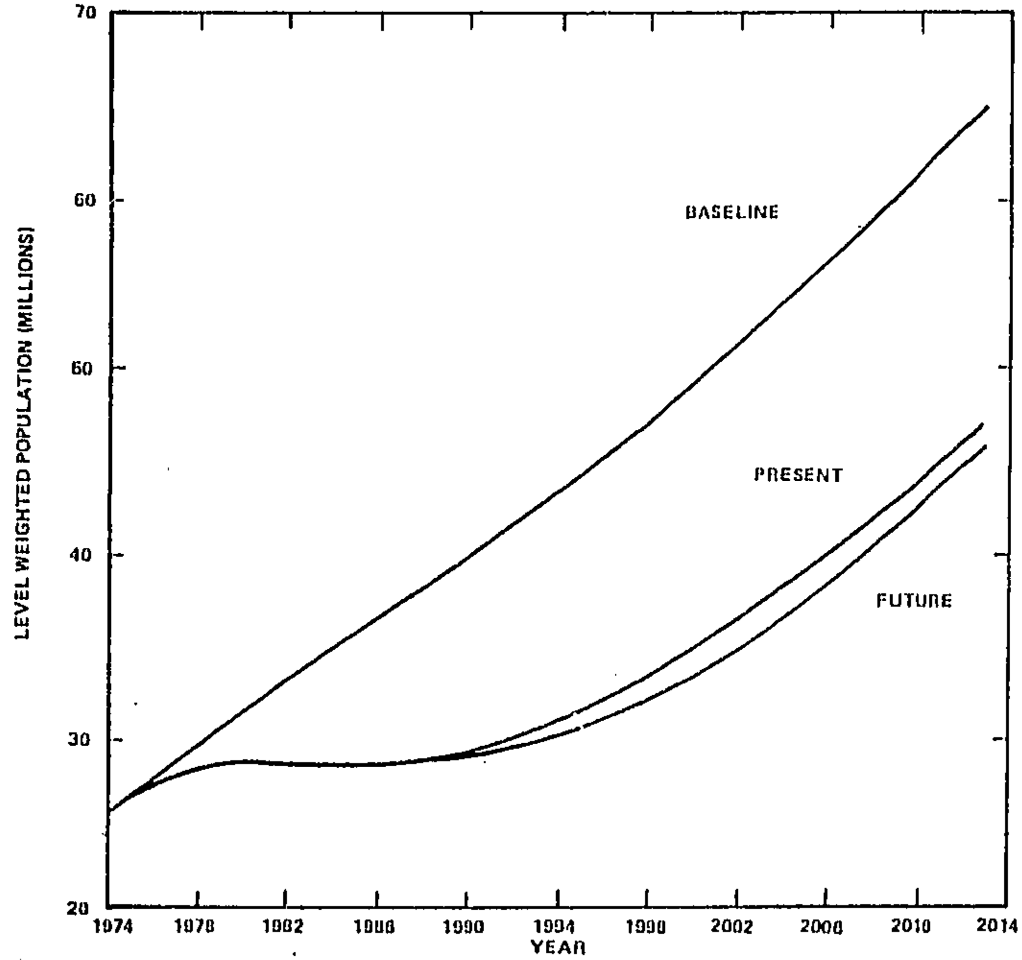


FIGURE 4-4 LEVEL WEIGHTED POPULATION VERSUS YEARS OF THE TIME STREAM: COMPARISON SCENARIO

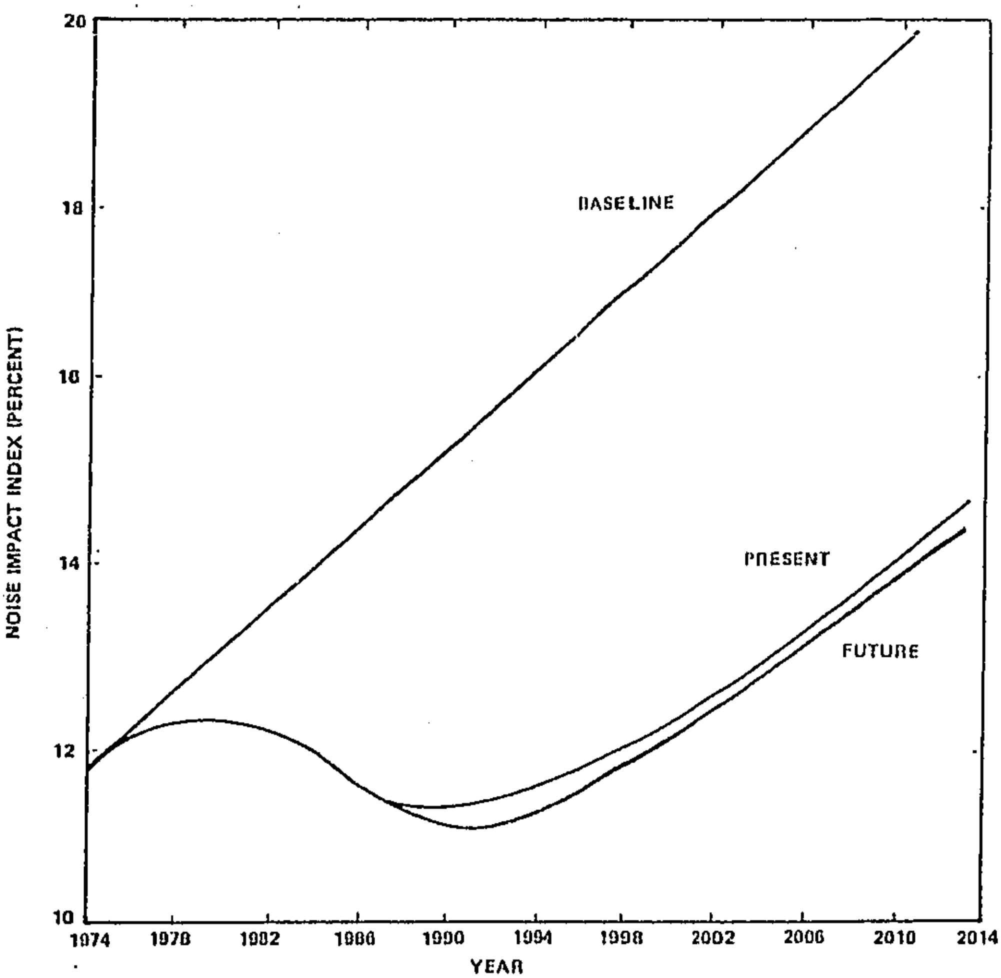


FIGURE 4-5 NOISE IMPACT INDEX VERSUS YEARS OF THE TIME STREAM: COMPARISON SCENARIO

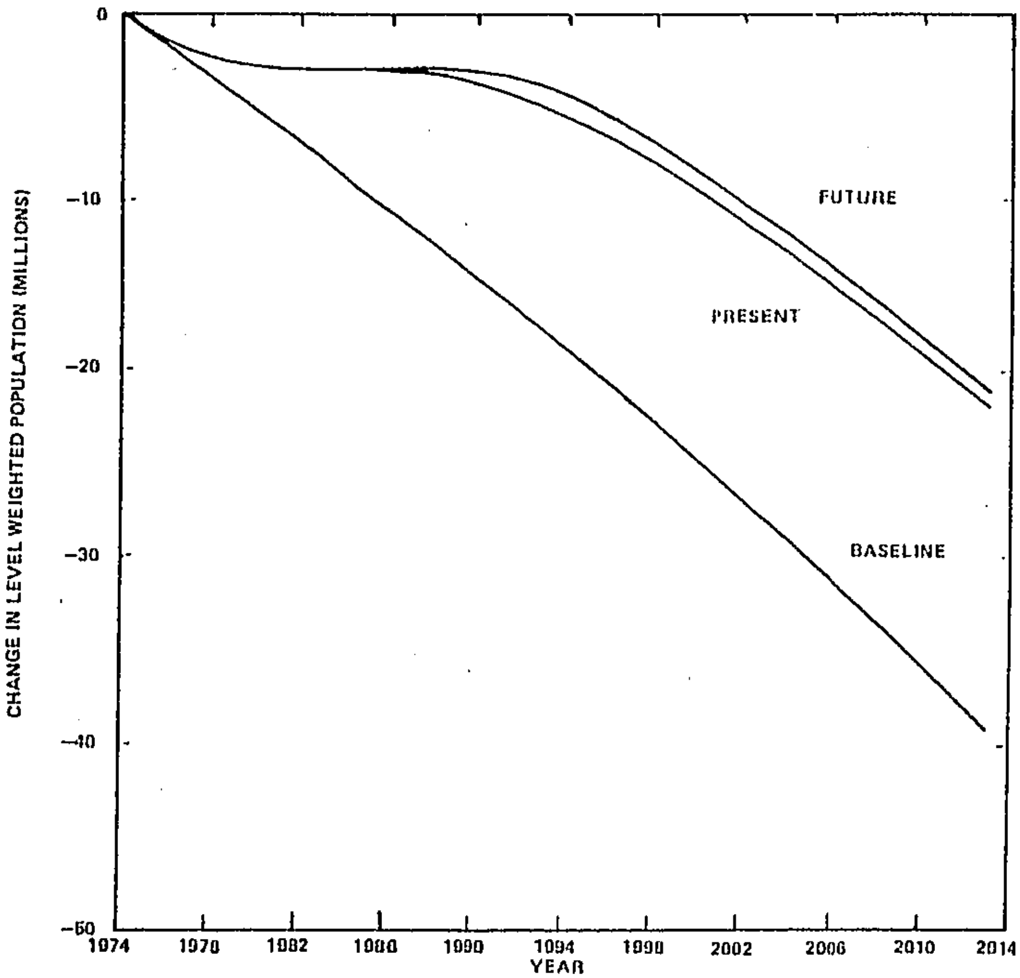


FIGURE 4-6 CHANGE IN LEVEL WEIGHTED POPULATION VERSUS YEARS OF THE TIME STREAM: COMPARISON SCENARIO

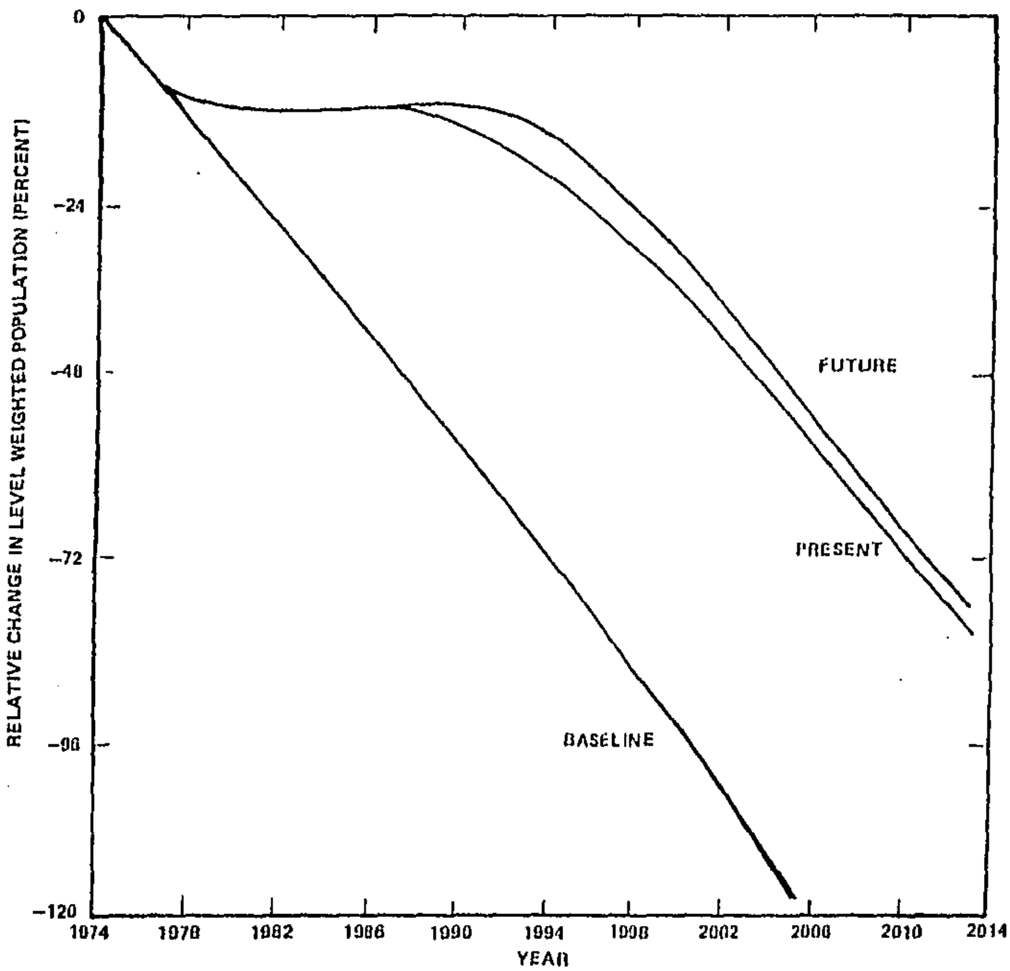


FIGURE 4-7 RELATIVE CHANGE IN LEVEL WEIGHTED POPULATION VERSUS YEARS OF THE TIME STREAM: COMPARISON SCENARIO

examine the noise levels at which the population is exposed. To consider the roadway traffic noise levels to which the population is exposed, one may utilize the estimates provided by the National Traffic Noise Exposure Model in Tables 9 and 10 (pages 3-25 and 3-36) of the output.

Using the Table 10 (page 3-26) estimates it is possible to develop the distribution of population with exposure level for any scenario. Figure 4-8 presents a comparison of the three scenarios on the basis of the cumulative distribution of population with day-night sound level. The vertical axis of Figure 4-8 is the cumulative population exposed to day-night sound levels greater than the L_{dn} values defined by the horizontal axis. The curve labeled "Baseline Scenario: 1974" represents the distribution of the 1974 population of 216.7 M with the day-night sound level. The curve labeled "Baseline Scenario: 2000" represents the distribution of the 2000 population of 285.11 M with day-night sound level. The curve labeled "Future Scenario: 2000" represents the distribution of the 2000 population assuming the defined noise regulations have been implemented.

For the "Baseline 1974" conditions, the population exposed above L_{dn} = 55 dB is estimated to be 81.78 M or 37.74 percent of the national population of 216.7 M. The estimated value of the Level Weighted Population in 1974 is 25.56 M. By the year 2000, it is estimated that the national population will have increased to 285.11 M. For the "Baseline Scenario: 2000," it is estimated that 148.48 M people will be exposed to sound levels above L_{dn} = 55 dB. This estimate represents 52.08 percent of the 2000 national population. The estimated value of the Level Weighted Population in 2000, assuming no noise regulations, is 49.84 M. Hence, for Baseline Conditions, the national population increases 31.57 percent between 1974 and 2000; the population exposed above 55 dB increases 81.56 percent; and the Level Weighted Population increases 94.99 percent.

For the "Future Scenario" in 2000, it is estimated that 113.16 M people are exposed above a day-night level of 55 dB. This estimate represents 39.69 percent of the 2000 national population. The estimated value of

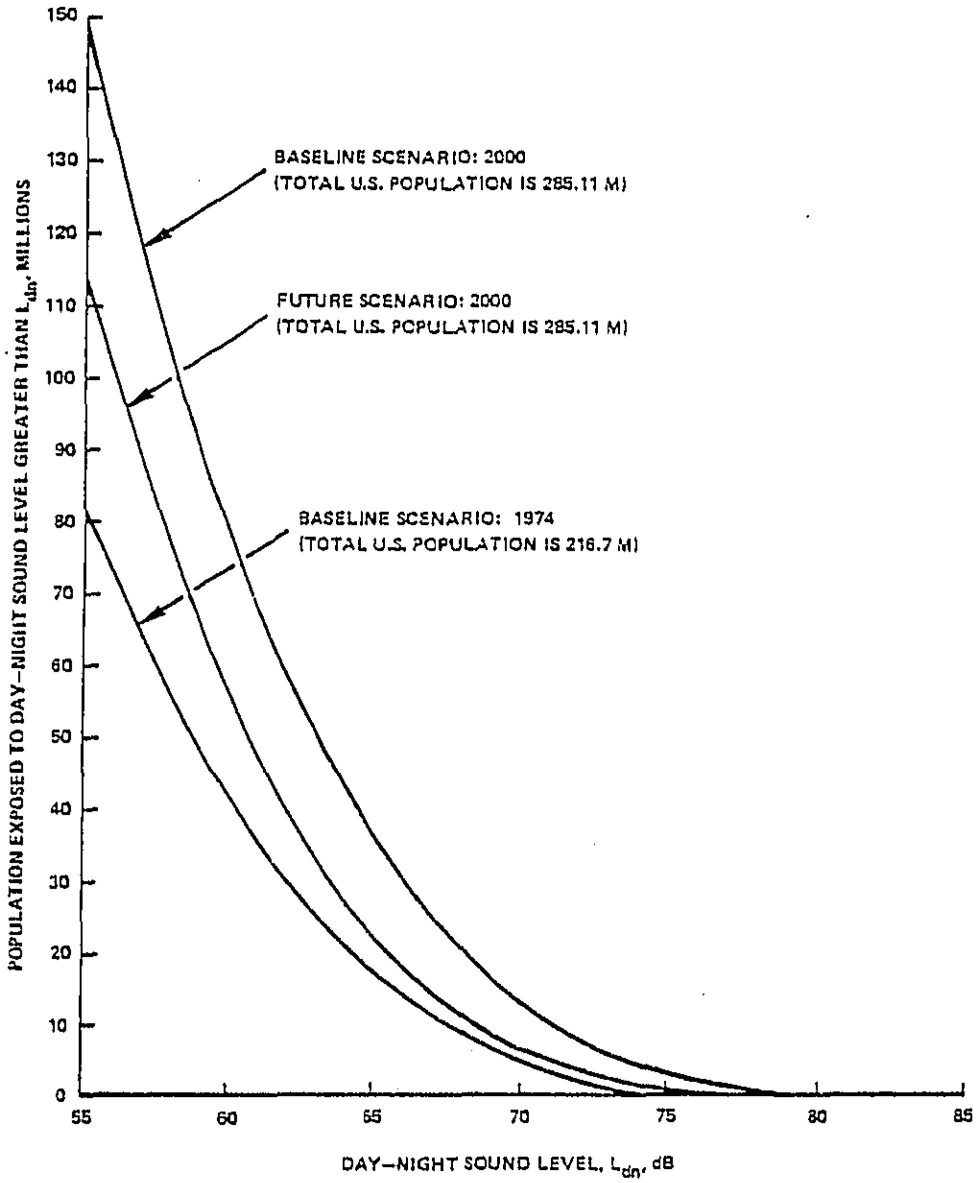


FIGURE 4-8 CUMULATIVE DISTRIBUTION OF POPULATION EXPOSED TO NOISE LEVELS GREATER THAN L_{dn}: COMPARISON OF BASELINE AND FUTURE SCENARIOS

the Level Weighted Population is 34.49 M. Hence, the "Future Scenario" estimates a 2000 noise environment slightly worse than the 1974 environment although both total population and vehicle usage have increased.

As indicated in Figure 4-8, the impact, in terms of the number of people exposed to day-night sound levels greater than 55 dB, for the "Future Scenario" is greater as compared to the 1974 Baseline due to the increase in population. For the "Baseline Scenario: 2000" the impact is significantly greater, as compared to the 1974 Baseline.

4.1.2 Comparison of the Model Predictions to the 100 Site Study

Figures 4-9 and 4-10 present a comparison of the baseline year (1974) population distributions to exposure sound level as estimated by the National Roadway Traffic Noise Exposure Model and the empirical results of the 100 Site Study.[1]

Figure 4-9 presents curves of the population exposed to values exceeding a given day-night sound level for the Model predictions and the 100 Site Study results. As indicated in the figure, the National Roadway Traffic Noise Exposure Model estimates that in 1974 the population exposed to roadway traffic noise greater than L_{dn} = 55 dB was 81.78 million with LWP = 25.56 million. The corresponding 100 Site Study results are: Population Exposed = 93.43 million and LWP = 34.22 million.

Figure 4-10 presents the distribution of population exposed above 55 dB with average annual day-night sound level. These results were obtained from the "dB band" estimates of the Model and values quoted in the 100 Site Study using the methodology of Reference 1. As indicated by the comparison of Level Weighted Population, the National Roadway Traffic Noise Exposure

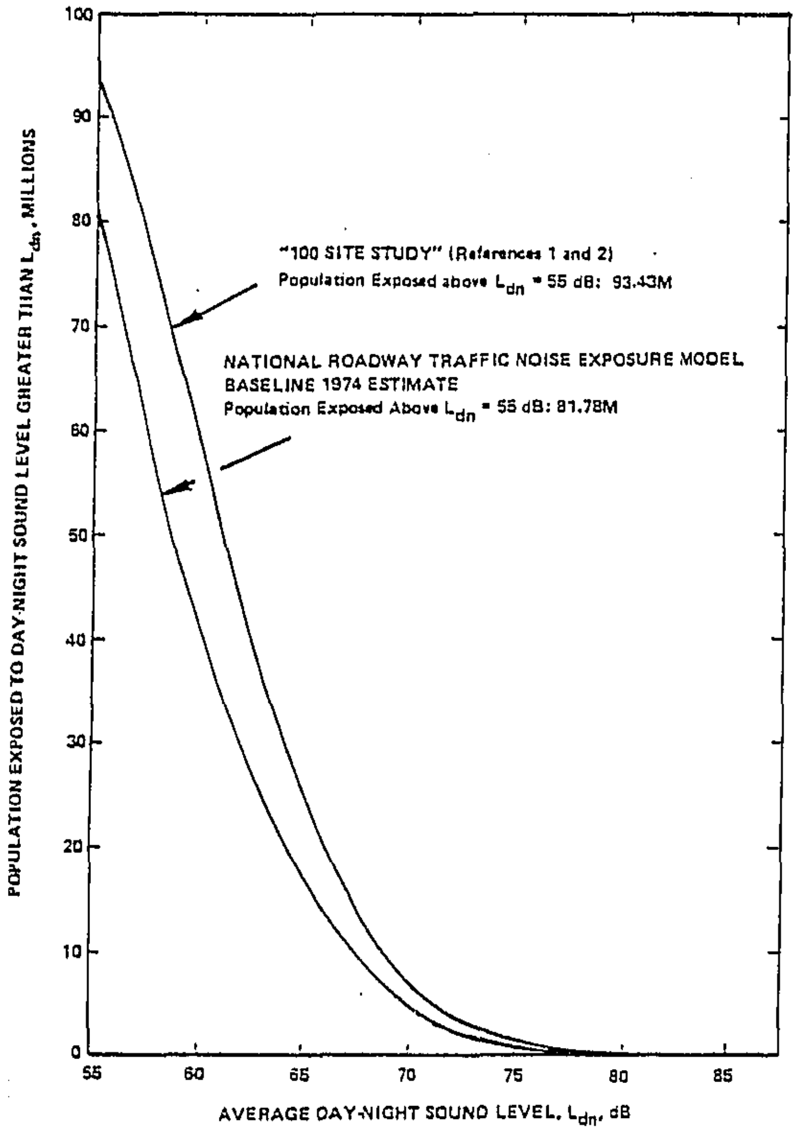


FIGURE 4-9 CUMULATIVE DISTRIBUTION OF POPULATION EXPOSED TO NOISE: COMPARISON OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL TO THE 100 SITE STUDY

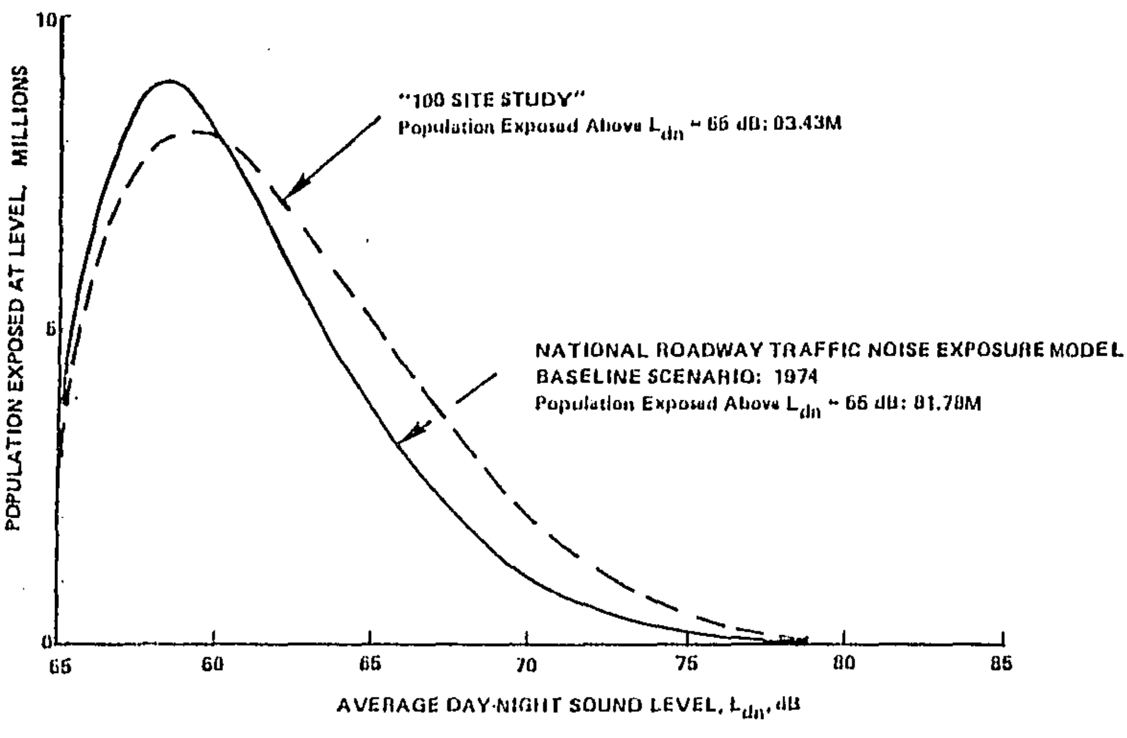


FIGURE 4-10 DISTRIBUTION OF POPULATION EXPOSED ABOVE L_{dn} = 55 dB IN EXPOSURE LEVEL: COMPARISON OF THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL TO 100 SITE STUDY RESULTS

Model estimates a population exposure at slightly lower exposure levels than the results quoted in the 100 Site Study; however, the results appear consistent.

It must be emphasized that the National Roadway Traffic Noise Exposure Model represents a defined estimation methodology resting on a consistent data base, while the 100 Site Study is an empirical result.

4.2 Single Event Model

4.2.1 Interpretation of Single Event Noise Estimates

The Single Event Model provides estimates of a vehicle's noise intrusiveness for a baseline year (1974) and for user-defined future years. These estimates are presented in both tabular format and plotted format. Additionally, both absolute estimates and percentage estimates of the noise effects are presented. The reader will immediately notice one salient aspect of the Single Event Model output when compared to the General Adverse Response estimates: Single Event noise impact estimates are much larger numbers than General Adverse Response estimates. The reason for this is simply that the Single Event estimates represent an accumulation of single intrusions on a national basis. For a single vehicle type the number of intrusions is usually a few percent of the Average Daily Traffic for a roadway. The ADT is typically a number on the order of 100 or 10^2. For a national population on the order of 200,000,000 or $2 \cdot 10^8$ the product of number of single events times national population is on the order of $2 \cdot 10^{10}$. The variation of the sound level of the population's noise exposure is a fraction (due to the Fractional Impact Methodology) between 0 and 1.0 and is hence on the order of 1/10 or 10^{-1}. Thus, the Level Weighted Population times the number of events is a number on the order of $2 \cdot 10^9$ or 2,000,000,000. Using a similar argument, the impacts determined from the General Adverse Response Model are numbers on the order of population times the Fractional Impact or $(2 \cdot 10^8)\ (10^{-1}) = 2 \cdot 10^7$.

Since the Single Event Model represents an accumulation of noise exposure estimates over many variables (see Figure 2-10 of this report) it is difficult to look at the estimates from as many viewpoints as is possible for the General Adverse Response Model. For example, the General Adverse Response Model provides the user with noise exposure estimates by place size (Index J), roadway type (Index K), and by level of noise exposure. The noise exposure estimates are provided both on the basis of population exposed and Level Weighted Population. The Single Event Model uses five noise exposure criteria to evaluate the effect of a vehicle's noise emissions and further classifies these criteria by daytime, nighttime, and 24-hour totals. Hence, ninety tabulations of estimates would be required to provide the user with <u>output</u> of single event noise exposure to the same level of detail as is standard practice for the General Adverse Response Model. It was felt that this level of detail would be too extensive to be of practical value.

To simplify the output problem for the Single Event Model, only national totals for the number of Level Weighted Population exposures are presented. These estimates are accumulated and presented, however, for daytime, nighttime, and 24-hour totals for each of the five single event noise exposure estimates conducted. When one is interpreting a scenario output, it must be constantly remembered that the estimates are national totals of the product of Level Weighted Population and the number of events estimated at each single event noise exposure level.

The condensed form of the output used by the Single Event Model does not, however, limit its flexibility. By using "masking" features described in the User's Manual, it is possible to conduct single event noise analyses that identify a vehicle's noise exposure effects down to the level of population place size (Index J) and roadway type (Index K). Hence, the flexibility of the National Roadway Traffic Noise Exposure Model is maintained for both the General Adverse Response Model and the Single Event Model.

4.2.2 Single Event Noise Exposure for Medium-Duty Trucks

Table 3-2, presented at the end of Section 3, is a listing of both the tabulated and plotted data of a typical single event noise exposure scenario. The vehicle type being considered is a medium-duty truck (Type 8 vehicle). From the listings presented in Table 3-1 in Section 3, it is seen that the scenario presented here stipulates an increase in future years of both medium truck population and inhabitant population. By the year 2013, the medium truck population will increase by a factor of 2.5 and the inhabitant population will increase by a factor of 1.4. Since the medium truck noise emissions do not decrease significantly, it may be expected that by the year 2013 single event noise exposure estimates for this scenario will all increase by a factor on the order of (2.5) (1.4) = 3.5 above the baseline year (1974) estimates.

Table 5.1* presents the single event sleep distruption estimate for medium-duty trucks for every five years between 1974 and 2013. As indicated in the tabulation, estimates are presented for the daytime, nighttime, and the 24-hour total. The estimates are Level Weighted Population (LWP) times the number of events at each exposure level accumulated over all exposure levels. For 1974, it is estimated that the LWP is $5.937 \cdot 10^8$ and that for the year 2013 the LWP is $1.933 \cdot 10^9$. To help in interpreting these results, the following tabulation is presented for the average daily estimates:

Year	Sleep Disruption LWP	Vehicle Population	Inhabitant Population	LWP per Vehicle	LWP per Person
1974	$5.937 \cdot 10^8$	$2.41 \cdot 10^6$	$2.167 \cdot 10^8$	246.3	2.74
2013	$1.933 \cdot 10^9$	$5.96 \cdot 10^6$	$3.109 \cdot 10^8$	324.33	6.22

*Table numbers refer to the computer-printed table numbers for output listed in Table 3-2 at the end of Section 3.

These results indicate that, on the average, one medium truck operating in 1974 completely disrupts the sleep of 246 people per day and in 2013 is estimated to disrupt the sleep of 324 people per day.* Alternately, in 1974 each person is estimated to have their sleep disturbed approximately three times per day and in 2013 the average number of sleep disruptions rises to 6.2 per day. As indicated in the first paragraph of this section, due to increases in both vehicle operations and inhabitant population, one would expect the baseline estimate to increase by a factor on the order of 3.5 by the year 2013. For sleep disruption, the LWP in the year 2013 is 3.26 times the baseline year estimate. This comparison illustrates the sensitivity of the Single Event Model to parameter variations related to vehicle and inhabitant population projections.

As indicated in Table 5.1, the Single Event Model provides the user with the Level Weighted Population (LWP) estimate and two additional parameters: DLWP and RCI. These parameters are estimated for the daytime, nighttime, and the 24-hour total. The parameter DLWP is the change or "delta" in the Level Weighted Population relative to the 1974 estimate of the LWP. A negative value of DLWP indicates that the noise exposure is increasing. The Relative Change in Impact or RCI is the DLWP value divided by the 1974 LWP estimate. The RCI is expressed as a percentage. If the RCI value is negative, the noise exposure has increased by the indicated percentage above the baseline year (1974) estimate.

Table 6.1 presents the sleep awakening LWP for the defined medium truck scenario. The interpretation of the outputs in Table 6.1 is similar to that discussed above for sleep disruption. From the Table 6.1 estimates it is seen that the 2013 LWP is 3.25 times the 1974 estimate. Further, the 1974 estimate corresponds to an average of 129 sleep awakenings per day per medium truck or 1.4 sleep awakenings per day per person.* For the year 2013

*On an equivalent or level weighted basis.

these averages are 169 sleep awakenings per day per medium truck or 3.2 sleep awakenings per day per person.

As described in Section 2 of this report, the sleep disruption and sleep awakening estimates apply to the same segment of the population (i.e., people asleep). The other estimates of single event noise intrusion, however, apply strictly to individual segments of the population.

Table 7.1 presents the indoor speech interference LWP for the defined medium truck scenario. The format of this tabulation is identical to that described for the sleep interference estimates in Tables 5.1 and 6.1. From this table it is seen that the indoor speech interference is dominated by the daytime contribution. Considering the population's average daily activity as presented in Figure 2-6, the indoor speech interference is based upon the segment of the population engaged in "Other Activities". As indicated in Figure 2-6, 73.8 percent of the national population is engaged in "Other Activities" during the day and only 12.9 percent is so engaged during the night. Additionally, medium trucks are assumed to operate 87 percent during daytime hours and 13 percent during nighttime hours (see Equation (2-9)). Hence, during the daytime a majority of the population is allocated to the activity related to indoor speech interferences and the vehicles operate predominately during the daytime. Based upon the 1974 estimates of 2.41 M medium trucks and a national population of 216.7 M people, the LWP estimate for 1974 given in Table 7.1 corresponds to an average LWP of 11.9 indoor speech interferences per day per vehicle or an average LWP of 0.1 indoor speech interference per day per person. For the year 2013, the corresponding average LWP values are 15.5 indoor speech interferences per day per vehicle or 0.3 indoor speech interference per day per person. In estimating the indoor speech interference, the indoor value of L_{eqT} is obtained from the outdoor level less the building exterior skin noise reduction. The noise reduction values used are presented in Table 2-9.

Table 8.1 presents the outdoor speech interference estimates for medium duty trucks. This estimate applies to the segment of the population engaged in activities outside their homes. As indicated in Table 8.1, no outdoor speech interference is estimated for the nighttime period from 2200 hours to 0700 hours. The reason for this is that no population is assigned to the activity category "Outside Home" during the nighttime. The interpretation of this table is identical to that discussed above for Tables 5.1 through 7.1.

Table 9.1 presents the pedestrian speech interference estimates for medium-duty trucks. This estimate is based upon the primary exposure of the pedestrian population. Pedestrians are assumed to be located along the roadways at the edge of the clear zone. The pedestrian population is estimated as a fraction of the working population as described in Section 2 and Appendix B of this report.

The tabulated data discussed above represents the national totals for each particular single event noise metric. In order to provide the user with additional descriptive information, the distribution of the single event LWP values with the single event sound level metrics is also presented.The distribution is provided in 5 dB bands for Sound Exposure Level (SEL) for sleep distruption and sleep awakening intrusions and in 5 dB bands of the single event equivalent sound level (L_{eqT}) for speech interference intrusions. Tables 10.1 through 14.1 in Table 3-2 present the dB band distribution of LWP values for the indicated activity interference. These distributions are for the 24-hour total single event noise exposure. That is, summing the dB band data over all the indicated bands yields the corresponding 24-hour estimates for each year. For example, summing the dB band estimate for sleep disruption in 1974 (Table 10. 1), one obtains a total 24 hour sleep disruption LWP of $5.937 \cdot 10^8$. In Table 5.1, the 24-hour sleep disruption is identically equal to this value. The discussion in Section 2.7 concerning primary and secondary noise exposure may assist the reader in interpretation of the dB band data for any particular vehicle type.

The reader should note that the dB band data are numbered as well as identified by an absolute level range. For example, band 15 always corresponds to the range 55 to 60 dB. The reason for this is that the user may desire to alter the single event noise exposure cut-off criteria for any metric. Altering the cut-off criterion may shift the lowest dB band interval printed in these tables. The LWP estimate presented in the lowest band is the result of all exposures equal to or greater than the cut-off criterion. For example, if the cut-off criterion was set at 57 dB for a metric, the LWP estimate given in the 55 to 60 dB band would include only those single event exposures from 57 to 60 dB. The cut-off criterion is based upon an assumed relationship for "masking" of the intruding sound by the ambient sound. This topic is discussed in Section 2.6.2 of this report.

Comparing the distributions of Tables 12.1 and 13.1, it is seen that the highest dB band for outdoor speech interference is band 12 (70 to 75 dB) and the highest band for indoor speech interference is band 16 (50 to 55 dB). The 20 dB difference is attributable to the building exterior skin noise reduction values assigned as indicated in Table 2-9. Further, the lower limit for outdoor speech interference is based upon an ambient of 55 dB and the lower limit for indoor speech interference is based upon an ambient of 45 dB.

Table 14.1 presents the distribution of pedestrian speech interference values for medium truck operations as defined for the scenario. Here it is seen that the highest level band corresponds to the 70 to 75 dB range. For any vehicle type, the highest level dB band indicated for pedestrian speech interference represents the highest exposure levels predicted by the model since pedestrians represent the segment of the population placed closest to the noise source.

The final listings presented in Table 3-2 represent computer line plots of the data presented in Tables 5.1 through 9.1. These plots are the 24-hour LWP and RCI estimates versus years of the time stream. These ten plots are a standard output option of the Single Event Model. However, as described in the User's Manual, the years specified for output estimates must be uniformly spaced over the time stream to obtain reasonable interpolations between calculated points.

The plots in Table 3-2 are rather unimpressive. Each plot is a continuously increasing curve of impact measure versus year. This result was anticipated at the beginning of the discussion since the vehicle noise emission levels for medium trucks did not change significantly due to the stipulated noise regulation scenario. The following scenario dealing with heavy-duty trucks, however, indicates more interesting results.

4.2.3 Single Event Noise Exposure for Heavy-Duty Trucks

Table 3-1 in Section 3 presents the tabulated output defining the basic scenario for the heavy-duty truck analysis presented in Table 3-3. The user-defined noise emission schedules correspond to the existing status under the promulgated noise regulation for new heavy-duty trucks (including the in-use regulation).

The noise emission schedule presented in Table 3-1 indicates a rather significant noise reduction due to the simulated regulation, especially when compared to the medium truck levels. Hence, it is expected that the noise exposure estimates will vary with year of the time stream more drastically than was the case illustrated for medium trucks. Since a single scenario is presented for heavy-duty trucks, it is not possible to compare the regulatory benefits with a "do nothing" baseline scenario. The intention here is to present typical prediction outputs of the Single Event Model rather than judge the value or benefits of a particular noise regulation scenario.

Table 3-3 presents the single event noise analysis for heavy-duty trucks. Tables 5.1* through 9.1 of the output present the single event LWP and RCI estimates for each defined year in the time stream. The interpretation of these results is identical to the disucssion for the corresponding metrics for medium-duty trucks presented in Section 4.2.2. However, it is noticed that each LWP metric reaches a minimum impact value around the year 1990. As indicated in the noise emission schedule for heavy-duty trucks, the

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*Table numbers refer to the computer-printed table number for output listed in Table 3-3 at the end of Section 3.

first stage of noise regulation is implemented in 1978 and the final stage in 1982. From the Model's data base the estimated mean life for trucks is 10.4 years and the age for 100 percent attrition is 19.1 years. Hence, about 23 years after the beginning of the time stream (1997) all heavy-trucks are essentially "regulated vehicles" with the older (and noisier vehicles) having been removed from the streets. Thus, in 1997 the population first sees a heavy-duty truck fleet comprised totally with "regulated vehicles." In the year 2002, the heavy-duty fleet has been replaced totally with vehicles exhibiting the lower 1982 noise emissions. Hence, around the year 2000, the total benefit due to the regulation has been achieved and the noise impacts increase monotonically due to projected increases in both vehicle fleet size and inhabitant population.

The distribution of single event LWP by dB bands of exposure level is presented in the output tables numbered 10.1 through 14.1 for the heavy-duty truck estimates of Table 3-3. By reviewing this estimate of LWP by dB bands, the estimated significance of vehicle noise control is realized. For all single event noise metrics, the noise regulation scenario defined for heavy-duty trucks results in removing population from exposure in the highest dB band. That is, the source noise control (which is on the order of 5 dB) results in an estimated reduction in population exposure (which is also on the order of 5 dB).

The remainder of Table 3-3 presents the plotted LWP and RCI outputs for each of the five single event noise metrics. These outputs correspond to the 24-hour single event estimates of Tables 5.1 through 9.1. The time stream plots are provided to assist the user in evaluating the significance of a noise reduction scenario.

4.3 Ranking of Vehicles as Noise Sources

One obvious use of the National Roadway Traffic Noise Exposure Model is to estimate the ranking of vehicle types as individual sources of environmental noise. To do this, both the General Adverse Response Model and the Single Event Model are used. Only baseline year 1974 results are discussed for this example. However, one could just as well use future years to illustrate the rankings and/or changes in ranking due to noise regulations.

In order to rank vehicles as noise sources, the individual vehicle's noise effects are required. Further, the ranking must be related to the measure of the noise effects. In order to be consistent, it was decided to use the Level Weighted Population (LWP) as the measure of the vehicle's noise effect. Using this approach, both the General Adverse Response Model and the Single Event Model were executed using each vehicle type. Outputs of these 28 runs were assembled so that the 14 vehicle types were categorized based upon the general adverse response LWP and the five single event LWP noise metrics. Recognizing that the single event LWP estimates are highly dependent upon the vehicle's total useage and population, it was decided to rank the vehicles on the basis of LWP per vehicle. That is, the LWP value estimated for each vehicle and each metric was divided by the vehicle's population. The results of this estimate are presented in Table 4-1.

The format of Table 4-1 ranks vehicle types using the vehicle index I. The correspondence between the vehicle index and the engineering characteristics of the vehicle are presented in Table 2-4. The ranking places the most intrusive vehicle as first (1ST) and the least intrusive as last (14TH). As indicated, in Table 4-1, heavy-duty trucks (Type 9 vehicles) rank consistently as the most significant noise source on the national roadway network. (This position is also held by heavy-duty trucks in terms of the absolute LWP). With the exception of the general adverse response LWP (based on L_{dn}), the four vehicle types that are highest ranked are: heavy-duty trucks, medium-duty trucks, transit buses, and modified motorcycles. Diesel light vehicles (Type 7) exhibit rather high noise emission levels but comprise the smallest segment of the national vehicle fleet. Hence, based upon an LWP per vehicle, they rank rather high in the single event simulation but rank as insignificant in the general adverse response simulation.

