TRANSPORTATION NOISE: IMPACTS AND ANALYSIS TECHNIQUES

by

K. E. Nelson and T. D. Wolsko

ARGONNE NATIONAL LABORATORY

CENTER FOR ENVIRONMENTAL STUDIES

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On page 58, the last term of the first line of the equation should read:

$$+ 20(\log \text{SAUTOS}(i))$$

instead of $+ 30(\log \text{SAUTOS}(i))$.

In the computer listing on page 88, the last term in line 0190 should read:

$$+20.0*$$

instead of $+30.0*$.

Technical Information Services Dept.
June 26, 1974

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Key

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	5
1.0 THE URBAN NOISE PROBLEM	6
1.1 Introduction	6
1.2 Effects of Urban Noise	9
1.2.1 Economic Impacts	9
1.2.2 Physiological Impacts	11
1.2.3 Psychological Impacts	18
1.2.4 Societal Impacts	20
1.2.5 Task Interference	23
2.0 CHARACTERISTICS OF TRANSPORTATION NOISE	25
2.1 Introduction and Generation	25
2.2 Effects of Transportation Noise	28
2.2.1 Economic Impacts	28
2.2.2 Physiological and Psychological Impacts	29
2.3 Measurement	30
2.4 Control	32
3.0 HIGHWAY NOISE MODEL	40
3.1 Introduction	40
3.2 General Description	41
3.3 Application	47
3.3.1 Hypothetical Example	47
3.3.2 Discussion of Sample Problem Output	49
3.3.3 Application to Transportation Planning	52
APPENDIX A - Detailed Explanation of Predictive Noise Model	54
APPENDIX B - Glossary of Input Variables, Including Their Range for a Constant Segment	78
APPENDIX C - Computer Copy of Noise Model, User's Manual, and Data for Test Run	84
•Computer Copy of Noise Model	85
•User's Manual	100
•Data for Test Run	105
APPENDIX D - Aircraft Noise Exposure Contour Model	108
ACKNOWLEDGMENTS	113
REFERENCES	114

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1	Threshold shift for a particular noise exposure vs. time after noise exposure	14
2	Threshold shift for a particular noise exposure vs. duration of noise exposure	15
3	Percent of occurrence for different physiological problems for two different noise environments	16
4	Ambient noise levels vs. talker-listener distances	21
5	Relationship between community response and noise levels	22
6	General flowchart of Program ENOISE	42
7	Example of "infinite" element and related highway segments	43
8	Determination of noise levels	46
9	Design of hypothetical highway	48
10	Computer output with contour lines for hypothetical highway	50
11	Comparison of land use map and noise levels of hypothetical highway	51
A.1	Location variables	55
A.2	Illustrations of segment types	59
A.3	Adjustment to account for semi-infinite segment length	60
A.4	Adjustment to account for finite segment length	61
A.5	Example locations of segments	64
A.6	Attenuation by acoustic shields	68
A.7	Adjustment for elevated roadway	69
A.8	Adjustment for depressed roadway	71
A.9	Adjustment for roadside barrier	73
C.1	Physical structure of deck of Program ENOISE	104

LIST OF TABLES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1	Sales growth of selected home equipment: 1959-1970	7
2	Hearing loss by age	12
3	Sources of urban noise	26
4	Maximum noise levels for new vehicles	35
5	Maximum noise levels for operating vehicles	37
6	Design noise level/land use relationships	39
A.1	Classification of road surface as it relates to surface influence on vehicle noise	74
A.2	Adjustment for increased noise level of trucks on gradients	74

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ABSTRACT

The principal objective of this report is to present background information for, and to describe, computerized models that can be used by transportation engineers, planners, and environmentalists to assess the impacts of transportation noise problems generated by highway and airport facilities. The characteristics of transportation noise are discussed in terms of generation, effects and impacts, measurement, and control. The economic, physiological, psychological, and societal effects of urban noise are described in detail.

A computerized highway noise model, developed by K. E. Nelson of the Center for Environmental Studies, for the prediction of noise levels generated by proposed highways, is described and is accompanied by a user's manual and a discussion of its application to transportation planning. Also described is a computerized noise model for the prediction of noise impacts of airports, developed by H. B. Safeer of the U.S. Department of Transportation.

1.0 THE URBAN NOISE PROBLEM

1.1 INTRODUCTION

In recent years, urban dwellers have experienced increasing noise levels in their environment. This is due, in part, to the population growth in the cities and their surrounding metropolitan areas, a growth that is a result of both population expansion and urbanization. Within the urban areas, residents are acquiring increasing numbers of noise generating possessions, such as automobiles, air conditioners, and power lawn equipment. Examples of the sales growth of some selected home equipment are given in Table 1.^{1*} It has been estimated that over the past 30-year period, the noise levels in U.S. cities have risen 30 decibels.² This increase in ambient noise level indicates that urban noise today is approximately 8 times as loud as it was 30 years ago.

The possibility of escape from noise within an urban area is rapidly decreasing. Within the home, the noise generated by dishwashers, vacuum cleaners, and garbage disposers invades one's privacy. Outside the home, but within the residential area, the environment is adversely affected by the sounds of aircraft, surface vehicles, and construction equipment. Due to the abundance of recreational vehicles and pets and the high density of people, parks and open spaces within the urban areas are no longer able to serve as refuges from noise. In fact, the problem of noise pollution is spreading so rapidly that it is thoughtlessly being allowed to decay the natural environment of the national parks and wilderness areas.

Until the recent past, noise had been accepted by the urban dweller. People had been willing to accept the unknown effects of noise in exchange for better accessibility and, in some cases, for lower rent. Urban residents appear to have grown accustomed to high noise levels, as illustrated by the location of residential areas adjacent to high-volume urban expressways and rapid-transit lines. In the past, people had felt that noise was a small price to pay for progress. This attitude was due mainly to their

*Numbers above the line refer to publications listed in the Reference Section at the back of the report.

Table 1. SALES GROWTH OF SELECTED HOME EQUIPMENT: 1959-1970¹

<u>Item</u>	<u>Growth in Units/Year (Thousands)</u>	<u>Growth Rate Percent/Year</u>	<u>Years Required for Number of to Double</u>
Automatic Washers	142.2	4.2	17.1
Window Air Conditioners	406.4	14.3	5.0
Power Lawn Mowers	184.8	4.2	17.1
Central Air Conditioning Units	126.6	17.5	4.1
Garbage Disposers	117.5	9.9	7.3
Dishwashers	176.4	15.9	4.5

ignorance of many of the subtle costs of noise, such as its cumulative effect on hearing. Studies have found that in some cases people have equated noise with power, efficiency, and even social recognition.³

The public has recently grown aware of air, water, and, finally, noise pollution. This new awareness has brought defeat to planned highway facilities that local residents believed would have negative environmental impacts. One example of this type of defeat is the Riverfront Expressway proposed for New Orleans. The opponents of the expressway were extremely concerned with the effects the facility would have on the surrounding environment. The Vieux Carre Historic District Demonstration Study analyzed a number of the anticipated environmental effects, including those caused by noise, of the proposed expressway.⁴ The study predicted a significant increase in noise levels and other negative environmental impacts. The outcome was the defeat of the expressway, presumably due to the desire of local residents to retain the quality of their environment.

In the late 1960s, the seriousness of the situation aroused the interest of the U.S. Government. The Congress in 1969 passed the Environmental Policy Act, which requires careful consideration of environmental impacts that may be expected from any federally-sponsored program or project.⁵ In August of 1971, the Federal Highway Administration (FHWA) issued Policy and Procedure Memorandum (PPM) 90-1, which set forth guidelines for the implementation of the Environmental Policy Act.⁶ More recently, in February, 1973, FHWA issued PPM 90-2.⁷ This memorandum provides noise standards that are to be used in the design of new highways. In June, 1973, the Federal Register provided noise standards and procedures that codify the policies and procedures contained in PPM 90-2.⁸

It is important to realize that the problems associated with noise are very real today. Over 150 million people, or three-quarters of the population of the United States, are subjected daily to annoying noise levels in their home environments.⁹ Unfortunately, they cannot close their ears to noise pollution as they can their eyes to visual pollution. There appears to be no alternative to noise abatement for solving the noise pollution problem.

1.2 EFFECTS AND IMPACTS OF URBAN NOISE

1.2.1 Economic Impacts

Overall, the economic cost of domestic noise is in the billions-of-dollars range. We are faced with a vast multitude of noise sources, including all surface vehicles, construction equipment, and power equipment. Noise from aircraft alone would cost many billions of dollars to reduce to a satisfactory degree. Besides the direct economic effects of noise, i.e., hearing loss and lower property values, there are indirect effects to consider, such as personal injuries and even death resulting from accidents that are caused by noise-induced stress and fatigue.

The magnitude of the problem has generated considerable research on the various effects and impacts of noise. In 1968, an estimated 15 million people, or 4 million households, were subjected to undesirable aircraft noise levels. By 1978, approximately 24 million people, or 6 million households, will be exposed to the undesirable levels. One category of impacts that appears to take precedence is that of economics. In a study completed by the U.S. Environmental Protection Agency,¹⁰ three alternative methods were suggested for calculating the economic impact of aircraft noise.

The first method the U.S. EPA examined involved a cost estimate for an easement around all major airports in order to compensate the property owners for the reduced land values due to aircraft noise. Experience from past purchases of flyover easements indicates that the cost estimate for obtaining easements in undesirable areas adjacent to airports in the U.S. varies from \$4 to \$18.5 billion in 1968 and from \$6 to \$27.75 billion in 1978.

The second U.S. EPA measurement of the economic impact of aircraft noise is an estimate of litigation costs. This is a payment that is made to the property owner as directed by the courts to compensate for noise damages. The cost estimate is based upon the 4 million households affected in 1968 and an "out of court" settlement of 10% of the amount asked. The total cost is approximately \$7.5 billion, consisting of damage suits for inverse condemnation, personal injury, and property damage.

The final U.S. EPA alternative involves an estimate of the cost of aircraft noise abatement through the insulation of the source (aircraft) and/or the receiver (home) for all areas exposed to NEF (noise exposure forecast) level of 30 or above. The cost of insulation for 4 million households would be approximately \$10.7 to \$35.7 billion, while providing only indoor relief.¹¹ On the other hand, the insulation of the aircraft itself, through an engine retrofit program for all jet aircraft, would only cost approximately \$3.8 to \$5.7 billion.¹²

The Commission on the Third London Airport has developed a methodology for predicting the economic losses due to aircraft noise.¹³ Basically, a maximum acceptable noise level was established for each type of land use. Next, the noise levels that would be generated by the airport were predicted for the adjacent areas. Finally, the costs of reducing the predicted noise levels to the prescribed standards were estimated. The costs represented insulation, relocation, and decreases in revenue, to name but a few factors.

Most of the research conducted on the economic loss due to aircraft noise has been concerned with only the noise levels in and immediately adjacent to the home. The noise levels generated by aircraft have had negative economic effects on other parts of our society as well. The high noise levels have created poor learning conditions in many of the affected schools. In many instances, the quietness of parks and recreational areas have been all but destroyed by noise levels. Finally, the overall outdoor environment is deteriorating, affecting many activities, from barbecues to bandshell concerts. Although it is extremely difficult to assess the economic losses incurred by these activities due to noise, they nonetheless exist.

In 1967, the federal government spent \$35 million in compensation for noise-related disabilities.¹⁴ In 1971, the U.S. Federal Budget included \$40 million for noise pollution control.¹⁵ From the economic losses due to noise, which were discussed at the beginning of this chapter, and the yearly compensation made by the federal government for noise-induced injuries, it appears that the annual expenditure by the federal government for the control of noise pollution is far too little. But the consumer must also

be willing to contribute his share to noise pollution control. It has been estimated that the manufacturing of quieter products will increase the retail costs anywhere from 2 to 20%.¹⁶

1.2.2 Physiological Impacts

Another major area affected by noise may be classified as physiological. It has been demonstrated that high intensity noises have caused irreversible ear damage and produced other physiological changes in man.¹⁷ Most hearing loss has been due to the high noise levels associated with the industrial and manufacturing environment. Stating limits for the length of exposure for various noise levels for interstate industries, the Walsh-Healey Public Contracts Act was passed in 1971. Industry-related hearing losses have decreased as a consequence of the passage of this Act.

The effects of noise are cumulative; therefore, it is not only the level but also the duration and number of exposures to noise that must be considered. Some workers are exposed to dangerous noise levels not only while at work, but also while commuting to and from work, in their homes, and even during recreational activities. The effects of the exposures build up over months and years. Six to 16 million workers in the U.S. are exposed to conditions that are potentially hazardous to their hearing.¹⁸ Another 10 million, operators of heavy trucks, motorcycles, and gas-engine-powered recreational vehicles, are also exposed to excessive noise levels.¹⁹ As shown by Table 2, nearly 3 million people in the U.S. suffer from noise-associated hearing losses.²⁰ The hearing acuity of young people is being reduced well before normal expectation, due to their exposure to high noise levels such as loud music.²¹

Research studies indicate that noise has negative effects on the circulatory system of the body. Dr. G. Jansen concluded that:

blood circulation does not adapt to continuing exposure to noise by a return of blood flow to its initial level. Instead, peripheral blood flow continues to be reduced as a result of continuing vaso-constriction and increased resistance. This phenomenon was first observed at 60 to 70 decibels and as sound intensity increased, it became more pronounced.²²

Table 2. HEARING LOSS BY AGE²⁰

Age Range	Population Totals (in thousands)	Loss of Hearing Totals (thousands)	Noise-Associated Hearing loss (thousands)
0-5	17,000	850	?
5-10	20,000	1,000-1,400	*200
10-18	32,500	650- 975	**150
18-65	113,000	2,260	2,000 (Approx)
over 65	20,000	4,000	400-600
TOTALS	202,500	8,760-11,135	2,750-2,950

* Most common cause is explosions from toy caps

** Firearms and toy caps

A Russian scientist, N. N. Shatalov, found different effects for two types of noise.²³ A continuous noise resulted in "arterial tension, downward trend in venous pressure, reduced peripheral resistance, and Bradycardia." On the other hand, an intermittent noise caused "hypertension, rising arterial pressure, and frequent capillary spasms." Miss Alice Suter of the National Association of Hearing and Speech Agencies suggests a link between the effect noise has on the circulatory system and the loss of hearing due to noise exposure:²⁴

The process of vascular constriction keeps on going and does not adapt, and it also limits the blood supply to the ear. Lack of proper blood supply over the years would definitely be a contributing factor to old-age hearing loss. The internal auditory artery which leads to the ear is the smallest artery in the body, and it is probably quite apt to suffer vascular constriction.

Excessive exposure to noise was found to destroy hair cells in the inner ear, cause possible collapse or complete degeneration of the organ of Corti, and possible degeneration of auditory neurons.²⁵ None of these cells in the inner ear can regenerate; once they are gone, they are lost forever. Figure 1 presents the relationship between the threshold shift and the time after the noise exposure has ceased, given the intensity of the noise and the duration;²⁶ and Figure 2 presents the relationship between the permanent threshold shift and the duration of the exposure, given the intensity of the noise exposure.²⁷

When industrial and non-industrial workers were compared, the industrial workers were found to have experienced a 10 to 30% greater hearing loss.²⁸ Besides the hearing loss associated with noisy industries, a number of other physiological problems arise out of the noisy environment. In Figure 3, the percent of occurrence for different physiological problems in two different noise environments is compared.²⁹ It can be seen that the noisy industrial environment had a higher percentage of occurrence for each of the three physiological problems considered.

Various research studies have revealed other noise-related physiological problems. Noise is associated with colitis, migraine headaches, and nervous disorders.³⁰ Sudden and unexpected noises may produce

Figure 2. Threshold shift for a particular noise exposure vs. duration of noise exposure. ²⁷

Figure 3. Percent of occurrence for different physiological problems for two different noise environments²⁹

increases in blood pressure, pressure in the heart, heart and respiratory rates, and muscle contractions, as well as interference with digestive functions, such as decreases in bowel activity and the flow of saliva and other digestive juices.³¹ A steady noise at 90 dBA was found to increase tension in many of the muscles in the human body.³²

Although many of the findings that are cited here indicate real physiological effects of noise, not all researchers are convinced of the existence of any medical problems, besides hearing loss, associated with exposure to high noise levels. Because of disagreements among researchers as to the physiological effects of noise, a statement made by Dr. G. Jansen appears to be well worth considering at the present time: "Experimental work and field studies concerned with disease other than occupational deafness must assume -- until the contrary is proven -- that noise can be harmful."³³

Outside of the effects noise has on man, studies have been done on the effects of noise on wildlife. Loud noises were found to produce damaging effects to the ears of laboratory animals.³⁴ Rodents were able to successfully adapt to noise alone, but when presented with another stressful condition, noise may cause damaging effects.³⁵ High-frequency noises were found to be more stressful to the lab animals than low-frequency noises. Rats which were exposed to intense noise became untidy, less active, more aggressive, and less apt to eat.