TABLE 4-1

RANKING OF VEHICLE TYPES AS NOISE SOURCES
(Baseline LWP Values Divided by Baseline Vehicle Population)
(See Table 2-4 for Vehicle Nomenclature)

	VEHICLE RANK AS A NOISE SOURCE													
CRITERIA FOR NOISE IMPACT	1ST	2ND	3RD	4TH	5TH	6TH	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH
SLEEP DISRUPTION	9	8	14	6	13	1	5	11	2	10	4	3	12	7
SLEEP AWAKENING	9	8	14	6	13	1	5	11	2	10	4	3	12	7
INDOOR SPEECH INTERFERENCE	9	5	8	14	6	1	13	2	11	4	3	7	10	12
OUTDOOR SPEECH INTERFERENCE	9	8	1	6	5	14	2	13	4	11	3	7	10	12
PEDISTRIAN SPEECH INTERFERENCE	9	1	8	6	5	2	13	4	14	11	3	10	12	7
GENERAL ADVERSE RESPONSE	9	14	8	1	6	5	2	13	4	(3, 7, 10, 11, 12)*				

* Impact too low to rank these vehicle types

A detailed discussion of the ranking indicated in Table 4-1 is beyond the scope of the present example. To understand why certain vehicles are ranked differently by different noise criterion would involve consideration of the LWP distribution with the noise exposure level and the population's primary and secondary exposure. However, the ranking of vehicle types, as presented in Table 4-1, does indicate that generally, trucks, buses, and motorcycles are <u>predicted</u> to be the noisier roadway traffic sources. This prediction is based upon the National Roadway Traffic Noise Exposure Model simulation and appears to agree with the public's opinion of the noise annoyance attributable to various categories of vehicles.

4.4 REFERENCES

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APPENDIX A

DATA BASE DESCRIPTION

This appendix describes the common data base used by both the General Adverse Response Model and the Single Event Model. It documents the sources used, analyses conducted, and the explicit results which comprise the complete data base for the National Roadway Traffic Noise Exposure Model.

A.1 Organization of the Data Base

The organization of the data base for the National Roadway Traffic Noise Exposure Model is directly related to the computational structure of the computer codes. Data elements are identified by subscripted arrays. Each subscript denotes one of the basic physical parameters used by the Model to simulate national noise exposure to roadway traffic noise. Basically, the organization of the data comprises three distinct groups:

- Population Data,
- Roadway and Traffic Data, and
- Vehicle Data.

Implicit in the above groupings is the time variation of the data. That is, the Model varies population, traffic, and vehicle data in future years in a defined fashion using time stream data. For example, the Model uses statistical projections for the national population in future years to simulate population growth. The population growth is defined by input data so that future population is estimated on an annual basis. The Model uses a baseline year in which all parameters are defined by explicit values. The baseline year is 1974. All time variations of the data are taken relative to the baseline year value.

The subscripts used by the computer codes to organize and manipulate the data correspond to physical conditions. For each of the three basic data groups defined above, the specific subscripts or indices used are as follows:

- Population Data:
  - Index J, Population Place Size (Nine categories)
  - Index ID, Population Density Range (Four categories)
- Roadway and Traffic Data
  - Index K, Roadway Classification (Six categories)
  - Index L, Average Travel Speed (Five categories)
  - Index M, Vehicle Operating Mode (Four categories)
- Vehicle Data:
  - Index I, Vehicle Type (Fourteen categories)

Each year in the time stream is denoted by the index IYRN. The current version of the Model allows the user to estimate conditions for 40 consecutive years from the baseline year of 1974.

As an example of the structure of the data base, reference vehicle noise emission characteristics are dependent upon vehicle type (I), vehicle operating mode (M) and average travel speed (L). Hence, to characterize completely the reference noise emissions from all vehicles types one must define, as a minimum, 280 noise emission levels (14 x 4 x 5 = 280). Further, the Model allows the user to define noise emission characteristics for each vehicle type for future years to simulate a noise emission regulation. Currently, the user must define levels for the baseline year (1974) and may optionally define levels for four future years for each vehicle type. Hence, the current version of the model allows the user to define 1400 distinct noise emission characteristics to simulate a noise regulation scenario. If the user desires, either an equivalent continuous noise level, L_0^{eq}, or a vehicle population mean level, $\bar{L}$, and standard deviation, σ, may be used. For the latter simulation, the user may define 1400 reference mean levels and 1400 corresponding standard deviations.

The following sections of this appendix describe the detail data base. In particular, the structure of the elements of the data base are emphasized. This approach is taken since elements of the data base are related through common subscripts or indicies. Hence, the user must recognize this relationship and the model formulation to appreciate the characteristics of the current data base and to expand an/or revise elements of the data base in the future.

A.2 National Population Data

The National Roadway Traffic Noise Exposure Model defines combinations of population, land area, roadway mileage, and traffic conditions to simulate the traffic noise environment and the noise exposure of the United States' population. The accurate simulation of these conditions requires that data be related in combination to reflect the national condition. Indeed, the structure of the national population data as described here, is based upon the functional classification of roadways used to define the roadway mileage and travel data base.

As described in Section A.3, the data base assembled by the U.S. Department of Transportations' Federal Highway Administration[1,2,3] provided the basis for allocation of population and land area to the appropriate roadway traffic conditions. Reference 1 contains detailed information concerning roadway mileage, travel data, and land areas related to population place size. Further, the Reference 1 data accumulated on a national basis, the population and land areas allocated to the FHWA functional classification of roadways. The FHWA data base[1], was subdivided to a further level of detail to define, by functional roadway classification and by average population density adjacent to the roadways, the distribution of mileage, travel, and average travel speed by population place size. This data subdivision or sorting was performed by the staff of the Procedural Development Branch, Program Management Division of the Federal Highway Administration. This task was performed by FHWA at the request of the EPA/ONAC staff and involved a resorting of the original NHIPS* data[1] by population density groupings and speed range groupings. Further, the FHWA data sorting identified roadway mileage and travel through vacant land contained in urban areas. Hence, the data base was established so that roadway traffic conditions could be defined by functional classification, average travel speed, population place size and population density.

A.2.1 Distribution of National Population

Although the FHWA data sorting grouped all of the roadway and traffic parameters according to population place size and population densities, the distribution of the population and population densities was not detailed. First, the FHWA population density data used to conduct the sorting were defined in terms of total population and total land area, aggregated on a national basis. As a result, the population density data generally appeared to be too low compared with the U.S. Bureau of Census data.[4] For example, the FHWA data estimated the maximum population density for all urban areas to be on the order to 6,000 people per square mile.[1] The Census data[4] indicated that over 25 percent of the urban population resides in urban areas characterized by population density values greater than 6,000 people per square mile. Hence, it was necessary to refine the population density estimates for the data groupings.

In order to refine the population density data on a consistent basis with the group FHWA roadway and traffic data census data[4] from 1970 were used. The link between the Bureau of Census data[4] and the FHWA data[1] was the definition of the "urban place size".

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*National Highway Inventory and Performance Study

The FHWA data grouped roadway and travel characteristics by nine categories of place size. Eight of these categories are used to describe urban areas and one category is used to describe rural areas. The total urban population for this data set is 152.52 M people residing in a total land area of 72,674.2 square miles in the baseline year 1974. The average urban population density is 2,099 people per square mile. The total rural population in 1974 is 64.18 M people residing in a total land area of 3,476,938 square miles. The average rural population density is 18 people per square mile.

Since the urban population densities could be refined using census data, it was decided to focus attention upon the distribution of urban population and urban land area and to consider rural areas to be homogeneous with an average population density of 18 people per square mile.

As emphasized in Section A.1, all data used in the Model are arrayed using subscripts or indices denoting a physical parameter. The index "J" is used in the Model to denote the population place size category. As used by the Model, the nine population place sizes are related to the index J as follows:

Population Place Size Category	Index, J
Population over 2 M	1
Population from 1 M to 2 M	2
Population from 500 k to 1 M	3
Population from 200 k to 500 k	4
Population from 100 k to 200 k	5
Population from 50 k to 100 k	6
Population from 25 k to 50 k	7
Population from 5 k to 25 k	8
Rural Population	9

With the above categories of population place size, it is necessary to always distribute the population and the land area on a consistent basis.

In order to refine the population density distributions for each population place size as aggregated by FHWA, the various data classifications used by the Bureau of Census[4] were reviewed. As a result of this review, the urban population place size as defined in Table 20 (pp 1-74 through 1-86) of Reference 4 appeared to correspond most closely with the FHWA place size definition. That is, the place size is defined by the population and the land area contained in a contiguous geographic area rather than, for example, an area defined by a legal boundary such as city limits.

The Bureau of Census Table 20 data[4] for 1970 were stored on a computer file so that both population and land area could be sorted by alternative definitions of place size and alternative definitions of population density groups. In total, this data comprises 560 distinct sets of population, and land area to distribute over place size and population density.

A.2.1.1 Urban Population Distribution

The Bureau of Census Table 20 data allowed definition of population and land area to a level of "inside central city" and "outside central city." For example, the Norfolk-Portsmouth, Virginia data are classified as indicated in Table A-2.1. To distribute this data, the total place size is 668,259 people with the population densities distributed as 1,147 (outside central cities); 3,826 (Portsmouth); and 5,855 (Norfolk).

The corresponding FHWA data[1] indicate a 1975 population of 728,280 people in 630 square miles for the Norfolk-Portsmouth, Virginia area. The average FHWA population density for this area is 1,156 people per square mile. Hence, it is seen that the FHWA data contain more land area for this place size than the Census data, but the total place size would be grouped in the 500 k to 1 M range (J=3) for either data set. Further, it is seen that the average FHWA population density of 1,156 corresponds reasonably well with the "outside central city" value of Table A-2.1. Hence, it was decided to distribute the Bureau of Census Table 20 data on the basis of total urban place size for purposes of comparisons with the FHWA data. Since the Census

TABLE A-2.1

EXAMPLE OF POPULATION, LAND AREA, AND POPULATION DENSITY SORTING: BUREAU OF CENSUS TABLE 20 DATA
(Reference 8 page 1-81)

Tabulated Census Data

Area	Population (1970)	Land Area Sq. Mile	Population Density
Norfolk - Portsmouth Va.	668,259	299.0	2,235
Inside Central Cities	418,914	81.6	5,154
Norfolk	307,951	52.6	5,855
Portsmouth	110,963	29.0	3,826
Outside Central Cities	249,345	217.4	1,147

Sorted Census Data

Place Size 668,259

Area	Population (1970)	Land Area Sq. Mile	Population Density
Norfolk	307,951	52.6	5,855
Portsmouth	110,963	29.0	3,826
Outside Central Cities	249,345	217.4	1,147
Total	668,259	299.0	2,235

data corresponded to 1970 and the FHWA data correspond to 1975, the distribution was accomplished on a percentage basis rather than on an absolute basis.

For both the FHWA data and the Census data, the urban population values were sorted by population place size and grouped into intervals of population place size. For this sorting, a logarithmic function was used in the form:

$$\text{Urban Place Size:} \quad x = 10\log(P/62.5). \qquad \text{(A-2.1)}$$

That is, all place size data were normalized to an urban place size of 62.5 thousand people. In grouping the data, equal intervals of $\Delta x = 3$ were used, i.e., each place size was grouped into intervals such that the higher limit of each interval was twice the lower limit of the interval. The reason for doing this was the large range of urban place sizes being considered. The result of this analysis was to develop histograms for urban population for the urban place size metric indicated in Equation A-2.1.

These histograms were then used to derive continuous functions of percentage distribution of urban population as a function of the urban place size metric, x. The technique used to develop these continuous distributions is described in detail in Reference 5. The rationale for using this approach was to compare the two population distributions with urban place size to indicate similarities and differences. It was expected that the two distributions would be different since the FHWA data grouped places from 5 k to 10 M population and the Table 20 Census data grouped places from 50 k to 16.2 M population.*

*New York City is a problem. Based upon the total place size as given in the Table 20 Census data, the New York area has a population of 16.2 M. Hence, the Table 20 data is weighted towards larger urban place sizes.

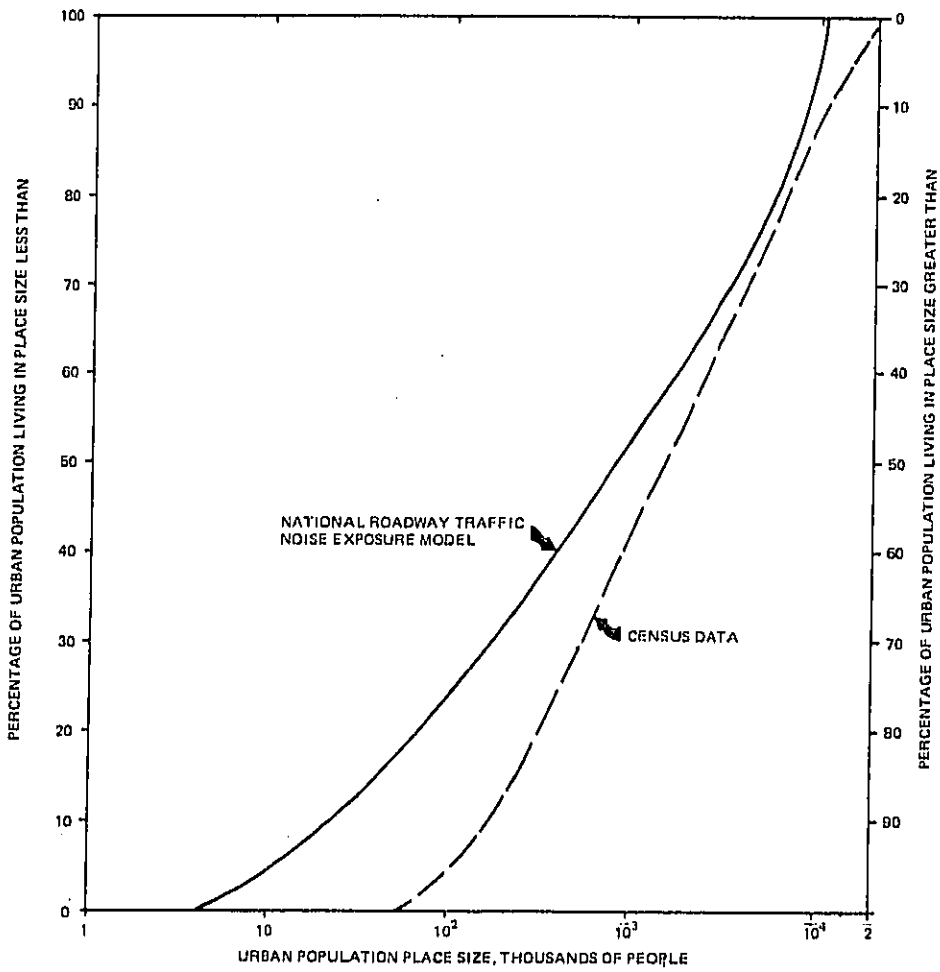


FIGURE A-2.1. COMPARISON OF FHWA AND CENSUS DISTRIBUTIONS OF URBAN POPULATION WITH URBAN PLACE SIZE

The distribution functions or frequency curves from the national urban population were integrated numerically to obtain cumulative distribution curves. This result is presented in Figure A-2.1. As expected, the cumulative distributions presented in Figure A-2.1 do not exactly agree. However, for the large urban place sizes (above 1 M population) the two curves agree reasonably well. Hence, for the purpose of refining the population density estimates for the FHWA data, it was assumed that distributions of population density for urban areas of a given place size, as defined by the Table 20 Census data, would apply equally to the FHWA place size description.

A.2.1.1 Urban Area Distribution

For the data base sorting described above, the land areas used in the FHWA data were also sorted by the urban place size so that for each urban place size interval, Δx, the populations and land areas were accumulated. This was done so that the distribution of population density for each urban place size could be developed.

In addition to this grouping of land area, it was recognized that within an urban area defined by a land area and population density, not all of the land is occupied. Whereas the FHWA data and the Census' data delete large areas devote to bodies of water, airports, etc., the land areas do include small parks, streets, and commercial areas not devoted to continued human habitation.

To estimate the adjustments necessary to calculate occupied land area knowing the total urban land area, data presented in Table 5.2, pages 142-144, of Reference 6 were used. These data present distributions of land area by land use category for 14 urban areas. Using these data, land areas were categorized into occupied areas and unoccupied area. Unoccupied areas, for example, comprised land use categories such as streets and alleys, parking and open spaces. For each of the 14 urban areas, the total area occupied was calculated. The data then comprised 14 points of occupied land

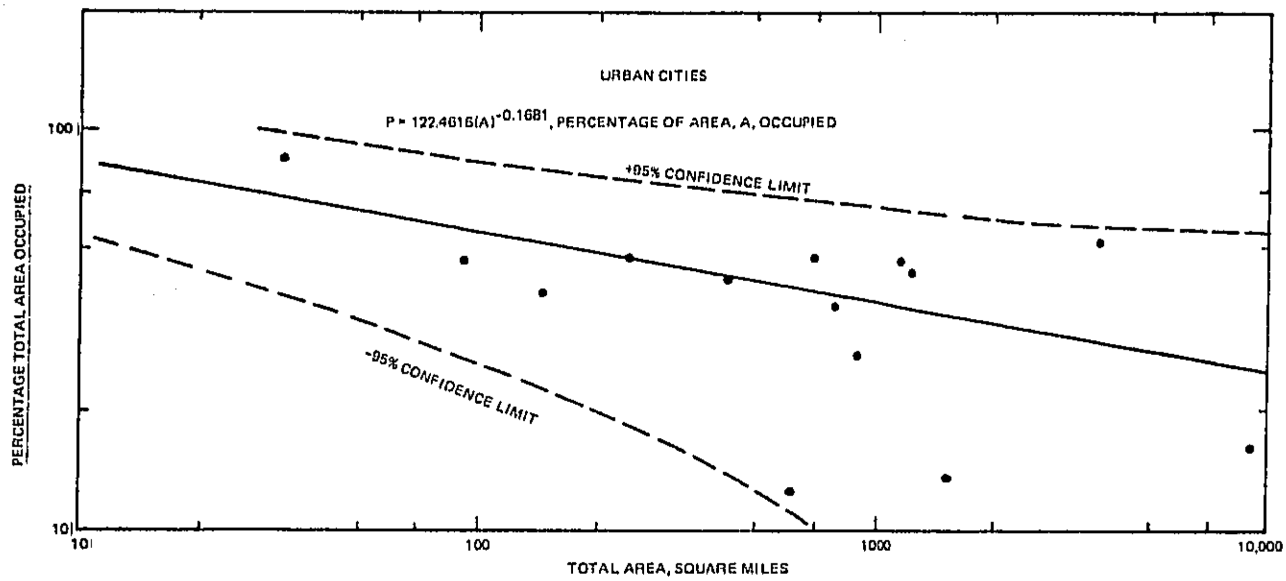


FIGURE A.2.2. PERCENTAGE OF TOTAL LAND AREA OCCUPIED VERSUS TOTAL LAND AREA: URBAN AREAS area and total land area. For each data point, the occupied land area was expressed as a percentage of the total land area. Using these data, a regression analysis was conducted using total land area as the independent variable. The results of this regression analysis are presented in Figure A-2.2.

This result is used, as described below, to adjust aggregated urban land areas assigned to an urban place size and population density range to obtain occupied land areas. As indicated in Figure A-2.2, the percentage of occupied urban land area decreases with increasing total land area. The National Roadway Traffic Noise Exposure Model uses these data explicity in that an "area factor" is assigned for each population place size and population density category. The "area factor" is defined as the fraction of the total urban land area that is occupied. Hence, storing total land area explicitly allows the Model to retain the national physical simulation of land area distribution and by using defined area factors, the land areas assigned to urban categories may be adjusted explicitly to obtain occupied land areas. The details of this adjustment are described below in relation to the population density distribution used by the Model.

A.2.1.3 Urban Population Density Distribution

The above two subsections describe the basic approach used to distribute both urban population and urban land area by a definition of urban place size. The objective of this approach was to estimate the distribution of population density for each urban place size category used by the FHWA roadway data base.[1]

The FHWA roadway data base was sorted into four population density categories. These categories are denoted by the index ID in the Model structure. The FHWA data were sorted, necessarily, on an absolute population density basis for each urban place size category. For the eight urban place size categories, four population density ranges were used. Hence, a matrix of 32 cells was formed distributing roadway data by urban place size and population density. To refine the distribution of population density for each urban place size, it was assumed that the distribution of population densities, as determined from the Bureau of Census Table 20 data, also applied to the FHWA data. Hence, histograms based upon the Table 20 Census data were developed for each of the eight urban place size categories. These histograms distributed urban population and the corresponding urban land area by population density groups or ranges.

Due to the wide range of population densities required to encompass all of the data from all urban place sizes, a logarithmic population density variable was defined as:

$$\text{Urban Population Density:} \quad y = 10\log(P/2.0) \qquad \text{(A-2.2.)}$$

That is, all population density data were normalized to an urban population density of 2,000 people per square mile. In grouping the population and land area data for each urban place size interval, equal intervals of $\Delta y = 3$ were used. Hence, the urban population, and land area data were distributed into 32 cells with each cell having an area of $\Delta x \, \Delta y = 9$ units. Additionally, the number of data points (population and land area sets) in each cell was obtained from the sorting so that an average land area could be calculated from the cell data.

The FHWA roadway data were sorted into four absolute population density ranges for each urban place size. The absolute intervals used in this sorting were 0-1499, 1500-2999, 3000-4499, and 4500 plus people per square mile. As indicated above, the FHWA data used gross population and gross land area to obtain population density. However, the FHWA data[1] did indicate the roadway mileage per square mile of land area in each urban place size. Hence, knowing the roadway mileage in each of the FHWA population density categories implied a defined land area for that category of population density and urban place size.

Using the distribution of urban land area with population density, as described above, the land areas and populations were reported for each urban place size such that the land areas of the FHWA data base corresponded with the land areas from the Census' data. Hence, for each of the 32 cells distributing urban place size and population density, the following data were aggregated:

- Population
- Land Area
- Number of Data Points,* and
- Roadway, Mileage by Roadway Type and Average Cruise Speed.

The average population density for each cell was obtained by dividing the total population by the total land area. Hence, as used by the National Roadway Traffic Noise Exposure Model, the four categories of average population density are relative categories for each urban place size. The classification is denoted by an index, ID and is categorized as:

Population Density Category	Index, ID
High Density	1
Medium to High Density	2
Medium to Low Density	3
Low Density	4

Based upon the FHWA data sorting by population density, there were no data points in the 0-1499 people per square mile category for some of the urban place sizes. For those cases, the low density category (ID=4) was assigned no population, no land area and no roadway mileage.

* A data point denotes the paired combination of land area and population.

Once the population and land area in each cell were determined, the average land area for one "place" in each cell was estimated by dividing the total land area by the total number of data points in the cell. Using the average land area, the "area factor" for the cell was estimated using the regression equation for the mean line given in Figure A-2.2.

Table A-2.2 presents the results of these data manipulations. For each row or population density category, the distribution of population, land area, and population density are presented. The indicated population density values are the result of dividing the total population in each cell by the occupied land area. The total occupied land area is calculated by multiplying the total area by the area factor for each cell. Each column in Table A-2.2 presents the distribution of population and land area within each population place size category.

The classification of population place size and population density as presented in Table A-2.2 is the basic structure of the National Roadway Traffic Noise Exposure Model. All data is structured and/or distributed by this classification scheme. Hence, the model always assigns roadway traffic conditions, and the resulting noise generated to a finite land area containing a finite population. At any time in the simulation, the land area and the traffic noise sources countained in that land area expose only the population assigned to that land area. Hence, as a basic assumption, the National Roadway Traffic Noise Exposure Model considers each cell in Table A-2.2 to be independent. That is, noise exposure and impact estimates are conducted on the basis of the conditions defined for each cell and are summed over all cells to estimate national conditions.

As an audit of the data manipulations resulting from the distribution of the urban population and land area, two additional comparisons of the data are presented. The comparisons are on the basis of urban population density distribution and the joint distribution of population density with urban place size. The comparisons are between the original Burea of Census's Table 20 data and the aggregated data summarized in Table A-2.2.

TABLE A-2.2

DISTRIBUTION OF POPULATION AND LAND AREA BY PLACE SIZE (INDEX J) AND POPULATION DENSITY CATEGORY (INDEX ID)

POPULATION PLACE SIZE--INDEX J

Population Density Area-Index ID	PARAMETER	1 >2M	2 1M -2M	3 500k -1M	4 200k -500k	5 100k -200k	6 50k -100k	7 25k -50k	8 5k -25k	URBAN TOTAL	9 RURAL
1	Population	5.61	2.10	0.36	1.61	1.16	1.07	0.47	1.85	14.23	64.18
	Area	134.2	272	63	215	279	329	58	220	1570.2	3,476,938
	P*	64,711	13,451	9,368	9,366	5,831	4,186	13,091	16,988	-	18.0
2	Population	22.28	4.08	2.04	10.43	2.93	2.12	2.98	4.97	51.83	0.0
	Area	3576	775	488	4558	1305	1115	896	1261	13970.0	0.0
	P*	12,638	9,092	6,967	3697.0	3,384	2,863	8,506	10,681	-	
3	Population	21.59	11.13	8.40	6.75	6.84	4.53	3.51	8.46	71.20	0.0
	Area	8358	5080	4426	5790	5266	4195	2230	4527	39872.0	0.0
	P*	6,107	5,014	3,842	2,264	2,011	1,612.0	4,698	6,271	-	
4	Population	0.0	5.35	5.30	0.0	0.0	0.0	1.92	2.70	15.27	0.0
	Area	0.0	4089	4584	0.0	0.0	0.0	2769	5820	17262.0	0.0
	P*	-	2,505	2,336	-	-	-	2,147	1,673	-	
TOTAL POPULATION		49.48	22.66	16.09	18.78	10.93	7.71	8.88	17.98	152.52	64.18
TOTAL AREA		12064.2	10216.0	9561.0	10563.0	6850.0	5639.0	5953.0	11828.0	72674.2	3476938

Total Population = 216.70 million

Total Land Area = 3,549,612.2 square miles

P* = Population/ (Area) (Area Factor), Adjusted Population Density in People per Square Mile

Figure A-2.3 presents the comparison between the distribution of urban population with population density for all urban place sizes based upon the original Bureau of Census Table 20 data and the data aggregated to construct Table A-2.2. As seen in Figure A-2.3, the distributions are quite similar. These distributions were integrated numerically to obtain cumulative distribution curves for the two data sets. Figure A-2.4 presents this result. It is evident that these distributions are essentially identical.

As a further comparison, the joint distribution of urban population with population density and population place size was considered. This comparison is made on the basis of a regression analysis of population density versus urban place size for the distribution of the urban population with both population density and with place size. Figure A-2.5 presents the results of this analysis. For both emphasis and for comparison, the analysis of the Bureau of Census Table 31 data (Reference 4, pp 1-122 through 1-170) is presented in Figure A-2.5 along with the Table 20 data and the Model data. The interesting result is that all three mean lines exhibit essentially the same slope. That is, population density varies, on the average, at the same rate for each urban place size description. This comparison also emphasizes the significance of the definition of "place size." The Table 20 data is based upon populations contained within contiguous urban areas. The Table 31 data is based upon populations contained within district urban boundaries. The place size designation used by FHWA and adopted for this study is similar to the Table 20 census data. Based upon the results presented in Figure A-2.1 and Figures A-2.3 through A-2.5, the distribution of urban population with urban place size and population density, as used by the National Roadway Traffic Noise Exposure Model, appears consistent with National census data. For completeness, the results of the regression analysis presented in Figure A-2.5 are detailed in Table A-2.3.

A.2.1.4 Rural Population and Population Densities

Neither the FHWA data[1] nor the Bureau of Census data[4] was sufficiently detailed to refine the distribution of population, land area,

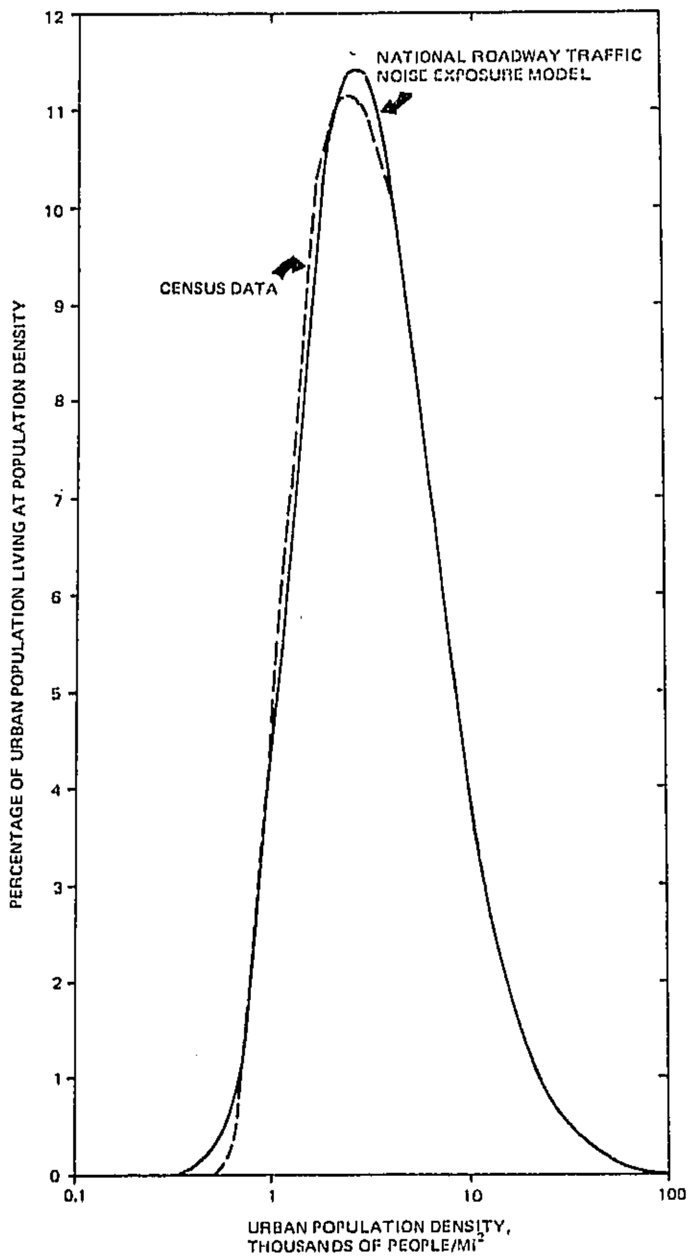


FIGURE A-2.3 PERCENTAGE OF URBAN POPULATION LIVING AT A POPULATION DENSITY: COMPARISON OF DATA SETS

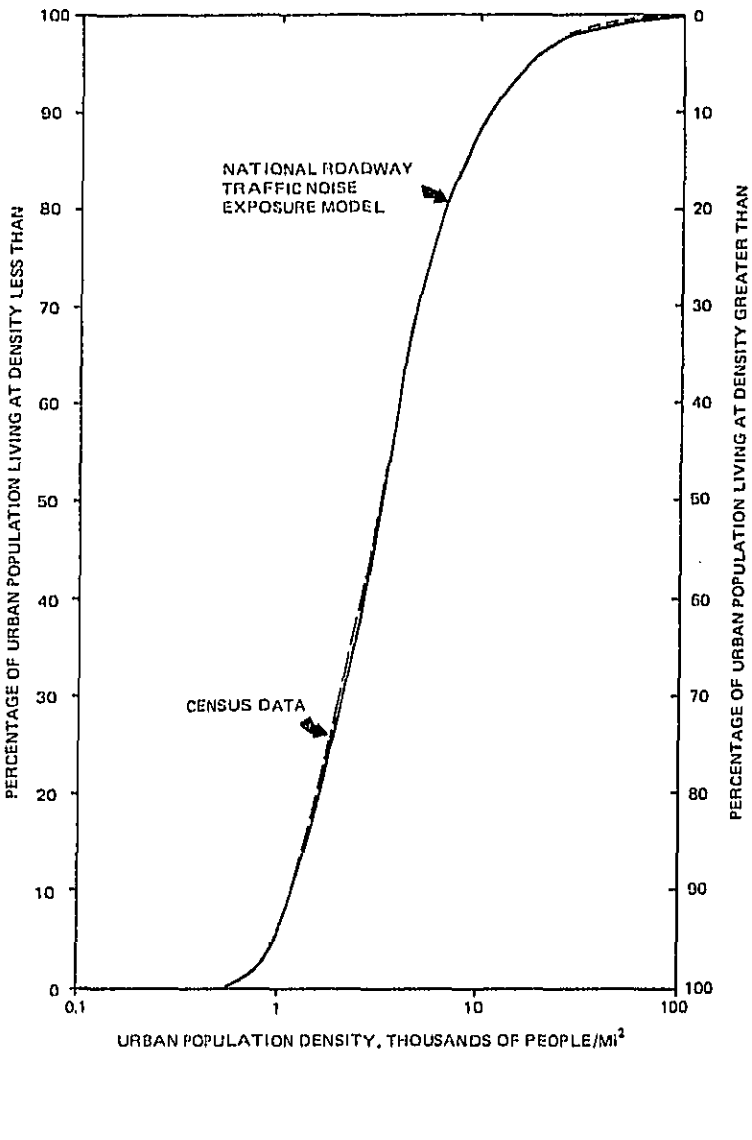


FIGURE A-2.4 CUMULATIVE DISTRIBUTION OF URBAN POPULATION: COMPARISON OF DATA SETS

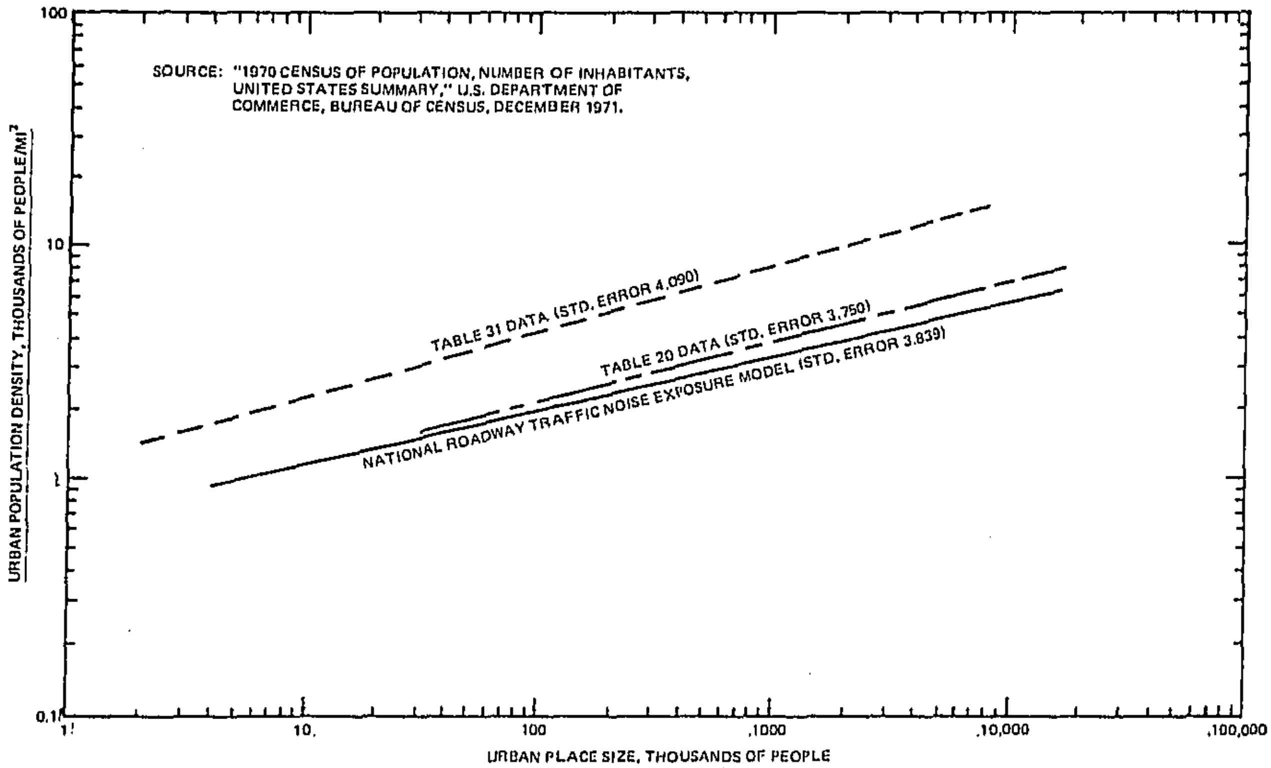


FIGURE A-2.5 JOINT DISTRIBUTION OF URBAN POPULATION WITH POPULATION DENSITY AND URBAN PLACE SIZE: COMPARISON OF DATA SETS

TABLE A-2.3

SUMMARY OF RESULTS: REGRESSION OF ρ AGAINST P

URBAN PLACE SIZE METRIC	EQN. OF REGRESSION LINE	MEAN VALUES $\bar{P}$	MEAN VALUES $\bar{\rho}$	STANDARD ERROR THOUSANDS OF PEOPLE PER SQ. MI.
Urban Area Place Size	$\rho = 0.60111(P)^{0.2646}$	1312.2	4.068	3.750
Urban Boundary Place Size	$\rho = 1.17070(P)^{0.2802}$	90.763	4.141	4.090
National Roadway Traffic Noise Exposure Model	$\rho = 0.69126(P)^{0.2290}$	572.8	2.959	3.839

ρ is population density in thousands of people per square mile.

P is the appropriate urban place size metric.

and roadway data for rural areas. As indicated in Table A-2.2, the distribution of population between urban and rural categories allocates 70.4 percent of the national population to urban areas. The national distribution of land area allocates 2.05 percent of the nation's land area to urban areas with populations greater than 5,000 people. Hence, as used by the National Roadway Traffic Noise Exposure Model, the "rural" place size category comprises urban places with population less than 5,000 people and distinctly rural areas as usually imagined.

The Model's structure allows for refinement of the "rural" place size category with respect to population density distribution. In the future, data may become available to allocate--on a consistent basis--population, land area, and roadway data to refine the rural noise impact estimates. Presently, however, the Model considers all rural areas to be characterized by a constant population density, in 1974, of 18 people per square mile, uniformly distributed along the roadway network, and traffic conditions defined by the FHWA data[1] for rural areas.

A.2.2. Growth of National Population

The National Roadway Traffic Noise Exposure Model allows the user to vary the national population with time. This feature simulates future changes in the population and may be varied to the level of the urban place size (Index, J). That is, the user may simulate population projections for each urban place size and the rural place size. This simulation is constrained only in the sense that the future total national population should correspond to the various Bureau of Census projections.[7]

As manipulated by the Model, a "population growth factor" is defined as a fraction of the 1974 population. Hence, for each population place size, future population is estimated by multiplying the 1974 population by the population growth factor. Figure A-2.6 presents the national population growth projections from 1975 through 2050 based upon the various Bureau

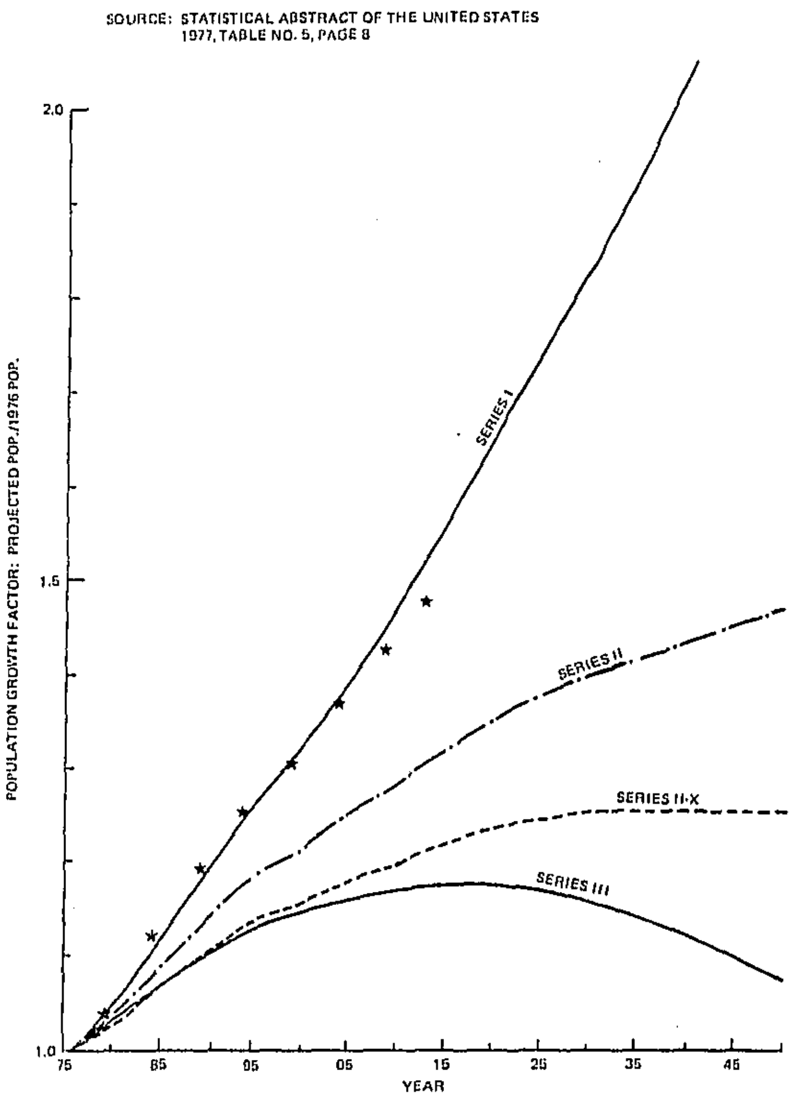


FIGURE A-2.6 PROJECTED POPULATION GROWTH FACTORS: 1975 to 2050 of Census scenarios. The vertical axis of Figure A-2.6 is the composite national population growth factor. The stars indicated in Figure A-2.6 are the data currently used by the National Roadway Traffic Noise Exposure Model. Hence, it is seen that the current data base simulates the Bureau of Census' Series I population projections. Table A-2.4 presents the population growth factors currently used by the Model by the place size Index J. These data were obtained from Reference 8, and as indicated in Figure A-2.6 simulate the Series I projections.