Loud noises also affect the reproductive processes of certain lab animals, which could endanger whole species.³⁶ As with humans, noise interferes with animal communication, as in the nesting of young and the detection of prey. Animals which were exposed to very high noise levels demonstrated that noise may interfere with resistance to viral diseases, and could produce other pathological effects.³⁷

Overall, the noise levels produced by man are much lower than those used in laboratory experiments. Little data is available on the effects of noise on animals in the wild. The exposure level in the wild is probably too low to have any damaging effects.³⁸ Most of the experiments to date have not been well controlled. The handling of animals and other fears instilled in the laboratory have distorted the results somewhat.

It is doubtful that any of the effects of noise are beneficial to animals. Furthermore, it is possible that some of the effects may decrease their chance of survival.

1.2.3 Psychological Impacts

Although neither of the previous groups of effects of noise are easily measured, the psychological effects of noise are even more difficult to estimate. Once again, the fact that the effects of noise are cumulative plays an important role when considering the psychological effects. Basically, noise becomes a source of annoyance by disturbing sleep, rest, and relaxation. Parrach found a close relationship between the level of noise intensity and the expressed annoyance.³⁹ Annoyance was also found to be closely related to the degree to which the noise producer is concerned with minimizing the effects of the noise on the receiver.⁴⁰ D. C. Glass tested the tolerance of subjects to noises and found that tolerances dropped when the noises were unpredictable. When the subject was able to control the noise source, the frustrations were significantly reduced.⁴¹ People were found to have low tolerances for noisy activities that the person does not use or need.

Going beyond sleep interference as a result of noise, H. A. Denzel states:

We know that noise interferes with rest and relaxation, and especially with sleep. While sleep, the complete withdrawal from the world around us, is an obvious necessity for physical and emotional health, less complete withdrawal into the quiet of our homes may also be necessary if we want to retain individual integrity.⁴²

In a study on sleep interference, it was found that 90% of the subjects were awakened by a 60 dBA noise level. With a 40- to 45 dBA level, there was 10 to 20% probability of the subject's shifting sleep levels to a lighter stage of sleep.⁴³ When the noise conditions are severe enough to disturb sleep on a regular basis, it may lead to mental and physical health problems.

A number of comparisons were made on the basis of sex and age concerning the effects of noise on sleep.⁴⁴ Women's sleep was found to be

more easily disturbed than men's sleep; women awakened faster and shifted toward lighter stages of sleep more frequently. People over 60 years of age were much more easily awakened and shifted toward a lighter stage of sleep more readily than middle-aged people and children. Also, it was harder for people over 60 to return to sleep after being awakened. Finally, children were slightly less sensitive to sleep disturbances than middle-aged people.

Assuming that noise has negative psychological effects on a "normal" person, the effects on a disturbed or an emotionally upset person would probably be stronger. Dr. L. E. Farr states that:

in disease states such as anxieties, duodenal ulcers, and other so-called tension ills, the additive deleterious effects of noise are real and immediate. Any disease which may be associated with an emotional change requires as part of the therapy a calm, relaxed, quiet environment. This is particularly true of disturbed emotional states.⁴⁵

Today, the number of people suffering from "tension ills" is reaching a significant size. On the other hand, in today's urban areas, a quiet environment is becoming more and more difficult to find.

Generally speaking, the psychological effect of noise on the "normal" person is best described in the words of Dr. Leiber:⁴⁶

Any person who is exposed to a high noise level to which he is not accustomed will at first only suffer a mild discomfort, but after a time he will be subjected to changes of mood. Emotional response may become more extreme, and it is not uncommon to fly off the handle at the slightest provocation.

The stated effects of noise, i.e., loss of hearing and sleep, and annoyance, may lead to distress and anxiety, which may initiate other indirect psychological effects of noise such as instability and depression.

1.2.4 Societal Impacts

Besides the effects that noise has on individuals, it also affects man as a member of society. Depending upon the intensity, noise may interfere with speech and communication. Loud noises are capable of masking important sounds such as emergency signals. In Figure 4, a graph is used to illustrate the relationship between ambient noise levels and the distance between the talker and listener with respect to their ability to communicate.⁴⁷

Noise was found to interfere with a number of social functions. Activities such as those that take place at schools and churches must be located near to the majority of the people, and therefore in areas with relatively high, and rising, ambient noise levels. A study at the major airports in Los Angeles, Chicago, Dallas, and Denver found that 98.6% of those surveyed reported one or more disturbances by noise in their daily activities.⁴⁸

There appear to be a number of different levels of social reaction to noise. In residential areas, individuals battle among themselves over privacy rights as related to the noise levels generated by neighbors. On the next level, citizens band together in localized areas and press for regulation of noises through laws, ordinances, and standards. Finally, people from across the nation unite to fight major noise-generating projects such as the SST. In Figure 5, the relationship between the predicted community response and a variety of noise levels is presented.⁴⁹

Once permanent ear damage is caused by exposure to noise, it may make an individual harder to employ.⁵⁰ The hard-of-hearing person will definitely be eliminated from any employment possibility that requires good hearing. With equal intellectual levels, the hard-of-hearing individual, on the average, has a poorer job than an individual with normal hearing. This, in turn, leads to a lower socioeconomic level and possibly to a lower standard of living for the hard-of-hearing person. It may also have indirect effects on income and location, which may mean a poorer environment and education for the persons's children.

Another noise-related social research finding is that low-income people are less able to escape to a quieter environment because they are

Figure 4. Ambient noise levels vs. talker-listener distance⁴⁷

RESPONSEVIGOROUS
LEGAL ACTIONTHREATS OF
LEGAL ACTIONSTRONG
COMPLAINTSMILD
COMPLAINTSMILD
ANNOYANCE

NO ANNOYANCE

Figure 5. Relationship between community response and noise levels⁴⁹

economically disadvantaged. In a given area, these people are less able to control noise sources due to their small part and influence in the political process. Finally, living in the inner city, they are exposed to higher ambient noise levels. When the racial background of many of the poor people in major urban areas is considered, the problems involved in escape or control of noise become even more blatant.

The destructive overpressures in the form of sonic booms, which are generated by supersonic aircraft, constitute an additional type of societal impact caused by noise. In two American national parks, prehistoric cliff dwellings and natural sandstone formations have been destroyed by sonic booms.⁵¹ Structural damage to other structures and historical monuments by sonic booms has occurred and will doubtlessly occur again. By 1970, the total noise damage claimed by households had reached \$4 billion.⁵² According to the Department of the Interior,⁵³ sonic booms from supersonic transports could cause damage amounting to \$35 to \$80 million per year. Less conservative estimates have put the damage at \$160 million per year.⁵⁴

1.2.5 Task Interference

Task interference due to noise is another area of consideration. When a task requires an auditory signal, any noise that is intense enough to mask or interrupt the signal will interfere with the performance and completion of the task. A number of interesting conclusions can be drawn from a consideration of the effects of noise on performance.⁵⁵ A steady noise without any special meaning usually does not interfere with human performance, unless it is greater than 90 dBA. On the other hand, irregular bursts of noise were found to be more disruptive than steady noises, and may interfere with human performance at levels of less than 90 dBA. High frequency noise components (greater than 1000 to 2000 hertz) may produce more interference with task performance than low frequency components. Overall noise does not influence the rate of work, but high noise levels may increase the variability of work. Noise is more likely to reduce accuracy than to reduce the total quantity of work. Finally, complex tasks are more likely to be adversely affected by noise.

In a study of the effects of a 90 dBA noise level, it was found that work output remained constant, but errors in observation increased.⁵⁶

Judgments of time intervals became somewhat distorted and a greater effort was required to stay alert. Noise levels greater than 90 dBA caused increasing errors and a failure to notice unexpected events. And, even when noise does not affect task performance, fatigue after completion of the task may increase, and physiological and psychological capacities to react to other demands may be reduced.⁵⁷

2.0 CHARACTERISTICS OF TRANSPORTATION NOISE

2.1 INTRODUCTION AND GENERATION

Numerous studies have shown that road traffic is a main source of urban noise.⁵⁸ Community noise studies have found that traffic is one of the major causes of complaints of noise disturbances in the home.⁵⁹ Some of the many contributors to the urban noise problem are shown in Table 3.⁶⁰ As can be seen, surface vehicles and aircraft generate high noise levels within the urban environment. From 1950 to 1970, vehicular registration in the U.S. increased 122%.⁶¹ In the same period, the number of motor vehicle miles traveled per year in the U.S. increased 146%.⁶²

The increases in ownership and miles traveled is probably due to the growth of highways and suburban areas around large concentrations of population. In the future, these variables may be expected to increase. Larger concentrations of vehicles on highways may also be expected due to the channelization of vehicles, especially trucks, on a limited number of high-capacity urban highways.

Generally speaking, the noise generated by an automobile is composed equally of engine-exhaust noise and tire-roadway interaction noise.⁶³ Large diesel trucks, on the other hand, generate most of their noise through the engine-exhaust system and only minor noise through tire-roadway interaction. Because the exhaust pipe on an automobile is located closer to the road surface than that of a truck, the automobile noise source is thus lower. Besides the higher exhaust stacks on trucks, their engines are mounted higher, which also results in a higher noise source.

The noise generated by an automobile increases with speed because of the increasing revolutions of the engine and the increasing rotation of the tires. On the other hand, the noise generated by a truck is more independent of its speed. The near-constant noise output is due to two factors. First, the majority of the noise generated by a truck is made up of engine-exhaust noise. Second, because of the large selection of gears, a truck normally runs at a relatively constant engine speed.

Table 3: SOURCES OF URBAN NOISE⁶⁰
(Noise Levels Given in dBA)

dB(A) Ref.: 0.0002 μbar	SUBJECTIVE IMPRESSION	COMMUNITY (Outdoor)	HOME OR INDUSTRY (Indoor)	RELATIVE LOUDNESS (Human Judgment of Different Sound Levels)
130				
120	Uncomfortably Loud	Military Jet Aircraft Take-off With After- Burner From Aircraft Carrier @ 50 ft (130)	Oxygen Torch (121)	32 Times as Loud
110		Turbo-Fan Aircraft @ Take-off Power @ 200 ft (118)	Riveting Machine (110) Rock-N-Roll Band (108)- 114)	16 Times as Loud
100	Very Loud	Jet Flyover @ 1000 ft (103) Boeing 707, DC-8 @ 6080 ft Before Landing (106) Bell J-2A Helicopter @ 100 ft (100)		8 Times as Loud
90		Power Mower (96) Boeing 737, DC-9 @ 6080 ft Before Land- ing (97), Motorcycle @ 25 ft (90)	Newspaper Press (97)	4 Times as Loud
80		Car Wash @ 20 ft (89) Prop. Plane Flyover @ 1000 ft (88), Diesel Truck, 40 mph @ 30 ft (84), Diesel Train, 45 mph @ 100 ft (83)	Food Blender (88) Milling Machine (85) Garbage Disposal (80)	2 Times as Loud
70	Moderately Loud	High Urban Ambient Sound (80), Passenger Car, 65 mph @ 25 ft (77), Freeway @ 50 ft from Pavement Edge, 10 AM (76+6)	Living Room Music (76) TV-Audio, Vacuum Cleaner (70)	REFERENCE LOUDNESS 70 dBA
60		Air Conditioning Unit @ 100 ft (60)	Cash Register @ 10 ft (65-70), Electric Type- writer @ 10 ft (64) Dishwasher (Rinse) @ 10 ft (60) Conversation (60)	1/2 as Loud
50	Quiet	Large Transformers @ 100 ft (50)		1/4 as Loud
40		Bird Calls (44), Lower Urban Ambient Sound (40)		1/8 as Loud

Exhaust noise is the primary problem associated with the operation of cars and trucks; however, rapid acceleration, braking, and cornering can alter the order of importance. Exhaust noise is usually the dominant source in the case of truck operation, but if the truck engine is well muffled and has rough tires, tire noise can be the most significant source. Truck tire noise ranges from 80 to 93 dBA, while exhaust noise ranges from a minimum of 50 dBA for muffled trucks at 500 rpm to 108 dBA for unmuffled trucks at 2400 rpm. The large spread in the muffled noise data (20 dBA) is attributable to the wide variation in muffling practices for diesel trucks.

Tire noise levels vary widely, depending upon the type of tire and wear. In the case of automobiles, the difference between snow and regular tires can account for 10 dBA. Studded snow tires do not necessarily produce higher sound levels than non-studded snow tires. The variation of noise levels among truck tires is greater because of the heavier loads and the different tire designs. The noise differential between ribbed and retreaded (cross-hatched design) truck tires is on the order of 20 dBA.

Bus noise is a major problem in the cities where these vehicles are typically operated with a wide-open throttle as they accelerate. As a result, fan and engine noise are the dominant noise sources. Exhaust noise is generally not a problem because the design configuration of most buses usually provides enough space for a very large muffler. Moreover, urban buses tend to be operated at relatively low speeds, so that tire noise is usually low.

There are a number of other urban vehicles that generate high noise levels. Motorcycles, for example, generate a wide range of noise levels due to the extensive variation in muffling practices. Because of the small number of motorcycles within the vehicle population, they are considered as a point source rather than a line source of pollution. Also, until a standard muffling practice has been established for motorcycles, they may be considered as deviant vehicles to be dealt with through the established legal noise limits.

Commuter rail systems also generate high noise levels, but due to the low volume on each set of tracks and the limited number of right-of-ways, they are considered point sources that affect only the people living

adjacent to the right-of-way.

Fairly high noise levels are generated by aircraft, especially in the immediate vicinity of an airport. Currently, jet aircraft are being altered to reduce the noise levels. As with commuter rail systems, aircraft are a point-source problem, which poses as a major noise source only in the area adjacent to the airport. On the other hand, because arterials and other fairly high volume roads are dispersed throughout the metropolitan areas, road vehicles constitute a major noise source throughout the community.

2.2 EFFECTS OF TRANSPORTATION NOISE

2.2.1 Economic Impacts

D. C. Colony studied the economic effects of noise levels generated by an urban highway upon adjacent residential property.⁶⁴ In subdivisions that were developed after the highway had been constructed, the lots near the highway were found to sell slower than the interior lots. However, because the selling prices were not significantly different, Colony concluded that there was no permanent economic loss due to the proximity to the highway right-of-way. In subdivisions that were built before the construction of the highway, the properties within 50 feet of the highway right-of-way failed to increase in value at a rate similar to that exhibited by properties beyond the 50-foot band.

An investigation of the effects of highway noise on apartment rents was undertaken by Town and Associates.⁶⁵ The difference in rents between comparable apartments with different highway noise environments was small. This result is possibly due to the fact that people living in apartments are more mobile and therefore less concerned with their neighborhood and its environment.

Bartholomous studied the effects of noise generated by the Chicago Loop Elevated Rapid Transit facility on commercial property.⁶⁶ A land contour map of the Chicago Loop showed a clear correlation between the elevated structure and reduced commercial land values adjacent to the structure. Although the negative economic effects of the transit line are

obvious, Bartholomous found it difficult to isolate the impacts of noise from the impacts of other factors, such as dirt and odor, which decrease the surrounding land values. Still, he concluded that noise is a major factor affecting the value of floor area for second floor commercial establishments located adjacent to an elevated rapid transit line.

The cost of noise abatement through the purchase of a noise right-of-way along major freeways in the U.S. was estimated by the U.S. Environmental Protection Agency.⁶⁷ Approximately 2.1 million people would have to be relocated from an area approximately 400 square miles in size. The cost of the land and the relocation of the displaced families was estimated at \$3.9 billion, excluding the many indirect effects of the relocation program.

2.2.2 Physiological and Psychological Impacts

A Swedish traffic noise survey found a close correlation between symptoms such as headaches, insomnia and nervousness, and annoyance measures of the severity of exposure.⁶⁸ Based on a 24-hour average, when noise levels are over 50 dBA, the probability that people will be annoyed increases linearly with increasing noise levels. As previously stated, experiments by Janson found vaso-constriction and increased resistance of blood flow beginning at 60 dBA. It is interesting to note, at this point, that it is not unusual for a highway to generate a 60-dBA noise level as far as 3000 feet from the centerline of the road. Also, a 24-hour average noise level of 50 dBA is common in the immediate vicinity of a high-volume, urban expressway.

Another study introduced traffic noise while subjects slept.⁶⁹ The noise, which had an 80 dBA peak and an average level in the mid-sixties, increased the time between retiring and reaching a deep sleep from 7 to 26 minutes. Also, the sleep during the first half of the night was much lighter than normal, while it was slightly deeper during the second half of the night. Sleep was disturbed throughout the entire sleeping period. Finally, low density traffic noise was found to be more disturbing than high density traffic noise, due mainly to the degree of fluctuation of the noise level. Another traffic noise study found that traffic noise disturbs sleep, conversation, television watching, and radio listening.⁷⁰

Bolt, Beranek and Newman, Inc., showed that people are conscious of noise when making a judgment of a highway.⁷¹ Four major dimensions were identified that accounted for the majority of attributes for living near a highway. They are: (1) convenience to work, recreation and shopping (2) lights and general appearance; (3) intrusion, which includes noise, vibration and odor; and (4) the need for the facility relative to the number of automobiles in the area.