The projection of population increase is based upon various assumptions concerning birth rates, immigration, and death rates. The various projections indicated in Figure A-2.6 are labeled with Roman numerals indicating the Bureau of Census projection series.[7] Series I, II, and III each assume a slight improvement in the mortality rate and a constant immigration rate. Each of these series differs in that Series I assumes an immigration and fertility rate based upon historical trends. Series II differs from Series I in that the fertility rate assumed represents a "replacement level," i.e., the population would exactly replace itself in the absence of net immigration. Series III represents a lower fertility rate as compared to both Series I and II. Series II-X is identical to Series II except that zero net immigration is assumed.

Hence, the Model allows the user to simulate changes in the national population in future years to estimate future noise exposure. The future noise exposure is, of course, dependent upon the data used to estimate future noise source emissions. In the allocation of population to roadways and, hence, noise sources, the Model assigns the future population to the 1974 land areas on the level of place size (J) and population density category (ID). The 1974 land areas are presented in Table A-2.2. The future population density, for each (J, ID) combination is calculated by dividing the future population by the 1974 land area. That is, the Model does not, currently, vary land area with time. Consistent with this assumption is the fact that the Model does not presently increase roadway mileage in future years. The rationale for this assumption is that urban areas generally

TABLE A-2.4

POPULATION GROWTH FACTORS BY PLACE SIZE (INDEX J)
FOR EVERY FIVE YEARS IN THE TIME SYSTEM

		AREA TYPE, J									
		1	2	3	4	5	6	7	8	9	ALL J
PLACE SIZE, THOUSANDS		OVER 2000	1000-2000	500-1000	200-500	100-200	50-100	25-50	5-25	RURAL	
YEAR	VARIABLE	POP(YEAR)/POP(BASELINE)									
1974		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1980		1.08	1.07	1.07	1.02	1.02	1.02	1.02	1.02	1.12	
1985		1.17	1.16	1.16	1.04	1.04	1.04	1.04	1.04	1.23	
1988		1.19	1.19	1.19	1.05	1.05	1.05	1.05	1.05	1.27	
1990		1.22	1.22	1.22	1.05	1.05	1.05	1.05	1.05	1.31	
1995		1.29	1.29	1.29	1.07	1.07	1.07	1.07	1.07	1.39	
2000		1.36	1.36	1.36	1.08	1.08	1.09	1.09	1.09	1.48	
2005		1.43	1.44	1.44	1.10	1.10	1.10	1.10	1.10	1.57	
2010		1.50	1.51	1.51	1.12	1.12	1.12	1.12	1.12	1.65	

contain sufficient land area to allow for increased population without vastly increased land areas. The structure of the Model, however, allows for the time variation of both land area and roadway mileage to be included if future data sources provide for such detailed considerations.

A.3 Roadway Mileage, Configuration, and Travel Data

The structure of the National Roadway Traffic Noise Exposure Model is based upon the requirement to relate noise generation (traffic conditions) to population. The FHWA data base[1,2,3] structured roadway characteristics by their functional classification. The functional classification is a process by which roadways are organized into classes or systems according to the character of service they provide. Most travel involves the movement through a roadway network and the functional classification defines the nature of this channelization process by defining the part that any particular roadway plays in serving the flow of trips through a highway network.

Related to this channelization is the dual role the roadway network plays in providing two services:

- Access to Land Uses,

- Travel Mobility.

Land access is needed at both ends of a trip, and mobility is needed along the path of a trip. The mobility is provided at various levels of service.

The concepts of travel channelization and levels of mobility lead to a hierarchy of functional classes and the relative travel distances served by these classes. This hierarchy can be related to the functional specialization in meeting both access and mobility requirements. For example, interstates, expressways, and arterials emphasize a high level of mobility for through travel. Local streets emphasize access to adjacent land. Collector roads offer a balance between mobility and land access. Since urban and rural areas differ as to population density, types of land use, density of roadway networks, travel patterns, and their interrelationship to the definition of highway function, rural and urban functional systems are different in nature.

Reference 1 presents the detailed definitions of the functional classification of the national roadway network. The relationship between this classification scheme and the National Roadway Traffic Noise Exposure Model, however, forms the basic structure of the Model. As described in Section A.2, the Model assigns population and land area into distinct categories for the purpose of estimating traffic noise exposure. Each of these population/area categories is a distinctly independent unit in that noise sources in one category do not directly expose population in another category.

However, by assigning explicit travel data for each mile of roadway in each population/area category, the Model indirectly accounts for exchanges of traffic (i.e., noise source interaction) between categories of population and land area. The allocation of roadway mileage and travel data to different categories of population/area was accomplished by the FHWA staff in a special sorting of the NHIPS data[1] to a level of detail sufficient to define traffic noise generation in these areas.

A.3.1 Classification of Roadway Mileage

The basic structure of the Model data base relating to roadways and travel encompasses the population place size, Index J, and the population density category, Index ID. The next two levels of data are the roadway functional classification, Index K, and the average travel speed, Index L.

The National Roadway Traffic Noise Exposure Model uses six functional categories of roadway to define the data base. These functional categories correspond to the FHWA categories,[1] and are:

Functional Roadway Classification:	Index, K
Interstate Highway	1
Freeways and Expressways	2
Major Arterials	3
Minor Arterials	4
Collectors	5
Local Roads and Streets	6

The Model allocates 3.586 million miles of the national roadway network to population place sizes representing a total of 216.7 million people and a land area of 3.549 million square miles. The roadway mileage, by Index K, is determined solely by the FHWA highway inventory data.[1] In order to conduct detailed traffic noise estimates, it is necessary to include vehicle speed and traffic volume as additional parameters.[9,10] Hence, the roadway mileage and travel are distributed over the population categories according to the functional classification and further distributed over average travel speeds for each functional classification.

A.3.2 Distribution of Roadway Mileage and Travel with Population

Table A-3.1 presents the summary of the distribution of baseline year (1974) roadway mileage and travel by population place size (Index J) and functional roadway classification (Index K). For example, the data in Table A-3.1 indicates that 1.998 miles of interstate highway (K=1) are assigned to urban areas with total population exceeding 2 million.

The FHWA data base[1] also accumulated the Daily Vehicle Miles Traveled (DVMT) on each functional class of roadway in each population place size. The DVMT value describes the total vehicle travel on the roadway. By dividing the DVMT value by the roadway mileage, the Average Daily Traffic (ADT) is estimated for roadway. Table A-3.1 presents the distribution of

TABLE A-3.1

DISTRIBUTION OF ROADWAY MILEAGE, AVERAGE DAILY TRAFFIC (ADT) AND DAILY VEHICLE MILES TRAVELED (DVMT) BY PLACE SIZE (J) AND ROADWAY TYPE (K)

PLACE SIZE		ROADWAY TYPE: INTERSTATE	OTHER F'WAY & EXP'WAY	MAJOR ARTERIALS	MINOR ARTERIALS	COLLECTORS	LOCAL
>2M	Miles	1,990	1,749	9,061	14,103	12,854	84,247
	ADT	74,066	66,470	18,760	9,315	3,783	1,129
	DVMT	149,502,260	116,256,030	185,071,240	131,369,445	48,626,682	95,114,063
1M to 2M	Miles	1,869	1,527	5,156	10,219	10,308	64,678
	ADT	60,228	32,545	17,397	6,898	3,496	656
	DVMT	112,566,132	49,700,796	89,690,932	70,498,662	36,036,768	42,428,768
500k to 1M	Miles	1,477	739	4,034	6,120	7,190	47,466
	ADT	46,997	34,016	16,359	8,045	3,760	672
	DVMT	69,414,569	25,152,604	65,992,266	50,844,400	27,034,400	31,897,152
200k to 500k	Miles	1,743	1,076	5,566	8,569	7,897	58,252
	ADT	40,367	28,812	16,029	8,470	3,812	839
	DVMT	70,359,681	31,001,712	89,217,414	75,579,430	30,103,364	48,873,420
100k to 200k	Miles	854	803	3,851	5,507	5,714	36,697
	ADT	32,190	22,984	14,904	7,301	3,287	649
	DVMT	27,490,260	18,456,152	57,352,943	40,170,102	18,781,918	23,816,353
50k to 100k	Miles	512	600	3,335	4,445	4,534	29,284
	ADT	21,913	19,971	12,376	6,057	2,917	645
	DVMT	11,219,456	11,982,600	41,273,960	26,923,365	13,225,670	18,888,180
25k to 50k	Miles	397	447	4,282	5,377	5,820	33,454
	ADT	23,251	16,875	11,384	5,430	2,484	631
	DVMT	9,230,647	7,541,125	48,746,298	29,197,110	14,476,752	21,109,479
5k to 25k	Miles	899	1,099	9,652	12,124	13,130	75,431
	ADT	18,206	13,244	8,922	4,255	1,946	495
	DVMT	16,367,144	13,343,016	86,115,144	61,587,620	25,550,900	37,338,345
Rural	Miles	31,744	85,716	155,547	435,517	307,917	1,942,733
	ADT	13,700	4,623	2,523	899	370	98
	DVMT	434,892,800	396,265,068	392,445,081	387,174,613	113,939,290	190,387,834

both DVMT and ADT for each roadway type and each population place size. The ADT value is the quantity used by the Model in calculating traffic noise generation on the roadway.

Table A.3.2 presents a detailed distribution of roadway mileage as a function of average travel speed. This distribution is defined to the level of population place size (Index J), population density cantegory (Index ID), and average travel speed (Index L). The Model uses five average travel speeds to distribute roadway mileage. The average travel speeds are taken as the center of a consecutive set of speed ranges. These speed ranges and the corresponding value of the speed Index L, are:

Average Travel Speed Range	Average Speed	Index, L
Less than 25 mph	20 mph	1
25 to 35 mph	30 mph	2
35 mph to 45 mph	40 mph	3
45 mph to 55 mph	50 mph	4
Greater than 55 mph	60 mph	5

The Model presently considers the ADT to be constant for all travel speeds. Hence, roadway mileage is categorized into 1,080 distinct combinations of popualtion place size, population density, roadway type and average travel speed. This data is derived from sorting the original FHWA data.[1]

The FHWA data sorting also indicated the roadway mileage in each population place size that passed through vacant land. Since the Model structure used an "area factor" to account for vacant land in urban areas, it was necessary to mechanically delete roadway mileage through vacant land. This is accomplished using a "roadway factor" that represents the fraction of the total roadway mileage, by roadway type, that passes through occupied land. Based upon the HWA data,[1] it was possible to define the "roadway factor" only to the level of place size (Index J), and roadway type

TABLE A-3.2

ROADWAY MILEAGE DATA

AVERAGE TRAVEL SPEED 20 MPH

ID = 1

HIGH POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	0	3	16	41	37	94	191
2	0	7	21	71	71	172	342
3	0	1	4	11	12	31	59
4	0	3	17	45	42	119	226
5	0	5	24	58	61	149	297
6	0	5	29	67	69	171	341
7	0	1	6	14	15	33	69
8	0	3	27	59	63	140	292
9	0	0	0	8698	6159	215859	230716
ALL J>	0	28	144	9064	6529	216768	232533

ID = 2

MEDIUM TO HIGH POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	6	78	438	1085	989	2494	5090
2	1	19	59	201	203	491	974
3	1	6	31	84	95	242	459
4	7	69	360	963	886	2514	4799
5	2	23	110	273	283	699	1390
6	1	18	99	229	233	579	1159
7	1	10	97	210	228	504	1050
8	1	16	154	336	364	804	1675
9	0	0	0	0	0	0	0
ALL J>	20	239	1348	3381	3281	8327	16598

TABLE A-3.2

ROADWAY MILEAGE DATA
(Continued)

AVERAGE TRAVEL SPEED 20 MPH

ID = 3

MEDIUM TO LOW POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	14	182	1025	2540	2314	5837	11912
2	7	125	384	1321	1333	3216	6386
3	7	51	280	761	866	2197	4162
4	9	88	458	1223	1125	3193	6096
5	7	92	444	1100	1142	2821	5606
6	4	67	372	860	877	2178	4358
7	1	25	241	523	568	1253	2611
8	3	58	554	1206	1306	2887	6014
9	0	0	0	0	0	0	0
ALL J>	52	688	3758	9534	9531	23582	47145

ID = 4

LOW POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	0	0	0	0	0	0	0
2	6	101	309	1063	1073	2589	5141
3	7	53	290	788	897	2276	4311
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	2	31	299	650	705	1556	3243
8	4	75	712	1551	1679	3712	7733
9	0	0	0	0	0	0	0
ALL J>	19	260	1610	4052	4354	10133	20428

TABLE A-3.2

ROADWAY MILEAGE DATA
(Continued)

AVERAGE TRAVEL SPEED 30 MPH

ID = 1
HIGH POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	1	8	43	83	76	422	633
2	1	16	54	144	145	775	1135
3	0	2	10	22	25	141	200
4	1	9	44	92	85	534	765
5	1	13	61	119	123	673	990
6	1	14	76	137	140	769	1137
7	0	2	16	28	30	147	223
8	1	7	70	120	129	631	958
9	0	1714	3111	43489	30792	863437	942543
ALL J>	6	1785	3485	44234	31545	867529	948584

ID = 2
MEDIUM TO HIGH POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	18	202	1138	2213	2017	11225	16813
2	4	44	152	411	415	2208	3234
3	2	15	80	171	195	1090	1553
4	22	182	937	1958	1805	11311	16215
5	5	60	286	556	577	3146	4630
6	3	46	257	466	475	2606	3853
7	2	26	251	429	465	2266	3439
8	3	42	401	685	742	3619	5492
9	0	0	0	0	0	0	0
ALL J>	59	617	3502	6889	6691	37471	55229

TABLE A-3.2

ROADWAY MILEAGE DATA
(Continued)

AVERAGE TRAVEL SPEED 30 MPH

ID = 3

MEDIUM TO LOW POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	42	472	2662	5179	4720	26264	39339
2	28	291	999	2693	2717	14473	21201
3	20	133	728	1551	1765	9888	14089
4	29	231	1191	2487	2293	14368	20599
5	20	241	1154	2242	2328	12695	18680
6	11	174	967	1753	1787	9803	14495
7	4	66	625	1068	1156	5639	8558
8	10	150	1441	2459	2664	12992	19716
9	0	0	0	0	0	0	0
ALL J>	164	1758	9767	19432	19430	106122	156673

ID = 4

LOW POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	0	0	0	0	0	0	0
2	22	234	805	2167	2187	11649	17064
3	21	138	754	1606	1828	10241	14588
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	6	81	776	1326	1436	7002	10627
8	13	193	1852	3161	3425	16702	25346
9	0	0	0	0	0	0	0
ALL J>	62	646	4187	8260	8876	45594	67625

TABLE A-3.2

ROADWAY MILEAGE DATA
(Continued)

AVERAGE TRAVEL SPEED 40 MPH

ID = 1
HIGH POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	1	5	29	24	21	422	502
2	2	10	36	41	41	775	905
3	0	1	7	6	7	141	162
4	1	6	29	26	24	534	620
5	1	9	41	34	35	673	793
6	1	9	51	39	40	769	909
7	0	1	11	8	9	147	176
8	1	5	47	34	37	631	755
9	0	10286	18666	130468	92375	863437	1115232
ALL J>	7	10332	18917	130680	92589	867529	1120054

ID = 2
MEDIUM TO HIGH POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	24	134	759	626	571	11225	13339
2	6	30	102	116	117	2208	2579
3	3	10	54	48	55	1090	1260
4	30	121	624	555	511	11311	13152
5	6	40	191	157	163	3146	3703
6	4	31	172	132	134	2606	3079
7	2	18	168	121	132	2266	2707
8	4	28	268	194	210	3619	4323
9	0	0	0	0	0	0	0
ALL J>	79	412	2338	1949	1893	37471	44142

TABLE A-3.2

ROADWAY MILEAGE DATA
(Continued)

AVERAGE TRAVEL SPEED 40 MPH

ID = 3
MEDIUM TO LOW POPULATION DENSITY AREAS

J V	K> 1	2	3	4	5	6	ALL K
1	55	315	1776	1465	1336	26264	31211
2	37	194	667	762	769	14473	16902
3	27	89	486	439	499	9888	11428
4	38	154	793	705	650	14368	16708
5	26	161	769	635	659	12695	14945
6	16	116	646	495	506	9803	11582
7	6	44	417	302	327	5639	6735
8	14	101	961	696	754	12992	15518
9	0	0	0	0	0	0	0
ALL J>	219	1174	6515	5499	5500	106122	125029

ID = 4
LOW POPULATION DENSITY AREAS

J V	K> 1	2	3	4	5	6	ALL K
1	0	0	0	0	0	0	0
2	30	156	537	614	619	11649	13605
3	28	92	503	455	517	10241	11836
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	7	54	518	375	407	7002	8363
8	18	129	1235	895	969	16702	19948
9	0	0	0	0	0	0	0
ALL J>	83	431	2793	2339	2512	45594	53752

TABLE A-3.2

ROADWAY MILEAGE DATA
(Continued)

AVERAGE TRAVEL SPEED 50 MPH

ID = 1

HIGH POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	8	3	16	8	7	0	42
2	17	6	21	14	14	0	72
3	3	1	4	2	2	0	12
4	12	3	17	9	8	0	49
5	12	5	24	11	12	0	64
6	10	5	29	13	13	0	70
7	1	1	6	3	3	0	14
8	6	3	27	11	12	0	59
9	5079	33427	60663	178931	126246	0	404346
ALL J>	5148	33454	60807	179002	126317	0	404728

ID = 2

MEDIUM TO HIGH POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	201	78	438	209	191	0	1117
2	48	17	59	39	39	0	202
3	26	6	31	16	18	0	97
4	256	69	360	185	170	0	1040
5	55	23	110	52	54	0	294
6	34	18	99	44	45	0	240
7	20	10	97	40	44	0	211
8	33	16	154	65	70	0	338
9	0	0	0	0	0	0	0
ALL J>	673	237	1348	650	631	0	3539

TABLE A-3.2

ROADWAY MILEAGE DATA
(Continued)

AVERAGE TRAVEL SPEED 50 MPH

ID = 3

MEDIUM TO LOW POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	470	182	1025	488	446	0	2611
2	317	112	384	254	256	0	1323
3	233	51	280	146	166	0	876
4	325	88	458	235	217	0	1323
5	224	92	444	211	220	0	1191
6	129	67	372	165	169	0	902
7	51	25	241	101	109	0	527
8	117	58	554	232	251	0	1212
9	0	0	0	0	0	0	0
ALL J>	1866	675	3758	1832	1834	0	9965

ID = 4

LOW POPULATION DENSITY AREAS

J V K>	1	2	3	4	5	6	ALL K
1	0	0	0	0	0	0	0
2	255	90	309	205	206	0	1065
3	241	53	290	152	172	0	908
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	63	31	299	125	135	0	653
8	151	75	712	298	323	0	1559
9	0	0	0	0	0	0	0
ALL J>	710	249	1610	780	836	0	4185

TABLE A-3.2

ROADWAY MILEAGE DATA
(Continued)

AVERAGE TRAVEL SPEED 60 MPH

ID = 1
HIGH POPULATION DENSITY AREAS

J V	K> 1	2	3	4	5	6	ALL K
1	13	1	6	2	1	0	23
2	29	2	7	3	3	0	44
3	6	0	1	0	C	0	7
4	21	1	6	2	2	0	32
5	20	2	8	2	2	0	34
6	17	2	10	3	3	0	35
7	2	0	2	1	1	0	6
8	10	1	9	2	2	0	24
9	26665	40289	73107	73931	52345	0	266337
ALL J>	26763	40298	73156	73946	52359	0	266542

ID = 2
MEDIUM TO HIGH POPULATION DENSITY AREAS

J V	K> 1	2	3	4	5	6	ALL K
1	343	26	147	42	38	0	596
2	83	6	20	8	8	0	125
3	44	2	10	3	4	0	63
4	437	23	120	37	35	0	652
5	94	7	37	10	11	0	159
6	59	6	33	9	9	0	116
7	35	3	32	8	9	0	87
8	55	5	51	13	14	0	138
9	0	0	0	0	0	0	0
ALL J>	1150	78	450	130	128	0	1936

TABLE A-3.2

ROADWAY MILEAGE DATA
(Continued)

AVERAGE TRAVEL SPEED 60 MPH

ID = 3
MEDIUM TO LOW POPULATION DENSITY AREAS

J V	K> 1	2	3	4	5	6	ALL K
1	802	60	343	98	90	0	1393
2	541	37	128	51	51	0	808
3	397	17	94	29	33	0	570
4	555	29	152	47	44	0	827
5	381	30	148	42	44	0	645
6	222	22	123	33	34	0	434
7	87	8	80	20	22	0	217
8	199	19	185	47	51	0	501
9	0	0	0	0	0	0	0
ALL J>	3184	222	1253	367	369	0	5395

ID = 4
LOW POPULATION DENSITY AREAS

J V	K> 1	2	3	4	5	6	ALL K
1	0	0	0	0	0	0	0
2	435	30	103	41	41	0	650
3	411	18	97	30	34	0	590
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	107	10	100	25	27	0	269
8	256	25	238	60	65	0	644
9	0	0	0	0	0	0	0
ALL J>	1209	83	538	156	167	0	2153

(Index K). Hence, the distribution of roadway mileage through occupied urban land is assumed constant for all population density categories (Index ID), and all travel speed ranges (Index L). The "roadway factors" currently used by the Model are presented in Table A-3.3. For example, the total interstate mileage in urban areas with population exceeding 2 million people is 1,998 miles (Table A-3.1). From Table A-3.3., the roadway factor for K=1 (interstates), and J=1 (urban places over 2 million population) is 0.764. Hence, the interstate mileage through occupied land in this urban place size is 1,526.5 miles. The Model uses the roadway factors at the level of detail presented in Table A-3.2 for roadway mileage distribution with population density category, and average travel speed.

To simulate future growth of roadway traffic, the National Roadway Traffic Noise Exposure Model uses total vehicular population. As described in Section A.4, the Model allows the user to define vehicle sales projections and, with the vehicle survivability data, project the future vehicle population. The Model uses the ratio of future total vehicle population to the 1974 vehicle population to vary the baseline ADT values in future years. That is, it is assumed that future changes in ADT are proportional to total vehicle population, and that these changes are uniformly distributed over all roadways. Further, it is assumed that all roadways remain at their average travel speed assigned in 1974. The assumption of constant travel speed implies that the level of service for all roadways remains at the 1974 conditions. It appears that this assumption is more sensitive to the roadway surface roughness than it is to the present design capacity of the national roadway network.[3] The dominance of highway funding in the future appears to be allocated to maintenance activities rather than new construction.[3] Hence, the Model allows for increased travel, but holds roadway mileage constant in future years.

A.3.3 Traffic Mix on Roadways

The Model assigns a baseline traffic mix for 1974 by population place size (Index J) and roadway type (Index K). These data are presented in Table A-3.4. This data set was developed from FHWA data[11] and data from

TABLE A-3.3
FRACTION OF ROADWAY MILEAGE THROUGH OCCUPIED URBAN LAND
(Reference 5 Data Sorting)

	Population Place Size, Index J								
K	1	2	3	4	5	6	7	8	9
1	0.764	0.764	0.764	0.764	0.764	0.764	0.656	0.656	1.000
2	0.738	0.738	0.738	0.738	0.738	0.738	0.679	0.679	1.000
3	0.866	0.866	0.866	0.866	0.866	0.866	0.843	0.843	1.000
4	0.845	0.845	0.845	0.845	0.845	0.845	0.849	0.849	1.000
5	0.852	0.852	0.852	0.852	0.852	0.852	0.867	0.867	1.000
6	0.852	0.852	0.852	0/852	0.852	0.852	0.867	0.867	1.000

J is Population Place Size Index

K is Roadway Type Index

TABLE A-3.4
PERCENTAGE VEHICLE MIX IN TRAFFIC FLOW BY PLACE SIZE AND FUNCTIONAL ROADWAY CLASSIFICATION BASELINE CONDITIONS

URBAN PLACE SIZES: Over 2M; 1M-2M; 500k-1M

VEHICLE TYPE	ROADWAY TYPE (INDEX K)					
	1	2	3	4	5	6
Light Vehicles	87.62	87.62	91.82	90.52	90.51	95.76
Medium Trucks	2.11	2.11	3.05	4.31	3.61	1.16
Heavy Trucks	9.17	9.17	4.03	3.11	3.82	0.99
Intercity Buses	0.03	0.03	0.03	0.00	0.00	0.00
Transit Buses	0.08	0.08	0.08	0.54	0.54	0.54
School Buses	0.00	0.00	0.00	0.02	0.02	0.02
Modified Motorcycles	0.88	0.88	0.88	1.32	1.32	1.32
Unmodified Motorcycles	0.12	0.12	0.12	1.18	1.18	1.18
	100.00	100.00	100.00	100.00	100.00	100.00

URBAN PLACE SIZES: 200k-500k; 100k-200k; 50k-100k

VEHICLE TYPE	ROADWAY TYPE (INDEX K)					
	1	2	3	4	5	6
Light Vehicles	87.64	87.64	91.84	90.71	90.70	95.98
Medium Trucks	2.11	2.11	3.05	4.31	3.61	1.16
Heavy Trucks	9.17	9.17	4.03	3.11	3.82	0.99
Intercity Buses	0.04	0.04	0.04	0.01	0.01	0.01
Transit Buses	0.04	0.04	0.04	0.30	0.30	0.30
School Buses	0.00	0.00	0.00	0.08	0.08	0.08
Modified Motorcycles	0.88	0.88	0.88	1.32	1.32	1.32
Unmodified Motorcycles	0.12	0.12	0.12	1.18	1.18	1.18
	100.00	100.00	100.00	100.00	100.00	100.00

NOTE: Some columns do not add up to exactly 100 because of rounding.

TABLE A-3.4
(Continued)

URBAN PLACE SIZES: 25k-50k; 5k-25k

VEHICLE TYPE	ROADWAY TYPE (INDEX K) 1	2	3	4	5	6
Light Vehicles	87.67	87.67	91.87	90.34	90.33	95.61
Medium Trucks	2.11	2.11	3.05	4.31	3.61	1.16
Heavy Trucks	9.17	9.17	4.03	3.11	3.82	0.99
Intercity Buses	0.03	0.03	0.03	0.00	0.00	0.00
Transit Buses	0.05	0.05	0.05	0.21	0.21	0.21
School Buses	0.00	0.00	0.00	0.52	0.52	0.52
Modified Motorcycles	0.88	0.88	0.88	1.32	1.32	1.32
Unmodified Motorcycles	0.12	0.12	0.12	1.18	1.18	1.18
	100.00	100.00	100.00	100.00	100.00	100.00

RURAL AREAS

VEHICLE TYPE	ROADWAY TYPE (INDEX K) 1	2	3	4	5	6
Light Vehicles	79.67	79.67	85.78	88.27	93.33	96.74
Medium Trucks	2.74	2.74	3.80	4.39	0.56	0.41
Heavy Trucks	16.16	16.16	8.99	5.14	3.91	0.65
Intercity Buses	0.24	0.24	0.24	0.00	0.00	0.00
Transit Buses	0.00	0.00	0.00	0.00	0.00	0.00
School Buses	0.19	0.19	0.19	0.70	0.70	0.70
Modified Motorcycles	0.88	0.88	0.88	1.32	1.32	1.32
Unmodified Motorcycles	0.12	0.12	0.12	1.18	1.18	1.18
	100.00	100.00	100.00	100.00	100.00	100.00

NOTE: Some columns do not add up to exactly 100 because of rounding.

EPA documents.[12,13] This section describes the procedures and assumptions used to define the data contained in Table A-3.4.

The FHWA data[11] provided estimates of the percentage of traffic mix for urban and rural areas and the type of highway system. The percentage mix was, however, expressed in terms of passenger vehicles and truck categories (page 8 of Reference 11). In order to correspond with the National Roadway Traffic Noise Exposure Model, however, it was necessary to assume a correspondence between roadway categories and to estimate the allocation of truck traffic on the basis of the vehicle categories used by the Model (see Section A.4 of this report).

Using the data from Figure 2, page 4, of Reference 11, the distribution of truck traffic by the truck categories used by the Model was obtained. The percentage of truck traffic as a component of the total traffic was allocated among the three truck catgeories (i.e., light-, medium-, and heavy-duty trucks). The allocation for light trucks was added to the passenger vehicle category since the Model considers light trucks to be one component of the light vehicle class. Hence, the traffic mix was detailed to the level of passenger vehicles, medium trucks, and heavy trucks.

The next distribution of the traffic mix comprised the estimation of bus mix and motorcycle mix on the roadways. These vehicle types are included in the FHWA passenger vehicle category estimated as described above. The mix of bus traffic was estimated using the data of Reference 12 and the mix of motorcycle traffic was estimated using the data of Reference 13. The percentage mix of light vehicle traffic was assumed to equal the passenger vehicle mix less the percentage mix attributable to buses and motorcycles. The results of this analysis are presented in Table A-3.4

The data presented in Table A-3.4 represents the baseline percentage traffic mix for 1974. The model alters this mix in future years in two ways. First, the future year traffic mix is adjusted based upon the sales data for each vehicle type used as input to the Model. Second, since the Model allows the user to define noise emission characteristics to simulate future year regulations, the vehicle mix in a future year is further categorized by the percentage of vehicles exhibiting defined noise emission characteristics. These adjustments are coded into the Model so that the input data is properly manipulated.

As indicated in Table A-3.4, the dominance of the traffic mix is comprised of light vehicles for all roadways. The Model, as presently structured, defines seven categories of light vehicles. The distribution of light vehicle traffic mix in terms of these seven categories is presented in Section A.4.

A.3.4 Roadway Configuration Data

The National Roadway Traffic Noise Exposure Model calculates noise emission from traffic conditions on the roadway. The basic traffic parameters are the average travel speed, the Average Daily Traffic (ADT), and the traffic mix on the roadway. The Model additionally considers details of the roadway configuration to simulate multilane traffic flows. The two basic parameters used by the Model are the number of lanes and the average width of a single lane. These data are used to distribute the traffic conditions and the location of the noise source relative to the edge of the pavement system. As described in the main text of this report, traffic is assumed to move along a straight line. The Model assumes that the total ADT for the roadway (see Table A-3.1) is uniformly distributed over all lanes. Further, the traffic mix for each roadway (Table A-3.4) is assumed to apply to each lane. The Model considers all lanes to be adjacent to each other (i.e., no medians are defined for any roadways).

Based upon summary data presently available,[1,3] the number of traffic lanes and the lane widths were assumed to be constant for each roadway type (Index K) for all population place sizes (Index J) and population density (Index ID) catgegories. These data are arrayed, accordingly, by roadway type (Index K) and population place size (Index J) and held constant at these values for each population density category (ID) and average travel speed (L).

Interstate highways (K=1) are characterized as four lane roads with a 15-foot lane width for all population place sizes (J=1, ..., 9). All freeways, major arterials, minor arterials, and collectors (K=2, ..., 5) are characterized as four lane roads with a 12-foot lane width for all population place sizes (J=1, ..., 9). All local roads or streets (K=6) are characterized as two lane roadways with 12-foot lane widths for all population place sizes (J=1, ..., 9).

A.3.5 Vehicle Operating Characteristics

The National Roadway Traffic Noise Exposure Model considers each vehicle type to spend a percentage of its total operating time on a roadway in one of four operating modes. The operating modes are denoted by an Index M in the Model and are defined as:

Vehicle Operating Mode	Index M
Acceleration from Idle	1
Deceleration from Cruise	2
Cruise	3
Idle	4

The vehicle operating mode (Index M) and the vehicle cruise speed (Index L) are used to define the vehicle noise emissions. The percentage of time in each operating mode is used to weight these levels to obtain an equivalent emission level (General Adverse Response Model), or to estimate the number of occurrences of a given mode of operation (Single Event Model) at the emission level for the mode.

The percentage of time in each operating mode is defined in the Model's data base by vehicle type (Index I), roadway type (Index K), and operating mode (Index M). The data is constant for these conditions for all population place sizes (Index J), population density categories (Index ID), and average travel speed (Index L) of the roadway. The estimates of percentage of time in an operating mode are based upon the best available data.[12,14] Basically, interstates (K=1), expressways (K=2) and major arterials (K=3) are assumed to exhibit identical operating characteristics and minor arterials (K=4), collectors (K=5), and local roads (K=6) are assumed to exhibit identical operating characteristics.[14] For the vehicle types recognized by the Model, light vehicles (I=1, ..., 7) and motorcycles (I=13, 14) are assumed to operate in the same manner.[13, 14] Medium trucks (I=8), heavy trucks (I=9), and intercity buses (I=10) are assumed to operate in the same manner.[12,16] Transit buses (I=11) and school buses (I=12) are each assumed to operate in a defined manner.[12]

The data array defining the percentage of time that a vehicle operates in a given mode on a given roadway with a defined travel speed in a specified population density area and population place size is, potentially, the largest data array that may be used by the Model. If data were available to extend the level of detail to the highest category possible, the array would contain 60,480 data elements for the present model structure.

The current data used by the Model to define the percentage of time that a vehicle operates in a given mode on a given roadway is presented in Table A-3.5.

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 1

ROADWAY TYPE	OPERATING MODE				TOTAL
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	
1	4.70	5.36	88.88	1.06	100.00
2	4.70	5.36	88.88	1.06	100.00
3	4.70	5.36	88.88	1.06	100.00
4	15.40	16.00	55.10	13.50	100.00
5	15.40	16.00	55.10	13.50	100.00
6	15.40	16.00	55.10	13.50	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 2
(Continued)

ROADWAY TYPE	OPERATING MODE				TOTAL
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	
1	4.70	5.36	88.88	1.06	100.00
2	4.70	5.36	88.88	1.06	100.00
3	4.70	5.36	88.88	1.06	100.00
4	15.40	16.00	55.10	13.50	100.00
5	15.40	16.00	55.10	13.50	100.00
6	15.40	16.00	55.10	13.50	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 3
(Continued)

ROADWAY TYPE	OPERATING MODE				TOTAL
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	
1	4.70	5.36	88.88	1.06	100.00
2	4.70	5.36	88.88	1.06	100.00
3	4.70	5.36	88.88	1.06	100.00
4	15.40	16.00	55.10	13.50	100.00
5	15.40	16.00	55.10	13.50	100.00
6	15.40	16.00	55.10	13.50	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 4
(Continued)

	OPERATING MODE				
ROADWAY TYPE	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	TOTAL
1	4.70	5.36	88.88	1.06	100.00
2	4.70	5.36	88.88	1.06	100.00
3	4.70	5.36	88.88	1.06	100.00
4	15.40	16.00	55.10	13.50	100.00
5	15.40	16.00	55.10	13.50	100.00
6	15.40	16.00	55.10	13.50	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 5
(Continued)

ROADWAY TYPE	OPERATING MODE				TOTAL
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	
1	4.70	5.36	88.88	1.06	100.00
2	4.70	5.36	88.88	1.06	100.00
3	4.70	5.36	88.88	1.06	100.00
4	15.40	16.00	55.10	13.50	100.00
5	15.40	16.00	55.10	13.50	100.00
6	15.40	16.00	55.10	13.50	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 6
(Continued)

ROADWAY TYPE	OPERATING MODE				TOTAL
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	
1	4.70	5.36	88.88	1.06	100.00
2	4.70	5.36	88.88	1.06	100.00
3	4.70	5.36	88.88	1.06	100.00
4	15.40	16.00	55.10	13.50	100.00
5	15.40	16.00	55.10	13.50	100.00
6	15.40	16.00	55.10	13.50	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 7
(Continued)

ROADWAY TYPE	OPERATING MODE				TOTAL
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	
1	4.70	5.36	88.88	1.06	100.00
2	4.70	5.36	88.88	1.06	100.00
3	4.70	5.36	88.88	1.06	100.00
4	15.40	16.00	55.10	13.50	100.00
5	15.40	16.00	55.10	13.50	100.00
6	15.40	16.00	55.10	13.50	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 8
(Continued)

ROADWAY TYPE	OPERATING MODE				
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	TOTAL
1	5.00	5.00	85.00	5.00	100.00
2	5.00	5.00	85.00	5.00	100.00
3	5.00	5.00	85.00	5.00	100.00
4	13.00	17.00	56.00	14.00	100.00
5	13.00	17.00	56.00	14.00	100.00
6	13.00	17.00	56.00	14.00	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 9
(Continued)

ROADWAY TYPE	OPERATING MODE				TOTAL
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	
1	5.00	5.00	85.00	5.00	100.00
2	5.00	5.00	85.00	5.00	100.00
3	5.00	5.00	85.00	5.00	100.00
4	13.00	17.00	56.00	14.00	100.00
5	13.00	17.00	56.00	14.00	100.00
6	13.00	17.00	56.00	14.00	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 10
(Continued)

ROADWAY TYPE	OPERATING MODE				TOTAL
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	
1	5.00	5.00	85.00	5.00	100.00
2	5.00	5.00	85.00	5.00	100.00
3	5.00	5.00	85.00	5.00	100.00
4	13.00	17.00	56.00	14.00	100.00
5	13.00	17.00	56.00	14.00	100.00
6	13.00	17.00	56.00	14.00	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 11
(Continued)

ROADWAY TYPE	OPERATING MODE				
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	TOTAL
1	5.00	5.00	85.00	5.00	100.00
2	5.00	5.00	85.00	5.00	100.00
3	5.00	5.00	85.00	5.00	100.00
4	20.00	20.00	26.00	34.00	100.00
5	20.00	20.00	26.00	34.00	100.00
6	20.00	20.00	26.00	34.00	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 12
(Continued)

ROADWAY TYPE	OPERATING MODE				TOTAL
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	
1	5.00	5.00	85.00	5.00	100.00
2	5.00	5.00	85.00	5.00	100.00
3	5.00	5.00	85.00	5.00	100.00
4	9.00	9.00	21.00	61.00	100.00
5	9.00	9.00	21.00	61.00	100.00
6	9.00	9.00	21.00	61.00	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 13
(Continued)

ROADWAY TYPE	OPERATING MODE				
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	TOTAL
1	4.70	5.36	88.88	1.06	100.00
2	4.70	5.36	88.88	1.06	100.00
3	4.70	5.36	88.88	1.06	100.00
4	15.40	16.00	55.10	13.50	100.00
5	15.40	16.00	55.10	13.50	100.00
6	15.40	16.00	55.10	13.50	100.00

TABLE A-3.5 PERCENT OF TIME IN OPERATING MODE: VEHICLE TYPE 14
(Continued)

ROADWAY TYPE	OPERATING MODE				TOTAL
	ACCELERATION M=1	DECELERATION M=2	CRUISE M=3	IDLE M=4	TOTAL
1	4.70	5.36	88.88	1.06	100.00
2	4.70	5.36	88.88	1.06	100.00
3	4.70	5.36	88.88	1.06	100.00
4	15.40	16.00	55.10	13.50	100.00
5	15.40	16.00	55.10	13.50	100.00
6	15.40	16.00	55.10	13.50	100.00

A.4 Vehicle Data

The National Roadway Traffic Noise Exposure Model defines 14 vehicles types to simulate noise emissions from the national roadway network. Each vehicle type is defined by its engineering characteristics and its noise emission characteristics. Each vehicle type is a distinct characteristics of the Model in that the vehicle population and noise emission characteristics are allowed to vary with time as defined by the input data to the Model.

A.4.1 Classification of Vehicle Types

The National Roadway Traffice Noise Exposure Model groups vehicles into four major categories. These four categories are further subdivided into classes of vehicles according to distinct engineering characteristics. The four major categories of vehicles are:

- Light Vehicles (passenger cars and light trucks)
- Trucks (medium and heavy trucks)
- Buses (intercity, transit and school buses)
- Motorcycles (unmodified and modified motorcycles).

Data related to the vehicle type is denoted, in the Model, by an Index I. The correspondence between the Index I, the vehicle type, and the engineering characteristics are presented in Table A-4.1.

A.4.2 Baseline Year (1974) Vehicle Population

The Model simulates vehicle sales and survival from the baseline year (1974) to estimate future size of the nation's traffic fleet. To conduct this simulation, it is necessary to initiate the calculations with the distribution of vehicle population for the model year 1974 and previous model years. To do this, historical data is used. For automobiles, the data of Reference 17, page 38 was used. For trucks, the data of Reference 17, page 39, was used. Data for buses and motorcycles were obtained from EPA background documents.[12,13]

The 1974 distribution of vehicle population, by model year is based upon the total 1974 registrations and the vehicle survivability data used by the Model. The 1974 vehicle populations used as stored data in the Model are grouped into major categories based upon the best available data.[17] That is, light vehicles (I=1, ..., 7), trucks (I=8, 9), intercity buses (I=10), transit buses (I=11), school buses (I=12), and motorcycle (I=13, 14) populations are the basis of the data set. These data are presented in Table A-4.2. As indicated in Table A-4.2, data for light vehicles, trucks, and motorcycles encompass vehicles of ages out to 16 years with the last group comprising vehicles of 17 years of age or older. Bus data[12] allowed the distribution to be estimated only for model years between 1971 and 1974 with the last group comprising buses five years of age or older.

To estimate the distribution of vehicle population by its engineering characteristics (Index I), the Model uses a distribution factor for each of the vehicle categories given in Table A-4.2. These distribution factors are listed in Table A-4.3 for the 1974 vehicle populations. For example, to estimate the 1972 model year Type 1 vehicle population in 1974, the Model multiplies 0.4673 (Table A-4.3) by 13,145,920 (Table A-4.2) to obtain 6,143,088 Type 1 vehicles. The populations, of course, represent vehicle registrations which include vehicles produced for domestic sales and imports. The distribution factors for light vehicles presented in Table A-4.3 were estimated for the U.S. Environmental Protection Agency.[18] The truck distribution was estimated from FHWA data[11] and from vehicle registration data.[17] The motorcycle distribution was estimated from Reference 17 data.

A.4.3 Survival of Vehicles with Age

To simulate the mixture of vehicles by model year in any future year, the Model continuously removes vehicles from the traffic stream and introduces new vehicles. The noise emissions for a given vehicle type correspond to the model year and the noise regulation defined for that model year.

The National Roadway Traffic Noise Exposure Model uses vehicle survivability arrays to simulate the number of vehicles of a model year remaining in operation on the nation's roadways in a future year. These data were developed from the best available data sources. The procedures used are described in Appendix G in this report. Currently, the Model uses two survivability arrays. One array is strictly based upon passenger cars, and is assumed to apply equally to motorcycles. This other array is based upon truck data and is assumed to apply equally to buses.

The passenger car survivability data was developed from registration data presented in Reference 17, page 38. The truck survivability data was developed from registration data presented in Reference 17, page 39. The results of the data analysis described in Appendix G are presented in Table A-4.4. The survivability curves corresponding to the data in Table A-4.4 are presented in Figure A-4.1.

For example, using the data in Table A-4.4, a passenger vehicle type with a model year production of one million units would have 987,700 units surviving after 5 years; 657,000 units surviving after 10 years; 85,700 units surviving after 15 years; and 5,700 units surviving after 18 years. After 19 years, the example model year vehicle type would be estimated to be effectively removed from operation (i.e., no vehicles of the type and model year survive beyond 19 years of age.).

TABLE A-4.1
CLASSIFICATION OF VEHICLE TYPES USED
BY THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL

Index, I	Vehicle Type	Engineering Characteristics
1	Passenger Car	8 cyl. Gasoline Engine Automatic Transmission
2	Passenger Car	6 cyl. Galoline Engine Automatic Transmission
3	Passenger Car	6 & 8 cyl. Gasoline Engine Manual Transmission
4	Passenger Car and Light Truck	4 cyl. Gasoline Engine Automatic Transmission
5	Passenger Car and Light Truck	4 cyl. Gasoline Engine Manual Transmission
6	Light Truck	6 & 8 cyl. Gasoline Engine
7	Passenger Car and Light Truck	Diesel Engine
8	Medium Truck	Two Axle (GVWR >10,000 lb)
9	Heavy Truck	Three or more Axles (GVWR >26,000 lb)
10	Intercity Buses	
11	Transit Buses	
12	School Buses	
13	Unmodified Motorcycles	
14	Modified Motorcycles	

TABLE A-4.2
BASELINE YEAR (1974) VEHICLE POPULATION
BY MODEL YEAR AND VEHICLE CATEGORY

Model Year	Light Vehicles	Trucks	Intercity Buses	Transit Buses	School Buses	Motorcycles
1974	13,959,524	447,576	1,479*	12,571	58,226	518,315
1973	14,599,524	457,770	2,246	6,706	47,511	579,971
1972	13,145,920	387,705	1,886	4,819	38,378	522,226
1971	11,107,210	281,879	1,084	3,319	28,263	443,740
1970	11,003,084	274,759	13,905*	42,057*	184,460*	437,103
1969	11,161,141	291,911	-	-	-	443,380
1968	10,274,987	229,451	-	-	-	408,177
1967	8,581,706	211,166	-	-	-	340,911
1966	8,461,220	211,814	-	-	-	336,125
1965	7,397,576	185,276	-	-	-	293,871
1964	5,151,096	152,266	-	-	-	204,629
1963	3,658,626	121,684	-	-	-	145,340
1962	2,348,827	97,573	-	-	-	93,308
1961	1,167,288	69,094	-	-	-	46,317
1960	883,563	70,227	-	-	-	35,063
1959	506,559	59,871	-	-	-	20,129
1958	2,100,082*	370,391*	-	-	-	83,436*

* Population includes all vehicles in this model year and older.

TABLE A-4.3
DISTRIBUTION OF VEHICLE POPULTION BY VEHICLE TYPE
FOR MODEL YEARS 1974 AND EARLIER

Vehicle		Fraction of Vehicle Category Population
Type 1		0.4673
Type 2		0.1420
Type 3		0.0167
Type 4		0.0168
Type 5		0.1603
Type 6		0.1514
Type 7		0.0005
	Total	1.0000
Type 8		0.6146
Type 9		0.3854
	Total	1.0000
Type 10		1.0000
Type 11		1.0000
Type 12		1.0000
Type 13		0.8800
Type 14		0.1200
	Total	1.0000

A.4.4 Vehicle Sales Projections

The National Roadway Traffic Noise Exposure Model allows the user to define total vehicle sales in future years in order to estimate the fleet mix, by vehicle type. The Model is structured so that vehicle sales are expressed, in a future year, as a multiplier of the 1974 vehicle production. The data base for vehicle sales is defined by the future year (Index IYRN) and the vehicle type (Index I). The technique used to define future year sales is based upon the current availability of projections in terms of the 14 vehicle types used by the model.

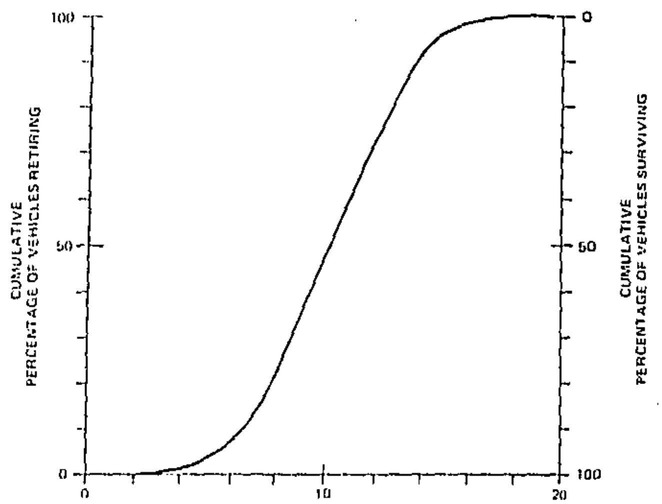
As described in Section A.4.2, the Model groups vehicles into six basic population categories as follows:

- Light Vehicles (I=1, ..., 7)
- Trucks (I=8, 9)
- Intercity Buses (I=10)
- Transit Buses (I=11)
- School Buses (I=12)
- Motorcycles (I=13, 14)

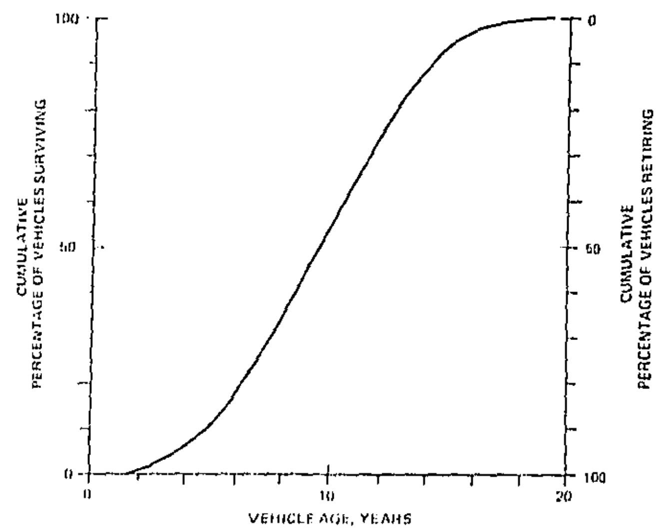
To further define the vehicle population, by explicit vehicle type, distribution factors are defined. Table A-4.3 presents the vehicle distribution factors for 1974 and earlier model year vehicles. To define future year vehicle populations, by explicit vehicle type, vehicle sales distribution factors are defined for specific years in the time stream. These factors simulate the future year distribution of vehicle sales by vehicle type. The Model uses linear interpolation between the baseline year and defined future years in which the vehicle sales distribution factors are

TABLE A-4.4
PERCENTAGE OF VEHICLES SURVIVING AFTER X YEARS

Vehicle X Years	Percentage of Passenger Cars Surviving	Percentage of Trucks Surviving
Less than 1	100.00	100.00
1 to 2	99.98	100.00
2 to 3	99.90	99.98
3 to 4	99.60	99.27
4 to 5	98.77	97.11
5 to 6	96.83	93.29
6 to 7	93.07	87.83
7 to 8	86.77	80.89
8 to 9	77.56	72.72
9 to 10	65.70	63.64
10 to 11	52.14	54.02
11 to 12	38.34	44.24
12 to 13	25.83	34.69
13 to 14	15.75	25.76
14 to 15	8.57	17.80
15 to 16	4.10	11.13
16 yo 17	1.68	5.98
17 to 18	0.57	2.48
18 to 19	0.00	0.62
19 to 20	0.00	0.13
20 to 21	0.00	0.13
Greater than 21	0.00	0.00



(a) PASSENGER CARS RETIRING/SURVIVING BY YEARS OF AGE



(b) TRUCKS RETIRING/SURVIVING BY YEARS OF AGE

FIGURE A-4.1 PERCENTAGE OF VEHICLES RETIRING WITH AGE: CUMULATIVE DISTRIBUTION defined. For years beyond the last specified sales distribution, the Model holds the sales distribution constant at these values.

Hence, the six basic vehicle population categories are used to define future vehicle sales for each category in each future year, and the sales distribution factors are used to estimate the explicit sales for the appropriate vehicle type within that category.

Currently, the Model's data base defines the 1974 vehicle distribution as presented in Table A-4.3 and allows the user to define sales distributions for two future years. Figure A-4.2 presents sales growth projections currently used in the Model's data base. The sales growth curve for light vehicles, trucks, and motorcycles is based upon an annual compounded growth rate of 2 percent.[18] The curves for buses are based upon EPA estimates.[12]

Table A-4.5 presents one set of light vehicle sales distribution factors used by the Model to simulate decreased sales for Type 1 vehicles and increased sales of other light vehicle types. Currently, sales distribution factors for trucks, buses, and motorcycles are held constant at their 1974 values.

Figure A-4.3 presents total vehicle registration trends based upon Bureau of Census data[11] and projection (indicated by the dots) estimated by the Model using the data and methodology described above. Table A-4.6 presents an output listing of the projected vehicle populations. The results presented in Tables A-4.5 and A-4.6 are standard output data provided by the Model with each execution to document completely the scenario used.

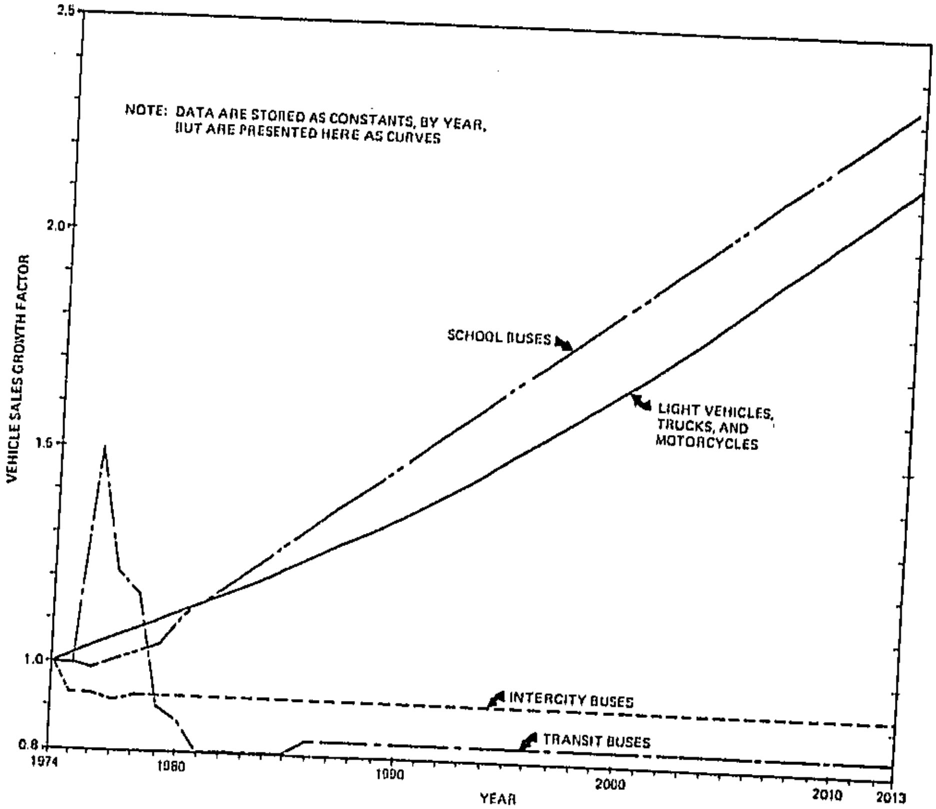


FIGURE A-4.2 VEHICLE SALES GROWTH PROJECTIONS

TABLE A-4.5
LIGHT VEHICLE SALES DISTRIBUTION FACTORS: 1957 - 2013

VEHICLE TYPE > / MODEL YEAR V	VEHICLE BREAKDOWN, VFD(I). ****PRNT11							SUM
	1	2	3	4	5	6	7	
1957	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1958	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1959	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1960	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1961	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1962	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1963	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1964	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1965	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1966	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1967	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1968	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1969	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1970	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1971	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1972	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1973	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1974	0.4673	0.1420	0.0167	0.0618	0.1603	0.1514	0.0005	1.0000
1975	0.4579	0.1388	0.0170	0.0612	0.1535	0.1709	0.0007	1.0000

TABLE A-4.5
(Continued)

VEHICLE TYPE > / MODEL YEAR V	****PRN111							SUM
	1	2	3	4	5	6	7	
	VEHICLE BREAKDOWN, VBD(I).							
1976	0.4464	0.1356	0.0173	0.0606	0.1468	0.1905	0.0008	1.0000
1977	0.4390	0.1324	0.0176	0.0600	0.1400	0.2100	0.0010	1.0000
1978	0.3929	0.1390	0.0185	0.0812	0.1417	0.2000	0.0271	1.0000
1979	0.3467	0.1456	0.0194	0.1025	0.1425	0.1905	0.0532	1.0000
1980	0.3066	0.1522	0.0203	0.1237	0.1437	0.1800	0.0794	1.0000
1981	0.2545	0.1588	0.0211	0.1456	0.1450	0.1700	0.1055	1.0000
1982	0.2084	0.1655	0.0220	0.1662	0.1462	0.1600	0.1316	1.0000
1983	0.1622	0.1721	0.0229	0.1875	0.1475	0.1500	0.1577	1.0000
1984	0.1161	0.1787	0.0238	0.2087	0.1487	0.1400	0.1839	1.0000
1985	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1986	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1987	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1988	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1989	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1990	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1991	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1992	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1993	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1994	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1995	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000

TABLE A-4.5
(Concluded)

VEHICLE TYPE > / MODEL YEAR V	****PRNT11							SUM
	1	2	3	4	5	6	7	
	VEHICLE BREAKDOWN, VBD(I).							
1996	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1997	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1998	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
1999	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2000	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2001	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2002	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2003	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2004	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2005	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2006	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2007	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2008	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2009	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2010	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2011	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2012	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000
2013	0.0700	0.1853	0.0247	0.2300	0.1500	0.1300	0.2100	1.0000

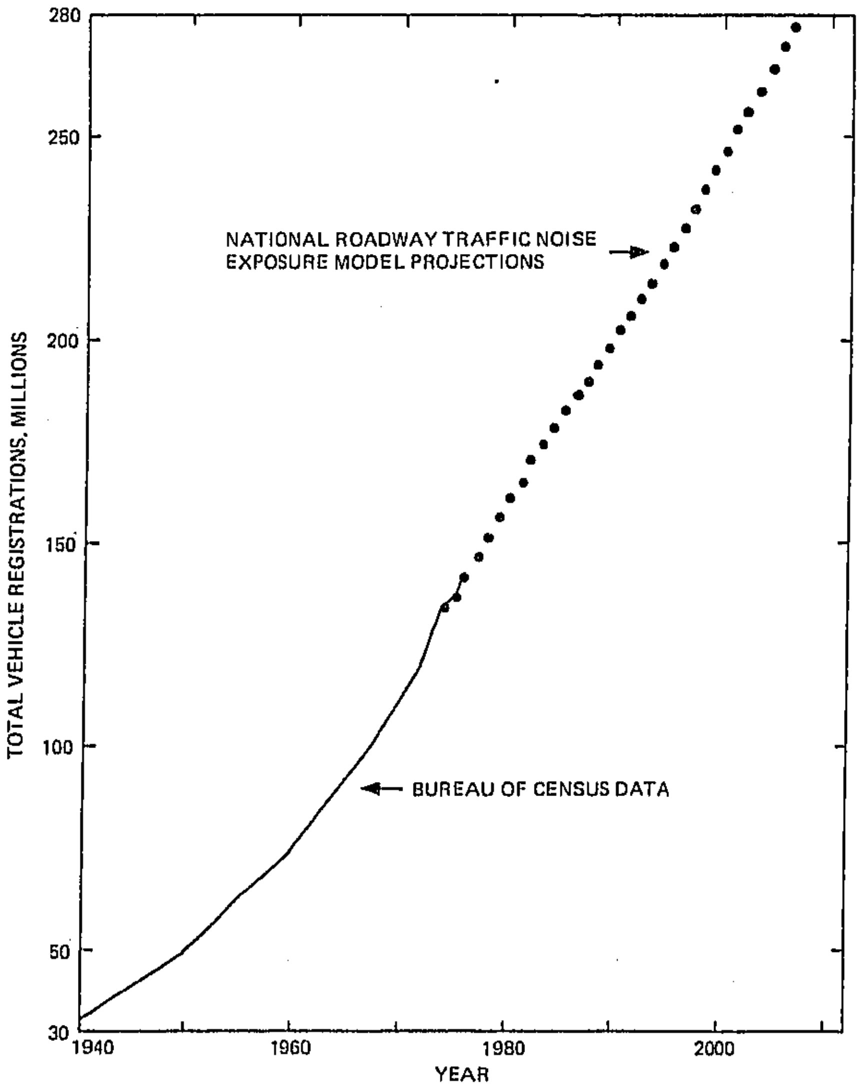


FIGURE A-4.3 TRENDS AND PROJECTIONS OF TOTAL U.S. VEHICLE REGISTRATIONS

TABLE A-4.6
EXAMPLE OF VEHICLE POPULATION PREDICTIONS

TYPE>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	ALL TYPES
CYLINDERS	8	6	6&8	4	4	6&8									
ENGINE	GAS	GAS	GAS	GAS	GAS	GAS	DIESEL								
TRANS-MISSION	AUTO-MATIC	AUTO-MATIC	MAN-UAL	AUTO-MATIC	MAN-UAL	----	----	----	----	----	----	----	----	----	
VEH. TYPE>	PC	PC	PC	PC&LT	PC&LT	LT TRK	PC&LT	MED TRK	HVY TRK	IC BUS	TR BUS	SCH BUS	LP MTCY	PT MTCY	
UNIT	MILLIONS									THOUSANDS X .01			MILLIONS		
YEAR															
1979	58.88	17.83	2.10	7.76	20.13	19.31	0.66	2.41	1.51	.21	0.60	3.57	4.34	.59	[illegible]
1980	63.60	21.21	2.66	11.16	22.63	26.26	2.59	2.87	1.65	.14	1.07	4.00	5.41	.66	[illegible]
1986	42.58	26.32	3.70	26.15	25.53	24.28	19.47	3.47	2.17	.16	1.22	7.16	5.69	.80	186.64
1988	33.35	30.63	4.07	32.17	26.64	27.69	26.36	3.63	2.27	.15	1.11	7.68	5.91	.81	[illegible]
1990	25.66	33.12	4.41	37.59	27.93	27.11	32.5[illegible]	3.78	2.37	.15	1.16	8.17	6.15	.86	[illegible]
1995	16.15	38.33	5.11	47.13	31.17	27.63	42.80	4.18	2.62	.15	1.14	9.36	6.86	.93	[illegible]
2000	16.10	42.56	5.57	52.62	34.46	29.07	48.23	4.61	2.89	.15	1.15	10.55	7.51	1.02	[illegible]
2005	17.75	46.98	5.26	56.31	38.03	32.96	53.24	5.09	3.19	.15	1.15	11.72	8.28	1.13	[illegible]
2010	19.59	51.86	6.91	64.37	41.98	36.38	58.77	5.62	3.52	3.15	1.15	12.91	9.14	1.25	300.61

A.5 Vehicle Noise Emission Data

The definition of vehicle noise emission data is a basic user-defined data set for the National Roadway Traffic Noise Exposure Model. As used by the Model, noise emissions are defined on the basis of:

- Vehicle Type (Index I)
- Vehicle Operating Mode (Index M)
- Average Cruise Speed (Index L)

Vehicle noise emissions are assigned to vehicles sold in a given year based upon the temporal sequence in which the vehicle noise emissions are defined. The main text of this report describes the theories upon which traffic noise emissions are calculated. The noise emission data described here represent equivalent (time averaged) A-weighted sound levels at a distance of 50 feet from the vehicle path. Strictly speaking, the levels are representative of what an observer would measure if he (or she) were to move with the vehicle at a distance of 50 feet during the vehicle operating mode.

At first thought, one may be disturbed with the concept of levels measured at a fixed distance and moving with the source. This strict condition is to emphasize the significance of the interface between the Model theory and the Model input data. For a vehicle operating in an idle mode, both the source and receiver are stationary and the noise source is steady (i.e., does not vary with time). For a vehicle operating in a steady noise mode (i.e. constant cruise speed and sound level), an observer traveling with the vehicle would measure a constant level whereas an observer standing at a fixed point would measure a time-varying level due to the time varying source-receiver distance. The stationary observer would measure a maximum pass-by level identical to the continuous level measured by the observer moving with the vehicle. (Both observers are located at 50 feet from the vehicle.) The Model's theory accounts for the time-varying source-receiver distance and steady source sound level as described in the main text of this report.

For vehicle acceleration from idle to cruise and for vehicle deceleration from cruise to idle, however, the vehicle's sound level is nonstationary (i.e., varies with time), and the source-receiver distance varies with time for an observer along the side of a road. Hence, for a stationary observer, the location of the vehicle during an acceleration or deceleration mode of operation relative to the stationary observer is, strictly, required to estimate the observer's noise exposure.

The Model's theory encompasses the consideration of an acceleration mode and a deceleration mode by distributing the vehicle's possible location along a roadway in a statistical sense, and averaging the time-varying noise exposure over the time of operation. The result of this approach is that all observers along the side of a roadway have equal probability of observing any mode of operation. Hence, for an acceleration mode or a deceleration mode of operation, the source noise emission is taken as a constant equivalent (time averaged) level as measured at a constant distance (50 feet) from the side of the vehicle and moving with the vehicle. For the stationary observer at the side of the road, the acceleration or deceleration equivalent sound level is used with the time varying source-receiver distance to calculate the observer's noise exposure.

A.5.1 Definition of Vehicle Noise Emission Data

The National Roadway Traffic Noise Exposure Model uses the maximum pass-by sound level for a given vehicle type as the basic sound level data. The Model uses data in the form of a reference level for each vehicle type (Index I), each operating mode (Index M), and each average cruise speed (Index L). All levels are referenced to a 50-foot distance from the vehicle path.[9,10]

The sound level data are population averages resulting from measurements of several identical vehicles operating in their specific mode. The Model accepts sound level input data in the form:

$$L_0^{eq} = \overline{L_0^{eq}} + 0.115\,\sigma_0^2 \qquad \text{(A-5.1)}$$

where

$\overline{L_0^{eq}}$ is the population mean level

σ_0 is the standard deviation of the levels.

This relationship, of course, assumes that the levels for the defined condition are normally distributed. Hence, the users may define both the mean level and the standard deviation of the levels in describing a vehicle's noise emissions.

A.5.2 Baseline Vehicle Noise Emission Data

The baseline vehicle noise emission data represents the basis from which the National Roadway Traffic Noise Exposure Model conducts its estimates. The data describes the noise emission characteristics of all vehicles in operation on the national roadway network up to the point in time at which new emission data is defined as input. The details of defining noise emission level input data for the Model are presented in the User's Manual. This section describes the source of the baseline noise emission data used by the Model. Future year noise emission schedules are user-defined inputs to simulate vehicle noise regulations.

Table A-5.1 presents the baseline vehicle noise emission data currently defined as part of the Model's data base. These emission levels were developed for the U.S. Environmental Protection Agency based upon extensive vehicle noise tests and appropriate data reduction methods.[24]

The baseline vehicle noise emission data are plotted in Figures A-5.1 through A-5.14. The solid lines in these figures represent the cruise emission level as a function of cruise speed. The solid squares represent the acceleration emission levels for a uniform acceleration from rest to the indicated cruise speed. The solid squares represent the deceleration emission levels for a uniform deceleration from the indicated cruise speed to rest.

The methodology developed in Reference 24 allows the calculation of vehicle noise emission data for each operational mode and cruise speed range given a "regulation level". As described in Reference 24, the regulation level is based upon the regulation test method for each vehicle type. This Methodology is used to develop noise emission schedules for the National Roadway Traffic Noise Exposure Model using future year regulation levels. The methodology also considers this noise for the acceleration and carrier modes.