It is obvious that the effects of the noise generated by vehicles is an immediate problem. The cost of noise abatement in this area is extremely expensive. As described in this section, a noise right-of-way along the urban highways alone would cost approximately \$4 billion. What is required is a model by means of which future noise levels can be predicted while highways are still in the planning and design stages. The high cost of noise abatement can then be minimized for many new projects through proper design and location.

2.3 MEASUREMENT

Basically, there are two general categories of noise measurement. The first represents the results of human judgments of noise under laboratory conditions. Usually, this type of measurement cannot be made directly in the field. One example of this category is the Loudness Level (LL). This scale is determined by a jury test. The jury adjusts the noise level of a standard sound (a 1000 hertz (Hz) pure tone) until it sounds equally as loud as the test noise. Once the level has been adjusted, a loudness level in phons is assigned to the test noise. More recently, schemes have been developed for calculating the Loudness Level as a substitute for auditory comparisons by subjects.⁷²

A better-known member of this group of noise measurements is the Perceived Noise Level (PNL). Initially, measurements are made of the sound pressure level in decibels (dB), in each of the eight octave bands. Sound pressure level is defined as $20 \log_{10} (P/P_0)$, where P is the sound pressure in microbars and P_0 is an international standard pressure of 0.0002 microbars. If greater accuracy is required, a decibel measurement may be made in each of the 24 one-third octave bands.

Once the sound pressure levels are obtained, they are converted to NOYS, which is a subjective measure of annoyance. Through a combination of the NOYS levels in each of the octave bands, a total NOYS level is calculated, as follows:

$$\text{NOYS}_{\text{Total}} = 0.15 \sum \text{NOYS} + 0.85 \text{NOYS}_{\text{Maximum}}^*$$

The value of $\text{NOYS}_{\text{Total}}$ is then converted to the Perceived Noise Level (PNL) in decibels by means of a nomogram accompanying a dB-to-NOYS table.

The noise from various aircraft operations is described by a series of equal PNL values that form a contour. The contours are based on a large number of measurements of various types of aircraft, under various take-off and flying conditions. Finally, adjustments are made to the contours for the duration of the noise and for daytime versus nighttime operations in order to arrive at the Composite Noise Rating (CNR) value. The Composite Noise Rating is used to forecast noise levels generated by military air bases.

The Perceived Noise Level (PNL) may be converted to the Effective Perceived Noise Level (EPNL) through the use of corrections for the duration of the noise and for pure tones. The duration of the noise is the time interval in seconds during which the noise level is within 10 DBA of the maximum PNL. The correction for pure tone is tabulated according to the one-third octave band in which the tone lies, and the extent to which the tone level exceeds the mean level in the adjacent band. Given the EPNL, the Noise Exposure Forecast (NEF) may be found by adding the EPNL to a correction factor that gives added weight to night flights as opposed to day flights.

The second type of noise measurement may be made directly at the site with reasonably simple equipment. It requires no human judgment and may

*This formula applies to one-third octave bands. For octave bands, the constants .03 and .07 are used.

be read directly from a meter. The best known example of this group of measurements is the dBA scale, which is the sound pressure level in decibels (dB) measured by a sound level meter with an A frequency weighting network. The A weighting network is designed to be closely related to the sensitivity of the human ear. Emphasis is given to frequencies over 1000 Hz, as the human ear is more sensitive to higher frequencies. The A scale correlates well with the relative loudness or annoyance of many common urban sounds.

The dBA scale has its main application in the measurement of road traffic noise. Basically, there are two criteria to satisfy for the proper choice of a measurement scale for traffic noise. The first criteria is a high correlation between human judgments of the acceptability of a noise level and the value assigned to the noise level by a particular noise scale. Second, the ease of direct measurement in field observations is necessary. According to a study conducted by Bolt, Beranek and Newman, Inc., the dBA scale satisfies the two criteria best as a measure of road traffic noise.⁷³ Many of the noise standards, such as those of the City of Chicago and the Federal Highway Administration (PPM 90-2), are given in units of dBA.

2.4 CONTROL

Analysis and control of highway noise should logically begin by considering the noise generation of individual vehicles. Total highway noise is a function of individual vehicular emissions, and therefore the control of individual vehicle noise is one approach to highway noise abatement. If standards for quieter vehicles can be developed and enforced, they may help to achieve a more pleasant highway environment.

The assumption is normally made that all automobiles generate the same noise levels and that all trucks have common noise patterns. This assumption is not completely correct, for vehicles generating excessive amounts of noise are regularly observed in the traffic stream. It is likely that the psychological reaction to highway noise is strongly affected by such deviant vehicles. From the perspective of both noise emission standards and the control of noise deviants, it is relevant to consider the policy and legal framework of single-vehicle noise controls.

There are three opportunities for the control of individual vehicle noise: at the point of manufacture of new vehicles, in the maintenance of used vehicles, and in the operation of both new and used vehicles. The Society of Automotive Engineers suggest noise standards for new vehicles.⁷⁴ For passenger cars and light trucks that weigh less than 6000 lbs gv (gross vehicular weight), a maximum noise level of 86 dBA at 50 feet is suggested. For trucks and buses that weigh more than 6000 gv, a maximum noise level of 88 dBA at 50 feet is proposed. A methodology is discussed by S.A.E. concerning the proper site selection and testing procedures for the application of these standards.

With standards and testing procedures established, the next consideration becomes their adoption and enforcement. At the present time, the federal government has assumed no legislative control over the noise levels produced by individual surface motor vehicles.⁷⁵ Although standards on the noise levels generated by airplanes and industry have been established, none have been enacted concerning surface motor vehicles. In 1971, the President proposed a Noise Control Act, which would:

empower EPA to set standards limiting the noise-generation characteristics of construction and transportation equipment and other equipment powered by internal combustion engines. The standards would cover such major sources of noise as automobiles, trucks, motorcycles, compressors and off-road vehicles.

With federal noise standards in developmental stages, state and local governments are presently responsible for establishing and enforcing noise standards. In order to illustrate local ordinances concerning noise, the recently adopted noise standards of the City of Chicago will be discussed. The Chicago Urban Noise Study, completed by Bolt, Beranek and Newman, Inc., suggested changes in Chicago's noise ordinances.⁷⁶ Many of the changes were adopted by the City of Chicago on March 10, 1971.

The elements of the Chicago noise ordinances concerning motor vehicles deal with four major topics: (1) the limitations of operating a motor vehicle while the vehicle is standing, (2) the maximum noise limits related to different classes of new vehicles, (3) the maximum noise limits related to the operation of different classes of motor vehicles, and (4) the

modification of the exhaust system of any motor vehicle. Topics 2 and 3 are of special interest to the discussion at hand. Concerning topic 2, Article IV, Section 17-4.7(b) of the Municipal Code of Chicago states that:

no person shall sell, or offer for sale, a new motor vehicle that produces a maximum noise exceeding the following noise limits at a distance of 50 feet from the center line of travel under the procedures established by Section 17-4.24.

The established noise limits are given in Table 4.⁷⁷ The Municipal Code concludes the section by stating that:

the manufacturer, distributor, importer, or designated agent shall certify in writing to the Commissioner that his vehicles sold within the city comply with the provisions of the section.

This section of Chicago's noise ordinance is an excellent beginning to the control of noise produced by individual vehicles. First, it establishes categories for different types of vehicles. Second, it gives the maximum noise levels in dBA, which allows for objective evaluation. With noise standards in dBA, the enforcement officer can measure the noise emitted by a vehicle and compare it to the noise standards. Without objective noise standards, the enforcement officer is forced to make a subjective judgment on whether or not the vehicle emits "excessive or unusual" noise. Third, the maximum allowable noise levels are lowered at future dates, which forces the manufacturer to improve his product, while allowing time for new designs and technical innovations. The ordinance places the liability for failure to comply upon the agents responsible for manufacturing the new vehicle.

The third topic of Chicago's Noise Ordinance concerns the operation of all vehicles related to the noise levels generated by these vehicles. Article IV, Section 17-4.7(c) states that:

no person shall operate within the speed limits specified in this section either a motor vehicle or combination of vehicles of a type subject to registration at any time or under any condition of grade, load, acceleration, or deceleration in such manner as to exceed the following noise limit for the category of motor vehicle, based on distance of not less than 50 feet from the center line of travel under test procedures established by Section 7-4.25 of this chapter.

Table 4. MAXIMUM NOISE LEVELS FOR NEW VEHICLES⁷⁷

	<u>Type of Vehicle</u>	<u>Date of Manufacture</u>	<u>Noise Limit</u>
(1)	Motorcycle	before 1 Jan. 1970	92 dB(A)
	Same	after 1 Jan. 1970	88 dB(A)
	Same	after 1 Jan. 1973	86 dB(A)
	Same	after 1 Jan. 1975	84 dB(A)
	Same	after 1 Jan. 1980	75 dB(A)
(2)	Any motor vehicle with a gross vehicle weight of 8,000 pounds or more	after 1 Jan. 1968	88 dB(A)
	Same	after 1 Jan. 1973	86 dB(A)
	Same	after 1 Jan. 1975	84 dB(A)
	Same	after 1 Jan. 1980	75 dB(A)
(3)	Passenger cars, motor-driven cycle and any other motor vehicle	before 1 Jan. 1973	86 dB(A)
	Same	after 1 Jan. 1973	84 dB(A)
	Same	after 1 Jan. 1975	80 dB(A)
	Same	after 1 Jan. 1980	75 dB(A)

The noise limits related to this section are given in Table 5.⁷⁸ Once again, types of vehicles are given, speed classes established, and objectives limits set.

Although each of the sections discussed indicate a number of positive attributes, there are some drawbacks. First, a person can avoid the noise limits placed on a new vehicle simply by purchasing the vehicle outside the city. This evasion can be circumvented by setting statewide, or even nationwide, controls over the noise levels generated by new vehicles. Also, continuity must exist throughout different locations concerning the maximum allowable noise generated by operating vehicles.

Once noise ordinances have been adopted, methods of enforcement are required. The City of Chicago relies upon procedures that have been established by the Society of Automotive Engineers.⁷⁹ To test whether vehicles comply with Sections 17-4.7(b) and (c) of Chicago's Noise Ordinance, test facilities are required. Basically, there are three methods that can be applied to enforce noise ordinances: (1) spot checks, (2) permanent or temporary testing stations, and (3) response to specific complaints. In order to enforce the standards for new vehicles and for the operation of all vehicles, a complete testing system would require use of all three of the above methods. One of the main problems associated with this system would be the high cost. Also, it would be very difficult to enforce the complex S.A.E. standards at a temporary testing station. S.A.E. standards are quite stringent concerning the site requirements of a testing station,⁸⁰ making it difficult to find appropriate locations. Once the public recognizes the location of noise testing stations, the effective enforcement will probably decrease significantly. Overall, the enforcement of noise ordinances dealing with the individual vehicle is difficult, costly, and rather limited.

Even after noise ordinances and testing procedures have been established, the need for the control of the total noise levels generated by highway facilities and their utilization patterns must be met in the planning and design process. No matter how quiet individual vehicles are made, thousands of them using major urban highways during peak periods will undoubtedly generate high levels of ambient noise. Standards for the highways themselves must be set relating the noise levels generated by the

Table 5. MAXIMUM NOISE LEVELS FOR OPERATING VEHICLES.⁷⁸

<u>Type of Vehicle</u>	<u>Noise Limit in Relation To Posted Speed Limit</u>	
	<u>35 MPH or Less</u>	<u>Over 35 MPH</u>
(1) Any motor vehicle with a manufacturer's GVW rating of 8,000 lbs. or more, and any combina- tion of vehicles towed by such motor vehicle.		
before 1 Jan. 1973	88 dB(A)	90 dB(A)
after 1 Jan. 1973	86 dB(A)	90 dB(A)
(2) Any motorcycle other than a motor-driven cycle		
before 1 Jan. 1978	82 dB(A)	86 dB(A)
after 1 Jan. 1978	78 dB(A)	82 dB(A)
(3) Any other motor vehicle and any combination of motor vehicles towed by such motor vehicle		
after 1 Jan. 1970	76 dB(A)	82 dB(A)
after 1 Jan. 1978	70 dB(A)	79 dB(A)

facilities to the surrounding land use. The federal government has taken a step in this direction with the establishment of PPM 90-2.⁸¹ Table 6 shows the relationship between the design noise level and surrounding land use.⁸²

Control over the noise levels generated by highways may be obtained through location and design. The results of this control can be identified only through the use of a predictive noise model. With such a model, highway noise levels can be predicted and changes in them related to a change in highway design or location can be found.

Table 6. DESIGN NOISE LEVEL/LAND USE RELATIONSHIPS⁸²

<u>Land Use Category</u>	<u>Design Noise Level - L10</u>	<u>Description of Land Use Category</u>
A	60 dBA (Exterior)	Tracts of lands in which serenity and quite are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. Such areas could include amphitheaters, particular parks or portions of parks, or open spaces which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet.
B	70 dBA (Exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, picnic areas, recreation areas, playgrounds, active sports areas, and parks.
C	75 dBA (Exterior)	Developed lands, properties or activities not included in categories A and B above.
D	--	For requirements on undeveloped lands see paragraphs 5.a(5) and (6) of PPM 90-2.
E	55 dBA (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals and auditoriums.

3.0 HIGHWAY NOISE MODEL

3.1 INTRODUCTION

The development of the Highway Noise Model was begun in 1972 at Northwestern University⁸³ and completed at the Center for Environmental Studies early this year. The program ENOISE, used in conjunction with its thirteen subroutines, calculates the expected noise levels (in dBA) at determined distances from the highway, along the entire route of the facility. The inputs required by the model (see Appendix B) describe the traffic using the facility, the physical dimensions of the facility, and the aspects of the environment bordering the facility that have an effect on the noise levels. The model calculates the noise levels, making adjustments for the physical dimensions of the facility and the environment.

The relationships that are used in the model are a result of the work completed by Bolt, Beranek and Newman on a forecasting model for noise generated by highway facilities.^{84,85} The relationships they established provide the capability to predict noise levels at various perpendicular distances from the highway, as a function of traffic speed and volume, and the distance from the facility to where noise levels are predicted. The Bolt, Beranek and Newman study also provides information for making adjustments to the noise levels for such factors as highway elevation or depression, grades, surface type, structures, barriers, and landscaping. The model described here has been developed to incorporate the relationships established by Bolt, Beranek and Newman, Inc., in a computer system that does the routine computations necessary to produce a noise contour map for a specified area adjacent to the highway. A manual method has also been developed for use on a limited number of areas for which a predicted noise level is required.⁸⁶

Basically, the model requires characteristics of the highway segments as input. The characteristics include a description of the traffic using the highway (the speeds and volumes of both automobiles and trucks), the physical dimensions of the facility (the elevation, depression, grades and surface types), and the aspects of the environment bordering the facility that have an effect on the noise levels (the landscaping, structures, and

barriers). Fundamentally, the model calculates a noise level at a particular point along the highway and a perpendicular distance away from the highway. Once this noise level is calculated, the model moves outward an incremental distance away from the facility and calculates another noise level. This process is repeated until the model reaches a maximum prescribed distance away from the highway. At this point, the model moves farther down the highway and calculates another group of noise levels. This is repeated until the model has covered the entire length of the highway. The model prints out a contour map of noise levels at given distances from the facility over the entire length of the facility.

Since the research completed by Bolt, Beranek, and Newman represents the most recent and complete research on highway noise, it has been assumed that their findings were the most valid available. However, as future research is completed and new relationships are established, these can easily be incorporated in the model. In this chapter, the model will be explained in general terms. A detailed description of the model may be found in Appendix A. The assumptions and relationships that are briefly explained here are explained in much greater depth in Appendix A.

3.2 GENERAL DESCRIPTION

Initially, the program locates the point at which the first noise level will be calculated. This point is located at a given distance from the beginning of the highway and a given perpendicular distance from the highway centerline. The "infinite" element on the roadway relative to the given location is then defined.⁸⁷ This element is considered infinite as no other part of the highway outside of this element contributes a significant amount to the noise level at the given location (see Flowchart of Program in Figure 6).

With this completed, ENOISE searches through the input data to find the first segment of the highway that is located in the "infinite" element (see Figure 7). A segment is a length of highway for which all of the variables (see Appendix C) are constant. An adjustment is then made to the noise level for the length of this segment relative to the length of the "infinite" element. If the entire "infinite" element is included

Figure 6. General flowchart of Program ENOISE

Figure 7. Example of "infinite" element and related highway segments

within the first segment, the adjustment will be zero. On the other hand, a negative adjustment will result if the segment is shorter than the "infinite" element. This is due to the fact that the segment under study is only one of a number of segments that contributes to the total noise level generated by the "infinite" element.

The program ENOISE then calculates the "base" noise levels for both automobiles and trucks. This is considered a "base" noise level as it is a result of only the speeds and volumes of the automobiles and trucks, and the perpendicular distance away from the highway. The "base" noise level, as all other noise levels that are calculated throughout the program, are in units of dBA.