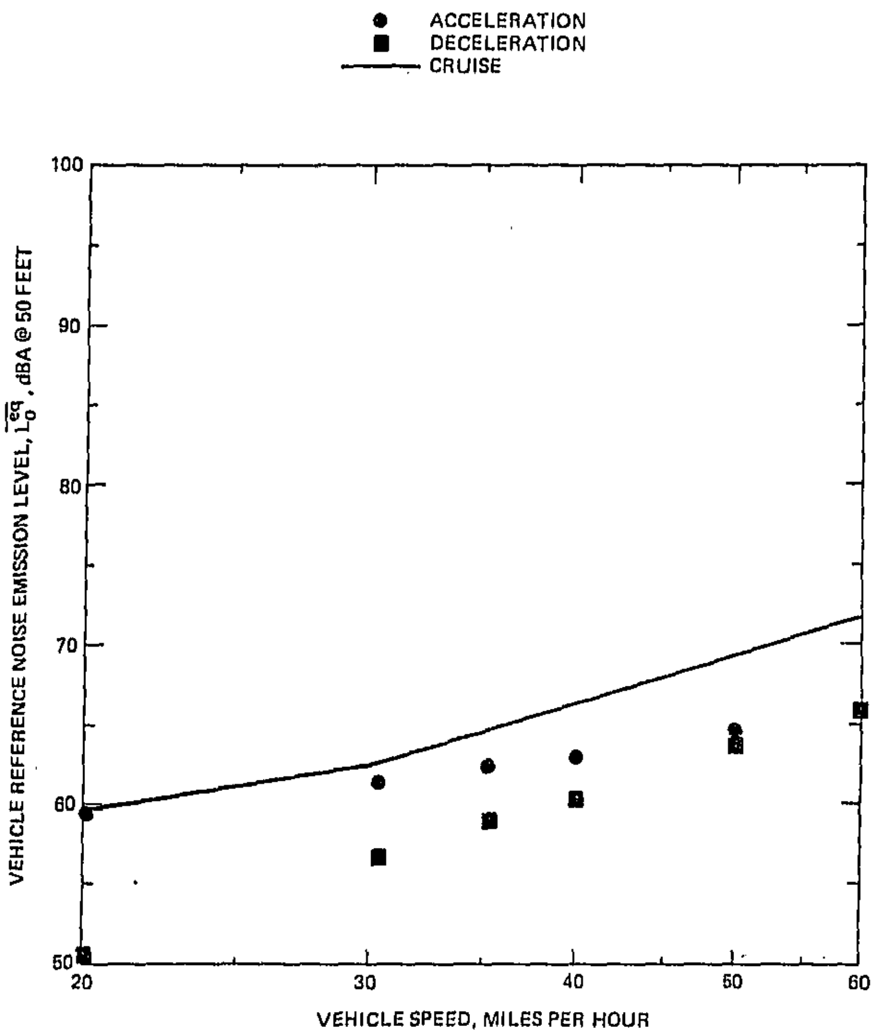


FIGURE A-5.1 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 1 VEHICLE

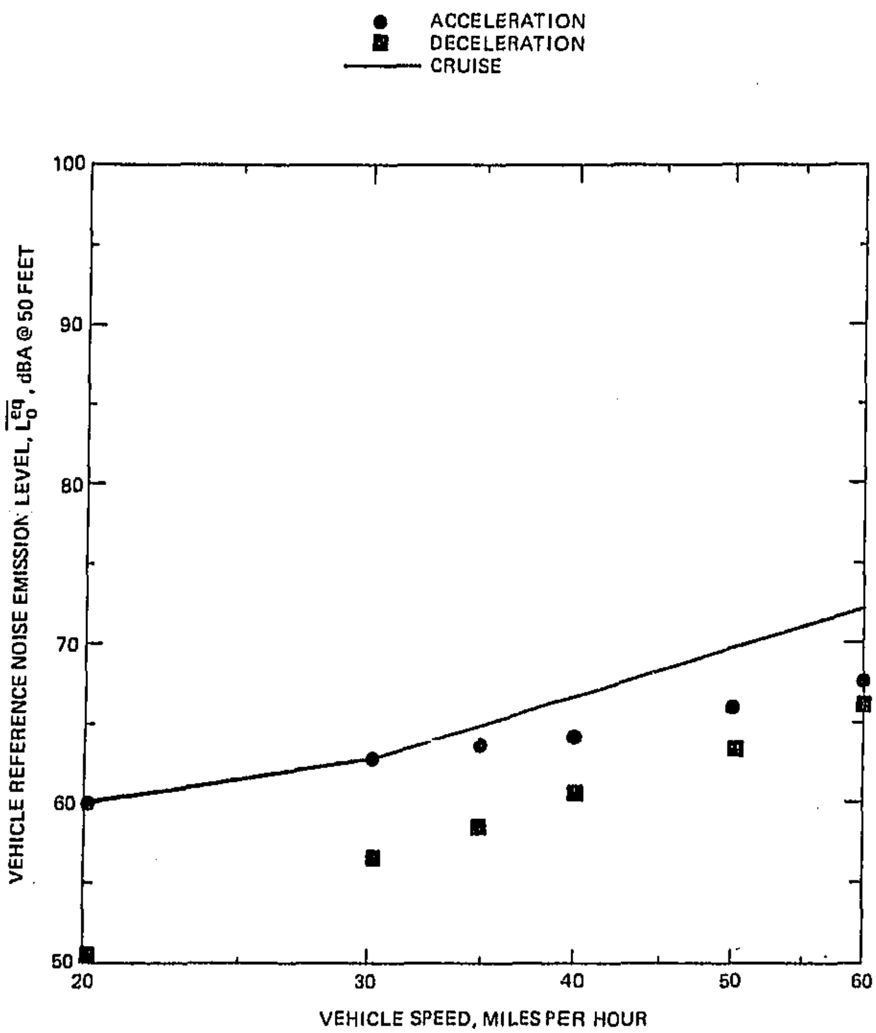


FIGURE A-5.2 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 2 VEHICLE

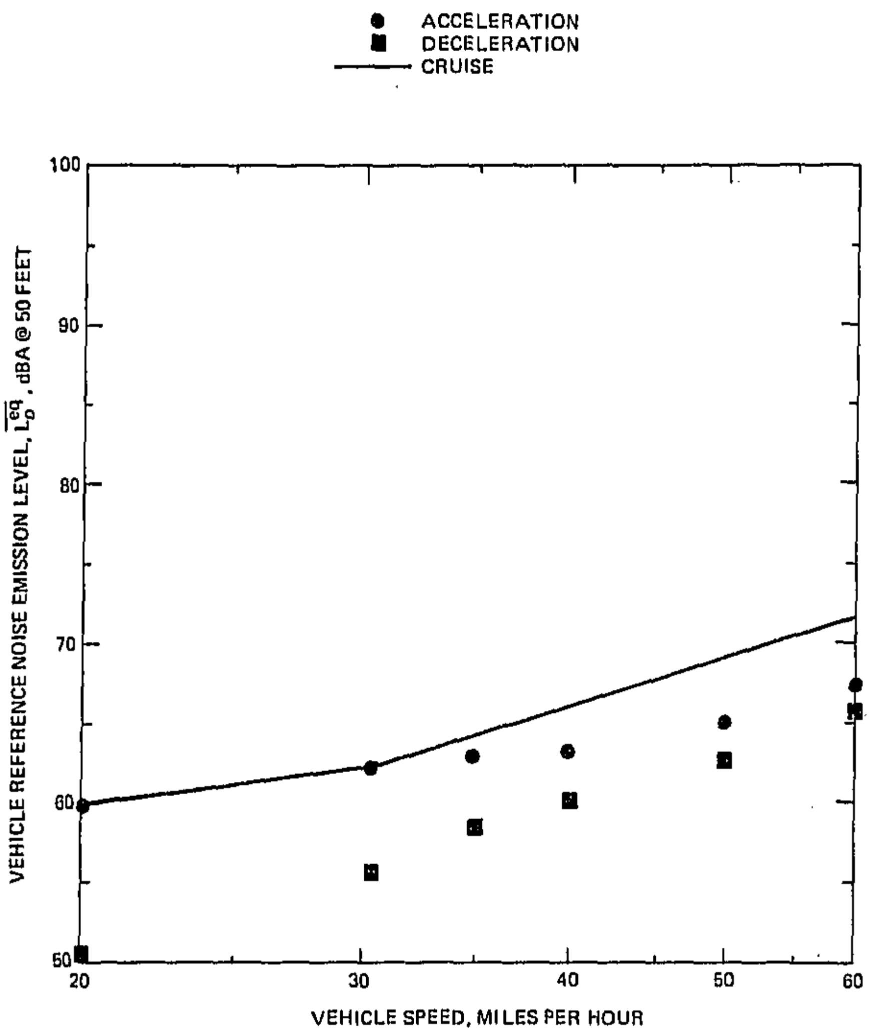


FIGURE A-5.3 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 3 VEHICLE

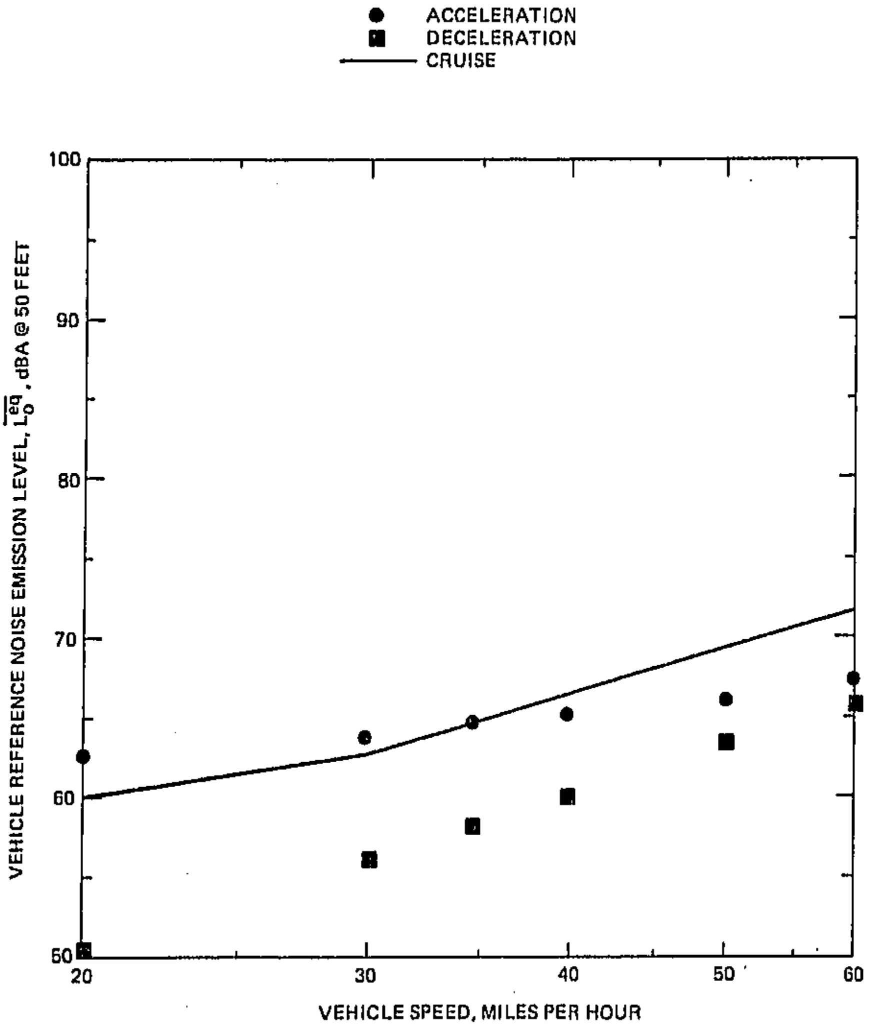


FIGURE A-5.4 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 4 VEHICLE

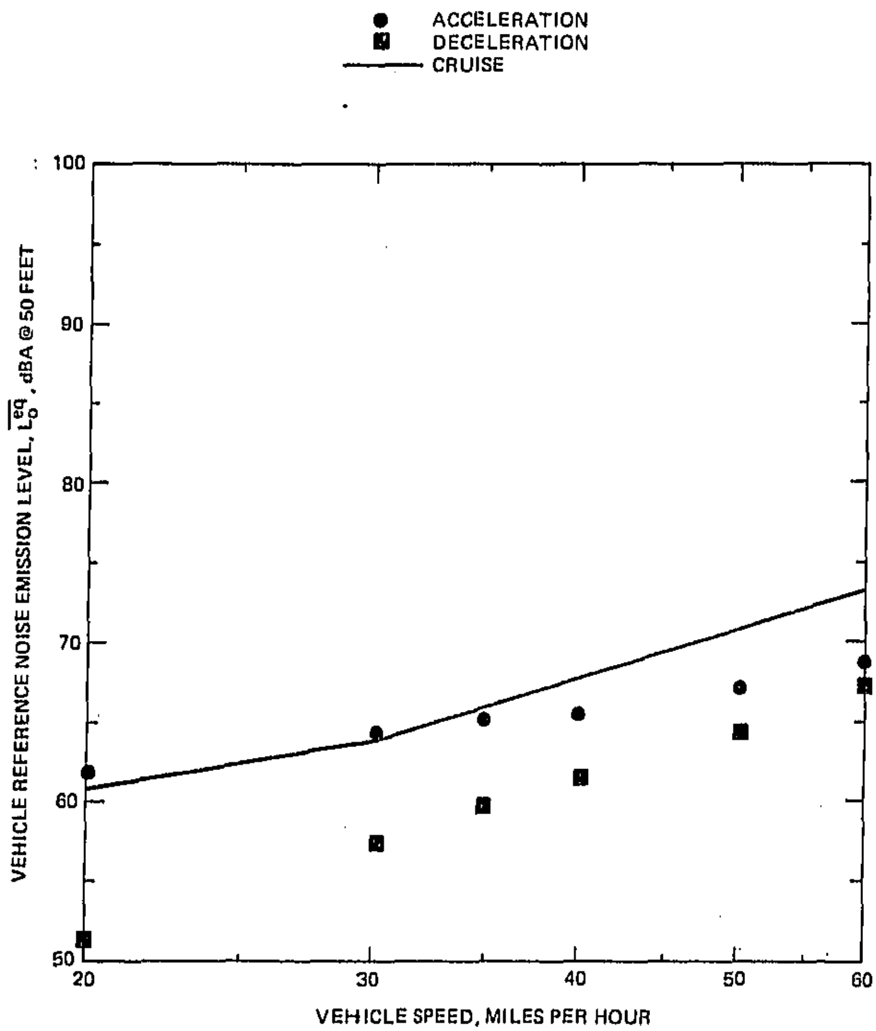


FIGURE A-5.5 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 5 VEHICLE

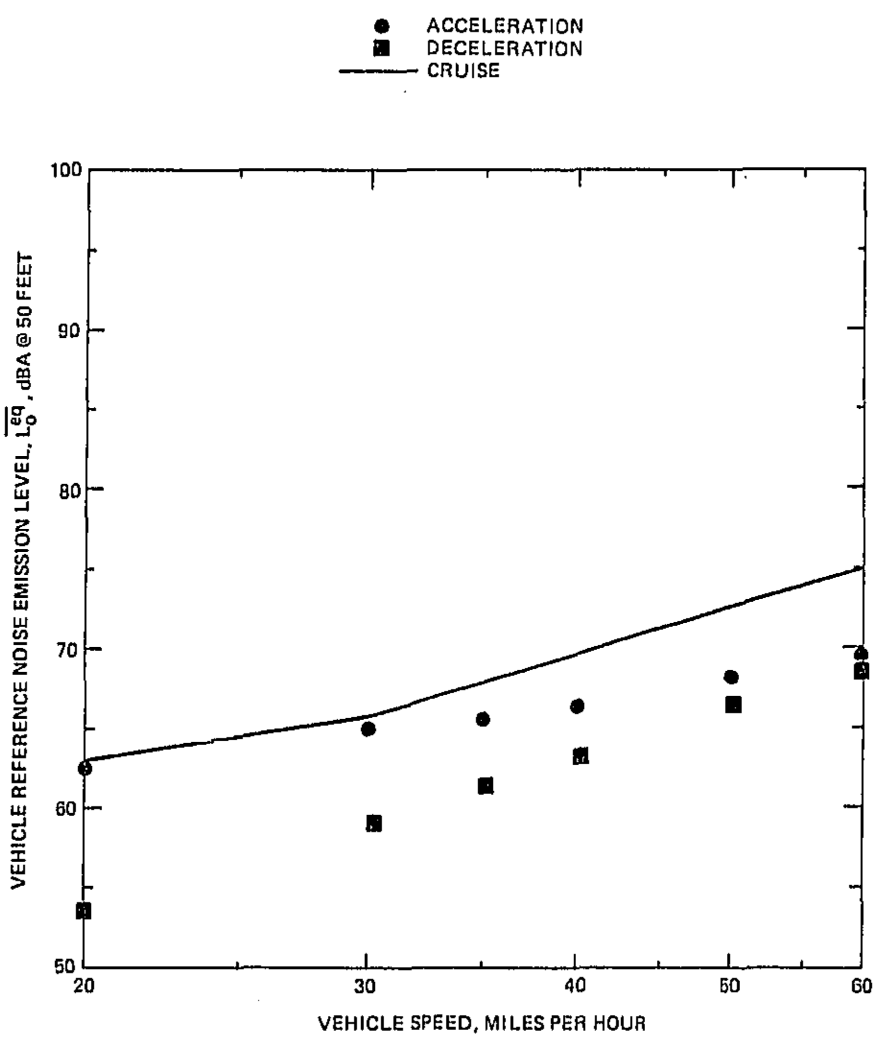


FIGURE A-5.6 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 6 VEHICLE

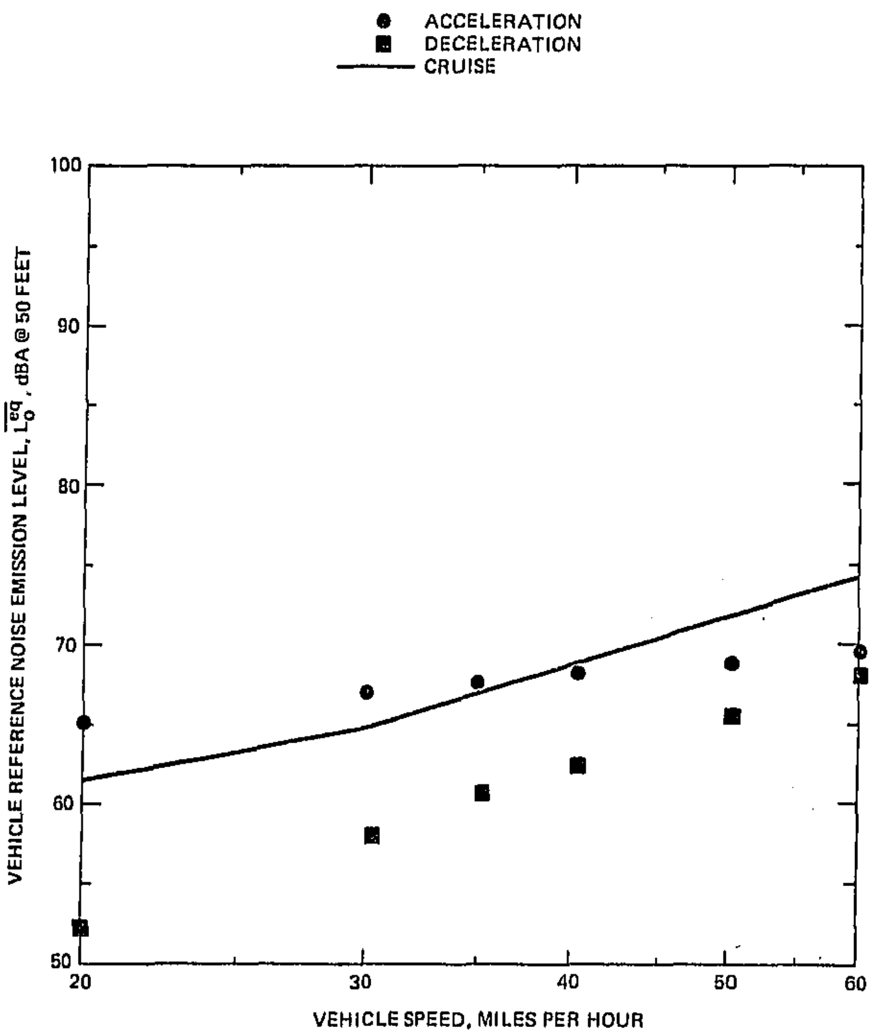


FIGURE A-5.7 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 7 VEHICLE

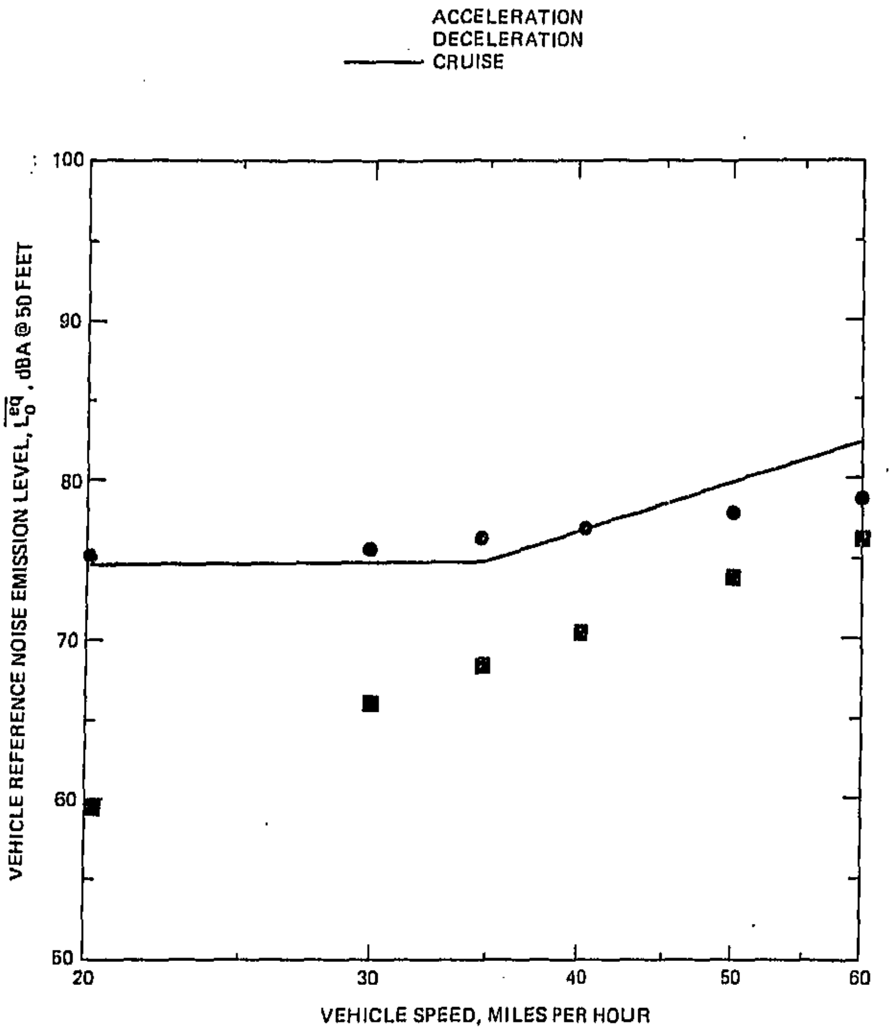


FIGURE A-5.8 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 8 VEHICLE

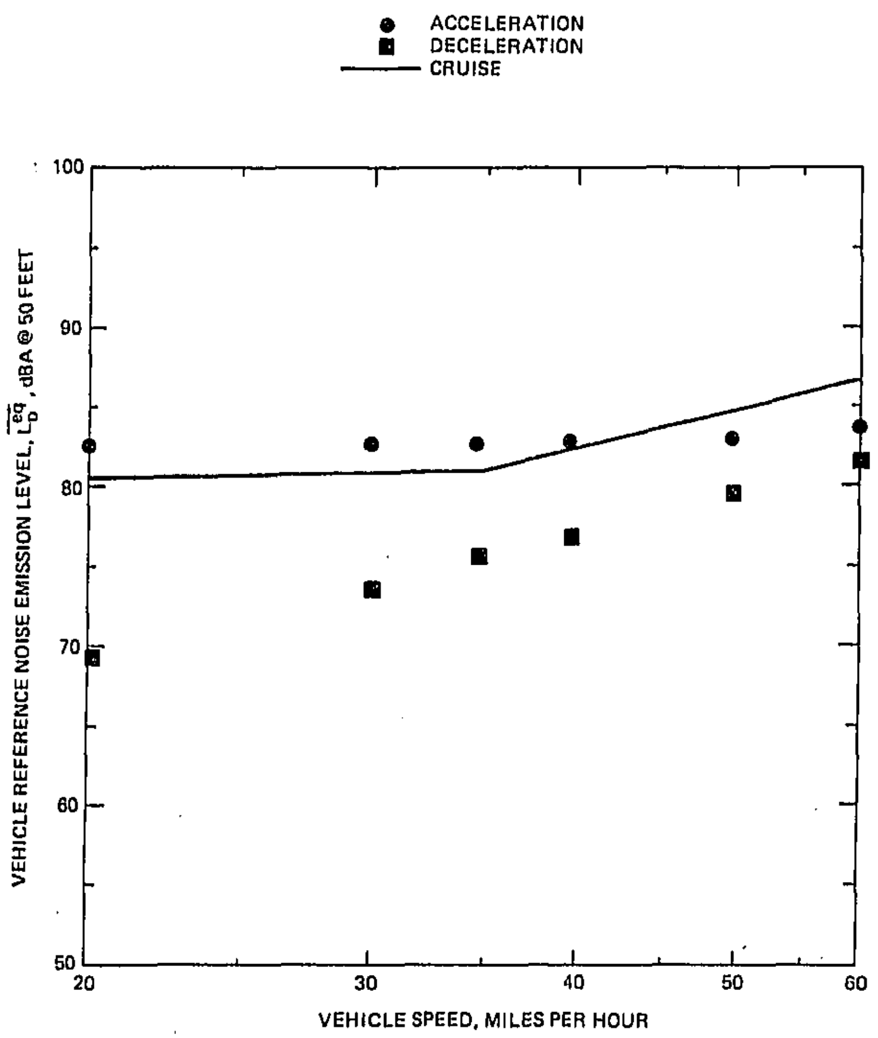


FIGURE A-5.9 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 9 VEHICLE

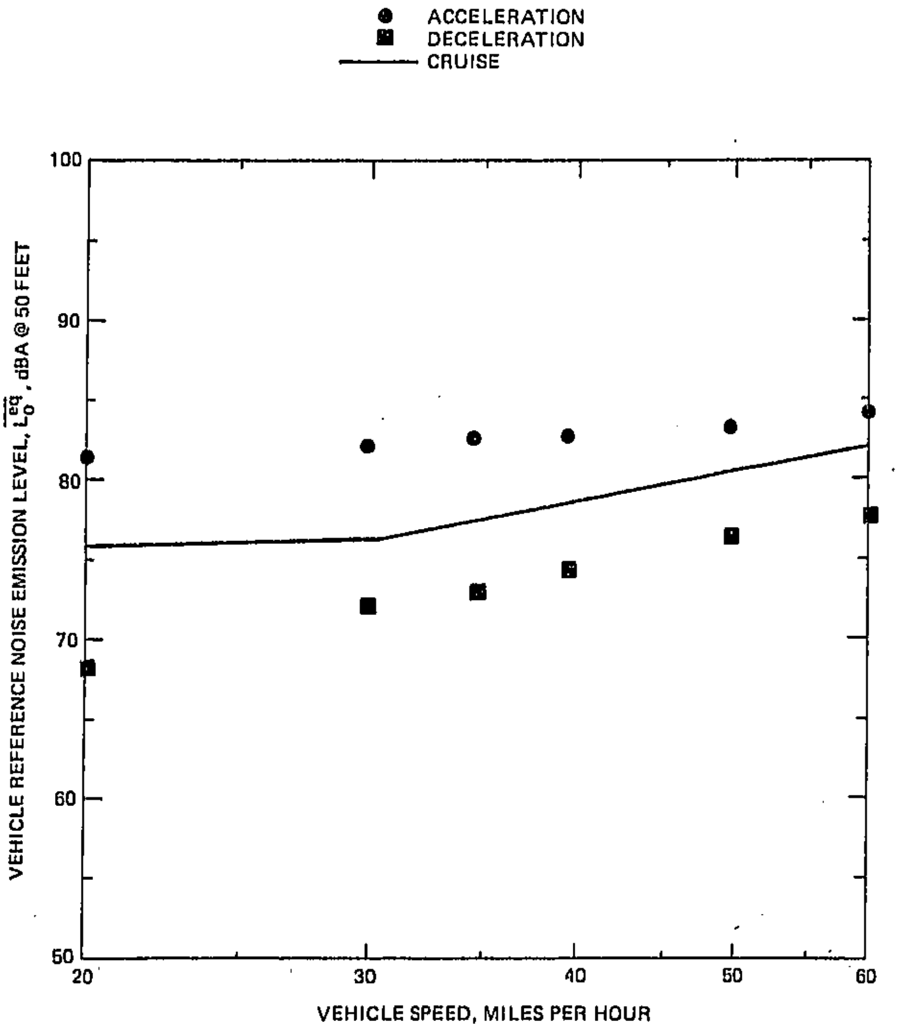


FIGURE A-5.10 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 10 VEHICLE

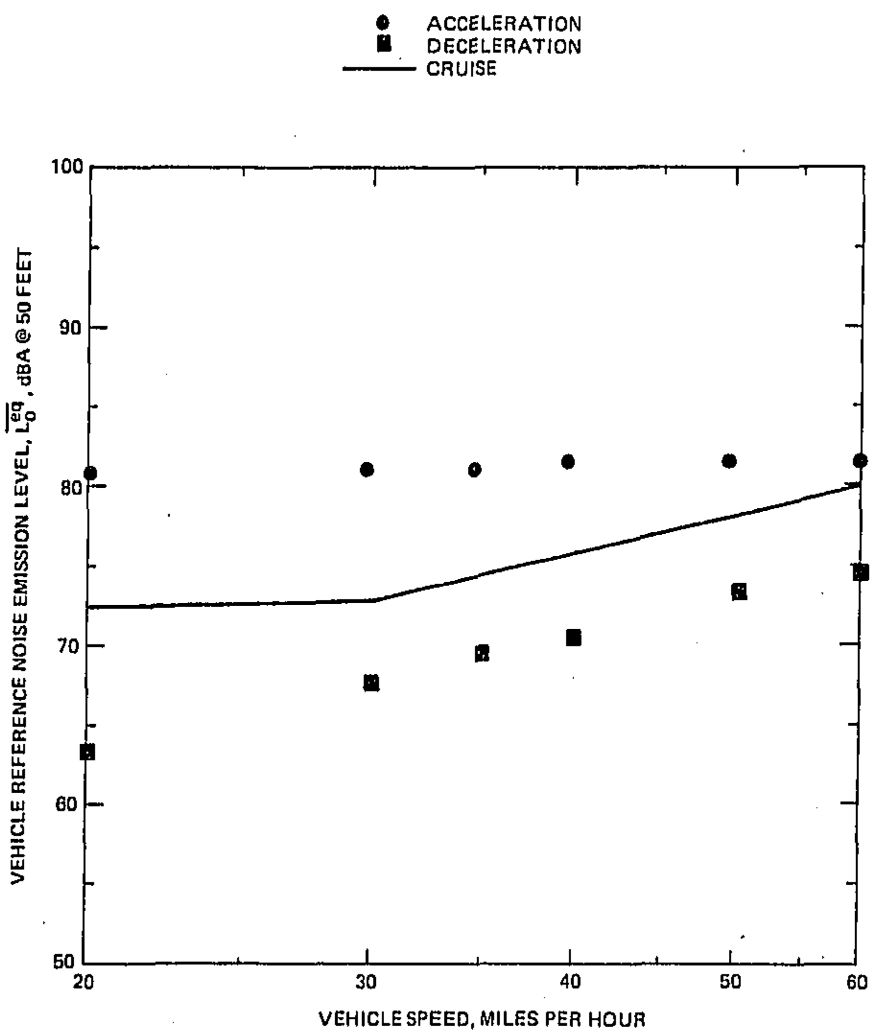


FIGURE A-5.11 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 11 VEHICLE

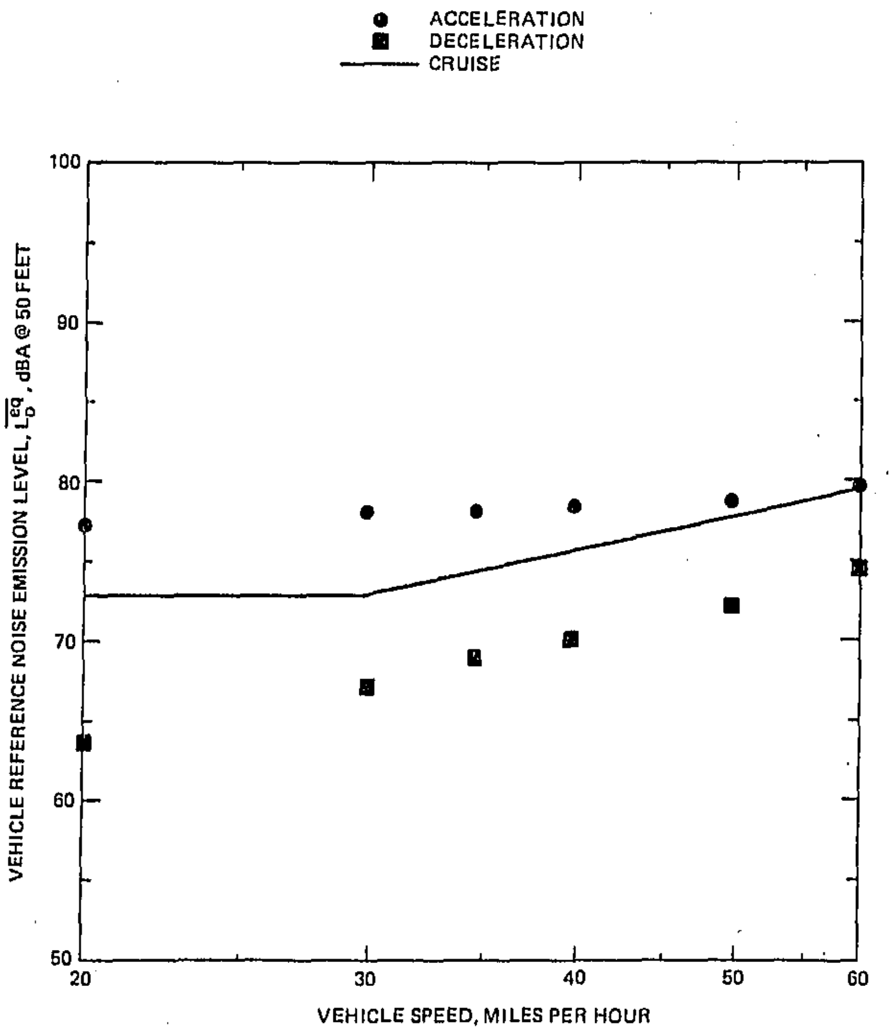


FIGURE A-5.12 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 12 VEHICLE

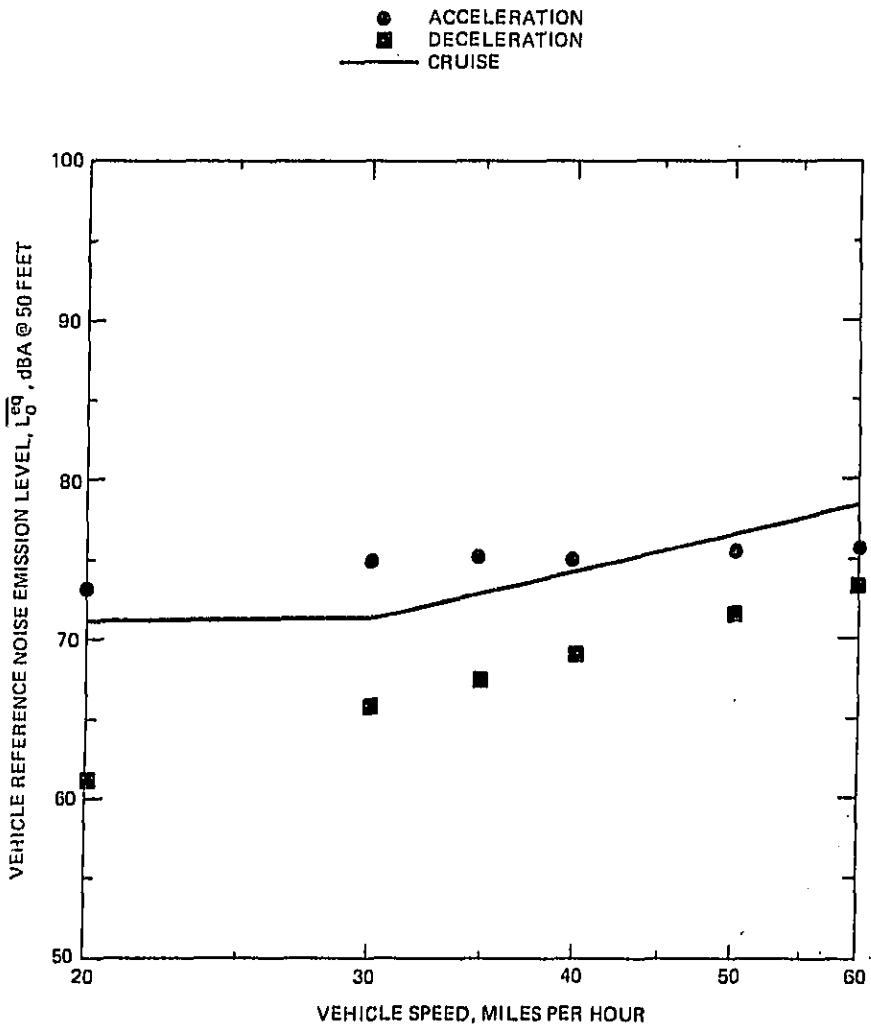


FIGURE A-5.13 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 13 VEHICLE

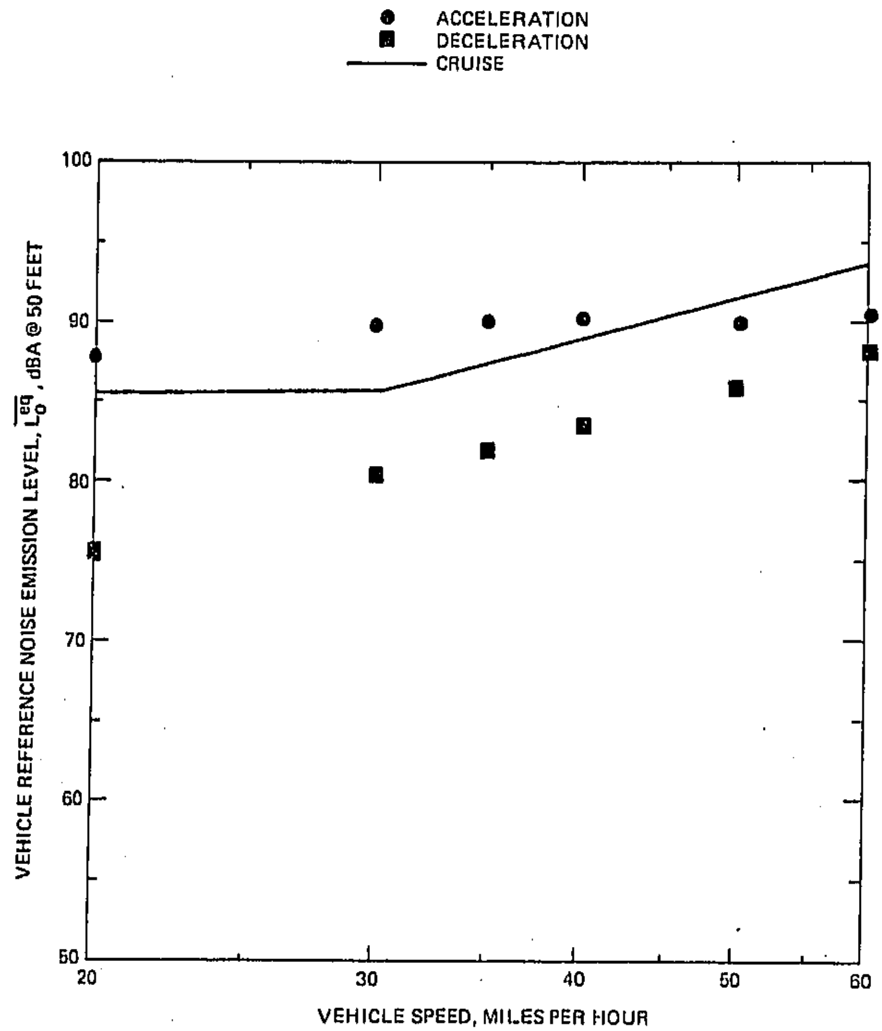


FIGURE A-5.14 BASELINE VEHICLE NOISE EMISSIONS (1974): TYPE 14 VEHICLE

A.6 Traffic Noise Propagation

This section documents the source references for the traffic noise propagation models used by the National Roadway Noise Exposure Model. The basic description and references contained in this section apply directly to the General Adverse Response Model. The Single Event Model requires a different propagation model due to the particular characteristics of the single event sound level metrics. The references presented in this section, however, form the basis for the single event propagation models.

The basic roadway configuration used by the Model comprises a pavement system and a clear zone adjacent to the pavement. The clear zone is an uninhabited area between the pavement and the inhabited area along the roadway. The inhabited or populated area is characterized by a constant population density. The clear zone and the inhabited area are assumed to be identical on each side of the roadway.

The pavement system and the clear zone simulate the roadway width and the adjacent land. The clear zone, for examle, simulates parking lanes, sidewalks, and front yards in urban areas for local streets, collectors, and arterials. For interstates and freeways, the clear zone would simulate the right-of-way adjacent to the pavement. The Model simulates noise propagation over the pavement/clear zone areas as a distinct consideration.

To simulate noise propagation through the inhabited areas, empirical distance attenuation functions are used. This propagation simulates the effect of shielding provided by buildings, etc. representative of the inhabited areas.

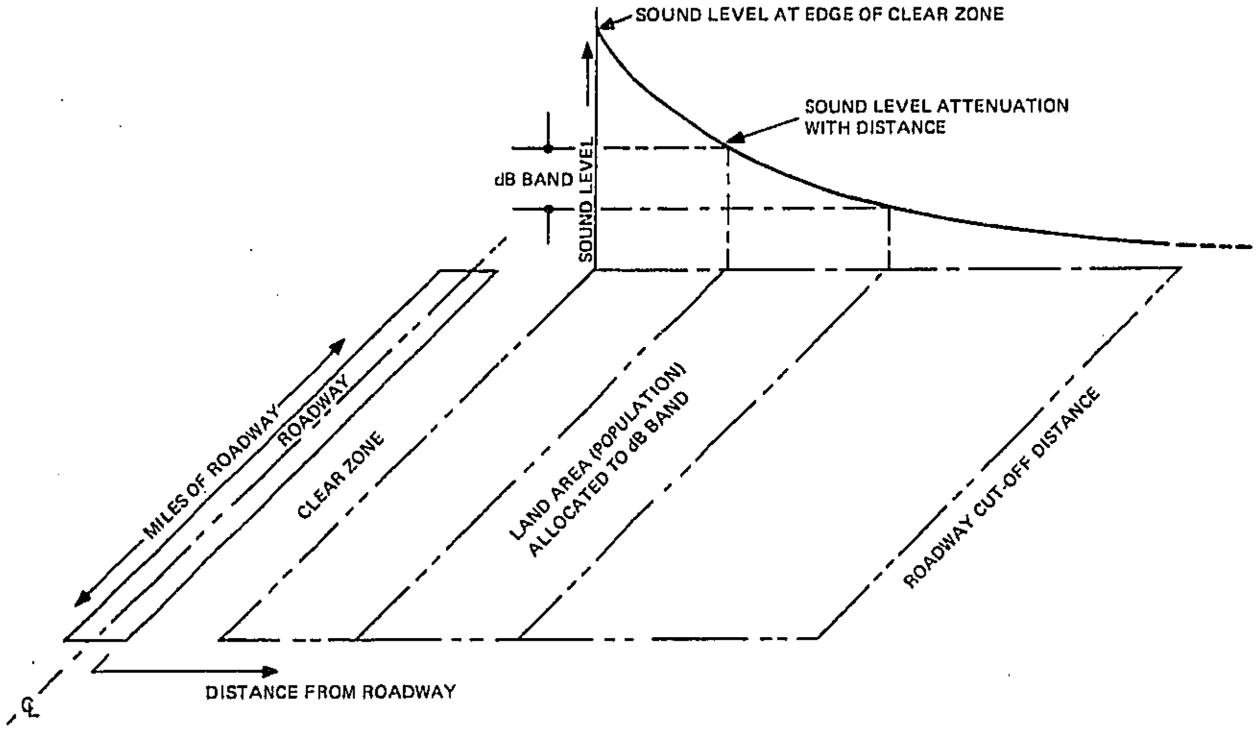
Figure A-6.1 presents the overall roadway-clear zone-inhabited area configuration and the two propagation models used.

A.6.1 Roadway/Clear Zone Configuration

The definition of the pavement geometry requires an average lane width and the number of lanes comprising the roadway. These data are described in Section A.3.4 of this report. The clear zone geometry is defined by a distance from the edge of the pavement. The definition of the clear zone distance in quantitative terms is based upon the best available information. [1,3,21] Table A-6.1 presents the clear zone distances currently used by the Model. The data is arrayed by population place size (Index J), roadway type (Index K), and population density category (Index ID).

The data for interstates (K=1) and for freeways and expressways (K=2) was estimated from References 1 and 3. For arterials (K=3, 4), collectors (K=5), and local roads and streets (K=6), the clear zone distances were developed from Reference 21 data by EPA staff. From Reference 21, explicit urban site geometry is presented with respect to microphone measurement locations from the edge of local streets and roads. These data were used to define the clear zone distances by average population density categories (ID=1, ...,4). It must be emphasized that the clear zone distances apply to populated areas rather than averages between populated areas and vacant land. The reason for this distinction is that the Model excludes vacant land and miles of roadway through vacant land in urban land areas (see Section A.3).

For traffic noise propagation over the pavement system and the adjacent clear zone, a variable distance attenuation model is used. The basic theory describing this model is presented in Appendix J of Reference 10. Figure A-6.2 presents the basic configuration for the pavement/clear zone system and the attenuation parameters corresponding to the pavement and to the clear zone. For the pavement system, it is assumed that the distance attenuation is characterized as propagation over an acoustically hard surface. That is, noise attenuates at 6 dB per distance doubling from a point source and at 3 dB per distance doubling for a line source. For the clear zone, it assumed that the distance attenuation is characterized as either propagation over an acoustically hard surface (gamma = 0) or an acoustically soft surface (gamma = 0.5). Acoustically hard clear zones would correspond to sites with paved parking lanes and/or sidewalks and little vegetation from



NOTE: LAND AREA AND POPULATION IS UNIFORMLY DISTRIBUTED ON BOTH SIDES OF THE ROADWAY.

FIGURE A-6.1 ROADWAY TRAFFIC NOISE EXPOSURE OF LAND AREA

TABLE A-6.1
CLEAR ZONE DISTANCES (IN FEET) BY ROADWAY TYPE (K),
POPULATION DENSITY CATEGORY (ID), AND POPULATION PLACE SIZE (J)

		Population Place Size, Index J								
K	ID	1	2	3	4	5	6	7	8	9
1	ALL	50.	50.	50.	50.	50.	50.	50.	50.	50.
2	All	30.	30.	30.	40.	40.	40.	40.	40.	50.
3	1	10.	10.	10.	10.	10.	10.	10.	10.	40.
	2	15.	15.	15.	20.	20.	20.	20.	20.	40.
	3	20.	20.	20.	30.	30.	30.	30.	30.	40.
	4	30.	30.	30.	40.	40.	40.	40.	40.	40.
4	1	10.	10.	10.	10.	10.	10.	10.	10.	40.
	2	15.	15.	15.	20.	20.	20.	20.	20.	40.
	3	20.	20.	20.	30.	30.	30.	30.	30.	40.
	4	30.	30.	30.	40.	40.	40.	40.	40.	40.
5	1	5.	5.	5.	10.	10.	10.	10.	10.	40.
	2	10.	10.	10.	20.	20.	20.	20.	20.	40.
	3	15.	15.	15.	30.	30.	30.	30.	30.	40.
	4	20.	20.	20	40.	40.	40.	40.	40.	40.
6	1	5.	5.	5.	10.	10.	10.	10.	10.	40.
	2	10.	10.	10.	20.	20.	20.	20.	20.	40.
	3	15.	15.	15.	30.	30.	30.	30.	30.	40.
	4	20.	20.	20.	40.	40.	40.	40.	40.	40.

Index K denotes highway type; Index ID denotes population density category the pavement to the edge of the populated area. Acoustically soft sites simulate grass covered areas adjacent to roadways such as rights-of-way next to interstates and freeways.

The acoustically soft sites defined by gamma = 0.5 simulate an attenuation of 7.5 dB per distance doubling for a point source and 4.5 dB per distance doubling for a line source. The theory used by the General Adverse Response Model simulates traffic noise propagation in terms of the hard pavement/hard or soft clear zone using a line source. The theory used by the Single Event Model simulates vehicle noise propagation in terms of the hard pavement/hard or soft clean zone using a point source.

The attenuation parameters currently used by the Model to simulate noise propagation over the pavement/clear zone system are presented in Table A-6.2. These data are arrayed by population place size (Index J) and highway type (Index K). For large urban areas (J=1, 2) all clear zones are assumed to be hard (i.e., essentially paved surfaces). For all other urban areas (J=3, ..., 8), clear zones are described as mixed hard and soft configurations. For rural areas (J=9), all clear zones are assumed to be soft.

A.6.2 Propagation of Traffic Noise in Populated Areas

To simulate traffic noise propagation in populated areas adjacent to roadways, the National Roadway Traffic Noise Exposure Model uses average attenuation functions related to the population density of the area.[12,22,23] Three population density ranges are used to specify the types of buildings in the area and hence, the noise attenuation with distance from the pavement. The relationship between these parameters is:

Housing Type	Population Density Range
Dense Urban Apartments	Greater than 13,000 people/mi^2
Urban Row Apartments and Surburban Duplexes	6,500 to 13,000 people/mi^2

- SOUND LEVEL ATTENUATION @ 3 dB/DD FOR DISTANCE D_r (HARD SITE)
- SOUND LEVEL ATTENUATION @ $3(1 + \gamma_2)$ dB/DD FOR DISTANCE $(D_{cr} - D_r)$ (HARD OR SOFT SITE)

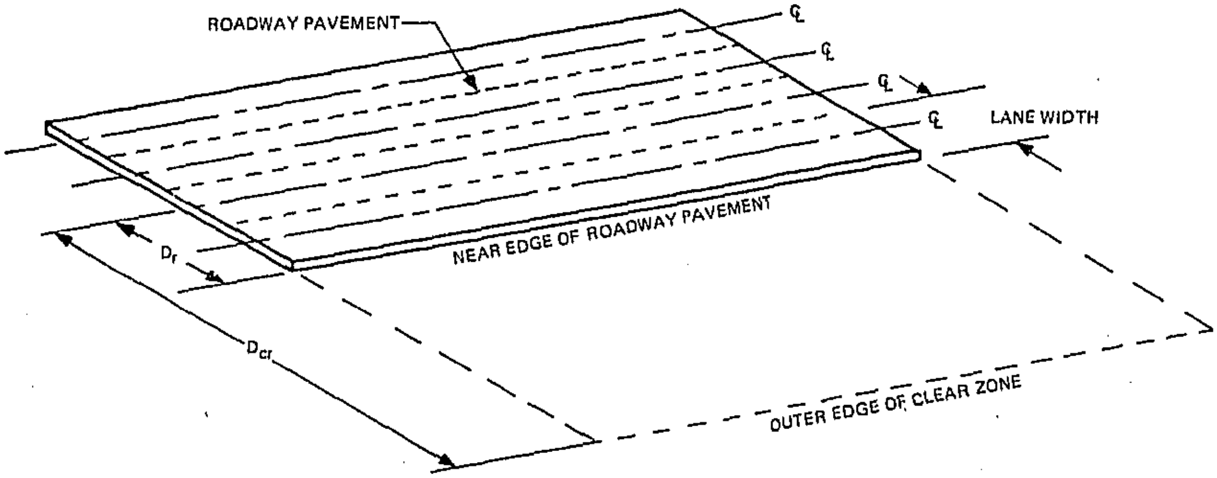


FIGURE A-6.2 ROADWAY/CLEAR ZONE GEOMETRY AND ASSUMED SOUND LEVEL ATTENUATION WITH DISTANCE

Single Family Detached	Less than 6,500 people/mi^2

As seen in Figure A-2.4, approximately 7.5 percent of the urban population reside in areas exceeding 13,000 people/mi^2; approximately 12.5 percent reside in areas with population density between 6,500 to 13,000 people/mi^2; and 80 percent reside in areas of less than 6,500 people/mi^2.

The General Adverse Response Model considers a line source attenuation of traffic noise in populated areas. Figure A-6.3 presents the line source attenuation curves used by the Model to estimate propagation in urban areas characterized by the average population density. These curves were developed from data and analysis presented in References 12 and 22. As indicated in Figure A-6.3, the curves are further defined by the clear zone distance in that the zero attenuation value corresponds to the clear zone distance. Hence, the Model selects the appropriate attenuation curve based upon the population place size (Index J), population density category (Index ID), and the roadway type (Index K).

The Single Event Model considers a point source attenuation of traffic noise in populated areas. Figure A-6.4 presents the line source attenuation curves used by the Model to estimate propagation in urban areas. The specialized nature of the single event propagation model is described in the main text of this report. The curves presented in Figure A-6.4 were developed from data and analysis presented in References 12 and 22.

The population densities used by the Model for each population place size and each population density category are presented in Table A-2.2.

TABLE A-6.2
CLEAR ZONE DISTANCE ATTENUATION CONSTANTS (γ_2)
BY ROADWAY TYPE (K) AND POPULATION PLACE SIZE (J)

	Population Place Size, Index J								
K	1	2	3	4	5	6	7	8	9
1	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
3	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5
4	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5
5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5
6	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5

NOTE: γ_2=0.0 simulates propagation over acoustically hard surfaces
γ_2=0.5 simulates propagation over acoustically soft surfaces

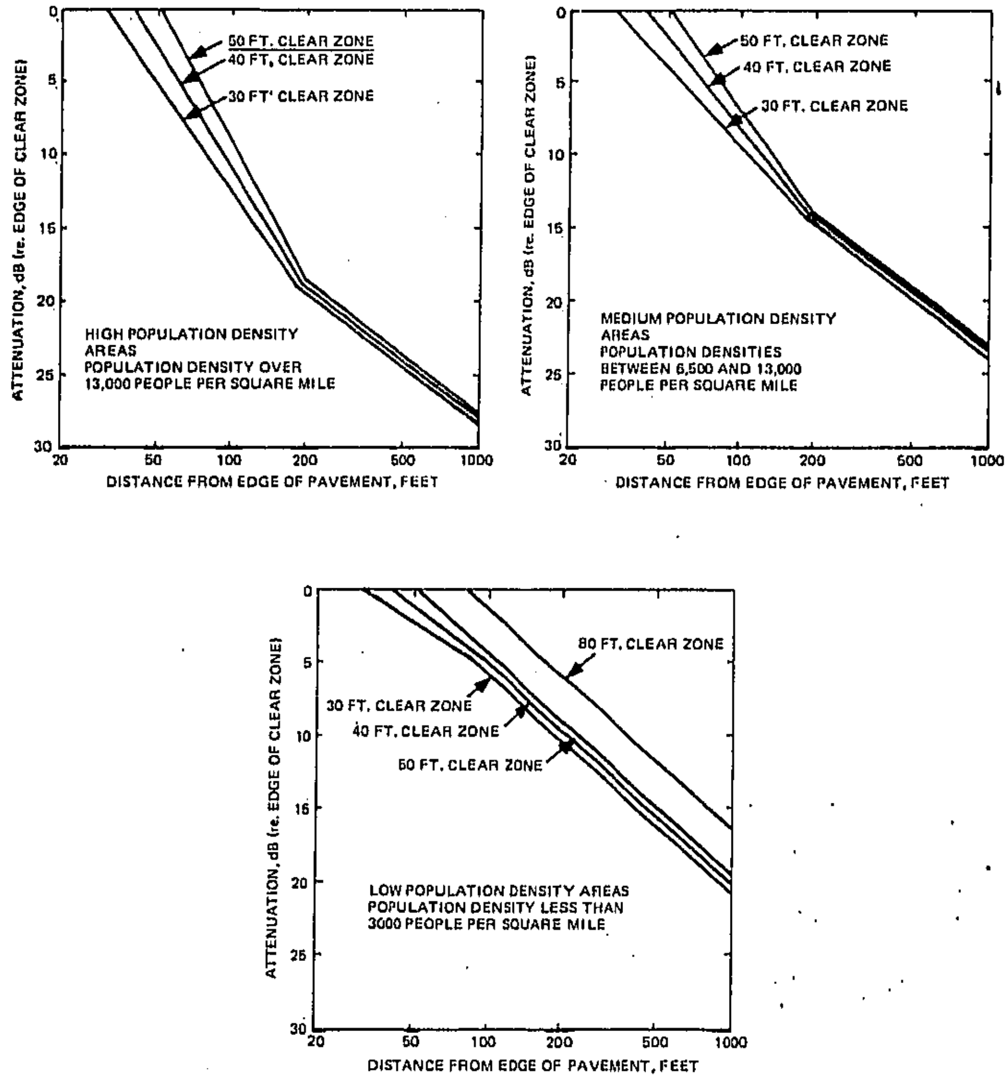


FIGURE A-6.3 SOUND LEVEL ATTENUATION CURVES: LINE SOURCE

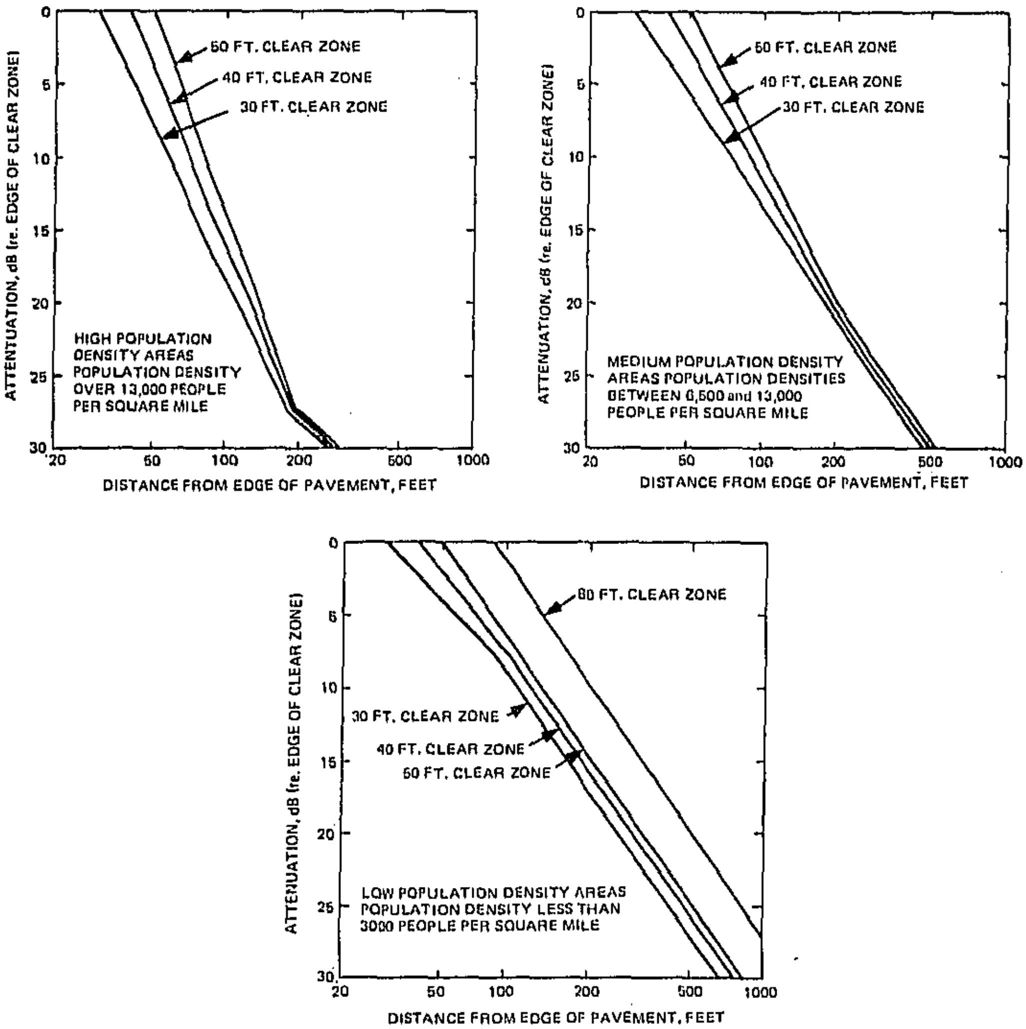


FIGURE A-6.4 SOUND LEVEL ATTENUATION CURVES: POINT SOURCE

A.7 REFERENCES

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APPENDIX B

ESTIMATES OF POPULATION ACTIVITY

The Single Event Model estimates the intrusiveness of noise by considering a person's activity when they are exposed to a given level of noise. Appendix E of this report describes the theory and defines the terminology for the equivalent single event sound level, L_{eqT}, and the Sound Exposure Level, SEL, for a vehicle operating on a roadway.