With the base noise levels calculated, adjustments are made for the noise level generated by automobiles for the prescribed point to the left of the highway. These adjustments are made for each side of the highway separately because their effects are different, depending on the side considered. The adjustments are calculated for an elevated or depressed facility, for the pavement type, and for barriers, structures, and landscaping on the left side of the highway. The elevation or depression of a highway structure decreases the noise levels generated by the facility (see Appendix A, Sections 2-B and 2-C). The pavement type may either increase or decrease the generated noise levels, depending on whether the pavement is rough or smooth (Appendix A, Section 2-E). Finally, the barriers, landscaping, and structures adjacent to the highway all have a decreasing effect on the noise level (Appendix A, Sections 2-D, 2-I, and 2-H). The fiftieth percentile subtotal noise level for automobiles is then calculated for the left side of the highway by adding the adjustments to the base noise level for automobiles. The fiftieth percentile noise level is that noise level that will be exceeded 50% of the time.

All of the above adjustments made for automobiles are made for trucks, including an adjustment that considers the grade of the highway, since highway grades have a significant effect on truck noise.⁸⁸ These adjustments are then added to the base noise level for trucks, which represents the fiftieth percentile subtotal noise level generated by trucks for the determined location on the left side of the highway. The subtotal noise

levels for automobiles and trucks are then combined, giving the total noise level generated by the first segment in the infinite element for the left side of the highway. This process is described in Figure 8.

ENOISE then repeats the same procedure to find the total noise level generated by the first segment for the defined location on the right side of the highway. The second segment in the infinite element is then located and its noise contributions to the points to the left and right sides of the highway calculated. These fiftieth percentile noise levels are then combined with the contribution of the first segment.

Finally, by repeating the above calculation, ENOISE combines the contributions of all the segments within the infinite element, thereby giving a total fiftieth percentile noise level for the defined points on the left and right sides of the highway.

With the first set of noise levels calculated, the model moves out to a new location along the highway and repeats the above steps to find another set of noise levels. The process is repeated until the model has moved out to a maximum prescribed distance. At this point, all of the noise levels calculated at a particular distance from the beginning of the highway are printed out in symbolic form.

The model then moves down the highway to a new, specified location. The fiftieth percentile noise levels at this point are calculated and printed. The model continues to move down the highway, calculating and printing noise levels at each point until the entire highway length has been covered. A listing of the program may be found in Appendix C.

Two options for estimating highway noise are available to the user of this model. The first allows the user to predict noise levels at various desired heights above ground level. This may be of special importance in an area that is composed of multi-story apartments and commercial structures. The second option allows the user to calculate the predicted noise levels in the fiftieth or tenth percentile noise levels. The tenth percentile noise level is that level that will be exceeded 10% of the time. The fiftieth percentile level is useful as it provides what may be termed the median noise level. On the other hand, the tenth percentile noise level will also be required as many of the applicable noise standards,

Figure 8. Determination of noise levels

including those established by FHWA and the City of Chicago, are written in terms of tenth percentile noise levels.

The output of the program consists of noise contours in symbolic form. This is extremely useful, as it permits the user to predict the noise levels generated by a facility of a particular location and design.

3.3 APPLICATION

3.3.1 Hypothetical Example

For successful planning of highway facilities, the noise levels predicted by the noise model must be used in conjunction with the land uses located adjacent to the highway. In order to demonstrate the use of the model, a hypothetical highway was designed.⁸⁹

Basically, the hypothetical highway is divided into four segments. The inputs concerning volume, speed, and some of the physical dimensions of the highway are constant over its entire length. The assumed volumes for automobiles and trucks are 6000 vph (vehicles per hour) and 1200 vph, respectively. The assigned speeds are 60 mph (miles per hour) for automobiles and 55 mph for trucks. The highway is a 6-lane facility, with a 200-foot right-of-way, 12-foot lanes, and a 20-foot median.

The first segment of the highway consists of an elevated structure 15 feet above the terrain (see Figure 9).⁹⁰ Three rows of structures are located on both sides of the segment at distances of 200, 350, and 500 feet from the center of the near lane. The segment contains a 3% gradient with a rough surface. The second segment is depressed 15 feet below the terrain. Two rows of landscaping at distances of 200 and 400 feet from the center of the near lane are located on both sides of the segment. This segment has a moderately rough surface with a 6% gradient. A 15-foot barrier, located 35 feet from the center of the near lane, exists along the entire length of both sides of the third segment. Three rows of structures are located 200, 350, and 500 feet from the center of the near lane on both sides of the segment. The segment has an 8% gradient with a smooth surface. The fourth segment runs at grade and has two rows of landscaping located 200 and 400 feet from the center of the near lane on

A) Side View

B) Top View

C) Cross Sectional Views

Figure 9. Design of hypothetical highway⁹⁰

both sides of the segment. The surface is moderately rough with a 4% gradient. Appendix C gives the inputs that were used for the noise model in describing the hypothetical highway.

3.3.2 Discussion of Sample Problem Output

A partial copy of the computer output for the sample problem is shown in Figure 10.⁹¹ As explained toward the end of Section 2.2, the user has the choice of predicting either L_{10} or L_{50} noise levels at any desired height above ground level. The output in Figure 10 is composed of L_{50} noise levels at a height of 0 feet above ground level. Also, noise contour lines have been graphically added to make the output easier to interpret.

A generalized version of the output of the noise model, with the location of the land uses adjacent to the highway, is given in Figure 11. Figure 11 is a summation of the computer output shown in Figure 10. As seen in Figures 10 and 11, segment 3, which contains a barrier, generates the lowest noise levels. Segment 2, which is depressed, generates noise levels approximately 5 dBA higher than those generated by segment 3. Theoretically, barriers and depressed structures have the same effect on noise levels. Therefore, the reason segment 2 generates higher noise levels than segment 3 is that the surface on segment 3 is smooth, while that on segment 2 is moderately rough. The elevated section of the highway (segment 1) generates lower noise levels near the highway than the section which is at grade (segment 4). As the distance from the highway increases, the noise levels generated by segment 1 surpass those generated by segment 4. This is due to a combination of two effects. First, an elevated structure tends to have its maximum effect in decreasing noise levels near the highway. As the distance from the highway increases, the effect of the elevated structure decreases. Second, the elevated structure has a rough surface, while the at-grade segment has a moderately rough surface.

After the noise levels have been predicted, the next requirement is a method for incorporating land uses adjacent to the facility for use in conjunction therewith. In Figure 11, a land use map has been appropriately

Figure 11. Comparison of land use map and noise levels of hypothetical highway

scaled, so that it may be used with the output in the form of an overlay. To the combination of noise levels and land use, the noise standards established by the U.S. Department of Transportation may be applied.⁹² As seen in Figure 11, all of the areas meet the standards except two strips of land along segments 1 and 4. Segment 1 could easily meet the standards if a smoother surface was applied, as its present surface is rough. There are a number of alternatives for decreasing the noise levels generated by segment 4. A smoother surface could be applied, the structure could be depressed, or barriers could be constructed. A number of runs of the model would be made, each run incorporating a different design alternative, and the effects of the alternatives on the generated noise levels would be demonstrated through the output. With the design costs at hand, the most economical alternative for meeting the standards would be chosen.

A number of advantages of using the highway noise model become apparent after the discussion of the hypothetical case. First, the model is extremely economical to run. The hypothetical highway was run six times for three different observation heights with an L_{10} and L_{50} level for each height at a computer cost of only \$12.00. Further, the required input variables are relatively easy to determine through the use of the highway design plans and aerial photographs of the area.

The model helps to reduce the costs of noise pollution by controlling noise before construction. The high cost of economic impacts and the difficulty of the control of noise after the completion of a facility may be avoided. Also, the unmeasurable costs of the many other effects and impacts may be eliminated.

3.3.3 Application to Transportation Planning

The hypothetical application discussed above demonstrates the use of the predictive noise model in transportation planning. Ideally, the noise model should be incorporated at two specific levels of the planning procedure. The first level is that of evaluating bands within a particular corridor. A band has a width of approximately 350 feet within the one-mile wide corridor. At this point in planning, only a limited amount of design information is known. Therefore, the noise model will be applied to a

simplified design, which contains a small number of segments. In this way, the output of the model will produce a simplified overview of the noise levels that may be expected. These noise levels may be compared to the noise standards established for particular land uses within and adjacent to the band under study, and the cost of meeting the noise standards through design may be estimated. After considering the noise generated by a facility located in each band and its impact on the surrounding land uses, the cost of the design in each band required to meet the noise standards may be compared. With these costs, the most economical band may be chosen relative to the noise levels generated and the adjacent land uses.

Once the band has been chosen, the location and design within the band must be established. At this point, more accurate noise levels may be predicted, based on the precise design characteristics of the proposed facility. By comparing the cost of right-of-way and design for various locations to the noise levels associated with particular land uses, the best location and design, relative to the noise generated by the facility and the adjacent land uses, may be chosen.

Overall, the predictive noise model allows the transportation planner to predict noise levels along the entire highway at any desired distances from the facility. Although some of the individual adjustments made to the noise levels have yet to be validated through field tests, the planner now has a fast, inexpensive method of predicting noise levels. The computer model was tested in Simi Valley, California, and the results were in agreement with the field data collected by the U.S. Environmental Protection Agency.⁹³ The combined use of the predicted noise levels and data on land use allows the planner to predict future noise levels relative to specific land uses. The model is currently as accurate as the research to date, and should be employed wherever possible. It is extremely important that the transportation planner now has the capability to predict future noise levels, for through the use of the model, many of the negative effects of highway noise can be eliminated.

APPENDIX A
DETAILED EXPLANATION OF PREDICTIVE NOISE MODEL

DETAILED EXPLANATION OF PREDICTIVE NOISE MODEL

In Section 3.0 entitled "Highway Noise Model," a general explanation of the model is given. In this Appendix, the program ENOISE and its related subroutines are explained in greater depth. This explanation is sufficiently detailed to provide future program users with the capability to update the model as new research on highway noise is completed. A detailed description of each of the required input variables and its range is given in Appendix B.

1. Main Program - ENOISE

The variable N represents the distance from the beginning of the highway to the point where the first set of noise levels is calculated (see Figure A.1).

Figure A.1: Location variables

At the option of the user, an increment for N is defined to determine the points along the highway where noise levels will be calculated. The increments in the input variables that affect noise outputs may be large for highways that have small or no changes over their length. An example of this

type of highway facility is one that connects two major cities and is located in a rural area. One would expect this type of highway to generate fairly constant noise levels over its entire route. On the other hand, an urban highway connecting the suburban areas of a city to the central business district will have frequent changes in the input variables that influence noise generation and propagation, thereby demanding that noise levels be sampled at more frequent intervals along its length. This type of facility would therefore require smaller increments of N .

The initial value of N is a function of NN , which is the perpendicular distance from the highway facility to the point where noise levels are calculated (see Figure A.1). A maximum NN is defined as the maximum distance from the highway for which ENOISE will calculate noise levels. Again, the user has the option of changing the maximum distance, depending on the type and location of the facility. The portion of the highway that contributes the total noise level to point A (see Figure A.1), a distance NN from the facility, is referred to as the "infinite" element. It has been found that the length of the "infinite" element is equal to $8NN$.⁹⁴ This element is considered infinite as no significant contributions are made to the noise level at A by the highway beyond the infinite element. Therefore, for the point A, a distance of NN from the highway and a distance of N from the beginning of the highway, the infinite element begins at $N-4NN$ and ends at $N+4NN$. With the relationship between NN and the length of the infinite element established, the initial value of N can be calculated, knowing the maximum value desired for NN . Referring again to Figure A.1, the initial value of N must be equal to or greater than four times the maximum value of NN . The user has the option at this point of selecting the increment to be used for NN . In an urban area, a fairly small increment would be desired, while in a rural area

this would not be necessary because of the low population density.

Once N and NN have been initialized and incremented, ENOISE calculates the beginning of the "infinite" element (NNN) and the end of the infinite element (NNNN) (see Fig. A.1). DOTCNL, which is set equal to NN, is the perpendicular distance from the point at which a noise level is calculated to the center of the near lane of the highway. A highway can be expected to have a large number of lanes (up to 12 or 14 in some cases) and in many instances, a median. Therefore, the difference in the noise contribution from the near and far lane may be significant, due to the difference in the distances from the point at which the noise level is calculated to the center of the near lane (DOTCNL) and to the center of the far lane (DOTCFL). In order to solve this problem, the concept of the "single-lane-equivalent" is introduced.⁹⁵ This is defined as the center line of an imaginary lane in which the total volume of traffic flow can occur to produce noise levels which are acoustically identical to the real, multiple lane situation. DOTCEL, the distance from the point at which the noise level is calculated to the equivalent lane of roadway, is defined as:

$$\text{DOTCEL} = (\text{DOTCNL} \cdot \text{DOTCFL})^{1/2}$$

Once this is completed, ENOISE searches through the input data to find the first segment i of the highway which is located within the "infinite" element under consideration. A segment of the highway is that length of the roadway for which all of the input variables may be considered constant. In Appendix B, the range for each input variable is given for which it is defined as constant. The first segment i located within the infinite element is found

by comparing ENDELE (i), which is the end of segment i, to NNN, which is the beginning of the infinite element, until an ENDELE (i) is found which is greater than NNN (see Fig. A.1). Once the required segment is found, ENOISE calculates an adjustment related to the length of segment i. If segment i is infinite, that is, if the entire infinite element is located within segment i, the adjustment (ADJELE) is equal to 0 (see Fig. A.2a). If segment i is not infinite, then it is defined as either semi-infinite or finite.⁹⁶ A finite segment is one which both begins and ends within the infinite element (see Fig. A.2b). A semi-infinite segment either begins before the infinite element and ends within it or begins within the infinite element and ends beyond it (see Fig. A.2c). The relationships that are contained in ENOISE for finding the necessary adjustments for a semi-infinite or finite segment are shown in Figs. A.3 and A.4.⁹⁷

Once ADJELE has been calculated, ENOISE calculates a "base" noise level for automobiles for segment i using the following equation:⁹⁸

$$\begin{aligned} L50AUT = & 10(\log VAUTOS(i)) - 15(\log DOTCEL) + 30(\log SAUTOS(i)) \\ & + 10(\log \tanh(1.19 \times 10^{-3} (\frac{VAUTOS(i)}{SAUTOS(i)} \cdot DOTCEL))) + 29 \text{ dBA} \end{aligned}$$

This is referred to as the "base" noise level for automobiles (L50AUT) as it only considers the speed (SAUTOS) and volume (VAUTOS) of automobiles, and the equivalent distance from the highway (DOTCEL). An explanation of these variables may be found in Appendix B. TANH is the hyperbolic tangent term which adjusts the line source representation to account for discrepancies between the lumped and distributed sources.⁹⁹ This effect is important for low densities (small values of VAUTOS) and/or small values of DOTCEL. As those variables become large, TANH approaches one and the logarithm of TANH becomes 0. The "Base" noise level for trucks (L50TCK) for segment i is found by using the following relationship:¹⁰⁰

a.) Infinite segment

b.) Finite segment

c.) Semi-Infinite segment

Figure A.2: Illustrations of segment types

a.) Determination of angle

b.) Determination of adjustment⁹⁷

Figure A.3: Adjustment to account for semi-infinite segment length

a.) Determination of angle

b.) Determination of adjustment⁹⁷

Figure A.4: Adjustment to account for finite segment length

$$L50TCK = 10(\log VTRUCK(i)) - 10(\log STRUCK(i)) - 15(\log DOTCEL) \\ + 10(\log \tanh(1.19 \times 10^{-3} (\frac{VTRUCK(i) \cdot DOTCEL}{STRUCK(i)}))) + 95 \text{ dBA}$$

This relationship includes only the speed (STRUCK) and volume (VTRUCK) of trucks, and the equivalent distance from the highway (DOTCEL).

L50AUT AND L50TCK represent the fiftieth noise percentile noise levels measured in dBA for automobiles and trucks. A fiftieth percentile noise level means that the calculated level may be expected to be exceeded 50% of the time.

Once the base noise levels have been calculated, ENOISE calls upon a number of subroutines to make adjustments for the noise level generated by automobiles calculated at points to the left of the highway. The base noise levels apply to points on both sides of the highway, because the variables are the same for either side of the highway. On the other hand, some of the input variables, such as barriers and landscaping, have an effect on one side of the highway and not on the other. There are also input variables, such as elevation, which may have a different effect for each side of the facility. Therefore, for these types of variables, each side of the highway must be dealt with separately. The subroutines ENOISE calls calculates adjustments for the elevation or depression of the facility, the type of pavement surface on the roadway and the barriers, landscaping, and structures on the left side of the highway. Once the adjustments have been calculated, the fiftieth percentile noise level in dBA generated by automobiles on segment i (L50ATL) for the left side of the highway is found. L50ATL is calculated by adding the above adjustments found through the use of the subroutines to the base noise level for automobiles.

ENOISE then calculates L50TRL, which is the fiftieth percentile noise level measured in dBA generated by trucks on segment i for the left side of the highway. The adjustments made for trucks include all of the adjustments made for automobiles, plus an additional one which considers the effect of the gradient of the highway. The gradient has a significant effect on the noise level generated by trucks while it has little influence on the noise generated by automobiles.¹⁰¹ ENOISE then computes a subtotal noise level (L50SSL) which is a combination of the noise levels generated by automobiles and trucks on segment i for points to the left of the highway.¹⁰² The method used for addition consists of first finding the difference between the two noise levels to be added, and depending upon the size of the difference, increasing the higher noise level to represent the summation.

Once this process is completed, the above steps are repeated to find the noise levels generated for points to the right of the highway. L50ATR and L50TRR are the 50% noise levels for automobiles and trucks generated by segment i for the right side of the highway. The adjustments for automobiles are then found for points on the right side of the highway. L50ATR is found by adding these adjustments to the "base" noise level. The proper adjustments for trucks are made and used in conjunction with the "base" noise level to calculate L50TRR. Finally, the subtotal noise level for the right side of the highway (L50SSR) is computed by adding the noise levels generated by automobiles (L50ATR) and trucks (L50TRR) for the right side of the highway.

Upon calculating the subtotal noise levels generated by segment i for both sides of the highway, ENDELE (i) is compared to NNNN. If ENDELE (i), which is the end of segment i , is not greater than NNNN, i is incremented by 1, and the entire process is repeated for segment $i + 1$ (see Fig. A.5). The subtotal noise levels generated by segment $i + 1$ for both sides of the highway are found. The sets of subtotal noise levels generated by segments i and $i + 1$ are then added, and a new set of subtotal noise levels (L50STL and L50STR) are found. ENDELE ($i + 1$) is now compared to NNNN. If ENDELE ($i + 1$) is found to be less than NNNN (as it is in Fig. A.5), $i + 1$ is incremented to $i + 2$, and the contribution of segment $i + 2$ within the infinite element (which begins at NNN and

Figure A.5: Example locations of segments

ends at NNNN in Fig. A.5) is found. Finally, the subtotal noise levels generated by segment $i + 2$ are added to the previous subtotals to arrive at new values for L50STL and L50STR.

Finally, when segment $i + n$ is reached for which ENDELE ($i + n$) is greater than or equal to NNNN (see Fig. A.5), all of the segments within the "infinite" element have been considered. Therefore, L50STL and L50STR represent the total noise level for the left and right sides of the roadway generated by the entire length of the infinite element. L50STL is then set equal to L50TOL (ii) and L50STR to L50TOR (ii). These levels, L50TOL (ii) and L50TOR (ii), represent the total noise levels at a distance N feet from the beginning of the highway and NN feet to the left and right of the highway.

With this completed, NN is incremented. The entire process described above is then repeated and L50TOL (ii + 1) and L50TOR (ii + 1) are calculated. ENOISE continues through the above operations, each time incrementing NN and comparing NN to the defined maximum value of NN. When NN is equal to or greater than the maximum value, the program is transferred to subroutine PRINT in order to print all of the noise levels calculated at a distance N from the beginning of the highway for both the left and right sides of the facility.

With one complete set of noise levels calculated and printed, ENOISE returns to the beginning of the program where N is incremented. The program then calculates and prints another set of noise levels at this point along the highway, and once again increments N. Each time N is incremented, it is compared to NROAD. NROAD represents the point along the highway for which the user wishes to end calculations. Once N is equal to or greater than NROAD, ENOISE is terminated. The previous discussion on the relationship between N and NN is also applicable to NROAD and the end of the highway for which information is given in the input data. The user must make certain that information is given for the highway for a distance of at least $4NN$ beyond the point NROAD.

2. Subroutines

2.1 General Comments

The subroutines, which are used to calculate an adjustment to the noise level for a depressed or elevated structure, and for barriers, structures, and landscaping on either side of the highway, are specific to a particular side of the highway. In other words, each of these possibilities demands two subroutines: one for the left side of the facility and one for the right. On the other hand, the adjustments made for the type of surface and the gradient of the highway are applicable to both sides of the highway.

The subroutines concerned with elevation and depression are applicable only to automobiles, while those calculating adjustments for barriers, surface type, structures, and landscaping apply to both automobiles and trucks. The adjustment made for the gradient of the facility, on the other hand, applies only to trucks.¹⁰¹ This does not imply that there are no adjustments made to the noise levels generated by trucks for elevation and depression. These adjustments are made in the main program ENOISE and have been set equal to the respective adjustments made for automobiles plus 5 dBA due to the higher location of truck noise source.¹⁰³

2.2 ELEL and ELER (Elevated Structure)

The subroutines ELEL and ELER determine the adjustments necessary to the noise levels for the left and right side of the highway for an elevated structure. Basically, the forms of ELEL and ELER are identical. The only difference is that a "side-specific" set of data is required for the input variables of each subroutine. The variables required for both subroutines are discussed in Appendix B. Because of the similarity between the subroutines, only ELEL will be discussed.

The relationships that are used in ELEL are a result of the research completed by Maekawa on the performance of semi-infinite acoustic shields.¹⁰⁴ However, his model applies only to a single source-receiver distance. Maekawa's findings were later extended by Galloway for application to highway design.¹⁰⁵ Galloway performed measurements of noise produced by traffic under conditions of elevated and depressed facilities. From these measurements, Galloway modified Maekawa's curves to make them linear (see Fig. A.6).¹⁰⁶ Through the use of Galloway's linearized designed curves under the following assumptions, Bolt, Beranek and Newman derived a set of curves that are used to calculate the adjustments required for elevated and depressed facilities and for barriers. The four assumptions are:¹⁰⁷

- 1) "The design curve is applicable to a lane of vehicles (line source) as well as to a single vehicle (point source).
- 2) All traffic can be assumed concentrated on a single lane whose position is that of the single-lane equivalent...
- 3) The effective wavelength of traffic noise is about 2 to 3 feet.
- 4) Automobile noise sources are located on or close to the road surface. The effective location of truck noise sources is somewhere between the road surface and the exhaust stack exits."

The set of curves derived by Bolt, Beranek and Newman for making adjustments for an elevated structure is shown in Fig. A.7.¹⁰⁸ The curves shown here were then transformed into equations and incorporated into ELEL.

DOTSLR, the distance from the point where the noise level is required to the vertical cut on the left shoulder of the elevated highway, and ELEVAL, which is equal to $(\text{HEIGHT})^2 / (\text{DOTCEL} - \text{DOTSLR})$, are the first variables calculated in ELEL. The physical representation of these variables is given in Fig. A.7. Once ELEVAL has been computed, the subroutine locates the proper relationship between $(\text{HEIGHT})^2 / \text{DOTSLR}$ and the adjustment in dRA (see Fig. A.7). HEIGHT is the

Figure A.6: Attenuation by acoustic shields¹⁰⁶

Figure A.7: Adjustment for elevated roadway¹⁰⁸

elevation of the highway in feet. From there, ELEL calculates the value of $(\text{HEIGHT})^2/\text{DOTSLR}$, locates its intersection with the appropriate relationship, and finds the proper adjustment.

2.3 DEPL and DEPR (Depressed structure)

The subroutines DEPL and DEPR determine the adjustments to the noise levels for the left and right sides of the highway due to a depressed structure. Once again, the forms of DEPL and DEPR are identical, with the exception of the required variables which are specific to a particular side of the highway. An explanation of the input variables required for each subroutine is given in Appendix B.

The relationships derived by Bolt, Beranek and Newman for a depressed structure are the result of the previously discussed work by Galloway. The final set of curves used for calculating adjustments for a depressed highway are shown in Fig. A.8.¹⁰⁹ These curves were then converted into equations and used in subroutines DEPL and DEPR.

Initially, DEPL calculates DOTCRL, which is the distance from the point where the noise level is to be calculated to the vertical cut on the left side of the depressed facility, and DEPREL, which is equal to $(\text{DEPTH})^2/\text{DOTCRL}$. DEPTH is the depression of the highway in feet. The physical representations of the above variables may be found in Fig. A.8. Once this has been completed, the proper relationship between the adjustment in dBA and $(\text{DEPTH})^2/(\text{DOTCEL} - \text{DOTCRL})$ is found, the intersection point with the proper relationship is located, and the appropriate adjustment for the depressed facility is returned to the main program.

Figure A.8: Adjustment for depressed roadway¹⁰⁹

2.4 BARL and BARR (Barrier along highway)

The subroutines BARL and BARR calculate the adjustments for the left and right sides of the roadway produced by a roadside barrier. Due to the similarity between the subroutines, only BARL will be discussed. The input variables required for each subroutine are discussed in Appendix B.

The relationships found by Bolt, Beranek and Newman for barriers (see Fig. A.9) are a result of Galloway's study.¹⁰⁹ The relationships were transformed into equations and then incorporated into the subroutines. The barriers that are considered here are solid, acoustically opaque ones. The relationships derived by Bolt, Beranek and Newman for finding the decrease in noise level due to barriers are based on the four assumptions previously stated.

The subroutine BARL first calculates DTBARL, which is the distance from the point at which the noise level is desired to the barrier, and BARRIL, which is equal to $(HTBARL)^2/DTBARL$ (see Fig. A.9). HTBARL is the height of the barrier relative to the terrain in feet. DTBARL then finds the appropriate relationship between $(HTBARL)^2/(DOTCEL - DTBARL)$ and the adjustment in dBA. The value for $(HTBARL)^2/(DOTCEL - DTBARL)$ is calculated, its intersection with the appropriate relationship is found, and the adjustment to the noise level for a roadside barrier is determined.

2.5 SUR (Surface type)

The adjustment made to the noise level for the influence of road surface is determined by the subroutine SUR. It has been shown that roadway surface characteristics influence highway noise.¹¹⁰ Table A.1 gives the relationship between surface type and the adjustment made to the noise level.¹¹¹ As seen in Table A.1, a rough surface will result in a positive adjustment, thereby increasing the noise level. On the other hand, a smooth surface will decrease the noise level.

Figure A.9: Adjustment for roadside barrier¹⁰⁹

TABLE A.1
CLASSIFICATION OF ROAD SURFACE AS IT RELATES
TO SURFACE INFLUENCE ON VEHICLE NOISE¹¹¹

Surface Type	Description	Adjustment (dB)
Smooth	Very smooth, seal-coated asphalt pavement	-5
Normal	Moderately rough asphalt and concrete surface	0
Rough	Rough asphalt pavement with large voids 1/2 in. or larger in diameter, grooved concrete	+5

TABLE A.2
ADJUSTMENT FOR INCREASED NOISE LEVEL
OF TRUCKS ON GRADIENTS¹¹⁴

Gradient (%)	Adjustment (dB)
≤ 2	0*
3 to 4	+2
5 to 6	+3
≥ 7	+5

* The influence of gradients of 2% or less is considered to be negligible.

The subroutine SUR takes the input variable SURTYP, and, depending on the type of surface, returns an adjustment factor which will either increase or decrease the noise level. This adjustment is the same for both sides of the highway. In Appendix B, a description of SURTYP as related to different types of roadway surfaces is given.

2.6 GRAD (Gradient)

The subroutine GRAD calculates the adjustment which considers the influence of the gradient of the highway on the noise level. Very little research has been completed on this topic. However, there is sufficient quantitative evidence to suggest that an increase in gradient causes an increase in the noise level generated by trucks due to the increase in power required to surmount the gradient.^{112,113} The relationship between gradients and adjustments to the noise level for trucks is given in Table A.2.¹¹⁴ As explained previously, gradients do not have a significant effect on the noise generated by automobiles.

In the subroutine GRAD, Table A.2 has been transformed into arithmetic expressions. GRADTO, the input variable required for GRAD, is placed into a particular class and the appropriate adjustment for the gradient is returned to ENOISE. A definition of GRADTO is given in Appendix B.

2.7 PRINT

The noise levels, which are calculated by ENOISE, are printed through the use of the subroutine PRINT. Basically, PRINT takes the numerical values of the noise levels, transforms them into symbols, and creates a simplified map of noise characteristics of the highway under study in order to aid the highway planner.

All of the input variables required for PRINT are discussed in Appendix B. IPR is used to transfer the total noise levels, L50TOL (ii) and L50TOR (ii) from ENOISE to PRINT. IUP and IDN represents the upper and lower limits of each class

of noise levels. The number of noise levels that will be calculated for each side of the highway is given by N. The number of classes of noise levels is read in as NCL. Finally, ICL, IPI, and IP give the information required for the symbolic representation of the noise levels and highway.

Once again, most of these variables may be adjusted to suit the needs of the user. Through the use of NCL, IUP, and IDN, the user may use as many classes of noise levels as needed, determining their limits according to his application. The number of noise levels that are calculated by ENOISE for a particular location along the highway (N) is a function of the initial and maximum values of NN. The user has the opportunity to change any of these variables depending on his application.

2.8 STRUCL and STRUCR (Structures)

The subroutines STRUCL and STRUCR find the necessary adjustments due to houses located on the left and right sides of the highway. Only STRUCL will be discussed, as the subroutines are the same, except for their input data, which is specific to a particular side of the highway. The variables required for STRUCL and STRUCR are defined in Appendix B.

Very little research has been completed in the area of noise shielding by structures. Sawley and Gordon have suggested that reasonable values for the reduction in noise levels due to houses are 3 to 5 dBA for each of the first three rows of houses.¹¹⁵ A maximum reduction of 10 dBA for houses is also assumed in the study. Other types of structures have not been considered, although it appears correct to assume that they may have different noise reduction characteristics.

In subroutine STRUCL, the first three rows of houses are considered, with a decrease of 3 dBA assigned to each row that prevents a direct line-of-site between the roadway and the point at which the noise level is calculated. STRUCL

compares the point at which the noise level is calculated to the location of the first three rows of houses. Depending on the number of rows of houses, if any, that are between this point and the highway, the appropriate adjustment is made.

2.9 LANDSL and LANDSR (Landscaping)

The adjustments made for landscaping on the left and right sides of the highway are performed by subroutines LANDSL and LANDSR. Since these two subroutines are very similar, only LANDSL will be explained. The inputs required for the subroutines are described in Appendix B.

It has been found that landscaping has very little effect on the noise levels generated by a highway. Unless the vegetation is sufficiently dense to obscure the line of sight between the observer and the highway, the reduction in noise will be insignificant. A reduction of 5 dBA for every 100 feet of dense vegetation at least 15 feet tall is used in LANDSL. A maximum decrease of 10 dBA is assumed: therefore, only the first two hundred feet of dense vegetation is considered by LANDSL.¹¹⁶

The point at which the noise level is calculated is compared to the location of the first two hundred feet of dense vegetation by LANDSL. Depending upon whether the point is beyond either or both of the two one-hundred-foot rows of vegetation, the appropriate adjustments are made.

APPENDIX B

GLOSSARY OF INPUT VARIABLES, INCLUDING THEIR RANGE
FOR A CONSTANT SEGMENT

GLOSSARY OF INPUT VARIABLES, INCLUDING THEIR RANGE
FOR A CONSTANT SEGMENT

The variables defined below appear in the order they are read into ENOISE. When there is a significant change in certain variables, the initiation of a new highway segment is mandatory. As long as the variable stays within the stated range, the segment is considered constant. 117

<u>Variable</u>	<u>Content</u>	<u>Range</u>
RDNAME	The name of the highway under study.	--
NPT	The total number of segments that make up the entire length of the highway under study	--
NDROAD	The point along the highway for which the last set of noise levels will be calculated	--
NCL	The number of classes used for printing the noise levels. For this program, 14 classes were used.	--
NI	The number of noise levels that will be calculated for each side of the highway at a particular location along the highway.	--
NOOBHT	The number of different observation heights for which a contour map of noise levels will be calculated. For example, if there are 3 different observation heights to be calculated using an L ₅₀ noise level, NOOBHT will be 3. But, if there are 3 different observation heights, and each is to be calculated using an L ₅₀ and L ₁₀ noise level, NOOBHT will equal 6.	--
NO	The distance from the beginning of the highway to the point where a set of noise levels are calculated.	--
NNO	The perpendicular distance from the highway.	--
INCN	The increment for N.	--
INCNN	The increment for NN.	--
INCDNL	The increment for DOTCNL.	--
OBSHGT	The distance above ground level, in feet, of each observation height. The number of values for OBSHGT must be equal to NOOBHT.	--
LL	The noise level, either L ₁₀ or L ₅₀ , for which the noise levels comprising each contour map will be calculated. Again, the number of values for LL must be equal to NOOBHT.	--

<u>Variable</u>	<u>Content</u>	<u>Range</u>
WIDROW	Width of the right-of-way of the highway in feet.	The width of the right-of-way is not used in any calculations, but is helpful in interpreting the output. If the other variables are constant over the segment i of the highway, use the average value of WIDROW.
XLANE	Number of lanes of highway in both directions.	Must begin a new segment i when the change is greater than 25% around the midpoint value.
WILANE	Width of a single lane in feet.	Same as XLANE.
WMEDIA	Width of the median which divides the opposing lanes, in feet.	Same as XLANE.
VAUTOS	Volume of automobiles, in vehicles per hour, for both directions of movement.	A change of greater than $\pm 10\%$ about the average volume requires a new segment i.
VTRUCK	Volume of trucks, in vehicles per hour, for both directions of movement.	Same as VAUTO
SAUTOS	Average speed of automobiles, in miles per hour.	A change of greater than $\pm 10\%$ about the average speed requires a new segment i.
STRUCK	Average speed of trucks, in miles per hour.	Same as SAUTOS.
HEIGHT	Height of an elevated roadway, relative to the surrounding terrain, in feet.	A change of more than $\pm 10\%$ in the elevation of the highway with respect to the terrain requires a new segment i.
WSHODL	Width of the left shoulder of the highway (including any emergency lane) in feet. It is measured from the edge of the outside lane on the left side of the highway to the point where the vertical cut begins.	A change of more than $\pm 25\%$ about the midpoint requires a new segment i.