To estimate the intrusiveness of this noise, it is necessary to relate a person's activity when he is exposed to the noise. This appendix describes the data sources and the methodology used to estimate the average daily activity on a national scale, of the United States' population. The approach taken is based upon the simulation capabilities of the Single Event Model and the categories of health/welfare criteria available to estimate the effect of noise on man. Basically, the National Roadway Traffic Noise Exposure Model considers only the noise exposure and the population activity surrounding the place of residence. The activity categories described in this appendix, however, include activities away from the place of residence (i.e., working and traveling). Hence, the Single Event Model excludes a portion of the national population from the noise impact estimate that corresponds to activities away from home. The methodology used is based upon the requirements to conserve person-hours of activity and to insure that no two segments of the national population are simultaneously allocated to different activities.

B.1 Basic Activity Categories and Population Distribution

For estimating the effects of noise on the national population The Single Event Model basically considers sleep interference and speech interference. Hence, it is necessary to estimate the fraction of the population that is asleep and awake during the daytime and during the nighttime. Although a person spends, on the average, a significant portion of his non-sleeping time at home, it is also necessary to estimate the distribution of the non-sleeping population with respect to activities both at home and away from home. This distribution must also recognize that the average person's activities are different during the daytime and during the nighttime. Additionally, it is necessary to consider that different segments of the population exhibit different daily activity patterns. For example, employed men exhibit different activity patterns than housewives. Hence, it is necessary to distribute the nation's population by specific segments for which activity patterns have been established.[1]

To develop an average national activity pattern suitable for the purpose of estimating noise exposure, activity patterns for population subgroups must be combined and averaged. The resulting national average activity pattern, used by the Single Event Model, is based upon six activities distributed by time of day and four categories of population.

The six activities considered by the Single Event Model are:

- Sleeping
- Working
- Traveling
- Walking
- Outside Home
- "Other"

The four categories of the national population used to develop the average national activity pattern defined for the Single Event Model are:

- Employed Males
- Employed Females
- Housewives
- "Other"

In the above classification of activities, "Other" activities comprise T.V. viewing, Other Media (radio, newspapers, etc.), Other Leisure, Semi-Leisure, Home and Family, and Eating. These categories are a condensation of the categories and the appropriate data contained in Reference 1. In the above categories of population, the national population is distributed as indicated in Table B-1.

TABLE B-1

CATEGORIZATION OF UNITED STATES POPULATION

Activity Pattern	Statistical Category (Reference 2)	Percentage of Total Population (1975)	Total Population* (1974)
Employed Males	Male Workers	22.385	48.508
	Active Military	0.997	2.160
Employed Females	Female Workers	17.327	37.548
Housewives	Females Not in Labor Force (16 years to 65 years old)	18.132	39.292
Other	16 Years Old or Younger	27.086	58.695
	Institutional Population	1.063	2.304
	Not in Labor Force (Over 65)	9.357	20.277
	Unemployed	3.653	7.916
	Total	100.000	216.700

*In millions of people

B.2 Activity Patterns By Time of Day and Population Category

The data base used to estimate activity patterns for the United States' population is described in detail in Reference 1, Section V, Tables 5.2-1 through 5.2-9. These data present percentages of a sample population engaged in nine activities for each hour of a weekday, a Saturday and a Sunday. For the United States, the "Forty-four City" data was used (See Reference 1). The sample populations comprise the following population categories:

- Employed Men
- Employed Women
- Housewives

For the purposes of this analysis, the nine activities presented in Section V of Reference 1 were condensed to four categories as follows:.

- Sleeping
- Working
- Traveling
- "Other"

As indicated in the Section V data of Reference 1, the "Other" activity used above comprised the following activities: Eating, Home and Family, Semi-Leisure, Other Leisure, T.V. Viewing, and Other Media. Reference 1 presents a detail description of each of these activities. For the purposes of this study, however, it is sufficient to recognize that the "Other" activities category includes activities outside and possibly away from the home. Hence, using the Reference 1 data base it was possible to develop detail activity profiles for the above three categories of population. However, it is not necessary, for the purpose of the National Roadway Traffic Noise Exposure Model, to consider these activities on an hour-by-hour basis. It is sufficient to condense the data, on a weighted basis, to estimate average daily activities during the daytime and during the nighttime. Hence, the weighting used must recognize the hour of the day and the day of the week for each of the population categories. Once these average activity patterns are obtained, they must be averaged over the population categories to obtain an "average person" activity.

To conduct the weighted averaging, two constraints were imposed: for each hour, the total population must be distributed over the four activities of sleeping, working, traveling, and "other"; and for each daytime period (i.e., day and night) the averaging must conserve person-hours of activity.

B.3 Arithmetic Used for Developing Weighted Averages

The Reference 1 data are in the form of percentages of a population category engaged in an activity during an hour of the day. Hence, the arithmetic used to derive a weighted average simply deals with manipulations of percentages. Additionally, activities are presented for weekdays, Saturday, and Sunday.

The notation used to define a single data point (percentage) is as follows:

P_{ijk} is the percentage of the ith population category engaged in the jth activity during the kth hour of the day

$(P_{ijk})WD$ is the weekday percentage data

$(P_{ijk})SAT$ is the Saturday percentage data

$(P_{ijk})SUN$ is the Sunday percentage data

i denotes a population category (e.g., Employed Men, Employed Women, and Housewives)

j denotes activity (e.g., Sleeping, Working, etc.)

k denotes hour of the day (k=1,...,9 denotes 2200 hours to 0700 hours and k=10,...,24 denotes 0700 hours to 2200 hours)

For any hour of the day, the weighted hourly percentage of population engaged in an activity is obtained using:

$$\overline{P}_{ijk} = \frac{5(P_{ijk})_{WD} + (P_{ijk})_{SAT} + (P_{ijk})_{SUN}}{7} \qquad (B\text{-}1)$$

For the nighttime period of 2200 hours to 0700 hours, the weighted nighttime hourly percentage for a weekly time period is obtained using:

$$(\overline{P}_{ijk})_N = (1/9) \sum_{k=1}^{9} \overline{P}_{jk} \qquad (B\text{-}2)$$

For the daytime period from 0700 hours to 2200 hours, the weighted daytime hourly percentage for a weekly time period is obtained using:

$$(\overline{P}_{ijk})_D = (1/15) \sum_{k=10}^{24} \overline{P}_{jk} \qquad (B\text{-}3)$$

The data insure that the population is distributed over all activities during each hour of the day. That is, the data are normalized so that:

$$\sum_j P_{ijk} = \sum_j (P_{ijk})_{WD} + \sum_j (P_{ijk})_{SAT} + \sum_j (P_{ijk})_{SUN} = 100.0$$

The only "gap" in the data of Reference 1 is that the percentages of the population were not reported for the following hours of the day: 0100 through 0400 hours and 0600 to 0700 hours. Hence, it was assumed for these time periods that the percentage quoted in the next successive hour applied to the previous unlisted hours. For example, the data of Reference 1 states that 95 percent of employed women were asleep during the period of 0400 to 0500 hours and 28 percent during the period 0700 to 0800 hours. Hence, it was assumed that 95 percent of employed women were asleep during the period 0100 through 0400 hours and 28 percent during the period 0600 to 0700 hours.

TABLE B-2

AVERAGE HOURLY ACTIVITY DISTRIBUTIONS
(Developed from Reference 1 Data)

Population Category	DAYTIME ACTIVITY, $(\bar{P}_{ijk})D$ 0700 Hrs. to 2200 Hrs.				NIGHTTIME ACTIVITY, $(\bar{P}_{ijk})N$ 2200 Hrs. to 0700 Hrs.			
	Sleeping	Working	Traveling	Other	Sleeping	Working	Traveling	Other
Employed Men	7.68	40.14	8.47	43.71	70.70	6.48	3.30	19.52
Employed Women	7.50	30.73	7.13	54.64	71.51	4.21	2.03	22.25
Housewives	6.84	N/A*	5.57	87.59	74.43	N/A*	0.86	24.71

*This does not imply that housewives do not work. Since the working activity is to be deleted from the noise impact assessment, it was deemed to consider housewives in an activity around their homes and hence included in the population exposed to roadway traffic noise.

Using the forty-four City data in Section V of Reference 1, the weighted daytime (Equation (B-3)) and the weighted nighttime (Equation (B-2)) hourly distributions of population activity were calculated. The results of these calculations are presented in Table B-2.

B.4 Outdoor Activities

The health/welfare criteria used by the Single Event Model consider the poulation activity of outdoor speech interference. Hence, it is necessary to estimate the percentage distribution of the population's activity associated with outdoor locations. As indicated in Section B.2 of this appendix, the general category of "Other" activities includes outdoor activities. Further, traveling activities include time that people are walking. To estimate average outdoor activity of the national population, two assumptions are made. First, it is assumed that pedestrians comprise only people working. This assumption is based upon practical considerations in that data describing the average walking time for workers is available.[1] It is recognized that this assumption will underestimate the number of pedestrians. However, to estimate more accurately pedestrian populations consistent with the other data of the National Roadway Traffic Noise Model was beyond the scope of the present effort. The basis for refining the estimate of the pedestrian population would require an analysis of urban demographic data consistent with the population data base of the Single Event Model and the data reported, for example, in Reference 3, Chapter 5. Next, it is assumed that the population's activity outside their residence may be considered as a fraction or component of "Other" activities indicated in Table B-2.

B.4.1 Pedestrian Activity

As indicated above, the estimation of pedestrian activity, as used by the Single Event Model, is confined to the working population of the United States. From Table 4, page 122, of Reference 1 it is indicated that the average duration of time spent walking by a worker when travelling to and from work for the United States is 30 minutes per day. This estimate has been weighted to ensure equality of days of the week. As indicated in Table B-2, the working poulation is comprised of Employed Males and Employed Females and that the hourly percentage varies between the daytime period and the nighttime period. Using the population distribution in Table B-1, it is seen that the total employed ~~poulation~~ population in 1974 is 88.216 million people. For each employed person spending 0.5 hour per day walking this represents 44.11 M person-hours of walking per day. Assuming that this estimate corresponds to a 5-day work week, the average person-hours of walking per day for a 7-day week is 44.11/7 = 31.51M person-hours per day. From the data in Table B-2, the total worker travel per day is estimated as 148.31M person-hours with 104.53M person-hours during the 15-hour day and 43.78M person-hours during the 9-hour night. Distributing the 31.51M person-hours of walking in the same day-night ratio as the total travel, one estimates that 22.32M person-hours occur during the 15-hour day and 9.30M person-hours occur during the 9-hour night. For each hour of the day this represents 1.488 million pedestrians and for each hour of the night 1.033 million pedestrians. For a population of 216.7M, the pedestrian activity represents 0.6867 percent of the national population for each hour of the daytime period and 0.4767 percent of the national population for the nighttime period.

B.4.2 Population Outdoors Around Their Home

To estimate the time spent outdoors around one's residence, the data of Reference 4 are used. Table 2-2, page 2-11, of Reference 4 indicates that for all population categories, the average person spends 0.1 hours per day outside their own home. For the purpose of the Single Event Model, it is assumed that this activity occurs during the 15-hour daytime period from 0700 to 2200 hours. Hence, it is assumed that percentage of the national population outdoors and around their own home is given by (0.1/15)(100) = 0.667 percent. This percentage is assumed to be applicable to all segments of the United States' population.

B.5 Average Activity Patterns for Categories of the U. S. Population

The above results estimate activity patterns for the following population categories:

- Employed Males
- Employed Females
- Housewives

As indicated in Table B-1, the above three population categories are included in the national total. However, the national total also includes "Other" population comprising almost 41.2 percent of population. The data described above does not indicate the activity patterns of the "Other" population category. This population category comprises the following groups:[2]

- People 16 years old or younger
- People over 65 years old and not in the labor force
- Institutional Population
- Unemployed

Hence, an assumed activity pattern for this population category is used. The assumptions are: everyone in this category is asleep during the 9-hour night and is awake during the 15-hour day; the daytime activity of this group is identical to the percentage distribution estimated for housewives neglecting the daytime sleeping distribution.

With the above analysis and assumptions, the population's activity pattern for an average 24-hour day is estimated. These results are presented graphically as indicated in Figures B-1 through B-4. These figures present time-of-day as the horizontal axis and cumulative percentage of population as the vertical axis. The left-hand edge of the figures correspond to 2200 hours (10:00 PM) and continue to 2200 hours at the extreme right edge. The dashed vertical line at 0700 hours denotes the separation between the 9-hour "EPA Night" and the 15-hour "EPA Day." Comparing Figures

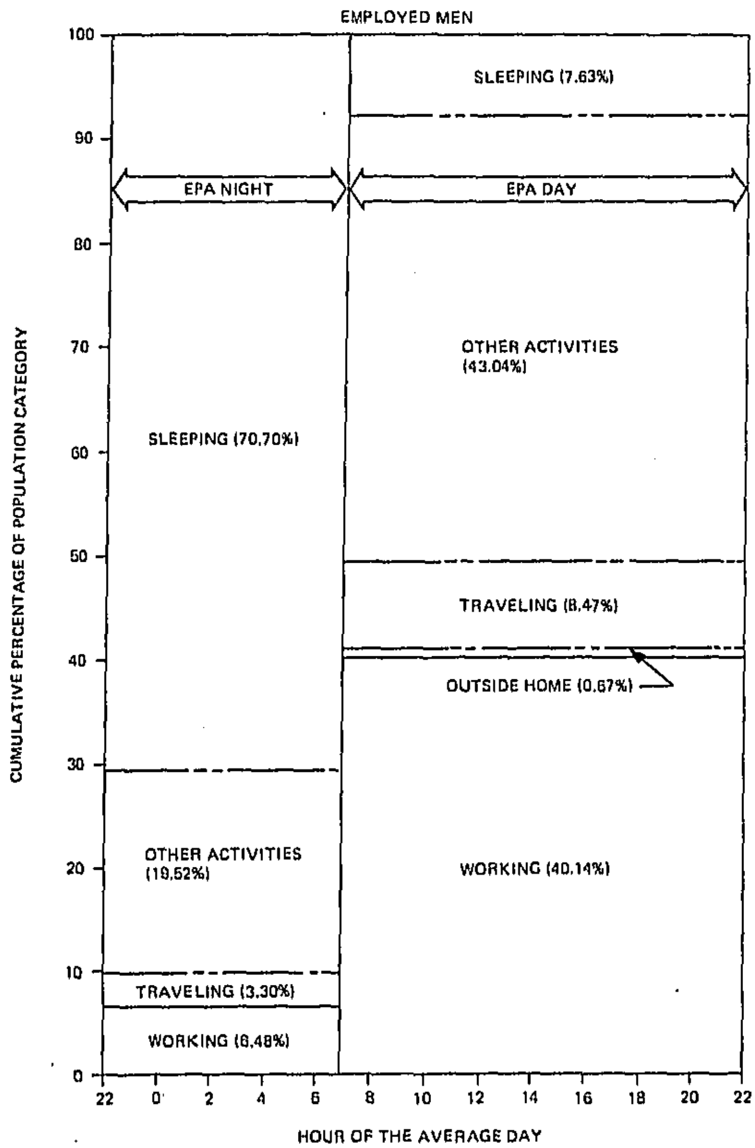

FIGURE B-1. AVERAGE ACTIVITY PATTERN FOR EMPLOYED MEN

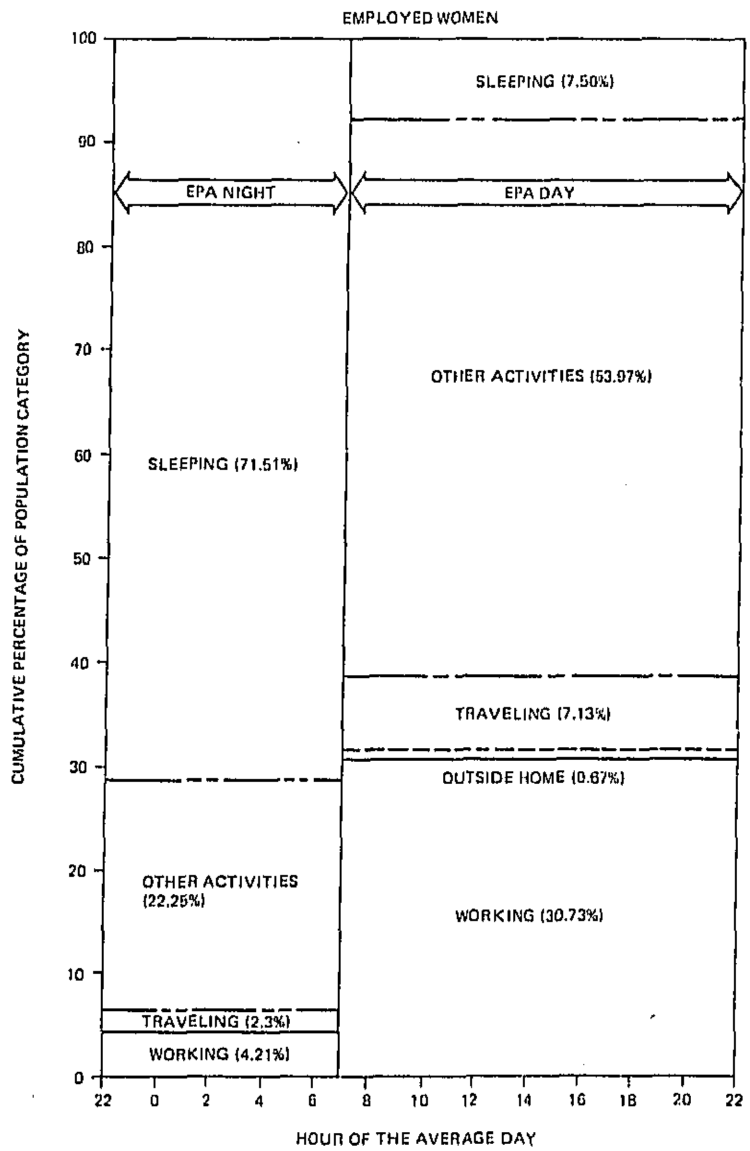

FIGURE B-2. AVERAGE ACTIVITY PATTERN FOR EMPLOYED WOMEN

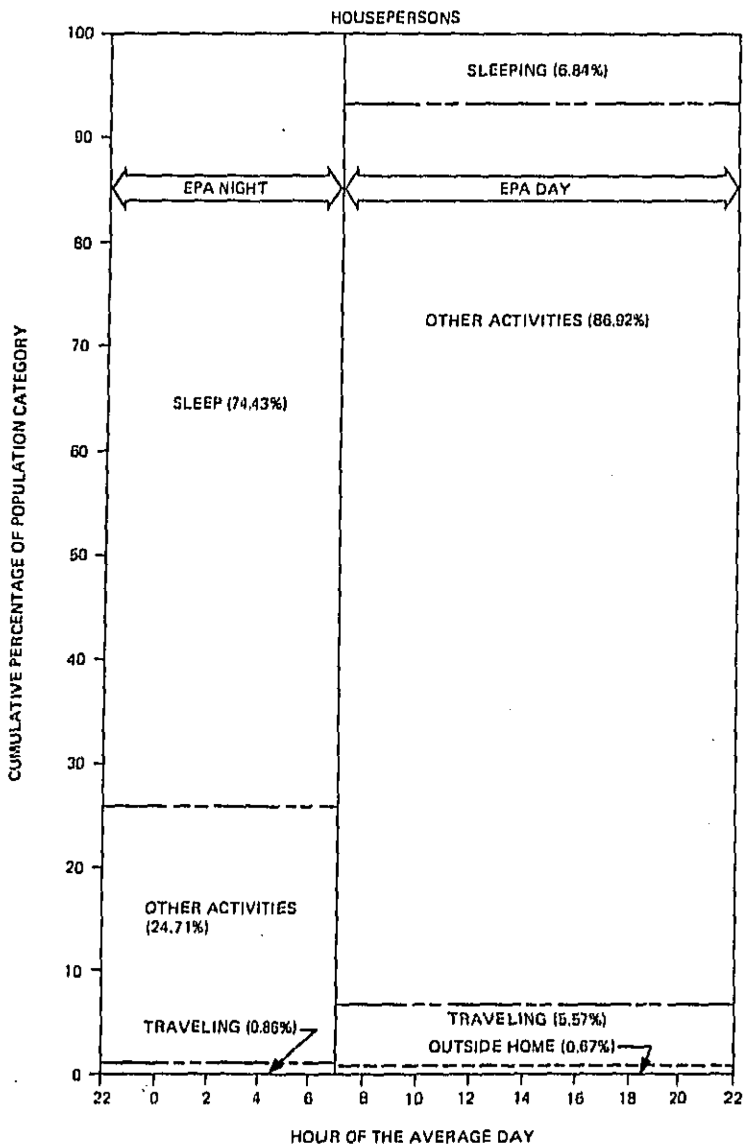

FIGURE B-3. AVERAGE ACTIVITY PATTERN FOR HOUSEWIVES

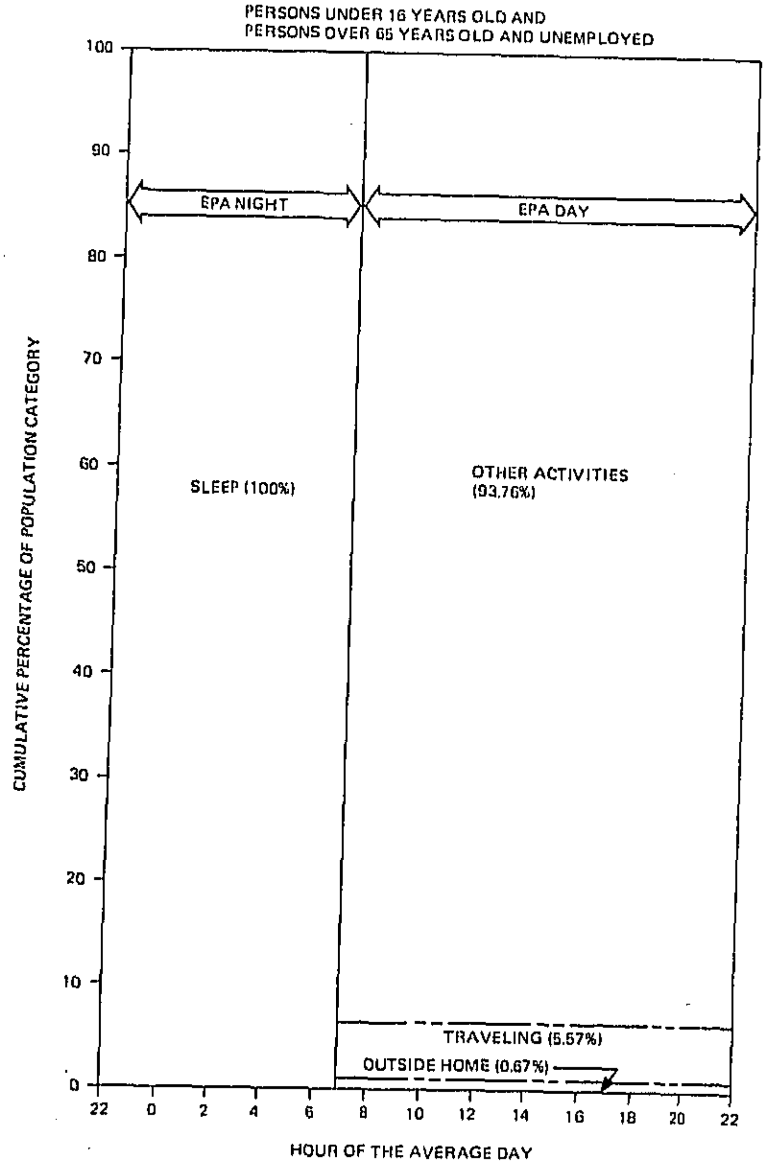

FIGURE B-4. AVERAGE ACTIVITY PATTERN FOR "OTHER" POPULATION

B-1 through B-4 with the data presented in Table B-2, it is seen that the "outside home" activity percentage in the figures has been subtracted from the "Other" activity percentage listed in the Table.

The horizontal dashed lines in Figures B-1 through B-4 separate the various activity categories as indicated. The percentage listed in parenthesis with each activity is the percentage of population engaged in the activity during the hour. These results indicate the average percentage distribution of population during the daytime and the nighttime periods used by the Single Event Model. They indicate that during any hour of the day, the total population is assigned, on the average, to a distinct activity. That is, during any hour, one individual may change his activity from one category to another and, on the average, another individual may exchange activities so that the percentage distributions indicated in Figures B-1 through B-4 remain constant. These figures are condensations of the more complete distributions presented in Reference 1.

B.6 Average National Activity Pattern

In the context used by the Single Event Model, the results of Figures B-1 through B-4 must be further condensed to estimate a single national activity pattern for the United States' population. To do this, the percentage data of Figures B-1 through B-4 must be weighted by their respective absolute populations and combined into an average national total. The population distribution presented in Table B-1 is used for this weighting. Hence, the Employed Male population of 50.668M is multiplied by the percentages given in Figure B-1 to obtain the Employed Male population engaged in each activity during the day and night. This is repeated for the Employed Females, Housewives, and "Other" population categories. The person-hours of activity are summed and divided by the total national population of 216.7M people to obtain the percentage distribution of activity for an "average" person in the United States. The results of this methodology are presented in Figure B-5. The distributions presented in Figure B-5 apply to the total U. S. population whereas the distributions in Figure B-1

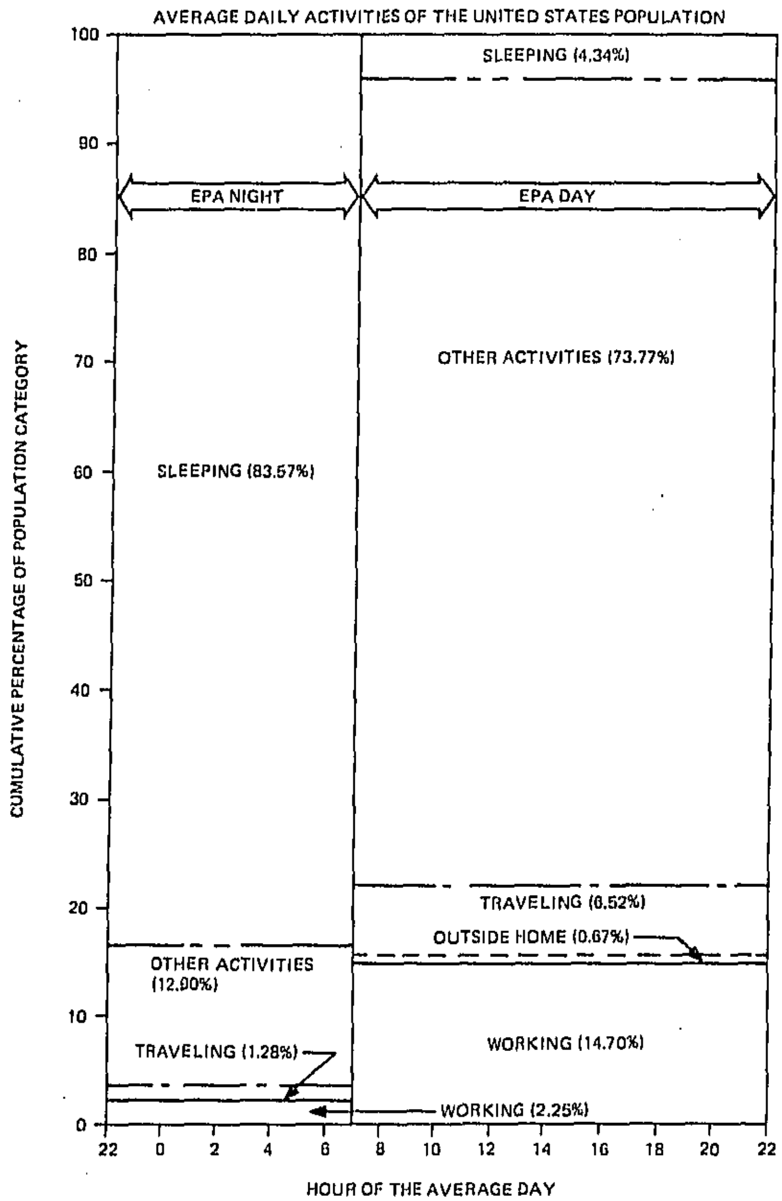

FIGURE B-5. AVERAGE ACTIVITY PATTERN FOR THE U.S. POPULATION through B-4 correspond to subcategories of the national population. For example, Figure B-5 indicates that during any hour of the daytime (0700 to 2200) hours) there are 31.86M people working (216.7 x 0.1470). From Table B-1 and Figure B-1, it is estimated that there are 20.33M men working and from Table B-1 and Figure B-2 there are 11.53M women working any hour of the daytime.

The distribution of population activity presented in Figure B-5 is the basis for allocation of population activity used by the Single Event Model to estimate noise intrusion due to single event roadway traffic noise.

B.7 Allocation of Activities for Single Event Model

The Single Event Model allocates the total national population to various activities to estimate the effects of roadway traffic noise. This allocation is conducted on the basis of average hourly activity during the daytime period 0700 to 2200 hours and the nighttime period 2200 to 0700 hours. The Model, however, assumes that certain activities are excluded from the noise intrusion analysis since these activities place the appropriate population segments away from the noise environment estimated for the place of residence.

Table B-3 presents the activities in Figure B-5 and activities used for noise intrusion estimates by the Single Event Model. As indicated in Table B-3, the Single Event Model excludes 20.53 percent of the U. S. population from noise intrusion during the daytime and 3.06 percent during the nighttime. The exclusions result from segments of the population traveling and working during an average hour.

Finally, the relationship between the various activity categories and the Fractional Impact criteria related to each category are as follows:

TABLE B-3

DISTRIBUTION OF POPULATION BY ACTIVITY FOR SINGLE EVENT MODEL

	DAYTIME		NIGHTTIME	
Activity	All Activities Figure B-5	Activities Used by Single Event Model	All Activities Figure B-5	Activities Used by Single Event Model
Sleeping	4.34	4.34	83.57	83.57
Other	73.77	73.77	12.90	12.90
Traveling				
• Walking*	0.69	0.69	0.47	0.47
• Other Modes	5.83	Excluded	0.81	Excluded
Outside Own Home	0.67	0.67	0.0	0.0
Working	14.70	Excluded	2.25	Excluded
TOTAL	100.00	79.47	100.00	96.94

*Estimate Based Upon Working Population Only. See Text.

Activity	Fractional Impact Criteria
Sleeping	Sleep Disruption and Sleep Interference
Other	Indoor Speech Interference
Walking (Pedestrians)	Outdoor Speech Interference
Outside Own Home	Outdoor Speech Interference

For each hour of the day and the night, the Single Event Model uses the activity distributions given in Table B-3 to estimate the population in each place size (Index, J) and each population density category (Index, ID) engaged in the respective activities. Only these segments of the population are used to conduct the respective noise intrusion estimates indicated by the above relations between activity and Fractional Impact. This approach does assume, however, that the population activity in various urban areas and the rural areas are identical. Further, as the Single Event Model alters total population in future years to simulate population growth, the percentage distribution of population activity remains constant. That is, the distribution of population, by population categories, presented in Table B-1; remains constant throughout the timestream. These limitations are based upon the present availability of data in a form necessary to relax the assumptions used to develop the national activity pattern.

B.8 REFERENCES

APPENDIX B

1. Szalai, A (Ed.), The Use of Time: Daily Activities of Urban and Suburban Populations in Twelve Countries, Moulton, The Hague, 1972.

2. Anon.: Statistical Abstract of the United States: 1977; U. S. Department of Commerce, Bureau of Census, September 1977.

3. Baerwald, J. E. (Ed.): Transportation and Traffic Engineering Handbook, Prentice-Hall, Inc., 1976.

4. Southerland, L. C. Braden, M. M. and Colman, R., "A Program for the Measurement of Environmental Noise in the Community and Its Associated Human Response; Volume I - A Feasibility Test of Measurement Techniques," U.S. Department of Transportation, Office of Noise Abatement, Report DOT-TST-74-5, December 1973.

APPENDIX C

CALCULATION OF VEHICLE POPULATION FROM SALES AND SURVIVABILITY DATA

This appendix presents a description of the methodology used by the National Roadway Traffic Noise Exposure Model to estimate the number of vehicles by vehicle type and production year. This estimate is conducted for each year in the time stream simulation. The data are used to simulate two time variations in the Model:

- Variation of Average Daily Traffic on Roadways,

- Variation of Vehicle Mix on Roadways.

Each of these variables is based upon the percentage changes of ADT and vehicle mix so that the absolute numbers estimated are not used by the Model, only the percentages. That is, ADT is increased on each roadway proportional to the increase in total vehicle population. The percentage mix of vehicle types on the roadways, by production year is altered from the baseline conditions proportional to the changes in vehicle population by vehicle type.

The simulation of noise emission regulations is, of course, extremely sensitive to the estimating procedure used to predict the mix of regulated vehicles to older unregulated vehicles on the national roadway system in any future year. The Model conducts this simulation by using historical vehicles sales[1,2] and projections of future vehicle sales. To account for attrition of each vehicle type with age (years from production), the Model uses survival or attrition data developed from historical trends.[1,2] The structure of the computing scheme is such that any simulation of vehicle sales and survivability is possible for each vehicle type used by the Model.

C.1 Baseline Conditions

In the baseline year, the National Roadway Traffic Noise Exposure Model, recognizes a vehicle population comprising vehicles of production year 1974 and earlier. These population data represent vehicles produced from 1945 through 1974 and surviving at the end of 1974. Based upon vehicle registration data,[1,2] the total vehicle population in the United States in 1974 comprised approximately 135 million vehicles of all types.

C.2 Estimating Vehicle Population Beyond 1974

The procedure used by the Model to estimate the number of vehicle types in any future year is rather simple. First, the original production value of the vehicle type is calculated. If the production year is 1974 or earlier, the Model estimates the original production by using the stored value of the population existing in 1974 and the stored value for the vehicle survivability corresponding to the age of the vehicle. If the production year is a future year beyond 1974, the Model estimates the future year production based upon the vehicle sales projections over the time stream. The Model uses tabulated data expressing any future year's sales as a ratio of the 1974 sales value. Hence, the Model is capable of either growing or terminating production of any vehicle type over the time stream simulation. Using this procedure, the Model estimates the number of each vehicle type produced or to be produced during the time interval from 1945 to the year 2014.

Using the annual production estimates, the Model then estimates, by production year, the number of vehicles surviving in any calendar year of the time stream. This estimate is conducted using the survivability data stored in the Model's data base. That is, the age of each vehicle in the calendar year is determined and the corresponding survivability factor is selected. The survivability factor is the fraction of original vehicle production surviving by years of age. The number of vehicles surviving in the calendar year is estimated by multiplying the original production number by the survivability factor. Using this scheme, the Model estimates the number of vehicles by vehicle type and production year in each calendar year of the time stream simulation.

C.3 Noise Emission Regulation

By estimating the number of vehicles by vehicle type and production year in any calendar year of the time stream, the Model allows the user to introduce a vehicle noise emission regulation in any calendar year of the time stream for any vehicle type. The Model considers a noise regulation to be effective with the production year and subsequent years until the regulation is redefined in a future year. Based upon the mix of unregulated and regulated vehicles of a given type in any calendar year, the equivalent A-weighted sound level for the vehicle type is calculated for each calendar year. The percentage mix of unregulated and regulated vehicles is calculated by the Model using the vehicle population data estimated as described above. That is, as older, unregulated vehicles retire from the vehicle mix, and newer regulated vehicles are introduced, the equivalent A-weighted sound level is decreased based upon this change. Hence, the Model attempts to simulate vehicle noise regulation in a manner consistent with vehicle sales and survivability characteristics.

Table C-1 presents a forty-year time stream simulation of net vehicle populations by year and vehicle type. This simulation was conducted using the data base described in Appendix A of this report.

TABLE C-1. EXAMPLE OF VEHICLE POPULATION PREDICTIONS

TYPE>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	ALL TYPES
CYLINDERS	8	6	6&4	4	4	6&8									
ENGINE	GAS	GAS	GAS	GAS	GAS	GAS	DIESEL								
TRANS-MISSION	AUTO-MATIC	AUTO-MATIC	MAN-UAL	AUTO-MATIC	MAN-UAL	----	----	----	----	----	----	----	----	----	
VEH. TYPE>	PC	PC	PC	PC&LT	PC&LT	LT TRK	PC&LT	MED TRK	HVY TRK	IC BUS	TR BUS	SCH BUS	LW MTCY	HV MTCY	
UNIT	MILLIONS									THOUSANDS X 0.1			MILLIONS		
YEAR															
1974	56.68	17.83	2.10	7.76	20.13	19.01	0.06	2.41	1.51	2.00	6.95	35.68	4.36	0.59	134.89
1980	63.60	21.21	2.66	11.16	22.63	26.26	2.59	2.87	1.70	1.41	10.69	50.03	5.01	0.68	161.09
1985	47.50	26.70	3.51	23.04	24.99	28.47	15.69	3.35	2.12	1.57	12.19	68.67	5.58	0.76	187.76
1990	25.66	33.17	4.41	37.55	27.93	27.11	32.50	3.78	2.27	1.51	11.80	81.66	6.15	0.84	212.42
1995	16.15	38.33	5.11	47.13	31.17	27.40	42.80	4.18	2.42	1.57	11.41	93.67	6.80	0.93	[illegible]
2000	16.10	42.56	5.67	52.87	34.46	29.87	48.23	4.61	2.89	1.57	11.45	105.46	7.51	1.02	246.93
2005	17.75	46.98	6.26	58.21	36.03	32.96	53.24	[illegible]	3.19	1.50	11.46	117.25	8.21	1.13	272.53
2010	19.59	51.86	6.51	64.37	41.96	36.30	58.77	5.07	3.52	1.50	11.46	129.11	9.14	1.25	[illegible]

C.4 REFERENCES
APPENDIX C

1. Anon., "1975 Automobile Facts & Figures," Motor Vehicle Manufacturers' Association, Detroit, Michigan 48202.

2. Anon., "1975 Motor Truck Facts," Motor Vehicle Manufacturers' Association, Detroit, Michigan 48202.

APPENDIX D

TRAFFIC FLOW NOISE MODEL

This appendix presents the traffic flow noise model used by the National Roadway Traffic Noise Exposure Model. The objective of this presentation is to detail the steps and assumptions used to develop the Model. Basically, the noise emission algorithm estimates the day-night equivalent spund level at a distance from a multi-lane roadway that carries a traffic flow comprised of several vehicle types.

As considered by the Model, each vehicle type is sub-categorized by the number of vehicles produced and/or surviving in a given year with identical noise emission characteristics. The vehicle noise emission characteristics are further defined in terms of vehicle operating modes: idle, acceleration, deceleration, and cruise.

The basic approach used by the Model in calculating traffic flow noise emissions assumes an infinite straight traffic lane. Noise propagation from the traffic lane is considered in terms of classical (3 dB/DD) and a constant "soft site" excess distance attenuation.[1] Multi-lane traffic flow is obtained by considering the lane spacing in estimating the traffic noise levels at a location adjacent to the roadway.

D.1 Basic Definitions

Throughout the development presented in the appendix, certain basic definitions are used. These definitions are presented here for clarity.

Time Averaged Mean Acoustic Intensity: The time-averaged mean acoustic intensity for a time interval $t_1 \leq t \leq t_2$ is defined as:

$$\overline{I} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} I(t)dt \qquad \text{(D-1)}$$

where $I(t) = I_o 10^{L(t)/10}$, the time-varying acoustic intensity (D-1)

$I_o = p^2_{ref}/\rho c$, reference acoustic intensity

$L(t)$, time-varying sound level (usually A-Weighted)

Equivalent Sound Level: The equivalent sound level is defined as:

$$L_{eq} = 10 \log (\overline{I}/I_o) \quad \text{(D-2a)}$$

or

$$L_{eqk} = 10 \log (\overline{I}_k/I_o) \quad \text{(D-2b)}$$

where the subscript 'k' denotes a time interval $t_k \leq t \leq t_{k+1}$ of a sequence of intervals $t_1, t_2, \ldots, t_n$.

The 24-Hour Equivalent Sound Level: The 24-hour equivalent sound level is defined as:

$$L_{eq}(24) = 10 \log \left\{ \frac{1}{24} \int_0^{24} 10^{L(t)/10} dt \right\} \quad \text{(D-3)}$$

where time is measured in hours.

The Daytime Equivalent Sound Level: The daytime equivalent sound level is defined as the equivalent sound level calculated for the 15-hour period 0700 to 2200 hours.

$$L_d = 10 \log \left\{ \frac{1}{15} \int_{0700}^{2200} 10^{L(t)/10} dt \right\} \quad \text{(D-4)}$$

The Nighttime Equivalent Sound Level: The nighttime equivalent sound level is defined as the equivalent sound level calculated for the 9-hour period 2200 hours to 0700 hours.

$$L_n = 10 \log \left\{ \frac{1}{9} \cdot \int_{2200}^{1700} 10^{L(t)/10} dt \right\} \qquad \text{(D-5)}$$

The Day-~~Time~~ Night Equivalent Sound Level: The day-night equivalent sound level is defined in terms of L_d and L_n as follows:

$$L_{dn} = 10 \log \left\{ \frac{15}{24} 10^{L_d/10} + \frac{9}{24} 10^{(L_n+10)/10} \right\} \qquad \text{(D-6a)}$$

as

$$L_{dn} = 10 \log \left\{ \frac{15}{24} 10^{L_d/10} + \frac{90}{24} 10^{L_n/10} \right\} \qquad \text{(D-6b)}$$

D.2 The Equivalent Sound Level for Random Noise Sources

For traffic noise emission models, it is usual to formulate the equivalent sound level, L_{eqk}, for a time period $t_k \leq t \leq t_{k+1}$ as an average of noise sources random in nature. That is, both the time sequence of occurrence and the type of occurrence, i.e., a vehicle type, are assumed to be random in nature.