<u>Variable</u>	<u>Content</u>	<u>Range</u>
WSHODR	Explanation of WSHODL applied to the right side of the highway.	Same as WSHODL
DEPTH	Depth, in feet, of a depressed highway relative to the surrounding terrain.	A change of more than + 10% in the depression of the highway with respect to the terrain requires a new segment i.
WSHOLL	Width of the left shoulder of the highway (including any emergency lane) in feet. WSHOLL is measured from the outside edge of the left lane of the highway to the point where the vertical cut begins.	Same as WSHODE
WSHOLR	Explanation of WSHOLL applied to the right side of the highway.	Same as WSHODE
HTBARL	Height of a barrier, relative to the terrain, on the left side of the highway, in feet.	A change exceeding + 10% in the height of the barrier requires a new segment i.
HTBARR	Explanation of HTBARL applied to the right side of the highway.	Same as HTBARE
DSBARR	Distance from the outer edge of the right lane of highway to a barrier on the right side of the highway, in feet.	A change of more than + 25% about the mid-point requires a new segment i.
DSBARL	Explanation of DSBARR applied to the left side of the highway.	Same as DSBARR
DSLTN1	Distance to the first line of houses on the left side of the highway from the center of the outside lane on the left side of the highway, in feet.	A change of more than + 50 feet requires a new segment i.
DSLTN2	Explanation of DSLTN1 applied to the second line of houses on the left side of the highway.	Same as DSLTN1
DSLTN3	Explanation of DSLTN1 applied to the third line of houses on the left side of the highway.	Same as DSLTN1

<u>Variable</u>	<u>Content</u>	<u>Range</u>
DSRTN1	Distance to the first line of houses on the right side of the highway from the center of the outside lane on the right side of the highway, in feet.	Same as DSLTN1
DSRTN2	Explanation of DSRTN1 applied to the second line of houses on the right side of the highway.	Same as DSLTN1
DSRTN3	Explanation of DSRTN1 applied to the third line of houses on the right side of the highway.	Same as DSLTN1
DLLTN1	Distance to the outside edge of the first line of landscaping on the left side of the highway from the center of the outside lane on the left side of the highway, in feet.	Same as DSLTN1
DLLTN2	Explanation of DLLTN1 applied to the second line of landscaping on the left side of the highway.	Same as DSLTN1
DLRTN1	Distance to the outside edge of the first line of landscaping on the right side of the highway from the center of the outer lane on the right side of the highway, in feet.	Same as DSLTN1
DLRTN2	Explanation of DLRTN1 applied to the second line of landscaping on the right side of the highway.	Same as DSLTN1
SURTYP	Indicates the texture of the material used for the highway's surface. a) Rough - 1. b) Normal - 2. c) Smooth - 3. Also, see Table A.1.	Must stay within limits stated in Table A.1 or a new segment is required.
BEGELE	Beginning of each segment of the highway under consideration; measured from the beginning of the highway, in feet. Number of segments equal NDT.	--
ENDELE	End of the segment of highway under consideration; measured from the beginning of the highway, in feet.	--

<u>Variable</u>	<u>Content</u>	<u>Range</u>
GRADTO	Gradient of the highway; measured in degrees regardless of whether the slope is positive or negative. Also, see Table A.2.	Must stay within the limits of Table A.2 or a new segment is required.
IUP	Represents the upper limit in dBA for a particular class of noise levels.	--
IDN	Represents the lower limit in dBA for a particular class of noise levels.	--

If any of the variables required for ENOISE are 0, simply read in the value of 0. Also, if either end of the highway is not connected to another roadway, data for the beginning of the roadway (from 0 to N) and for the end of the roadway (from NROAD to the end) may be read in as 0. In that way, noise levels may be calculated for the entire length of the roadway.

APPENDIX C

COMPUTER COPY OF NOISE MODEL, USER'S MANUAL, AND
DATA FOR TEST RUN

COMPUTER COPY OF NOISE MODEL

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ISN 0002      INTEGER ADJELL,ADJDEL,ADJBAL,ADJSUR,ADJSL1,ADJSL2,ADJSL3,
               1      ADJL11,ADJL12,ADJELR,ADJDER,ADJBAR,ADJSR1,ADJSR2,
               1      ADJSR3,ADJLR1,ADJLR2,ADJELT,ADJDLT,ADJBLT,
               1      ADJGRA,ADJERT,ADJDRT,ADJBRT,ADJELE,ADAL10,ADTL10
ISN 0003      INTEGER ENDELE,BEGELE,GRADTO
ISN 0004      DIMENSION IPRINT(57,2),IUP(14),IDN(14),ICL(14),RDNAME(6),OBShGT(10
               1),LL(10)
ISN 0005      EQUIVALENCE (IPRINT(1,1),L50TOL(1)),(IPRINT(1,2),L50TOR(1))
ISN 0006      DIMENSION WIDROW(1),XLANE(1),WILANE(1),WMEDIA(1),VAUTOS(1),
               1      VTRUCK(1),SAUTOS(1),STRUCK(1),HEIGHT(1),WSHODL(1),
               1      WSHODR(1),DEPTH(1),WSHOLL(1),WSHOLR(1),HTBARL(1),
               1      HTBARR(1),DSBARR(1),DSBARL(1),DSL TN1(1),DSL TN2(1),
               1      DSL TN3(1),DSRTN1(1),DSRTN2(1),DSRTN3(1),DLL TN1(1),
               1      DLL TN2(1),DLRTN1(1),DLRTN2(1),SURTYP(1),BEGELE(1),
               1      ENDELE(1),GRADTO(1)
ISN 0007      DIMENSION L50TCL(60),L50TOR(60)
ISN 0008      DIMENSION RNOISE(100,29),NOISE(100,3)
ISN 0009      EQUIVALENCE (RNOISE(1,1),WIDROW(1)),(RNOISE(1,2),XLANE(1)),
               1      (RNOISE(1,3),WILANE(1)),(RNOISE(1,4),WMEDIA(1)),
               1      (RNOISE(1,5),VAUTOS(1)),(RNOISE(1,6),VTRUCK(1)),
               1      (RNOISE(1,7),SAUTOS(1)),(RNOISE(1,8),STRUCK(1)),
               1      (RNOISE(1,9),HEIGHT(1)),(RNOISE(1,10),WSHODL(1)),
               1      (RNOISE(1,11),WSHODR(1)),(RNOISE(1,12),DEPTH(1)),
               1      (RNOISE(1,13),WSHOLL(1)),(RNOISE(1,14),WSHOLR(1)),
               1      (RNOISE(1,15),HTBARL(1)),(RNOISE(1,16),HTBARR(1)),
               1      (RNOISE(1,17),DSBARR(1)),(RNOISE(1,18),DSBARL(1)),
               1      (RNOISE(1,19),DSL TN1(1)),(RNOISE(1,20),DSL TN2(1)),
               1      (RNOISE(1,21),DSL TN3(1)),(RNOISE(1,22),DSRTN1(1)),
               1      (RNOISE(1,23),DSRTN2(1)),(RNOISE(1,24),DSRTN3(1)),
               1      (RNOISE(1,25),DLL TN1(1)),(RNOISE(1,26),DLL TN2(1)),
               1      (RNOISE(1,27),DLRTN1(1)),(RNOISE(1,28),DLRTN2(1)),
               1      (RNOISE(1,29),SURTYP(1)),(NOISE(1,1),BEGELE(1)),
               1      (NOISE(1,2),ENDELE(1)),(NOISE(1,3),GRADTO(1))
ISN 0010      DATA IP/' $',IPI/' ',ICL/'A','B','C','D','E','F','G','H','I'
               1,'J','K','L','M','N'/'
ISN 0011      1001 FORMAT(11F7.0)
ISN 0012      1002 FORMAT(11I7)
ISN 0013      1005 FORMAT(6A4)
ISN 0014      READ(5,1005) RDNAME
ISN 0015      READ(5,1002) NPT,NROAD,NCL,NI,NOOBHT
ISN 0016      READ(5,1002) NC,NNQ,INCN,INCNN,INCNNL
ISN 0017      READ(5,1001) (OBShGT(III),III=1,NOOBHT)
ISN 0018      READ(5,1002) (LL(III),III=1,NOOBHT)
ISN 0019      READ(5,1001)((RNOISE(I,J),I=1,NPT),J=1,29)
ISN 0020      READ(5,1002)((NOISE(I,J),I=1,NPT),J=1,3)
ISN 0021      READ(5,1002)(IUP(I),I=1,NCL)
ISN 0022      READ(5,1002)(IDN(I),I=1,NCL)
ISN 0023      III=1
ISN 0024      GO TO 96
ISN 0025      95 III=III+1
ISN 0026      IF(III.GT.NOOBHT) STOP
ISN 0028      96 WRITE(6,1111)
ISN 0029      1111 FORMAT(1H1)
ISN 0030      WRITE(6,1009) LL(III),RDNAME
ISN 0031      1009 FORMAT(9X,' THE FOLLOWING L',12,' PREDICTED NOISE LEVELS IN DBA RE
               1PRESENT THE NOISE LEVELS GENERATED BY THE ',6A4)
ISN 0032      WRITE(6,1010) OBShGT(III)
ISN 0033      1010 FORMAT(/,44X,' AT A HEIGHT OF ',F3.0,' FEET ABOVE GROUND LEVEL.',/
               1/)
               C      ADJUSTMENTS MADE FOR FINITE AND SEMI-INFINITE ELEMENTS.
ISN 0034      N=NO-INCN
ISN 0035      23 N=N+INCN
               C      N IS THE DISTANCE FROM THE END OF THE ROADWAY.
               C      INCN IS THE INCREMENT FOR N
ISN 0036      NX=0
ISN 0037      IF(N.GE.NROAD) GO TO 90
ISN 0039      II=0
ISN 0040      NN=NNQ-INCNN
ISN 0041      25 NN=NN+INCNN
               C      NN IS THE PERPENDICULAR DISTANCE FROM THE HIGHWAY.
               C      INCNN IS THE INCREMENT FOR NN
ISN 0042      MAXNN=(NI*INCNN)+NNQ

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ISN 0043		IF(NN.GE.MAXNN) GO TO 41
ISN 0045	C	MAXNN IS THE MAXIMUM VALUE FOR NN
ISN 0046		L50STR=0
ISN 0047		L50STL=0
ISN 0048		II=II+1
ISN 0049		NX=NX+1
ISN 0051		IF(NX.EQ.1) GO TO 33
		DOTCNL=DOTCNL+INCONL
	C	INCONL IS THE INCREMENT FOR DOTCNL
ISN 0052	33	IF(NX.NE.1) GO TO 31
ISN 0054		NNN=N-4*NN
	C	NNN IS THE BEGINNING OF THE ELEMENT UNDER STUDY.
ISN 0055		NNNN=N+4*NN
	C	NNNN IS THE END OF THE ELEMENT UNDER STUDY.
ISN 0056		I=0
ISN 0057	2	I=I+1
ISN 0058		IF(ENDELE(I).GE.NNN) GO TO 1
ISN 0060		GO TO 2
ISN 0061	1	CONTINUE
ISN 0062		DOTCNL=NN
ISN 0063		DOTCFL=DOTCNL+(XLANE(I)-1.0)*WILANE(I)+WMEDIA(I)
ISN 0064		DOTCEL=SQRT((DOTCNL)*(DOTCFL))
ISN 0065		NN=DOTCEL+0.5
ISN 0066	31	NNN=N-4*NN
ISN 0067		NNNN=N+4*NN
ISN 0068		DOTCEL=NN
ISN 0069		I=0
ISN 0070	24	I=I+1
ISN 0071		IF(ENDELE(I).GE.NNN) GO TO 32
ISN 0073		GO TO 24
ISN 0074	32	CONTINUE
ISN 0075		IF(BEGELE(I).LE.NNN.AND.ENDELE(I).GE.NNNN) GO TO 3
ISN 0077		IF(BEGELE(I).LE.NNN.AND.ENDELE(I).GE.N) GO TO 4
ISN 0079		IF(BEGELE(I).LE.NNN.AND.ENDELE(I).GE.NNN) GO TO 5
ISN 0081	3	ADJELE=0
	C	ADJELE IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL MADE FOR A
	C	FINITE OR SEMI-INFINITE ELEMENT OF THE ROADWAY.
ISN 0082		GO TO 20
ISN 0083	4	X1=ENDELE(I)-N
ISN 0084		X2=NN
ISN 0085		RADIAN=ATAN2(X1,X2)
ISN 0086		XANGLE=-(RADIAN*57.3)
ISN 0087		ADJELE=-0.045*XANGLE-3.0+0.5
ISN 0088		GO TO 20
ISN 0089	5	X1=N-ENDELE(I)
ISN 0090		X2=NN
ISN 0091		RADIAN=ATAN2(X1,X2)
ISN 0092		XANGLE=(RADIAN*57.3)
ISN 0093		IF(XANGLE.LT.40.0) GO TO 6
ISN 0095		IF(XANGLE.GE.40.0) GO TO 7
ISN 0097	6	ADJELE=-0.045*XANGLE-3.0+0.5
ISN 0098		GO TO 20
ISN 0099	7	ADJELE=-0.1625*XANGLE+1.5+0.5
ISN 0100		GO TO 20
ISN 0101	15	CONTINUE
ISN 0102		I=I+1
ISN 0103		IF(BEGELE(I).GE.N.AND.ENDCLE(I).GE.NNNN) GO TO 8
ISN 0105		IF(BEGELE(I).GE.N.AND.ENDELE(I).LT.NNNN) GO TO 9
ISN 0107		IF(BEGELE(I).LT.N.AND.ENDELE(I).GE.NNNN) GO TO 10
ISN 0109		IF(BEGELE(I).LT.N.AND.ENDELE(I).GE.N) GO TO 11
ISN 0111		IF(BEGELE(I).LT.N.AND.ENDELE(I).LT.N) GO TO 12
ISN 0113	8	X1=BEGELE(I)-N
ISN 0114		X2=NN
ISN 0115		RADIAN=ATAN2(X1,X2)
ISN 0116		XANGLE=(RADIAN*57.3)
ISN 0117		IF(XANGLE.LT.40.0) GO TO 13
ISN 0119		IF(XANGLE.GE.40.0) GO TO 14
ISN 0121	13	ADJELE=-0.045*XANGLE-3.0+0.5
ISN 0122		GO TO 20
ISN 0123	14	ADJELE=-0.1625*XANGLE+1.5+0.5
ISN 0124		GO TO 20
ISN 0125	9	X1=ENDELE(I)-N

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ISN 0126      X2=NN
ISN 0127      RADIA1=ATAN2(X1,X2)
ISN 0128      XANGL1=RADIA1*57.3
ISN 0129      X3=BEGELE(I)-N
ISN 0130      RADIA2=ATAN2(X3,X2)
ISN 0131      XANGL2=RADIA2*57.3
ISN 0132      XANGLE=XANGL1-XANGL2
ISN 0133      IF(XANGLE.LE.40.0) GO TO 16
ISN 0135      IF(XANGLE.GT.40.0) GO TO 17
ISN 0137      16 ADJELE=0.2*XANGLE-14.0+0.5
ISN 0138      GO TO 20
ISN 0139      17 ADJELE=0.054*XANGLE-8.0+0.5
ISN 0140      GO TO 20
ISN 0141      10 X1=N-BEGELE(I)
ISN 0142      X2=NN
ISN 0143      RADIAN=ATAN2(X1,X2)
ISN 0144      XANGLE=-(RADIAN*57.3)
ISN 0145      ADJELE=-0.045*XANGLE-3.0+0.5
ISN 0146      GO TO 20
ISN 0147      11 X1=N-BEGELE(I)
ISN 0148      X2=NN
ISN 0149      RADIA1=ATAN2(X1,X2)
ISN 0150      XANGL1=RADIA1*57.3
ISN 0151      X3=ENDELE(I)-N
ISN 0152      RADIA2=ATAN2(X3,X2)
ISN 0153      XANGL2=RADIA2*57.3
ISN 0154      XANGLE=XANGL1+XANGL2
ISN 0155      IF(XANGLE.LE.40.0) GO TO 18
ISN 0157      IF(XANGLE.GT.40.0) GO TO 19
ISN 0159      18 ADJELE=0.2*XANGLE-14.0+0.5
ISN 0160      GO TO 20
ISN 0161      19 ADJELE=0.054*XANGLE-8.0+0.5
ISN 0162      GO TO 20
ISN 0163      12 X1=N-BEGELE(I)
ISN 0164      X2=NN
ISN 0165      RADIA1=ATAN2(X1,X2)
ISN 0166      XANGL1=RADIA1*57.3
ISN 0167      X3=N-ENDELE(I)
ISN 0168      RADIA2=ATAN2(X3,X2)
ISN 0169      XANGL2=RADIA2*57.3
ISN 0170      XANGLE=XANGL1-XANGL2
ISN 0171      IF(XANGLE.LE.40.0) GO TO 22
ISN 0173      IF(XANGLE.GT.40.0) GO TO 21
ISN 0175      22 ADJELE=0.2*XANGLE-14.0+0.5
ISN 0176      GO TO 20
ISN 0177      21 ADJELE=0.054*XANGLE-8.0+0.5
ISN 0178      GO TO 20
ISN 0179      C   CALCULATES NOISE LEVELS.
ISN 0181      20 IF(VAUTOS(I).NE.0.0) GO TO 80
ISN 0182      L50AUT=0
ISN 0183      GO TO 81
ISN 0184      80 UA=(0.0019*VAUTOS(I)*DOTCEL)/SAUTOS(I)
ISN 0186      IF(UA.GT.2.51) GO TO 78
ISN 0187      UEXPA=2.71828**UA
ISN 0188      TANHUA=(UEXPA-(1.0/UEXPA))/(UEXPA+(1.0/UEXPA))
ISN 0189      GO TO 77
ISN 0190      78 TANHUA=1.0
ISN 0190      77 L50AUT=10.0*(ALOG10(VAUTOS(I)))-15.0*(ALOG10(DOTCEL))+30.0*
      1(ALOG10(SAUTOS(I)))+10.0*(ALOG10(TANHUA))+29.0+0.5
ISN 0191      C   L50AUT IS THE 50 PERCENT NOISE LEVEL DUE TO AUTOMOBILES FOR THE
ISN 0192      C   SEGMENT UNDER STUDY ( WITH NO ADJUSTMENTS ).
ISN 0193      81 IF(VTRUCK(I).NE.0.0) GO TO 82
ISN 0194      L50TCK=0
ISN 0195      GO TO 675
ISN 0196      82 UT=(0.0019*VTRUCK(I)*DOTCEL)/STRUCK(I)
ISN 0197      IF(UT.GT.2.51) GO TO 79
ISN 0198      UEXPT=2.71828**UT
ISN 0199      TANHUT=(UEXPT-(1.0/UEXPT))/(UEXPT+(1.0/UEXPT))
ISN 0200      GO TO 76
ISN 0201      79 TANHUT=1.0
ISN 0202      76 L50TCK=10.0*(ALOG10(VTRUCK(I)))-10.0*(ALOG10(STRUCK(I)))-15.0*
      1(ALOG10(DOTCEL))+10.0*(ALOG10(TANHUT))+95.0+0.5

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      C      L50TCK IS THE 50 PERCENT NOISE LEVEL DUE TO TRUCKS FOR THE
      C      SEGMENT UNDER STUDY ( WITH NO ADJUSTMENTS ).
ISN 0203      IF(HEIGHT(I).EQ.0.0) GO TO 230
ISN 0205      A=HEIGHT(I)
ISN 0206      CALL ELEM ( WSHODL(I),A,WILANE(I),DOTCNL,DOTCEL,ADJELL,OBShGT(III) )
ISN 0207      GO TO 270
ISN 0208      230 ADJELL=0
      C      FINDS ADJUSTMENT DUE TO ELEVATION ( FOR LEFT SIDE OF ROADWAY ).
ISN 0209      270 IF(DEPTH(I).EQ.0.0) GO TO 330
ISN 0211      A=DEPTH(I)
ISN 0212      CALL DEPL ( A,WSHOLL(I),WILANE(I),DOTCNL,DOTCEL,ADJDEL,OBShGT(III) )
ISN 0213      GO TO 370
ISN 0214      330 ADJDEL=0
      C      FINDS ADJUSTMENT DUE TO DEPRESSION ( FOR LEFT SIDE OF ROADWAY ).
ISN 0215      370 IF(HTBARL(I).EQ.0.0) GO TO 430
ISN 0217      A=HTBARL(I)
ISN 0218      B=OBShGT(III)
ISN 0219      CALL BARL ( A,DSBARL(I),WILANE(I),DOTCNL,DOTCEL,ADJBAL,B)
ISN 0220      GO TO 470
ISN 0221      430 ADJBAL=0
      C      FINDS ADJUSTMENT FOR BARRIERS ( FOR LEFT SIDE OF ROADWAY ).
ISN 0222      470 IF(SURTYP(I).EQ.0.0) GO TO 710
ISN 0224      CALL SUR (SURTYP(I),ADJSUR)
ISN 0225      GO TO 770
ISN 0226      710 ADJSUR=0
      C      FINDS ADJUSTMENT DUE TO TYPE OF SURFACE OF ROADWAY.
ISN 0227      770 IF(DSLTN1(I).EQ.0.0) GO TO 560
ISN 0229      CALL STRUCL (DOTCEL,XLANE(I),WMEDIA(I),WILANE(I),DSLTN1(I),DSLTN2(
      11),DSLTN3(I),ADJSL1,ADJSL2,ADJSL3)
ISN 0230      GO TO 565
ISN 0231      560 ADJSL1=0
ISN 0232      ADJSL2=0
ISN 0233      ADJSL3=0
      C      FINDS ADJUSTMENT DUE TO STRUCTURES ( FOR LEFT SIDE OF ROADWAY ).
ISN 0234      565 IF(DLLTN1(I).EQ.0.0) GO TO 670
ISN 0236      CALL LANDSL (DOTCEL,XLANE(I),WMEDIA(I),WILANE(I),DLLTN1(I),DLLTN2(
      11),ADJLL1,ADJLL2)
ISN 0237      GO TO 675
ISN 0238      670 ADJLL1=0
ISN 0239      ADJLL2=0
      C      FINDS ADJUSTMENT DUE TO LANDSCAPING ( FOR LEFT SIDE OF ROADWAY ).
ISN 0240      675 L50ATL=L50AUT+ADJELE+ADJELL+ADJDEL+ADJBAL+ADJSUR+ADJSL1+ADJSL2
      1+ADJSL3+ADJLL1+ADJLL2
ISN 0241      IF(LL(III).EQ.50) GO TO 91
ISN 0243      RATIOA=(VAUTOS(I)*DOTCEL)/SAUTOS(I)
ISN 0244      IF(RATIOA.GE.40000.) ADAL10=1
ISN 0246      IF(RATIOA.LT.40000.) ADAL10=2
ISN 0248      IF(RATIOA.LT.9000.) ADAL10=3
ISN 0250      IF(RATIOA.LT.4000.) ADAL10=4
ISN 0252      IF(RATIOA.LT.2400.) ADAL10=5
ISN 0254      IF(RATIOA.LT.1600.) ADAL10=6
ISN 0256      IF(RATIOA.LT.1000.) ADAL10=7
ISN 0258      IF(RATIOA.LT.740.) ADAL10=8
ISN 0260      IF(RATIOA.LT.550.) ADAL10=9
ISN 0262      IF(RATIOA.LT.440.) ADAL10=10
ISN 0264      IF(RATIOA.LT.340.) ADAL10=11
ISN 0266      IF(RATIOA.LT.270.) ADAL10=12
ISN 0268      IF(RATIOA.LT.130.) ADAL10=13
ISN 0270      L10ATL=L50ATL+ADAL10
ISN 0271      L50ATL=L10ATL
ISN 0272      91 IF(L50ATL.LE.0) L50ATL=0
      C      L50ATL IS THE 50 PERCENT NOISE LEVEL FOR THE LEFT SIDE
      C      OF THE ROADWAY ( INCLUDING ALL ADJUSTMENTS FOR AUTOMOBILES ).
ISN 0274      IF(ADJELL.LT.-5) GO TO 231
ISN 0276      ADJELL=0
ISN 0277      GO TO 232
ISN 0278      231 ADJELL=ADJELL+5
ISN 0279      232 IF(ADJDEL.LT.-5) GO TO 331
ISN 0281      ADJDEL=0
ISN 0282      GO TO 332
ISN 0283      331 ADJDEL=ADJDEL+5
ISN 0284      332 ADJBAL=ADJBAL

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ISN 0285      432 IF(GRADTO(I).LE.2) GO TO 110
ISN 0287      CALL GRAD (GRADTO(I),ADJGRA)
ISN 0288      GO TO 150
ISN 0289      110 ADJGRA=0
ISN 0290      C      FINOS ADJUSTMENT DUE TO GRADIENT OF ROADWAY ( TRUCKS ONLY ).
150 L5OTRL=L5OTCK+ADJELE+ADJELT+ADJDLT+ADJBLT+ADJSUR+ADJGRA+
1ADJSL1+ADJSL2+ADJSL3+ADJLL1+ADJLL2
ISN 0291      IF(LL(III).EQ.50) GO TO 92
ISN 0293      RATIOI=(VTRUCK(I)*DOTCEL)/STRUCK(I)
ISN 0294      IF(RATIOI.GE.40000.) ADTL10=1
ISN 0296      IF(RATIOI.LT.40000.) ADTL10=2
ISN 0298      IF(RATIOI.LT.9000.) ADTL10=3
ISN 0300      IF(RATIOI.LT.4000.) ADTL10=4
ISN 0302      IF(RATIOI.LT.2400.) ADTL10=5
ISN 0304      IF(RATIOI.LT.1600.) ADTL10=6
ISN 0306      IF(RATIOI.LT.1000.) ADTL10=7
ISN 0308      IF(RATIOI.LT.740.) ADTL10=8
ISN 0310      IF(RATIOI.LT.550.) ADTL10=9
ISN 0312      IF(RATIOI.LT.440.) ADTL10=10
ISN 0314      IF(RATIOI.LT.340.) ADTL10=11
ISN 0316      IF(RATIOI.LT.270.) ADTL10=12
ISN 0318      IF(RATIOI.LT.130.) ADTL10=13
ISN 0320      L1OTRL=L5OTRL+ADTL10
ISN 0321      L5OTRL=L1OTRL
ISN 0322      92 IF(L5OTRL.LE.0) L5OTRL=0
C      L5OTRL IS THE 50 PERCENT NOISE LEVEL FOR THE LEFT SIDE
C      OF THE ROADWAY ( INCLUDING ALL ADJUSTMENTS FOR TRUCKS ).
ISN 0324      NDIFF=L5OATL-L5OTRL
ISN 0325      IF(NDIFF.LE.1.AND.NDIFF.GE.-1) GO TO 800
ISN 0327      IF(NDIFF.LE.4.AND.NDIFF.GE.-4) GO TO 801
ISN 0329      IF(NDIFF.LE.9.AND.NDIFF.GE.-9) GO TO 802
ISN 0331      IF(NDIFF.GE.10.OR.NDIFF.LE.-10) GO TO 803
ISN 0333      800 L5OSSL=MAX0(L5OATL,L5OTRL)+3
C      L5OSSL IS THE 50 PERCENT NOISE LEVEL ( AUTOS + TRUCKS ) FOR THE
C      ROADWAY SEGMENT UNDER STUDY ( FOR LEFT SIDE OF ROADWAY ).
ISN 0334      GO TO 804
ISN 0335      801 L5OSSL=MAX0(L5OATL,L5OTRL)+2
ISN 0336      GO TO 804
ISN 0337      802 L5OSSL=MAX0(L5OATL,L5OTRL)+1
ISN 0338      GO TO 804
ISN 0339      803 L5OSSL=MAX0(L5OATL,L5OTRL)
ISN 0340      804 CONTINUE
ISN 0341      NDIFF=L5OSSL-L5OSTL
ISN 0342      IF(NDIFF.LE.1.AND.NDIFF.GE.-1) GO TO 820
ISN 0344      IF(NDIFF.LE.4.AND.NDIFF.GE.-4) GO TO 821
ISN 0346      IF(NDIFF.LE.9.AND.NDIFF.GE.-9) GO TO 822
ISN 0348      IF(NDIFF.GE.10.OR.NDIFF.LE.-10) GO TO 823
ISN 0350      820 L5OSTL=MAX0(L5OSSL,L5OSTL)+3
ISN 0351      GO TO 824
ISN 0352      821 L5OSTL=MAX0(L5OSSL,L5OSTL)+2
ISN 0353      GO TO 824
ISN 0354      822 L5OSTL=MAX0(L5OSSL,L5OSTL)+1
ISN 0355      GO TO 824
ISN 0356      823 L5OSTL=MAX0(L5OSSL,L5OSTL)
ISN 0357      824 CONTINUE
C      L5OSTL IS THE 50 PERCENT NOISE LEVEL ( AUTOS + TRUCKS ) FOR
C      ACCUMULATED SEGMENTS IN ELEMENT UNDER STUDY.
ISN 0358      IF(ENDELE(I).GE.NNNN) GO TO 30
ISN 0360      GO TO 111
ISN 0361      30 L5OTOL(II)=L5OSTL
C      L5OTOL(II) IS THE TOTAL 50 PERCENT NOISE LEVEL FOR ALL SEGMENTS
C      IN THE ELEMENT ON LEFT SIDE OF ROADWAY ( AUTOS + TRUCKS ).
ISN 0362      111 IF(HEIGHT(I).EQ.0.0) GO TO 280
ISN 0364      A=HEIGHT(I)
ISN 0365      CALL ELER (WSHODR(I),A,WILANE(I),DOTCNL,DOTCEL,ADJELR,OBESHGT(III))
ISN 0366      GO TO 290
ISN 0367      280 ADJELR=0
C      FINDS ADJUSTMENT FOR ELEVATION ( FOR RIGHT SIDE OF ROADWAY ).
ISN 0368      290 IF(DEPTH(I).EQ.0.0) GO TO 380
ISN 0370      A=DEPTH(I)
ISN 0371      CALL DEPR (A,WSHOLR(I),WILANE(I),DOTCNL,DOTCEL,ADJDER,OBESHGT(III))
ISN 0372      GO TO 390

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ISN 0373      380 ADJDER=0
                C FINDS ADJUSTMENT FOR DEPRESSION ( FOR RIGHT SIDE OF ROADWAY ).
ISN 0374      390 IF(HTBARR(I).EQ.0.0) GO TO 480
ISN 0376      A=HTBARR(I)
ISN 0377      B=CBSHGT(III)
ISN 0378      CALL BARR (A,DSBARR(I),WILANE(I),DOTCNL,DOTCEL,ADJBAR,B)
ISN 0379      GO TO 490
ISN 0380      480 ADJBAR=0
                C FINDS ADJUSTMENT FOR BARRIER ( FOR RIGHT SIDE OF ROADWAY ).
ISN 0381      490 IF(DSRTN1(I).EQ.0.0) GO TO 570
ISN 0383      CALL STRUCR (DOTCEL,XLANE(I),WMEDIA(I),WILANE(I),DSRTN1(I),DSRTN2(
                I),DSRTN3(I),ADJSR1,ADJSR2,ADJSR3)
ISN 0384      GO TO 575
ISN 0385      570 ADJSR1=0
ISN 0386      ADJSR2=0
ISN 0387      ADJSR3=0
                C FINDS ADJUSTMENT DUE TO STRUCTURES ( FOR RIGHT SIDE OF ROADWAY ).
ISN 0388      575 IF(DLRTN1(I).EQ.0.0) GO TO 680
ISN 0390      CALL LANDSR (DOTCEL,XLANE(I),WMEDIA(I),WILANE(I),DLRTN1(I),DLRTN2(
                I),ADJLR1,ADJLR2)
ISN 0391      GO TO 685
ISN 0392      680 ADJLR1=0
ISN 0393      ADJLR2=0
                C FINDS ADJUSTMENT DUE TO LANDSCAPING ( FOR RIGHT SIDE OF ROADWAY ).
ISN 0394      685 L5OATR=L5OATR+ADJELE+ADJELR+ADJDER+ADJBAR+ADJSUR+ADJSR1+ADJSR2+
                1ADJSR3+ADJLR1+ADJLR2
ISN 0395      IF(LL(III).EQ.50) GO TO 93
ISN 0397      L1OATR=L5OATR+ADAL10
ISN 0398      L5OATR=L1OATR
ISN 0399      93 IF(L5OATR.LE.0) L5OATR=0
                C L5OATR IS THE 50 PERCENT NOISE LEVEL FOR THE RIGHT
                C SIDE OF THE ROADWAY ( INCLUDING ALL ADJUSTMENTS FOR AUTOMOBILES ).
ISN 0401      IF(ADJELR.LT.-5) GO TO 233
ISN 0403      ADJERT=0
ISN 0404      GO TO 234
ISN 0405      233 ADJERT=ADJELR+5
ISN 0406      234 IF(ADJDER.LT.-5) GO TO 333
ISN 0408      ADJORT=0
ISN 0409      GO TO 334
ISN 0410      333 ADJORT=ADJDER+5
ISN 0411      334 ADJBRT=ADJBAR
ISN 0412      434 L5OTRR=L5OTCK+ADJELE+ADJERT+ADJORT+ADJBRT+ADJSUR+ADJGRA+
                1ADJSR1+ADJSR2+ADJSR3+ADJLR1+ADJLR2
ISN 0413      IF(LL(III).EQ.50) GO TO 94
ISN 0415      L1OTRR=L5OTRR+ADTL10
ISN 0416      L5OTRR=L1OTRR
ISN 0417      94 IF(L5OTRR.LE.0) L5OTRR=0
ISN 0419      NDIF=L5OATR-L5OTRR
ISN 0420      IF(NDIF.LE.1.AND.NDIF.GE.-1) GO TO 810
ISN 0422      IF(NDIF.LE.4.AND.NDIF.GE.-4) GO TO 811
ISN 0424      IF(NDIF.LE.9.AND.NDIF.GE.-9) GO TO 812
ISN 0426      IF(NDIF.GE.10.OR.NDIF.LE.-10) GO TO 813
ISN 0428      810 L5OSSR=MAX0(L5OATR,L5OTRR)+3
ISN 0429      GO TO 814
ISN 0430      811 L5OSSR=MAX0(L5OATR,L5OTRR)+2
ISN 0431      GO TO 814
ISN 0432      812 L5OSSR=MAX0(L5OATR,L5OTRR)+1
ISN 0433      GO TO 814
ISN 0434      813 L5OSSR=MAX0(L5OATR,L5OTRR)
ISN 0435      814 CONTINUE
ISN 0436      NDIF=L5OSSR-L5OSTR
ISN 0437      IF(NDIF.LE.1.AND.NDIF.GE.-1) GO TO 830
ISN 0439      IF(NDIF.LE.4.AND.NDIF.GE.-4) GO TO 831
ISN 0441      IF(NDIF.LE.9.AND.NDIF.GE.-9) GO TO 832
ISN 0443      IF(NDIF.GE.10.OR.NDIF.LE.-10) GO TO 833
ISN 0445      830 L5OSTR=MAX0(L5OSSR,L5OSTR)+3
ISN 0446      GO TO 834
ISN 0447      831 L5OSTR=MAX0(L5OSSR,L5OSTR)+2
ISN 0448      GO TO 834
ISN 0449      832 L5OSTR=MAX0(L5OSSR,L5OSTR)+1
ISN 0450      GO TO 834
ISN 0451      833 L5OSTR=MAX0(L5OSSR,L5OSTR)