Formally, the equivalent sound level, L_{eqk}, for the k^{th} time interval is a time-averaged level defined as an acoustic intensity ratio (see equation (D-2)):

$$10^{L_{eqk}/10} = \frac{1}{t_{k+1}-t_k} \int_{t_k}^{t_{k+1}} 10^{L(t)/10} dt = \langle 10^{L(t)/10} \rangle_k \qquad \text{(D-7)}$$

where $\langle\ \rangle_k$ denotes the time average over the k^{th} time interval.

The level variations from many time-varying records, $L(t_i) = L_i$, resulting from the same source characteristics define a statistically expected value of the acoustic intensity ratio. The statistically expected value is defined as:

$$E\,[10^{L_i/10}] = \int p(L_i)10^{L_i/10}dL_i \qquad \text{(D-8)}$$

where $p(L_i)$ is the probability density function of the sound level variation $L(t_i) = L_i$ for the collection of records characterized by a local variation t_i.

The random sound level variations $L(t_i)$ occur over a global time span comprised of intervals of local time t_i. If it is assumed that the random process described by the sound level variations is statistically stationary, then $p(L_i)$ is independent of the time interval t_i. For a stationary random process, the statistically expected value of the acoustic intensity is expressed as:

$$E\,[10^{L(t)/10}] = \int p(L)10^{L/10}dL \qquad \text{(D-9)}$$

Further, within the class of stationary random processes is a subclass called an ergodic random process which implies that $p(L_i)$ is identical to the probability density function $p(L)$ determined for any single member (event) of the random process.

Assuming that the sound level variation is represented as an ergodic random process, it can be shown that the expected value (Equation (D-9)) is equal to the time-averaged value (Equation (D-7)).

Hence, the equivalent sound level formally defined as a time average may be expressed in terms of a weighted level average as:

$$10^{L_{ek}/10} = \langle 10^{L(t)/10} \rangle_k = E[10^{L(t)/10}] \qquad \text{(D-10a)}$$

L_{eqk}

and

$$10^{L_{eqk}/10} = \int p(L) 10^{L/10} dL \qquad \text{(D-10b)}$$

The result of Equation (D-10b) is usually quoted without discussion concerning the underlying assumptions.

Further extension of the result of Equation (D-10) is possible. This extension, for the National Roadway Traffic Noise Exposure Model, recognizes that noise emission field test data for a given vehicle type result in data related to operation of that vehicle type. The data usually are obtained in the form of peak levels, L_O, at a reference distance, D_O, from the vehicle operating in a specified mode.

For a given vehicle type operating in a specified mode, p(L) denotes the probability density function resulting from field test data on many identical vehicles. If one assumes that p(L) is a Gaussian or Normal Distribution, then the result of Equation (D-10) becomes:

$$L_{eqk} = \overline{L_O} + 0.115\, \sigma_O^2 \qquad \text{(D-11)}$$

where

$\overline{L_O}$ is the mean (expected) value of the data points L_O
σ_O is the standard deviation of the data points L_O
$0.115 = \ln(10)/20 = \log_e(10)/20$

D.3 Day-Night Sound Level for Single Lane Traffic Flow

In the development of the traffic flow noise model, it is necessary to clearly keep track of the time of day, the vehicle type and the vehicle operating mode. To do this, the following notation is utilized:

subscript i denotes a vehicle type
subscript j denotes an operational mode
subscript k denotes an hourly time period.

With this notation the following parameters are defined:

$L_{oij}(t)$ The time-varying A-Weighted sound level for vehicle type i operating in mode j as measured at the distance D_o.

$P_{ij}(L)$ The probability density function of the peak vehicle sound levels for a vehicle type i operating in mode j as determined at the distance D_o.

$\overline{L}_{oij}$ The mean value of the peak A-Weighted sound levels of vehicle type i operating in mode j as determined at a distance D_o.

σ_{oij} The standard deviation of the peak A-Weighted sound levels of vehicle type i operating in mode j as determined at a distance D_o.

$\overline{\lambda}_{ijk}$ The source concentration of vehicle type i operating in mode j during the k^{th} hour.

D_o A standard reference distance for determining vehicle noise emissions (usually 50 feet or 15 m).

Basically, all highway traffic noise prediction models rely upon the concept of a source concentration parameter, λ, that is usually considered to be constant over the length of the roadway segment. The dimension of the source concentration parameter is the number of vehicles per unit length of roadway.

For a mixed traffic flow condition, the instantaneous acoustic intensity at the receiver, I(t), is the summation of intensities contributed from each vehicle type on the roadway:

$$I(t) = \sum_i I_i(t) \tag{D-12}$$

For the roadway-receiver geometry defined in Figure D-1, the instantaneous intensity at the receiver for a single vehicle type is:

$$I_i(t) = C \; I_o \; \lambda_i(t) \;\; 10^{L_i(t)/10} \tag{D-13}$$

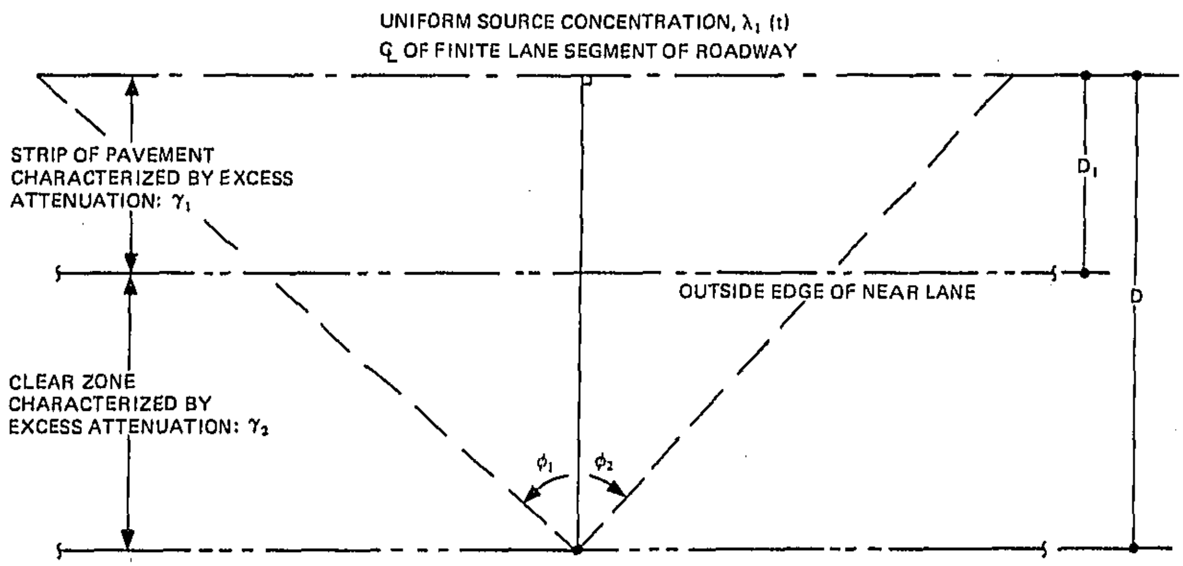

FIGURE D-1. SOURCE RECEIVER GEOMETRY

where I_0 is the reference acoustic intensity (See Equation (D-1))

$$C = \pi D_0^2 [(D_0/D_1)^{\gamma_1}(D_1^{\gamma_2}/D^{\gamma_2+1})] G_{\gamma_1}(\Phi_1, \Phi_2)$$

$$C = \pi D_0^2 \left[D_{01}^{\gamma_2}/D^{\gamma_2+1} \right] G_{\gamma_1}(\Phi_1, \Phi_2) \qquad \text{for } \gamma_1 = 0$$

$$G_{\gamma_1}(\Phi_1, \Phi_2) = \frac{1}{\pi} \int_{\Phi_1}^{\Phi_2} \cos^{\gamma_1}(\phi) d\phi$$

The parameter C in Equation (D-13) is a site parameter dependent only on the receiver distance, D, from the roadway; the relative orientation of the receiver to the roadway (angles Φ_1 and Φ_2); and the excess distance attenuation parameter γ.*

For the k^{th} hourly time period, the time averaged mean acoustic intensity at the receiver is for all vehicular sources and all operating modes:

$$\bar{I}_k = \frac{1}{T_k} \int_{t_k}^{t_{k+1}} I(t)dt = \sum_i \sum_j \bar{I}_{ijk} \qquad \text{(D-14a)}$$

$$\bar{I}_{ijk} = \frac{CI_0}{T_k} \int_{t_k}^{t_{k+1}} \lambda_{ij}(t) 10^{L_{oij}(t)/10} dt \qquad \text{(D-14b)}$$

In the above result it is assumed that the vehicle concentration and the reference emission levels are functions of time during the k^{th} hour.

Then considering the accumulated time during each hour that the vehicle type i operates in the j^{th} mode, the hourly time interval $[t_k, t_{k+1}]$ is subdivided into operational time intervals such that:

* See Appendix J of Reference 4.

$$\int_{t_k}^{t_{k+1}} (\quad)_j dt = \sum_j \int_{t_{i,j}}^{t_{i,j+1}} (\quad)_k dt \qquad \text{(D-15)}$$

Assuming that the vehicle source concentration $\lambda_{ij}(t)$ does not change during the k^{th} hour, i.e., $\lambda_{ij}(t) = \lambda_{ijk}$, then the average mean acoustic intensity is:

$$T_{ik} = CI_o \sum_j \lambda_{ijk} \frac{\Delta t_{ij}}{T_k} \left\{ \frac{1}{\Delta t_{ij}} \cdot \int_{t_{i,j}}^{t_{i,j+1}} 10^{L_{oij}(t)/10} dt \right\}_k \qquad \text{(D-16)}$$

where $\Delta t_{ij} = t_{i,j+1} - t_{i,j}$ is the accumulated time (during the k^{th} hour that the vehicle type i operates in the j^{th} mode). (Note that the subscript k is implied.)

Assuming that the sound level $L_{oij}(t)$ is an ergodic random process, then the term in braces in Equation (D-16) is identical to the definition of the equivalent sound level for the j^{th} operating mode of the vehicle and may be alternately defined as:

$$10^{L^{eg}_{oijk}/10} = \left\{ \int p_{ij} (L_o)\ 10^{L_o/10} dL_o \right\}_k \qquad \text{(D-17)}$$

Then, using the results of Equations (D-16) and (D-17) in the expression for the time-averaged acoustic intensity at the receiver (Equation (D-14)), one obtains:

$$T_{ik} = CI_o \sum_j \bar{\lambda}_{ijk} \cdot f_{ijk} 10^{L^{eg}_{oijk}/10} \qquad \text{(D-18)}$$

where $\bar{\lambda}_{ijk}$ is the source concentration for the i^{th} vehicle type operating in the j^{th} mode during the k^{th} hour.

$f_{ijk} = \Delta t_{ij}/T_k$ is the fraction of time during the k^{th} hour that vehicle type i operates in mode j.

$$L^{eq}_{oijk} = 10 \log \left\{ \frac{1}{\Delta t_{ij}} \int_{t_{i,j}}^{t_{i,j+1}} 10^{L_{oij}(t)/10} dt \right\}_k$$

or,

$$L^{eq}_{oijk} = 10 \log \left\{ \int p_{ij}(L_o) 10^{L_o/10} dL_o \right\}_k$$

Finally, using the result of Equation (D-18) in Equation (D-14), the expression for the time average acoustic intensity at the receiver due to all vehicle types on the roadway is:

$$\overline{I}_k/I_o = C \sum_i \sum_j \overline{\lambda}_{ijk} f_{ijk} 10^{L^{eq}_{oijk}/10} \quad \text{(D-19)}$$

and the hourly equivalent sound level for the traffic flow during the k^{th} hour of the day is:

$$L_{eqk} = 10 \log \left\{ \overline{I}_k/I_o \right\} \quad \text{(D-20)}$$

where $\overline{I}k/I_o$ is given by Equation (D-19).

It is now assumed that the vehicle concentration on the roadway remains constant at the value defined for the cruise condition. That is, the vehicles do not group together for the idle, acceleration, and deceleration modes. With this assumption (See Equation (D-19)):

$$\overline{\lambda}_{ijk} = (N_i/S_c)_k = (N/S_c)_k \, \eta_{ik} \quad \text{(D-21)}$$

where N_i is the number of vehicles of type i in the traffic count for the k^{th} hour

S_c is the cruise speed for the k^{th} hour

$\eta_{ik} = (N_i/N)_k$ is the fraction of type i vehicles in the total traffic count N during the k^{th} hour.

Now, for each hour of the day a traffic noise condition is defined by the equivalent level given by Equation (D-20). Using the definitions for the daytime equivalent sound level (Equation D-4), the nighttime equivalent sound level (Equation D-5), the nighttime equivalent sound level (Equation D-5), and the day-night equivalent sound level (Equation D-6b), the expression for the day-night sound level from the flow of traffic is obtained in the form:

$$L_{dn} = 10 \log \left\{ \frac{1}{24} \sum_{k=1}^{15} 10^{L_{eqk}/10} + \frac{10}{24} \sum_{k=16}^{24} 10^{L_{eqk}/10} \right\} \quad \text{(D-22)}$$

where
$$10^{L_{eqk}/10} = C \left(\frac{N_k}{S_{ck}} \right) \sum_i \eta_{ik} \sum_j f_{ijk} 10^{L^{eq}_{oijk}/10}$$

$$C = \pi D_0{}^2 \left[D_1^{\gamma_2} / D^{\gamma_2 + 1} \right] G_{\gamma_1}(\phi_1, \phi_2)$$

$$G_\gamma(\phi_1, \phi_2) = \frac{1}{\pi} \int_{\phi_1}^{\phi_2} \cos^\gamma(\phi) d\phi$$

The result of Equation (D-22) is quite general in that if the vehicle mix (η_{ik}), vehicle operating characteristics (f_{ijk}), hourly traffic count (N_k) and average hourly cruise speed (S_{ck}) are all defined, then the calculation of L_{dn} for the finite roadway segment at a distance (D) and orientation ($\phi 1$ and $\phi 2$) from the receiver for a site characterized by excess distance attentuation (γ) is very straightforward. Unfortunately, national data for roadway traffic conditions are not available at this level of detail. Hence, the general result of Equation (D-22) must be reduced to a level compatible with the best available data related to national traffic characteristics. It is recognized that for any specific roadway sufficient data could be obtained to utilize Equation (D-22) without further assumptions.

The reduction of the result of Equation (D-22) to the level of available data will be taken in stages. First, it will be assumed that traffic conditions are constant during the daytime (0700 to 2200 hours) and are constant during the nighttime (2200 to 0700 hours). Hence, in general, the daytime conditions will include an averaging of the morning and evening rush hour periods and the nighttime conditions will exclude rush hour periods.

With this assumption the day-night equivalent sound level for the traffic flow is expressed as:

$$L_{dn} = 10 \log\left\{\frac{15}{24}\,\overline{N}_d\overline{S}_d 10^{L_d^{eq}/10} + \frac{90}{24}\,\overline{N}_n\overline{S}_n 10^{L_n^{eq}/10}\right\} + 10 \log\left(\frac{CN}{S_c}\,\varepsilon\right) \qquad \text{(D-23)}$$

where N is the average hourly traffic count for 24 hours (equals $(15N_d + 9N_n)/24$)

S_c is the average hourly cruise speed for 24 hours

$\overline{N}_r = N_r/N$ is the fraction of the average hourly traffic count during daytime hours (r=d) or nighttime hours (r=n)

$\overline{S}_r = S_r/S_c$ is the ratio of the average hourly daytime cruise speed (r=d) or nighttime cruise speed (r=n) to the average hourly cruise speed for 24 hours.

$$10^{L_r^{eq}/10} = \sum_i n_{ir} \sum_j f_{ijr} 10^{L_{oijr}^{eq}/10}$$

r = d denotes average hourly daytime conditions

r = n denotes average hourly nighttime conditions.

The result of Equation (D-23) is too general for use in a national simulation model. Generally, only average daily (24-hour) data are available to define the traffic conditions on the roadway. However, data are available to estimate the fractions of the total traffic count for the daytime and nighttime periods. All other data must be assumed constant over the 24-hour period.

Assuming that the average cruise speed (S_{cr}), traffic mix (η_{ir}), and the vehicle operating parameters (f_{ijr}) are constant for each hour of the day, then $L_d^{eq} = L_n^{eq}$ and the daynight equivalent sound level is expressed as:

$$L_{dn} = L_o^{eq} + 10 \log(N/S_c) + 10 \log (10 - 9F_d) + 10 \log(C) \qquad \text{(D-24)}$$

where $F_d = (15N_d)/24N)$ is the fraction of the traffic count occurring during the daytime

$F_n = (9N_n)/(24N)$ is the fraction of the traffic count occurring during the nighttime

$F_d + F_n = 1$

Finally, national data were not available to estimate an average roadway orientation defined by the angular coordinates (ϕ_1, ϕ_2). However, it is assumed that the location at which the traffic noise estimate is to be made is at the edge of a clear zone adjacent to the roadway. The clear zone is assumed to be uninhabited but to possibly exhibit an excess distance attenuation described by the constant Y_2 (see Figure D-1). Hence, at the edge of the clear zone, it will be assumed that a receiver would view the roadway as an infinite line source. Further, it is assumed that the pavement surface is acoustically hard. With these assumptions, the following parameter values are: $\phi_1 = -\pi/2$, $\phi_2 = +\pi/2$, and $\gamma_1 = 0$. These parameters are contained in the term denoted by "C" in Equation (D-24). The parameter C is defined in Equation (D-23) and for an infinite roadway with acoustically hard pavement, one obtains:

$$10 \log(C) = 10\log(D_r^{\gamma_2}/D_{cr}^{\gamma_2+1}) + 10 \log(\pi D_o^2) \qquad \text{(D-25)}$$

where D_r is the propagation distance over the acoustically hard pavement

D_{cr} is the propagation distance from the r^{th} lane centerline to the edge of the clear zone

γ_2 is the excess distance attenuation constant for the clear zone. Distance $D_{cr} - D_r$.

Substituting the result of Equation (D-25) into Equation (D-24), one obtains for the r^{th} roadway lane:

$$L_{dnr} = L_{or}^{eq} + 10 \log(N_r/S_{cr}) + 10 \log(10 - 9F_d)_r$$

$$+ 10 \log(D_r^{\gamma_2}/D_{cr}^{\gamma_2+1}) + 10 \log(\pi D_o^2) \qquad \text{(D-26)}$$

The first term in Equation (D-26) is the reference traffic noise source term. This term is the weighted equivalent sound level of the traffic defined for the roadway lane. It comprises the traffic mix, the fraction of time that each vehicle type operates in each mode, and the reference vehicle noise emission levels. The vehicle noise emission levels are referenced to the distance D_o and depend upon the traffic speed. This term is defined in Equation (D-23).

The second term in Equation (D-26) is the traffic source concentration (number of vehicles per unit length of roadway). The third term accounts for the split of the total traffic between daytime and nighttime. The fourth term is the noise distance attenuation considering an acoustically hard propagation across the pavement and an excess attenuation over the clear zone. The last term incorporates the reference distance, D_o, and the integration for the infinite length line source.

Equation (D-26) applies to a single traffic lane and may incorporate any consistent set of dimensional units for length and time. Expressing length in feet, speed in miles per hour, and traffic count in terms of the Average Daily Traffic (ADT) count, Equation (D-26) becomes:

$$L_{dnr} = L_{or}^{eq} + 10 \log (\overline{N}_r/S_{cr}) + 10 \log(D_{\theta_r}^{\gamma_2}/D_{cr}^{\gamma_2+1}) + C_1 \qquad \text{(D-27)}$$

where $C_1 = 10 \log \left|\pi D_0^2(10 - 9F_d)_r/(24 \cdot 5280)\right|$

On a national basis, it appears reasonable to assume that 87 percent of the total traffic operates during the day and that 13 percent of the total traffic operates during the night.[3] Further, it is reasonable to assume that this day-night traffic split applies for each traffic lane. With these assumptions, the expression for the day-night sound level for the r^{th} traffic lanes becomes:

$$L_{dnr} = L_{or}^{eq} + 10 \log (\overline{N}_r/S_{cr}) + 10 \log(D_{\theta_r}^{\gamma_2}/D_{cr}^{\gamma_2+1}) - 8.71 \qquad \text{(D-28)}$$

where $D_o = 50$ feet

$$-8.71 = 10 \log [\pi(50)^2(10 - 9(0.87))/24 \cdot 5280)]$$

Equation (D-28) applies to a single lane of traffic of infinite extent at a Distance D_{cr} feet from the edge of the clear zone to the center line of the lane. The distance from the lane centerline to the near edge of the pavement is denoted by D_r. The Parameter γ_2 denotes the excess distance attenuation for the traffic noise propagating over the clear zone. This propagation distance is $(D_{cr} - D_r)$ feet.

D.4 Day-Night Sound Level for Multi-Lane Traffic Flow

To extend the result of Equation (D-28) to multi-lane roadway traffic conditions, it is only necessary to sum the sound level contributions from each lane on an intensity basis. Estimates for the number of lanes, average lane widths, and clear zone distances are possible. The traffic parameters appearing in Equation (D-28) apply for each lane. National data are not available to estimate a non-uniform distribution of traffic over all lanes. Hence, it must be assumed that the total ADT for the roadway is uniformly distributed over each lane and that the average cruise speed for each lane is equal to the cruise speed for the roadway. With these assumptions, the expression for the day-night sound level at the edge of the clear zone is:

$$L_{dn} = L_o^{eq} + 10 \log (\overline{N}/(nS_c)) + 10 \log \left(\sum_{r=1}^{n} (D_r^{\gamma/2}/D_{cr}^{\gamma/2+1}) \right) -8.71 \qquad \text{(D-29)}$$

where l_o^{eq} is the weighted equivalent sound level referenced
L_o^{eq} to D_o = 50 feet for the defined traffic flow mix, vehicle operating characteristics, and speed S_c

$\overline{N}$ is the ADT for the roadway

n is the number of lanes

D_r is the distance from the r^{th} lane centerline to the near edge of the pavement

D_{cr} is the distance from the r^{th} lane centerline to the edge of the clear zone.

Figure D-2 presents the roadway/clear zone geometry and the assumptions used for excess distance attenuation from the source to the edge of the clear zone.

The first term in Equation (D-29) is the source reference noise emission level. This term is the equivalent sound level of the traffic noise source weighted by the vehicle mix and the vehicle operating characteristics. This quantity is defined in Equation (D-23). The second term is the traffic

- SOUND LEVEL ATTENUATION @ 3 dB/DD FOR DISTANCE D_r (HARD SITE)
- SOUND LEVEL ATTENUATION @ $3(1 + \gamma_2)$ dB/DD FOR DISTANCE ($D_{cr} - D_r$) (HARD OR SOFT SITE)

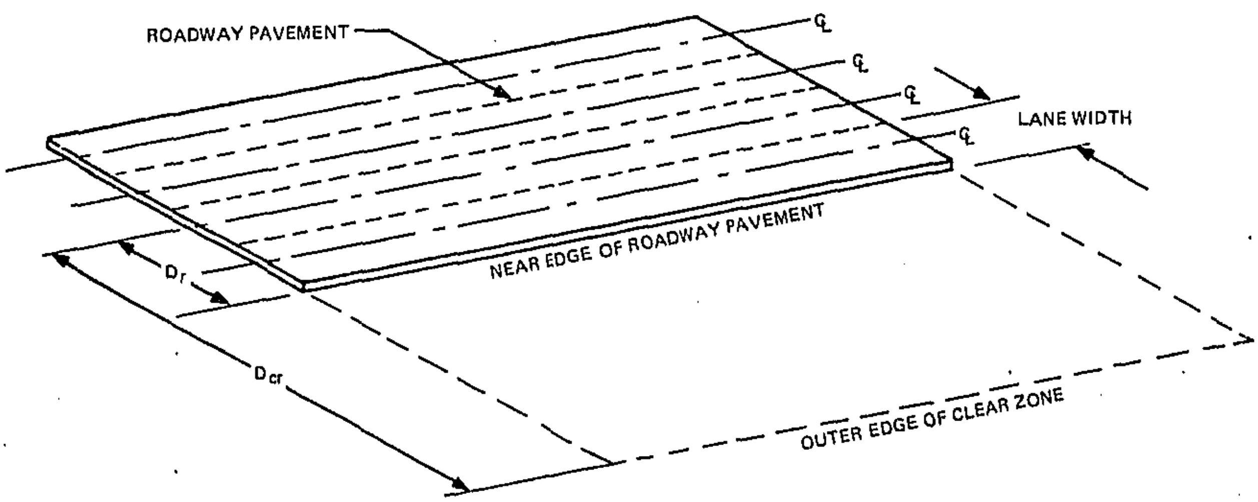

FIGURE D-2. ROADWAY/CLEAR ZONE GEOMETRY AND ASSUMED SOUND LEVEL ATTENUATION WITH DISTANCE noise source concentration for each lane defined in terms of the total roadway ADT ($\overline{N}$), the number of lanes (n), and the average cruise speed. The third term is the traffic noise propagation term for the varying distances from each lane to the edge of the clear zone.

Equation (D-29) is the algorithm used by the National Roadway Traffic Noise Exposure Model to estimate noise emissions for the specific traffic conditions and roadway configurations as defined by the Model. As used by the Model, the distances in Equation (D-29) are calculated from lane width data and clear zone distances defined as input. The Model uses Equation (D-29) to estimate the traffic noise level at the outer edge of the clear zone. The distance attenuation functions used by the Model for noise propagation into populated areas are described in Section 2.5 of the main text of this report.

D.5 REFERENCES

APPENDIX D

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APPENDIX E

SINGLE EVENT TRAFFIC NOISE THEORY

E.1 Definition of Single Event Sound Levels

To estimate the sound exposure of a receiver resulting from a discrete noise event, one requires the determination of the total acoustic intensity received from the source during a defined time period. The definition of the time period usually depends upon the characteristics of the source. For example, solid waste compactor (i.e., garbage truck) noise may be estimated using the compaction cycle time in order to characterize the source's noise emissions. For a discrete event, such as characterized by the passage of an aircraft, a railway train, or a roadway vehicle, the "10 dB down duration" is used to characterize the vehicle's noise signature.[1] That is, the time required for the sound level to rise from 10 dB below the maximum level to the maximum level and then to decay to 10 dB below the maximum level is commonly used.

For a single discrete noise intrusion, the total acoustic intensity received during the defined time period is used to define appropriate sound levels. One level, called the Sound Exposure Level or SEL, is simply a measure of the total received acoustic intensity. Another level, called the equivalent sound level is a time average of the total received acoustic intensity. The equivalent sound level, is a measure of the average acoustic intensity received during any instant of the defined time period.

For a time varying sound level, $L(t)$, that is symmetric about the maximum level at $t = 0$, the following definitions apply for the defined time period $-T/2 \leq t \leq T/2$:

- Sound Exposure Level*

$$SEL = 10 \cdot \log \left\{ \int_{-T/2}^{T/2} 10^{L(t)/10} dt \right\} \qquad \text{(E-1a)}$$

*This may also be denoted as L_{AE} (see Reference 1).

• Equivalent Sound Level (for the time T)

$$L_{eqT} = 10 \cdot \log \left\{ \frac{1}{T} \int_{-T/2}^{T/2} 10^{L(t)/10} dt \right\} \qquad \text{(E-1b)}$$

From the definitions given in Equation (A-1), the following relationships between the Sound Exposure Level and the equivalent sound level is obtained:

$$SEL = L_{eqT} + 10 \cdot \log (T) \qquad \text{(E-1)}$$

Using the result of Equation (E-2), one may relate the two sound levels rather easily provided that the noise exposure duration, T, at the receiver is known. Generally, the duration depends upon the source's operating characteristics and the closest pass-by distance between the source and the receiver. The purpose of this Appendix is to present explicit expressions for SEL, L_{eqT}, and T in terms of the source operating characteristics and the sound level attenuation between the source and the receiver.

E.2 Single Event Noise Analysis for a Vehicle Pass-by

Figure E-1 presents the source-receiver geometry for a single vehicle noise source moving with speed V along a straight roadway. The receiver's distance from the roadway is denoted by the parameter D. Time is measured relative to the instant that the source is at the distance D from the receiver. Alternately, the source may be located at any instant by using the time-varying angle, $\phi(t)$, as indicated in Figure E-1.

$$R(t) = [D^2 + (Vt)^2]^{1/2} = D/COS(\phi(t)) \qquad \text{(E-3)}$$

where $\phi(t) = TAN^{-1}(Vt/D)$

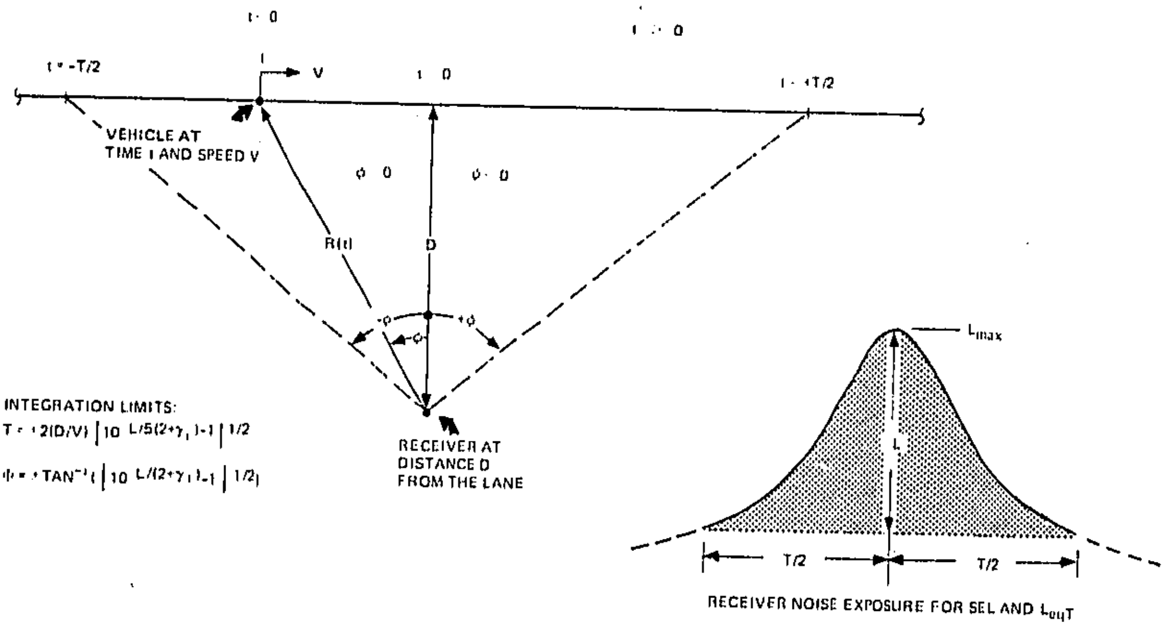


FIGURE E-1. ROADWAY LANE/RECEIVER GEOMETRY FOR SINGLE EVENT NOISE ANALYSIS OF VEHICLE PASS-BY

At any instant, t, the source sound level propagates towards the receiver and attenuates as a function of the time varying source-receiver distance R(t). Hence, the time-varying sound level at the receiver may be expressed in the general form:

$$L(t) = L_o + 10 \cdot \log [FR(R)] \qquad (E-4)$$

where L_o is the vehicle's reference level
$10 \cdot \log [F(R)]$ is the distance attenuation

For the moment, the function F(R) is considered to be general, but it must satisfy the following conditions:

(1) $F(R) = 1.0$ when $D = D_o$ and $t = 0$ (i.e., $L(0) = L_o$ @ $D = D_o$)

(2) $0 < F(R) \leq 1.0$ for $D \geq D_o$ (i.e., the sound level attenuates)

The first condition simply states that with the receiver at a distance D_o, the maximum level at the receiver is the vehicle reference level, L_o. The second condition simply states that the sound level attenuates with increasing distance from the roadway beyond the reference distance D_o.

Using the time varying sound level, L(t), as presented in Equation (E-4), the definitions given in Equation (E-1), and transforming the time integration to an angular integration, one obtains:

$$SEL = L_o + 10 \cdot \log (D/V) + 10 \cdot \log \left\{ \int_{-\Phi}^{\Phi} SEC^2\phi \cdot F(\phi) d\phi \right\} \qquad (E-5a)$$

$$L_{eqT} = L_o + 10.\log (D/VT) + 10 \cdot \log \left\{ \int_{-\Phi}^{\Phi} SEC^2\phi \cdot F(\phi) d\phi \right\} \qquad (E-5b)$$

$$\Phi = TAN^{-1}(VT/2D) \qquad (E-5c)$$

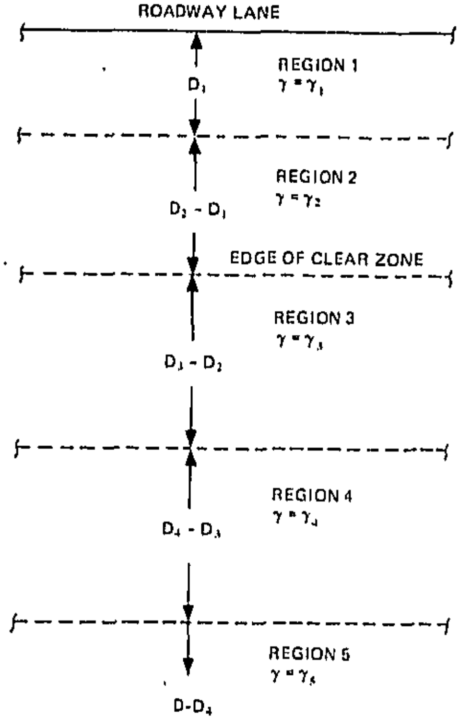
In Equation (E-5), the sound exposure duration is taken as T. The above results are the basic functional forms for calculating the Sound Exposure Level and the equivalent sound level for a single event vehicle pass-by.

E.3 Propagation of Sound for Single Event Analysis

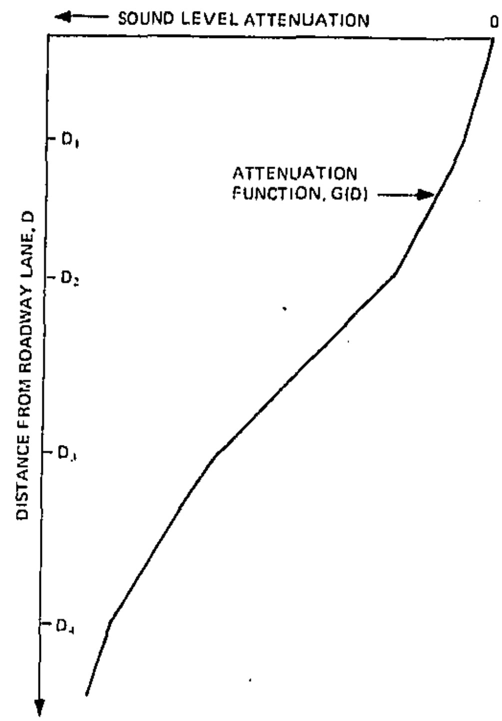
The propagation of sound through an urban area is not an ideal process. For a single point source, one would ideally assume that acoustic intensity varies inversely as the square of the distance from the source. Hence, one aspect of urban noise propagation is to simulate attenuation of acoustic intensity in excess of the inverse square relationship. Further, urban areas are built up with buildings of various heights with various widths between the buildings. Hence, one must use empirical results to simulate distance attenuation of vehicle noise in urban areas.[2]

Based upon the available empirical data,[2,3,4] however, it appears reasonable to assume that urban noise propagation may be simulated, approximately, by defining an appropriate distance attenuation function. The approach taken here is to assume that the empirical distance attenuation function may be described using a connected series of straight line segments when presented in the form of attenuation versus the logarithm of the distance from the source. Figure E-2 presents the general concept of the assumed form of the attenuation function.

As an extension of the roadway traffic noise model developed by FHWA and described in Appendix J of Reference 5, it is assumed that the distance attenuation may be simulated by a series of adjacent regions parallel to the roadway. Each region is characterized by a width and by an "excess attenuation" parameter, γ. This configuration is illustrated in Figure E-2.



(a) PLAN VIEW OF CONCEPTUAL SITE



(b) SOUND LEVEL DISTANCE ATTENUATION

FIGURE E-2. DISTANCE ATTENUATION FUNCTION USED FOR SINGLE EVENT NOISE ANALYSIS

The attenuation function may be expressed mathematically as a product of distance ratios raised to an appropriate power. The functional form used for the attenuation function is:

$$G_r(D) = (D_0/D_1)^{2+\gamma_1} (D_r/D)^{2+\gamma_r} \cdot \prod_{i=1}^{(r-1)} (D_i/D_{i+1})^{2+\gamma_{i+1}} \qquad \text{(E-6)}$$

where D_0 is a reference distance for the vehicle reference level, L_0.

D_r is the distance from the roadway to the far edge of the r^{th} strip

D is the receiver distance from the roadway

$D_{r-1} \leq D \leq D_r \qquad r = 2, 3, \ldots$

The sound level attenuation as a function of distance from the roadway is given as:

$$\text{Attenuation, dB} = 10 \cdot \log [G_r(D)] \qquad \text{(E-7)}$$

for the distance D in the range $D_{r-1} \leq D \leq D_r$.

The result of Equation (E-7) is extended to the moving vehicle source using the relationship of Equation (E-3):

$$R(t) = D/COS(\phi(t)) \qquad \text{(E-8)}$$

Similarly, the distances, D_i, used to define the attenuation function, $G_r(D)$, given by Equation (E-6) are expressed as:

$$R_i(t) = D_i/COS(\phi(t)) \qquad \text{(E-8b)}$$

Using the result of Equation (E-8) one obtains the relationship

$$D_i/D_{i+1} = R_i(t)/R_{i+1}(t) \quad i = 1, 2, \ldots \tag{E-9}$$

Hence, other than the ratio, D_0/D_i, appearing in Equation (E-6), all other terms are independent of time and/or the vehicle's position relative to the closest pass-by location. Substituting, the relationships of Equations (E-8) and (E-9) into Equation (E-6), the distance attenuation function for an arbitrary vehicle position relative to the receiver is obtained. The result is:

$$F_r(\phi) = G_r(D)[COS(\phi(t))]^{2+\gamma_1} \tag{E-10}$$

Hence, the time varying sound level at the receiver is obtained by substituting Equation (E-10) into Equation (E-4):

$$L_r(t) = L_0 + 10\cdot\log\,[G_r(D)] + 10(2+\gamma_1)\cdot\log\,[COS(\phi(t))] \tag{E-11}$$

The Sound Exposure Level is obtained by substituting Equation (E-11) into the SEL definition of Equation (E-1a) or substituting the attenuation function of Equation (E-10) into Equation (E-5a). Using either approach one obtains:

$$SEL = L_0 + 10\cdot\log\,[G_r(D)] + 10\cdot\log\left\{\int_{-\Phi}^{\Phi} COS^{\gamma_1}\, d\phi\right\} + 10\cdot\log(D/V) \tag{E-12}$$

where $D_{r-1} \leq D \leq D_r$

$$\Phi = TAN^{-1}(VT/2D)$$

From Equation (E-12), it is seen that the Sound Exposure Level is a function of the vehicle reference level, L_0; the distance from the roadway, D; the vehicle speed, V; the exposure time, T; and the excess attenuation parameter, γ_1. From either the relationship between SEL or L_{eqT} (See Equation (E-2)) or Equation (E-5b) one sees that the single event equivalent sound level, L_{eqT}, depends upon the same parameters as the Sound Exposure Level. The only parameter yet to be estimated is the exposure time T.

E.4 Single Event Exposure Time

As mentioned in Section E.1, the single event exposure time must be known to evaluate either the Sound Exposure Level or the single event equivalent sound level, L_{eqT}. In this section, the analytical estimation of the exposure time, T, for a single event is obtained. The result if dependent upon the form of the distance attenuation function assumed for the problem as described in Section E.3.

The time-varying sound level is given by Equation (E-11). The maximum sound level at the receiver for the single event pass-by occurs at time t=0. The " ΔL dB duration" is obtained from Equation (E-11) by subtracting the time varying level from the maximum level. The result expresses the level variation between the maximum level and the level at the time $t = \pm T/2$. The result is simply:

$$L = -10(2 + \gamma_1)\cdot\log\cdot[\mathrm{COS}(\phi(T/2))] \qquad \text{(E-13)}$$

To determine the single event noise exposure duration, T, Equation (E-13) must be solved for the duration. Using the definition of the time-varying source-receiver distance given by Equation (E-3), one obtains:

$$T = 2(D/V)\,[10^{\Delta L/5(2+\gamma_1)} - 1]^{1/2} \qquad \text{(E-14)}$$

The result of Equation (E-14) expresses the single event noise exposure duration, T, in terms of the distance, D; the vehicle speed V; the level difference, ΔL; and the excess attenuation parameter γ_1.

To complete the discussion, it is necessary to evaluate the integration limits appearing in Equations (E-5). Substituting the result of Equation (E-14) into Equation (E-5c), the subtended angle swept by the source as it passes by the receiver is simply:

$$\Phi = \mathrm{TAN}^{-1}\left([10^{\Delta L/5(2+\gamma_1)} - 1]^{1/2}\right) \qquad \text{(E-15)}$$

This is, perhaps, the most revealing aspect of the entire discussion. That is, the angular view that the receiver "sees" as the vehicle passes by depends only upon the level difference, ΔL, and the parameter γ_1. This result is, of course, dependent upon the form of the attenuation function assumed in Equation (E-6).

E.5 Summary of Results

The main results of the single event noise analysis are summarized in this section. Basically, the results are the quantitative evaluation of the Sound Exposure Level, SEL, and the single event equivalent sound level, L_{eqT}, in terms of the vehicle operating parameters and the site characteristics. The results, of course, present the quantitative evaluation of the single event exposure time or duration, T. The results apply to a single vehicle moving along a roadway with constant speed, V, and the receiver located at a distance, D, from the roadway.

The Sound Exposure Level for the single event is given by:

$$SEL = L_o + 10\cdot\log(D/V) + 10\cdot\log\,[G_r(D)] + 10\cdot\log\left\{\int_{-\Phi}^{\Phi} COS^{\gamma_1}(\phi)d\phi\right\} \qquad \text{(E-16a)}$$

The single event equivalent sound level is given by:

$$L_{eqT} = L_o + 10\cdot\log\,(D/VT) + 10\cdot\log\,[G_r(D)] + 10\cdot\log\left\{\int_{-\Phi}^{\Phi} COS^{\gamma_1}(\phi)d\phi\right\} \qquad \text{(E-16b)}$$

The single event duration, T, and the angular limit ϕ are given by:

$$T = 2\,(D/V)[10^{\Delta L/5(2+\gamma_1)} - 1]^{1/2} \qquad \text{(E-16c)}$$

$$\Phi = TAN^{-1}\,\{[10^{\Delta L/5(2+\gamma_1)} - 1]^{1/2}\} \qquad \text{(E-16d)}$$

E.6 Application of Results

For a single vehicle pass-by noise event, the summary of results presented in Section E.5 may be condensed to practical application by assigning representative values to the various parameters. First, the value of ΔL required to estimate the exposure time, T, is set to 10 dB. Next, the physical interpretation of the parameter γ_1 is required. If the distance, D_1 is defined as the "clear zone distance", the site is either "hard" ($\gamma_1 = 0$) or "soft" ($\gamma_1 = 0.5$).[5] With these conventions and the results of Equations (E-16c) and (E-16d) one obtains:

$$T = 6(D/V) \text{ and } \Phi = 1.2490 \text{ radian for a "hard" site} \qquad \text{(E-17a)}$$

$$T = 4.6085(D/V) \text{ and } \Phi = 1.1613 \text{ radian for a "soft" site} \qquad \text{(E-17b)}$$

For the single event Sound Exposure Level and the equivalent sound level, it is required to evaluate the integral appearing in Equations (E-16a) and (E-16b). The results are[5]:

$$10 \cdot \log \left\{ \int_{-\Phi}^{\Phi} \cos^{\gamma_1}(\phi)\, d\phi \right\} = \begin{cases} +\ 3.98 \text{ dB for a "hard" site} & \text{(E-18a)} \\ +\ 2.87 \text{ dB for a "soft" site} & \text{(E-18b)} \end{cases}$$

The result of Equation (E-18b) is obtained from Figure 7, page 23, of Reference 5.

Using these results, the Sound Exposure Level is expressed as:

$$SEL = L_o + 10 \cdot \log\,[G_r(D)] + 10 \cdot \log(D/V) + C_1 \qquad \text{(E-19)}$$

and the single event equivalent sound level is expressed as:

$$L_{eqT} = L_o + 10 \cdot \log\,[G_r(D)] + C_2 \qquad \text{(E-20)}$$

The constants C_1 and C_2 in Equations (E-19) and (E-20) basically depend upon the "10 dB down duration" and the values of $_1$ corresponding to a "hard" or a "soft" site. Using the results of Equations (E-17) and (E-18) one obtains:

$$C_1 = \begin{cases} +3.98 \text{ dB for a "hard" site} \\ +2.87 \text{ dB for a "soft" site} \end{cases} \qquad \text{(E-21)}$$

$$C_2 = \begin{cases} -3.80 \text{ dB for a "hard" site} \\ -3.86 \text{ dB for a "soft" site} \end{cases} \qquad \text{(E-22)}$$

This result is the basic algorithm used to estimate the Sound Exposure Level, SEL, and the single event equivalent sound level, L_{eqT}, used by the Single Event Model of the National Roadway Traffic Noise Exposure Model.

E.7 Single Event Noise Exposure With Ambient Sound Present

In order to estimate the single event noise exposure in terms of realistic conditions at the receiver, it is necessary to consider the ambient sound level present during the noise intrusion. If the maximum level of a time-varying intruding noise exceeds the receiver's ambient level by several dB, the receiver will be able to distinguish the intruding noise above the ambient. However, if the maximum level is equal to or less than the ambient level, then the intruding noise will be "masked" or obscured by the ambient level. Hence, expressions for the Sound Exposure Level, SEL, and the single event equivalent sound level, L_{eqT}, in terms of both the intruding noise and the receiver's ambient sound level are required.

Assume that the time-varying ambient level at the receiver is given by $L_a(t)$. From Equation (E-11), the time-varying intruding sound from a vehicle pass-by is given by:

$$L(t) = L_{max} + 10(2 + \gamma_1)\cdot \log[\cos(\phi(t))] \qquad \text{(E-23)}$$

where $L_{max} = L_o + 10\cdot\log\, G_r(D)$ is the maximum sound level at the receiver during the pass-by.

For the receiver simultaneously exposed to the time-varying ambient and the vehicle's pass-by noise, the total exposure level at the receiver is:

$$\mathcal{L}(t) = 10\cdot\log\left\{10^{L_a(t)/10} + 10^{L(t)/10}\right\} \qquad \text{(E-24)}$$

Using Equation (E-23), one may estimate the Sound Exposure Level and the single event equivalent sound level in terms of the ambient level and the vehicle's noise emission characteristics. Substituting Equation (E-23) into Equation (E-24) and using the definitions for SEL and L_{eqT}, one obtains the receiver's total single event noise exposure. The receiver's Sound Exposure Level, with ambient, is:

$$SEL = 10\cdot\log\left\{10^{SEL_a/10} + 10^{L_{max}/10}(D/V)\cdot \int_{-\Phi}^{\Phi}\cos^{\gamma_1}\phi\, d\phi\right\} \qquad \text{(E-25)}$$

where $SEL_a = 10\cdot\log\left\{\int_{-T/2}^{T/2} 10^{L_a(t)/10}\, dt\right\}$

The receiver's single event equivalent sound exposure level, with ambient, is:

$$L_{eqT} = 10\cdot\log\left\{10^{L_{eqa}/10} + 10^{L_{max}/10}(D/VT)\cdot \int_{-\Phi}^{\Phi}\cos^{\gamma_1}\phi\, d\phi\right\} \qquad \text{(E-26)}$$

where $L_{eqa} = 10\cdot\log\left\{\frac{1}{T}\cdot \int_{-T/2}^{T/2} 10^{L_a(t)/10}\, dt\right\}$

In Equation (E-25), SEL_a is the Sound Exposure Level of the ambient. In Equation (E-26), L_{eqa} is the equivalent sound level of the ambient. The averaging time, T, is the vehicle's single event duration given by Equation (E-14). From the above results, it is seen that the Sound Exposure Level attributable to the ambient is realted to the ambient equivalent sound level as:

$$SEL_a = L_{eqa} + 10 \cdot \log(T) \qquad \text{(E-27)}$$

Substituting Equation (E-27) into Equation (E-25), and factoring out the terms containing L_{max} and T, the receiver's total Sound Exposure Level is expressed as:

$$SEL = L_{max} + 10 \cdot \log(T) + 10 \cdot \log \left\{ 10^{(L_{eqa} - L_{max})/10} + I \right\} \qquad \text{(E-28)}$$

where: $$I = (D/VT) \cdot \int_{-\phi}^{\phi} \cos^{\alpha 1} \phi \, d\phi \qquad \text{(E-29)}$$

Similarly, the receiver's total single event equivalent sound exposure level is expressed as:

$$L_{eqT} = L_{max} + 10 \cdot \log \left\{ 10^{(L_{eqa} - L_{max})/10} + I \right\} \qquad \text{(E-30)}$$

where I is defined by Equation (E-29)

Now, suppose that the maximum intruding sound level, L_{max}, exactly equals the receiver's ambient equivalent sound level. Thus, the receiver's total Sound Exposure Level is:

$$SEL = L_{eqa} + 10 \cdot \log(T) + 10 \cdot \log \left\{ 1 + I \right\} \qquad \text{(E-31)}$$

and the receiver's total single event equivalent sound level is:

$$L_{eqT} = L_{eqa} + 10 \cdot \log \left| 1 + I \right| \qquad \text{(E-32)}$$

The usefulness of Equations (E-28) through (E-32) is that the receiver's total noise exposure may be estimated in terms of an ambient level and an intruding level. Hence, by establishing a level difference between the ambient level, L_{eqa}, and the maximum value of the intruding time varying level, L_{max}, that results in an acceptable "masking" of the intruding sound, the corresponding values of the receiver SEL and L_{eqT} may be estimated. These values are criteria limits below which the intruding sound is not distinguishable above the ambient level. Unfortunately, however, there does not appear to be a recognized level difference $\Delta L = L_{eqa} - L_{max}$ to quantify "masking." As a rule-of-thumb, acoustical engineers may use 3 dB to 6 dB as deemed appropriate.

Figure E-3 presents an illustration of the combination of ambient sound level with the intruding single event sound level and the assumption used to define "masking."

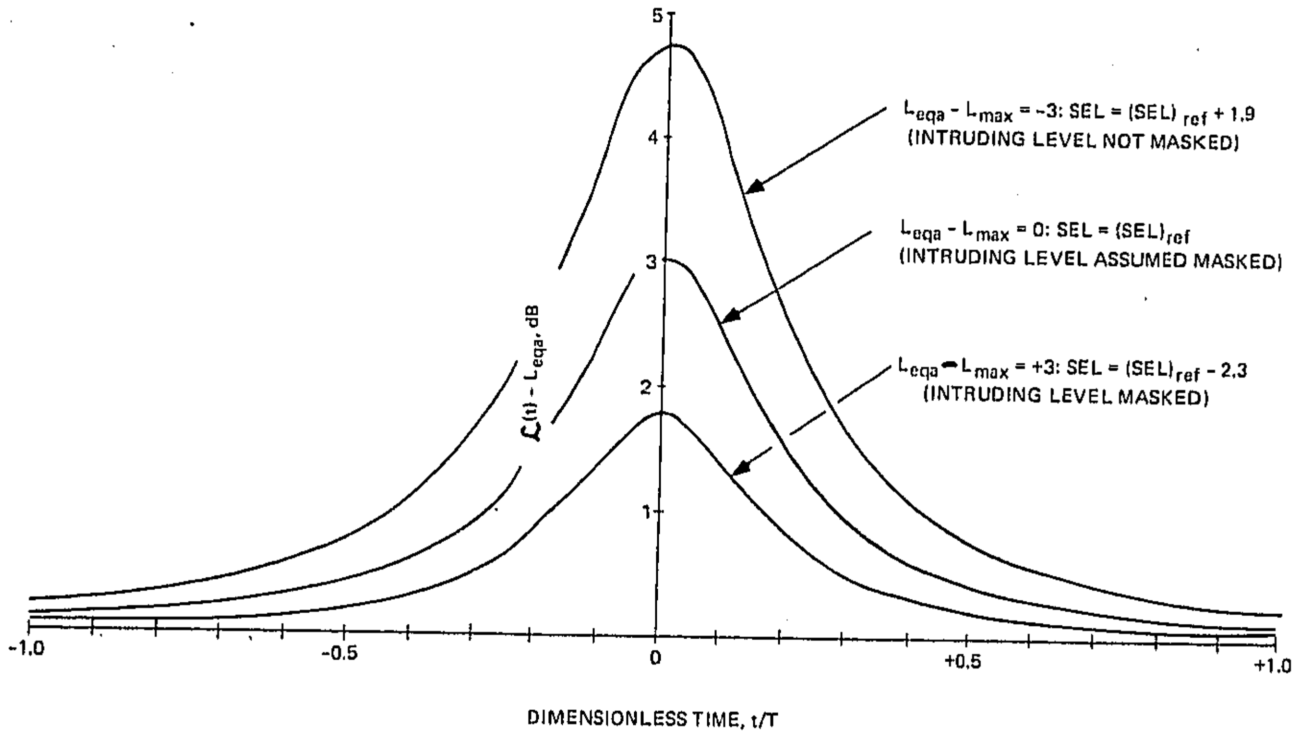


FIGURE E-3. COMBINATION OF SINGLE EVENT INTRUSION WITH AMBIENT SOUND

E.8 REFERENCES

APPENDIX E

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3. Rackl, R.,; Sutherland, L.; and Swing, J.: "Community Noise Countermeasures Cost-Effectiveness Analysis," Wyle Research Report WCR 75-2, Motor Vehicle Manufacturers Association, July 1975.

4. Wyvill, C. (Ed.): "Discussion of Sound Propagation," Technical Meeting, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, held at Crystal City, 14 October, 1977.

5. Barry, T.M. and Reagan, J.A.: "FHWA Highway Traffic Noise Prediction Model," U.S. Department of Transportation, Federal Highway Administration, Report FHWA-RD-77-108, December 1978.

APPENDIX F

SECONDARY NOISE EXPOSURE CALCULATION THEORY

F.1 Noise Exposure Calculation Scheme

In order to appreciate the noise impact methodology used by the National Roadway Traffic Noise Exposure Model, it must be remembered that the basic requirement for the simulation is the allocation of population to roadways. The Model distributes the nation's population and land area into 36 categories of constant population density. (The Model uses population and land area to define population density.) In each land area of constant population density, roadway mileage and traffic conditions are defined. Since the Model's data base recognizes only roadways within an inhabited land area, the total land area is prorated among the roadway mileage defined for the area. Based upon the roadway mileage and the allocated land area, the Model calculates a maximum width* for the strip of land adjacent to each roadway which is allowed to contain the population. Hence, the Model assigns a fraction of the total population and the total land area to each mile of roadway by roadway type and traffic condition. The allocation scheme places the total population adjacent to the total roadway mileage. The maximum width or distance away from the roadway is called the "cut-off" distance for purposes of discussion. The cut-off distance represents the limit in the noise exposure calculation scheme to ensure that the estimates do not represent a "double-counting" of the exposed population.

Everyone is aware that in a typical urban situation, a receiver at a given location is potentially exposed to several distinct roadway noise sources during a typical day. That is, a receiver may be living on a local street a few blocks from an interstate highway and although the maximum sound

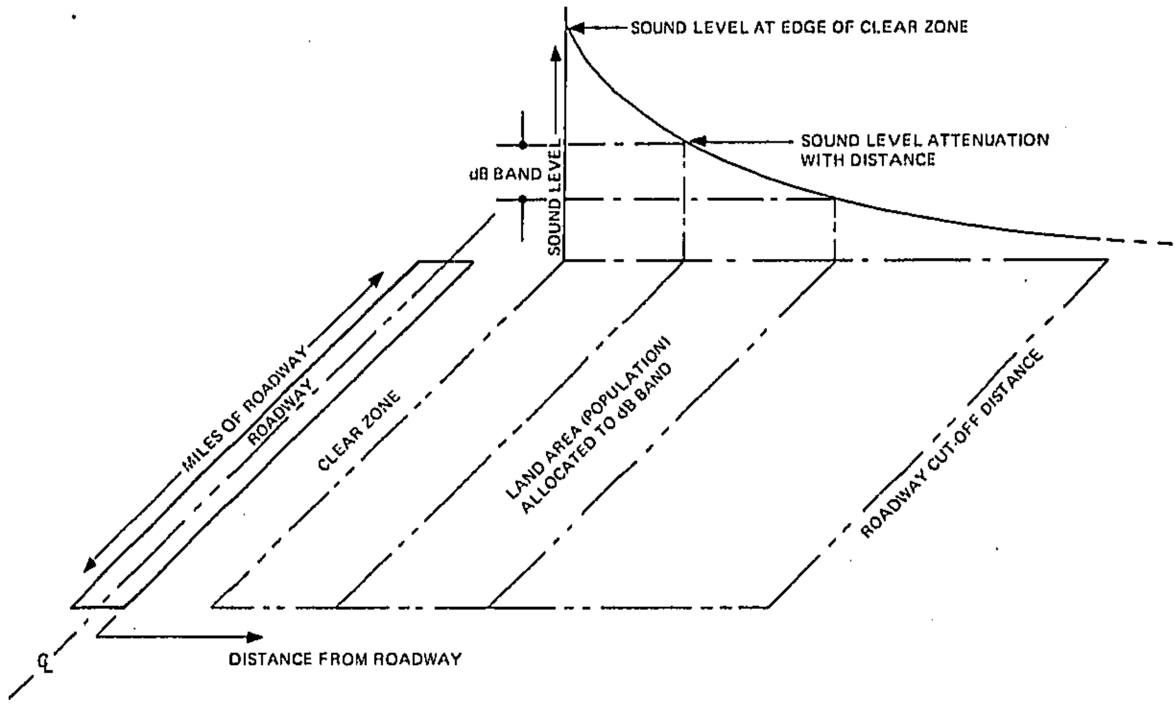
*This calculation is performed in the baseline year and remains constant throughout the time stream.

levels to which he is exposed may result from traffic on the local street, most of the long-term noise exposure may result from traffic on the interstate. The National Roadway Traffic Noise Exposure Model recognizes this aspect of the problem by classifying roadway traffic noise exposure into primary exposure and secondary exposure. Primary Noise Exposure is the noise exposure of the population assigned to a roadway generated by the traffic on that roadway. Secondary Noise Exposure is the noise exposure of the population assigned to a roadway generated by traffic on other roadways defined for the same population density land area.

The Model conducts a two-stage noise exposure calculation. The Primary Noise Exposure calculation is a deterministic scheme in that all parameters required for the calculation are defined for each mile of roadway. The Secondary Noise Exposure calculation is a probabilistic scheme since the relative alignment of all roadways in a land area and hence, the noise propagation distances, can only be defined in a random sense. By assigning cut-off distances to be used with the noise distance attenuation curves (Figure F-1), the Model insures that the Primary Noise Exposure calculation will not result in double-counting and that the Secondary Noise Exposure levels are not greater than the levels at the cut-off distance for the secondary roadway.

F.1.1 General Adverse Response Model

The General Adverse Response Model estimates the noise exposure of inhabitants by accumulating the population exposed to roadway traffic noise within discrete sound level intervals (dB bands). The population so exposed is assigned the sound level at the center of the band. The current version of the General Adverse Response Model uses 3 dB bands for the purpose of accumulating population noise exposure. However, the coded format allows other sound level intervals to be specified. For the primary exposure estimates, population noise exposure below the criteria limit of 55 dB is accumulated. The secondary noise exposure level for each dB band is estimated and the total noise exposure for the population in that band is calculated by adding the primary and secondary levels on an intensity basis.



NOTE: LAND AREA AND POPULATION IS UNIFORMLY DISTRIBUTED ON BOTH SIDES OF ROADWAY.

FIGURE F-1. ROADWAY TRAFFIC NOISE EXPOSURE OF LAND AREA

F.1.2 Single Event Model

The Single Event Model estimates the noise exposure of inhabitants by accumulating the population exposures within discrete sound level intervals or dB bands. Currently, the Single Event Model uses 5 dB bands for this estimation procedure. Since the Single Event Model must consider the population's activity and use appropriate Fractional Impact Criteria, the population defined for an area is first sorted into activity categories.

The pedestrian population is estimated and subtracted from the total population. Pedestrians are assumed to be located along the roadway used for the primary noise exposure estimate and hence, they are only exposed to primary roadway noise. For the remainder of the population, it is assumed that they are uniformly distributed over the inhabited area and are thus exposed to both primary roadway noise and secondary roadway noise. For indoor activities, the sound level estimates are attenuated to simulate building exterior skin noise reduction. For each activity category, the appropriate segment of the population is sorted into a "local" set of dB bands. The exposure level is assumed to be the center of the "local" dB band and the appropriate value for the Fractional Impact is used to estimate the value for the Level Weighted Population. Since this distribution of Level Weighted Population corresponds to a single event, each LWP value in the "local" or dB bands is multiplied by the number of identical events for each lane of roadway. These products of events times LWP are then sorted and accumulated into "global" dB bands as described in Section 2.7.

For the Single Event Model, the primary noise exposure estimate and the secondary noise exposure estimate are independent calculations. That is, an individual will be exposed to a distribution of single event noise levels both for vehicles on the primary roadway and vehicles on the secondary roadways. These exposure levels and their distribution are estimated based upon the mix of vehicles of the same type but with different noise emission characteristics, the various operating modes, and the distance variation due to lane separation. Of course, the single event estimates are conducted for both daytime and nighttime periods.

F.2 Secondary Noise Exposure: Overview

The Model simulates the multiple-source roadway traffic noise exposure of the population using a probabilistic approach. This approach for estimating secondary noise exposure was selected to simulate the randon orientation of roadways within an area and the resulting random propagation distances from one roadway noise source into land area assigned to another roadway.

As used by the Model, a roadway is more properly considered as a noise source. That is, a roadway is defined by its functional classification (e.g., interstate, collector, etc.) and by the traffic conditions on the roadway (e.g., ADT, vehicle mix, cruise speed, etc.). Hence, when considering multiple-sources in conducting the secondary exposure calculation, the Model uses all combinations of roadways on a paired basis. That is, each roadway is considered to be a primary roadway with its assigned population sorted into dB bands and all other roadways are considered, one at a time, to contribute secondary noise to the primary roadway.

The Model begins a secondary noise exposure calculation by selecting a primary roadway and a secondary roadway. The primary roadway defines the land area (population) exposed to levels of noise from the primary roadway. The secondary roadway is considered to be an additional noise source.

For the secondary roadway, the Model propagates the traffic noise generated by the secondary roadway beyond the cut-off distance of the secondary roadway. The land area exposed to secondary noise thus excludes the land area (population) assigned to the secondary roadway. This land area is subdivided into dB bands with the secondary exposure level assigned to the center of the dB band.

Considering all roadways to be randomly oriented within the total land area of constant population density, the probability of the secondary noise exposure level is estimated. This estimate is calculated as the ratio of the area of the dB band assigned to the secondary exposure level to the total land area assigned to the total roadway network. This probability represents the likelihood of the secondary noise exposure level occurring at any location in the total land area.

The Model then considers the intensity summation of the secondary noise exposure level with the primary noise exposure level (primary dB band). This summation defines the total noise exposure level. However, since the roadways are assumed to be randomly oriented, only a fraction of the population in the primary dB band will be exposed to the total level. This fraction of the population is calculated by multiplying the population in the primary dB band by the probability calculated for the secondary noise exposure level. The population exposed to the total noise level is subtracted from the population in the primary dB band and sorted into a dB band of total exposure.

The population exposed to the secondary single event levels are multiplied by the appropriate Fractional Impact values to estimate the LWP distribution for the secondary exposure. This LWP distribution is then multiplied by the number of identical single events estimated for the vehicle operating on the secondary roadway. Once this calculation is completed, the estimates are sorted and accumulated in the "global" set of dB bands as described in Section 2.7.

The Model continues the above scheme until all combinations of primary and secondary noise exposure have been considered that result in a total exposure level exceeding the cut-off criteria for the Fractional Impact Functions. The Model then selects the next combination of primary roadway population and secondary roadway noise exposure until all combinations have been considered. Finally, the Model sorts the remaining fractions of the original primary roadway population into the total noise exposure bands by considering the primary noise exposure levels to be total levels.

The above scheme is repeated for each of the roadway networks defined for the 36 areas of constant population density recognized by the

Model. The reader rocognizes that the dB band width used by the scheme has an extensive effect on the computing time required to conduct a simulation. It is estimated that the computing time varies inversely as the square of the ratio of two different band widths. For example, a simulation using 1dB bands would require approximately nine times the computing effort using 3dB bands. The reader must also recognize that these calculations are repeated for each year in the time stream that is specified by the user.

F.3 Secondary Noise Exposure: Theory

The theory used to calculate the secondary noise exposure is quite simple. The Model estimates the probability of a segment of the population being exosed simultaneously to a given primary level and a secondary level. Figure F-2 presents a plan view illustrating the conceptual geometric relationship between a primary roadway and a secondary roadway. The primary roadway variables are denoted by an Index, K. The secondary roadway variables are denoted by an Index, k.

For the primary roadway, the population exposed to noise generated by the primary roadway has been calculated with the population sorted into dB bands. Figure F-2 illustrates a dB band of primary noise exposure. The land area contained in the dB band is A_K, and the exposure level is L_K.

For the secondary roadway, a dB band of area A_k, at a secondary exposure level L_k, is determined by the Model based upon the traffic noise generated on the secondary roadway and the noise distance attenuation function assigned to the total land area, A. The total land area is also assigned a constant population density. As indicated in Figure F-2, the secondary dB band is estimated at a distance beyond the cut-off distance for the secondary roadway. Hence, the population assigned to the primary roadway cannot be exposed to a secondary noise level greater that the levels used for the population assigned to the secondary roadway.

It is assumed that all roadways within the total land area are randomly oriented with respect to each other. Since the total land area is

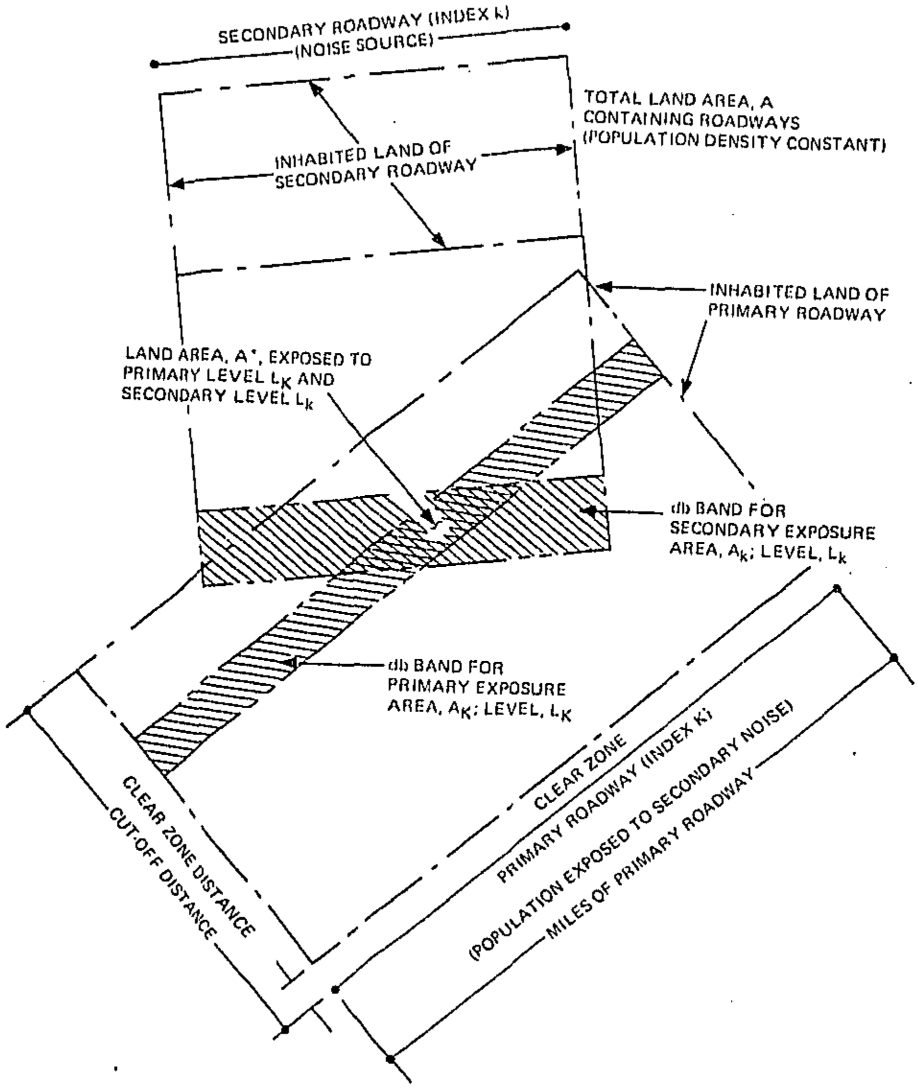


FIGURE F-2. LAND AREAS EXPOSED TO PRIMARY NOISE AND SECONDARY NOISE inhabited, it is assumed that the probability of being exposed to a secondary noise level, L_k, is equal to the ratio of the secondary dB band area, A_k, to the total land area, A. Hence, the probability of secondary noise exposure at a level L_k is:

$$\text{Probability of Secondary Exposure @ } L_k = A_k/A \tag{F-1}$$

This probability is assumed to be uniformly distributed over the total land area.

The population assigned to the primary exposure dB band of level L_K is simply the area of the band, A_K, times the population density. The population within the primary dB band simultaneously exposed to the primary level, L_K, and the secondary level, L_k, is the product of the population in the primary dB band times the probability of the secondary exposure given by Equation (F-1).

Hence, the population originally assigned to the primary land area is classified two ways: the population exposed to the primary level, L_K; and the population exposed to the secondary level, L_k. The results are:

$$\text{Population Exposed to Secondary Level} = \rho A_K A_k/A \tag{F-2}$$

$$\text{Population Exposed to Primary Level} = \rho A_K \tag{F-3}$$

where ρ is the population density
L_k is the secondary exposure level
L_K is the primary exposure level.

The Model repeats the caluclations for all primary exposure dB bands so that all of the population assigned to the primary roadway is sorted into dB bands of exposure. The calculations are continued so that all roadways are considered, on a paired basis, as primary and secondary roadways.

APPENDIX G
VEHICLE SURVIVABILITY

This appendix describes the procedures used to develop the vehicle survivability data used in the National Roadway Traffic Noise Exposure Model. These data are developed from national annual vehicle registrations for passenger cars and trucks.[1] As described in the main body of this report, the survivability data for passenger cars is assumed to apply to all light vehicles and motorcycles. The survivability data for trucks is assumed to apply to all trucks and bus categories recognized by the Model.

G.1 Basic Approach Used

The basic approach used to develop the vehicle survivability data was to estimate vehicle attrition with age and to define vehicles surviving in a future year as the original model year sales less the cumulative attrition up to that year.

The vehicle attrition was obtained in the form of a histogram of average percentage of model year vehicles retired for each year of age. The histogram data was used to develop continuous functions of age defining the percentage of model year vehicle retired. The methodology used to develop the continuous frequency functions or distributions is described in Reference 2. The distribution functions were integrated numerically to redistribute the vehicle attrition by age in the form of cumulative percentage of original vehicles retired from service. The probability of vehicles surviving with years was obtained by subtracting the percentage of vehicles retired from 100 percent.

For the purpose of this development, vehicle survival is defined as vehicles of a model year registering in a future year. Vehicle retirement is defined as vehicles of a model year failing to register in the next subsequent future year. That is, vehicle registration data is used as the basis of the analysis.

The rationale for developing continuous distributions, numerically integrating these to obtain cumulative distributions, and redistributing data into discrete distributions is based upon the form of the original data.[1] The original data defined vehicle registrations for only the first 14 years of age with all vehicles older than 14 years being grouped into one age category. Hence, the original data could not define either vehicle attrition or survival beyond 15 years of age. The methodology of Reference 2 is a procedure for statistically estimating distributions that may exceed the grouping limits of original data. Hence, it is possible to refine the estimates of vehicle survival beyond the 15 year limit of the original data base.

G.2 Average Vehicle Attrition With Age

The basic data used to estimate vehicle attrition are presented in Reference 1. The data are a tabulation of vehicles in operation by model year. Passenger car data are presented on page 38 of Reference 1 and truck data are presented on page 39 of Reference 1. Using these data, a tabulation of vehicles retiring at each year of age was constructed by subtracting the registration data in a subsequent year from the previous year's registration and assigning the difference to the previous year. Hence, the tabulation represented the number of vehicles of each model year that retired from service in a future year. Vehicle model years ranged from 1949 to 1972 and calendar years in which the vehicle registrations were available ranged from 1964 to 1975. One tabulation of vehicles retired was created for passenger cars and one tabulation of vehicles retired was created for trucks.

For all model years, the attrition values were summed, by year of age, to create a tabulation of vehicles retired by age. This tabulation was expressed as a percentage to obtain a histogram of percentage of total vehicles retired, averaged over model years 1949 to 1972. These results are presented in Table G-1 for passenger cars and for trucks.

TABLE G-1
PERCENTAGE OF VEHICLES RETIRING FROM USE
(Developed from Reference 2 Data)

Vehicle Age Years	Percentage of Passenger Cars Retiring from Use	Percentage of Trucks Retiring from Use
0 to 1	0.0	0.0
1 to 2	0.0	0.0
2 to 3	0.9153	2.1948
3 to 4	1.3407	3.5371
4 to 5	2.1669	3.6096
5 to 6	3.4338	4.6798
6 to 7	5.0187	5.3510
7 to 8	7.8321	5.9496
8 to 9	11.4302	7.6002
9 to 10	14.2467	9.2690
10 to 11	14.9022	9.7043
11 to 12	12.8231	10.1034
12 to 13	10.0404	10.1397
13 to 14	7.0934	9.4141
14 to 15	5.0509	9.3416
Over 15	3.7056	9.1058

TABLE G-2

CONTINUOUS DISTRIBTUION FUNCTIONS
(Percentage of Vehicles Retiring at Age X)

PASSENGER CAR RETIREMENT AT AGE X YEARS

$$p_1(X) = 13.9638 \left[1 - \left(\frac{X - 10.1536}{242.7623}\right)^2\right]^{14.1256}, \text{ percent}$$

$-5.43 < C < 25.74$

Mean Age = $\overline{X}$ = 10.1536 years.

TRUCK RETIREMENT AT AGE X YEARS

$$p_2(X) = 9.8012 \left[1 - \frac{(X - 10.4042)^2}{75.8744}\right]^{1.5322}, \text{ percent}$$

$1.694 < X < 19.11$

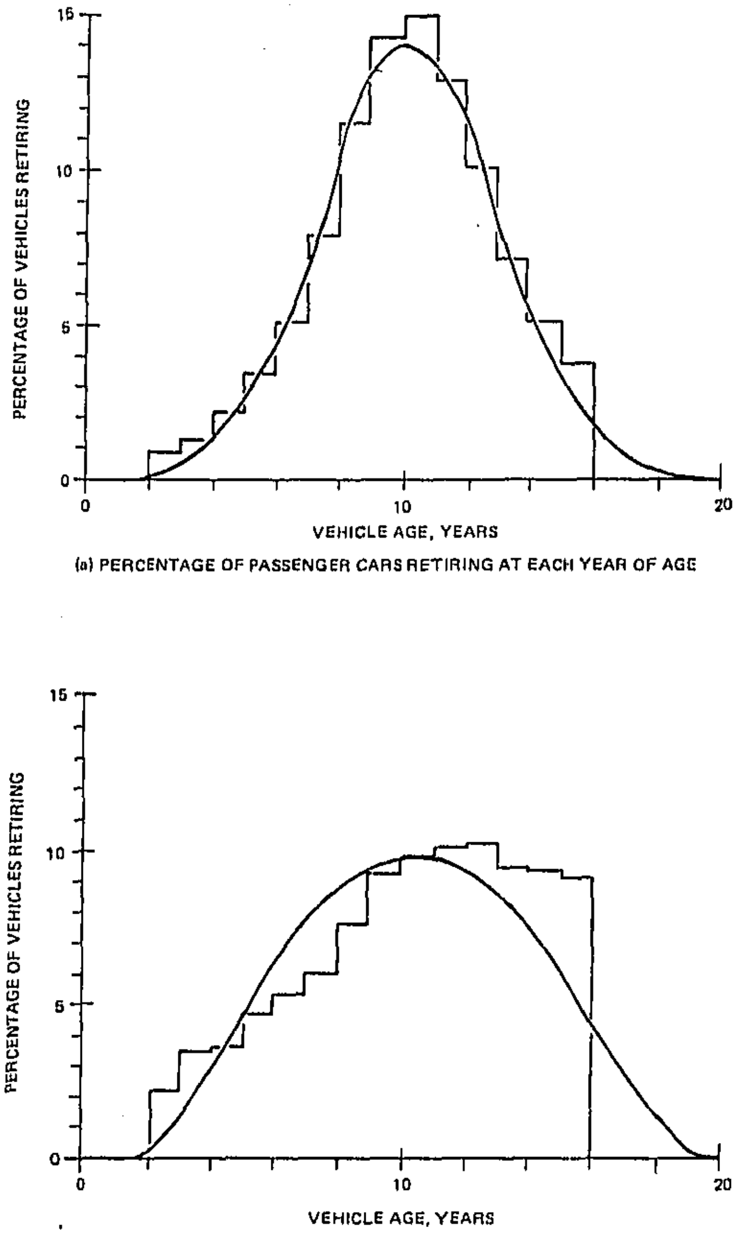
Mean Age = $\overline{X}$ = 10.4042

NOTES: Cumulative Percentage Retiring by Age X is

$$P_1(X) = \int_{-5.43}^{X} p_1(x)dx \quad \text{for Passenger Cars}$$

$$P_2(X) = \int_{1.694}^{X} p_2(x)dx \quad \text{for Trucks}$$

$$P_2(25.74) = P_2(19.11) = 100.00 \text{ percent}$$



(a) PERCENTAGE OF PASSENGER CARS RETIRING AT EACH YEAR OF AGE

(b) PERCENTAGE OF TRUCKS RETIRING AT EACH YEAR OF AGE

FIGURE G-1. FREQUENCY OF VEHICLE RETIREMENT WITH AGE: COMPARISON WITH HISTOGRAM DATA (TABLE G-1)

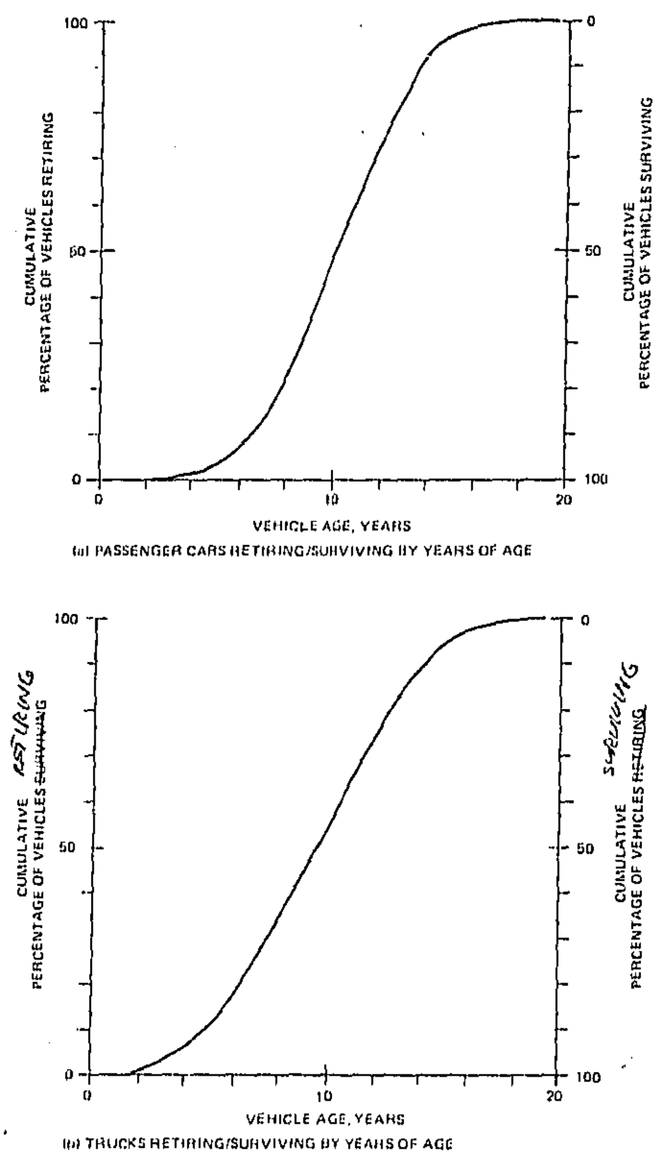


FIGURE G-2. PERCENTAGE OF VEHICLES RETIRING WITH AGE: CUMULATIVE DISTRIBUTION

TABLE G-3
PERCENTAGE OF VEHICLES SURVIVING AFTER X YEARS

Vehicle X Years	Percentage of Passenger Cars Surviving	Percentage of Trucks Surviving
Less than 1	100.00	100.00
1 to 2	99.98	100.00
2 to 3	99.90	99.98
3 to 4	99.60	99.27
4 to 5	98.77	97.11
5 to 6	96.83	93.29
6 to 7	93.07	87.83
7 to 8	86.77	80.89
8 to 9	77.56	72.72
9 to 10	65.70	63.64
10 to 11	52.14	54.02
11 to 12	38.34	44.24
12 to 13	25.83	34.69
13 to 14	15.75	25.76
14 to 15	8.57	17.80
15 to 16	4.10	11.13
16 to 17	1.68	5.98
17 to 18	0.57	2.48
18 to 19	0.00	0.62
19 to 20	0.00	0.13
20 to 21	0.00	0.13
Greater than 21	0.00	0.00

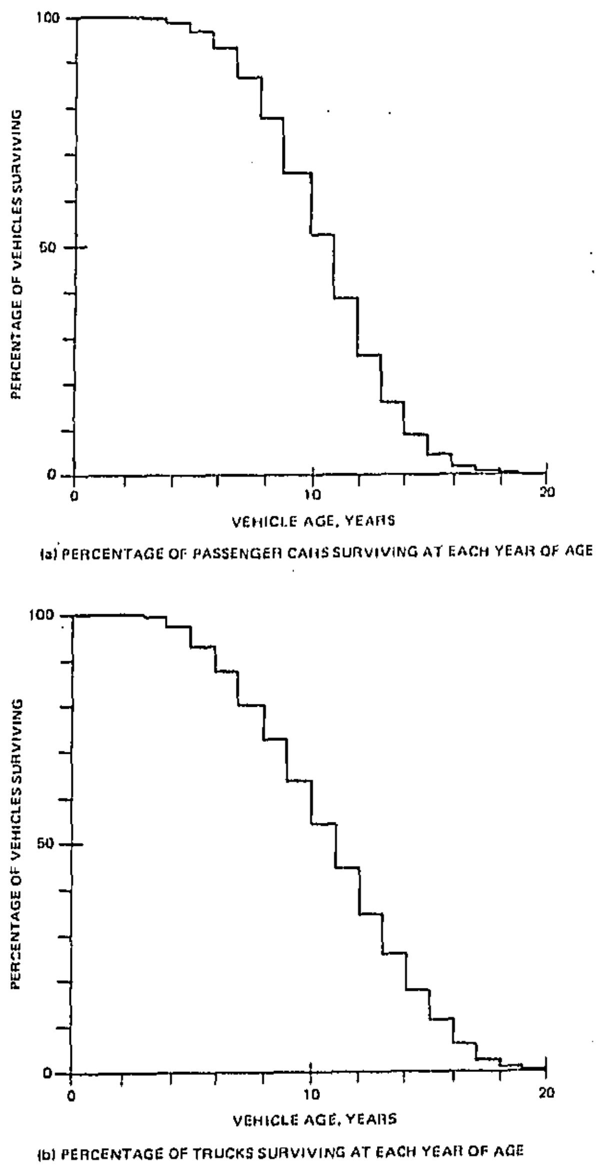


FIGURE G-3. VEHICLE SURVIVAL DATA USED BY THE NATIONAL ROADWAY TRAFFIC NOISE EXPOSURE MODEL

G.6 REFERENCES
APPENDIX G

1. Anon: "Motor Vehicle Facts and Figures, '76", Motor Vehicle Manufacturers Association of the United States, Inc., Detroit, Michigan.

2. Elderton, W.P., and N.L. Johnson, Systems of Frequency Curves, Cambridge University Press, 1969.