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ISN 0452      834 CONTINUE
ISN 0453      IF(ENDELE(I).GE.NNNN) GO TO 40
ISN 0455      GO TO 15
ISN 0456      40 L5OTOR(II)=L5OSTR
ISN 0457      GO TO 25
                C   L5OTOR(II) IS THE TOTAL 50 PERCENT NOISE LEVEL FOR ALL SEGMENTS
                C   IN THE ELEMENT ON RIGHT SIDE OF ROADWAY ( AUTOS + TRUCKS ).
ISN 0458      41 CONTINUE
ISN 0459      CALL PRINT (IPRINT,IUP,IDN,NI,NCL,ICL,IP,IPI)
ISN 0460      GO TO 23
ISN 0461      90 WRITE(6,1012)
ISN 0462      1012 FORMAT(///,54X,' DESCRIPTION OF SYMBOLS')
ISN 0463      WRITE(6,1013)
ISN 0464      1013 FORMAT(//,20X,' SYMBOL ',12X,'A',4X,'B',4X,'C',4X,'D',4X,'E',4X,
                1'F',4X,'G',4X,'H',4X,'I',4X,'J',4X,'K',4X,'L',4X,'M',4X,'N')
ISN 0465      WRITE(6,1014) (IUP(I),I=1,NCL)
ISN 0466      1014 FORMAT(//,16X,' UPPER LIMIT (DBA)',7X,I3,3X,I2,3X,I2,3X,I2,3X,I2,3X,
                1,I2,3X,I2,3X,I2,9X,I2,3X,I2,3X,I2,3X,I2,3X,I2,3X,I2)
ISN 0467      WRITE(6,1015) (ICL(I),I=1,NCL)
ISN 0468      1015 FORMAT(//,16X,' LOWER LIMIT (DBA)',8X,I2,3X,I2,3X,I2,3X,I2,3X,I2,3X,
                1,I2,3X,I2,3X,I2,3X,I2,3X,I2,3X,I2,3X,I2,4X,I1)
ISN 0469      IF(I1.LT.NOOBHT) GO TO 95
ISN 0471      42 STOP
ISN 0472      END

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ISN 0002		SUBROUTINE ELEV (WSHODL,HEIGHT,WILANE,DOTCNL,DOTCEL,ADJELL,OB SHGT)
ISN 0003		INTEGER ADJELL
ISN 0004		IF(OBSHGT.GE.HEIGHT) GO TO 204
ISN 0006		IF(OBSHGT.GT.0.0) HEIGHT=HEIGHT-OBSHGT
ISN 0008		DOTSLR=DOTCNL-(1.0/2.0)*WILANE-WSHODL
ISN 0009		ELEVAL=(HEIGHT**2.0)/(DOTCEL-DOTSLR)
ISN 0010		ELLLOG=ALOG10((HEIGHT**2.0)/DOTSLR)
ISN 0011		IF(ELEVAL.GT.0.0.AND.ELEVAL.LT.10.0) GO TO 201
ISN 0013		IF(ELEVAL.GE.10.0.AND.ELEVAL.LT.100.0) GO TO 202
ISN 0015		IF(ELEVAL.GE.100.0) GO TO 203
ISN 0017	201	FACTOL=(HEIGHT**2.0)/DOTSLR
ISN 0018		IF(FACTOL.LE.0.1) GO TO 204
ISN 0020		IF(FACTOL.GT.0.1.AND.FACTOL.LE.3.1) GO TO 205
ISN 0022		IF(FACTOL.GT.3.1) GO TO 206
ISN 0024	204	ADJELL=0
	C	ADJELL IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL MADE FOR AN
	C	ELEVATED FACILITY - FOR LEFT SIDE OF ROADWAY.
ISN 0025		GO TO 215
ISN 0026	205	ADJELL=-10.1548*(1.0+ELLLOG)-1.0+0.5
ISN 0027		GO TO 215
ISN 0028	206	ADJELL=-15
ISN 0029		GO TO 215
ISN 0030	202	FACTOL=(HEIGHT**2.0)/DOTSLR
ISN 0031		IF(FACTOL.LT.0.35) GO TO 208
ISN 0033		IF(FACTOL.LT.10.0.AND.FACTOL.GE.0.35) GO TO 209
ISN 0035		IF(FACTOL.GE.10.0) GO TO 210
ISN 0037	208	ADJELL=0
ISN 0038		GO TO 215
ISN 0039	209	ADJELL=-10.1548*(1.0+ELLLOG)+4.5+0.5
ISN 0040		GO TO 215
ISN 0041	210	ADJELL=-15
ISN 0042		GO TO 215
ISN 0043	203	FACTOL=(HEIGHT**2.0)/DOTSLR
ISN 0044		IF(FACTOL.LT.1.2) GO TO 212
ISN 0046		IF(FACTOL.GE.1.2.AND.FACTOL.LT.32.0) GO TO 213
ISN 0048		IF(FACTOL.GE.32.0) GO TO 214
ISN 0050	212	ADJELL=0
ISN 0051		GO TO 215
ISN 0052	213	ADJELL=-10.1548*(1.0+ELLLOG)+10.0+0.5
ISN 0053		GO TO 215
ISN 0054	214	ADJELL=-15
ISN 0055		GO TO 215
ISN 0056	215	CONTINUE
ISN 0057		RETURN
ISN 0058		END

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ISN 0002      SUBROUTINE ELER (WSHODR,HEIGHT,WILANE,DOTCNL,DOTCEL,ADJELR,OB SHGT)
ISN 0003      INTEGER ADJELR
ISN 0004      IF(OBSHGT.GE.HEIGHT) GO TO 254
ISN 0006      IF(OBSHGT.GT.0.0) HEIGHT=HEIGHT-OBSHGT
ISN 0008      DOTSRR=DOTCNL-((1.0/2.0)*WILANE-WSHODR)
ISN 0009      ELEVAR=(HEIGHT**2.0)/(DOTCEL-DOTSRR)
ISN 0010      ELRLOG=ALOG10((HEIGHT**2.0)/DOTSRR)
ISN 0011      IF(ELEVAR.GT.0.0.AND.ELEVAR.LT.10.0) GO TO 251
ISN 0013      IF(ELEVAR.GE.10.0.AND.ELEVAR.LT.100.0) GO TO 252
ISN 0015      IF(ELEVAR.GE.100.0) GO TO 253
ISN 0017      251 FACTOR=(HEIGHT**2.0)/DOTSRR
ISN 0018      IF(FACTOR.LE.0.1) GO TO 254
ISN 0020      IF(FACTOR.LE.3.1.AND.FACTOR.GT.0.1) GO TO 255
ISN 0022      IF(FACTOR.GT.3.1) GO TO 256
ISN 0024      254 ADJELR=0
                C ADJELR IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL MADE FOR AN
                C ELEVATED FACILITY - FOR RIGHT SIDE OF ROADWAY.
ISN 0025      GO TO 265
ISN 0026      255 ADJELR=-10.1548*(1.0+ELRLOG)-1.0+0.5
ISN 0027      GO TO 265
ISN 0028      256 ADJELR=-15
ISN 0029      GO TO 265
ISN 0030      252 FACTOR=(HEIGHT**2.0)/DOTSRR
ISN 0031      IF(FACTOR.LT.0.35) GO TO 258
ISN 0033      IF(FACTOR.LT.10.0.AND.FACTOR.GE.0.35) GO TO 259
ISN 0035      IF(FACTOR.GE.10.0) GO TO 260
ISN 0037      258 ADJELR=0
ISN 0038      GO TO 265
ISN 0039      259 ADJELR=-10.1548*(1.0+ELRLOG)+4.5+0.5
ISN 0040      GO TO 265
ISN 0041      260 ADJELR=-15
ISN 0042      GO TO 265
ISN 0043      253 FACTOR=(HEIGHT**2.0)/DOTSRR
ISN 0044      IF(FACTOR.LT.1.2) GO TO 262
ISN 0046      IF(FACTOR.GE.1.2.AND.FACTOR.LT.32.0) GO TO 263
ISN 0048      IF(FACTOR.GE.32.0) GO TO 264
ISN 0050      262 ADJELR=0
ISN 0051      GO TO 265
ISN 0052      263 ADJELR=-10.1548*(1.0+ELRLOG)+10.0+0.5
ISN 0053      GO TO 265
ISN 0054      264 ADJELR=-15
ISN 0055      265 CONTINUE
ISN 0056      RETURN
ISN 0057      END

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ISN 0002      SUBROUTINE DEPL (DEPTH,WSHOLL,WILANE,DOTCNL,DOTCEL,ADJDEL,OB SHGT)
ISN 0003      INTEGER ADJDEL
ISN 0004      DOTCRL=DOTCNL-((1.0/2.0)*WILANE-WSHOLL)
ISN 0005      IF(OBSHGT.EQ.0.0) GO TO 398
ISN 0007      RATIO=(((DOTCEL-DOTCRL)/(DEPTH))/((DOTCRL)/(OB SHGT)))
ISN 0008      IF(RATIO.GT.1.0) RATIO=1.0
ISN 0010      DEPTH=DEPTH-(DEPTH*RATIO)
ISN 0011      IF(DEPTH.EQ.0.0) GO TO 304
ISN 0013      398 DEPREL=(DEPTH**2.0)/DOTCRL
ISN 0014      DELLOG=ALOG10((DEPTH**2.0)/(DOTCEL-DOTCRL))
ISN 0015      IF(DEPREL.GT.0.0.AND.DEPREL.LT.10.0) GO TO 301
ISN 0017      IF(DEPREL.GE.10.0.AND.DEPREL.LT.100.0) GO TO 302
ISN 0019      IF(DEPREL.GE.100.0) GO TO 303
ISN 0021      301 FACTAL=(DEPTH**2.0)/(DOTCEL-DOTCRL)
ISN 0022      IF(FACTAL.LE.0.1) GO TO 304
ISN 0024      IF(FACTAL.GE.0.1.AND.FACTAL.LT.3.0) GO TO 305
ISN 0026      IF(FACTAL.GE.3.0) GO TO 306
ISN 0028      304 ADJDEL=0
                C ADJDEL IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL MADE FOR A
                C DEPRESSED FACILITY - FOR LEFT SIDE OF ROADWAY.
ISN 0029      GO TO 315
ISN 0030      305 ADJDEL=-10.1548*(1.0+DELLOG)-1.0+0.5
ISN 0031      GO TO 315
ISN 0032      306 ADJDEL=-15
ISN 0033      GO TO 315
ISN 0034      302 FACTAL=(DEPTH**2.0)/(DOTCEL-DOTCRL)

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ISN 0035      IF(FACTAL.LT.0.35) GO TO 308
ISN 0037      IF(FACTAL.GE.0.35.AND.FACTAL.LT.10.0) GO TO 309
ISN 0039      IF(FACTAL.GE.10.0) GO TO 310
ISN 0041      308 ADJDEL=0
ISN 0042      GO TO 315
ISN 0043      309 ADJDEL=-10.1548*(1.0+DELLOG)+4.5+0.5
ISN 0044      GO TO 315
ISN 0045      310 ADJDEL=-15
ISN 0046      GO TO 315
ISN 0047      303 FACTAL=(DEPTH**2.0)/(DOTCEL-DOTCRL)
ISN 0048      IF(FACTAL.LT.1.2) GO TO 312
ISN 0050      IF(FACTAL.GE.1.2.AND.FACTAL.LT.32.0) GO TO 313
ISN 0052      IF(FACTAL.GE.32.0) GO TO 314
ISN 0054      312 ADJDEL=0
ISN 0055      GO TO 315
ISN 0056      313 ADJDEL=-10.1548*(1.0+DELLOG)+10.0+0.5
ISN 0057      GO TO 315
ISN 0058      314 ADJDEL=-15
ISN 0059      315 CONTINUE
ISN 0060      RETURN
ISN 0061      END

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ISN 0002      SUBROUTINE DEPR (DEPTH,WSHOLR,WILANE,DOTCNL,DOTCEL,ADJDER,OBSSHGT)
ISN 0003      INTEGER ADJDER
ISN 0004      DOTCRR=DOTCNL-(1.0/2.0)*WILANE-WSHOLR
ISN 0005      IF(OBSSHGT.EQ.0.0) GO TO 399
ISN 0007      RATIO=((DOTCEL-DOTCRR)/(DEPTH))/((DOTCRR)/(OBSSHGT))
ISN 0008      IF(RATIO.GT.1.0) RATIO=1.0
ISN 0010      DEPTH=DEPTH-(DEPTH*RATIO)
ISN 0011      IF(DEPTH.EQ.0.0) GO TO 354
ISN 0013      399 DEPRER=(DEPTH**2.0)/DOTCRR
ISN 0014      DERLOG=ALOG10((DEPTH**2.0)/(DOTCEL-DOTCRR))
ISN 0015      IF(DEPRER.GT.0.0.AND.DEPRER.LT.10.0) GO TO 351
ISN 0017      IF(DEPRER.GE.10.0.AND.DEPRER.LT.100.0) GO TO 352
ISN 0019      IF(DEPRER.GE.100.0) GO TO 353
ISN 0021      351 FACTAR=(DEPTH**2.0)/(DOTCEL-DOTCRR)
ISN 0022      IF(FACTAR.LT.0.1) GO TO 354
ISN 0024      IF(FACTAR.GE.0.1.AND.FACTAR.LT.3.0) GO TO 355
ISN 0026      IF(FACTAR.GE.3.0) GO TO 356
ISN 0028      354 ADJDER=0
ISN 0028      C ADJDER IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL MADE FOR A
ISN 0028      C DEPRESSED FACILITY - FOR RIGHT SIDE OF ROADWAY.
ISN 0029      GO TO 365
ISN 0030      355 ADJDER=-10.1548*(1.0+DERLOG)-1.0+0.5
ISN 0031      GO TO 365
ISN 0032      356 ADJDER=-15
ISN 0033      GO TO 365
ISN 0034      352 FACTAR=(DEPTH**2.0)/(DOTCEL-DOTCRR)
ISN 0035      IF(FACTAR.LT.0.35) GO TO 358
ISN 0037      IF(FACTAR.GE.0.35.AND.FACTAR.LT.10.0) GO TO 359
ISN 0039      IF(FACTAR.GE.10.0) GO TO 360
ISN 0041      358 ADJDER=0
ISN 0042      GO TO 365
ISN 0043      359 ADJDER=-10.1548*(1.0+DERLOG)+4.5+0.5
ISN 0044      GO TO 365
ISN 0045      360 ADJDER=-15
ISN 0046      GO TO 365
ISN 0047      353 FACTAR=(DEPTH**2.0)/(DOTCEL-DOTCRR)
ISN 0048      IF(FACTAR.LT.1.2) GO TO 362
ISN 0050      IF(FACTAR.GE.1.2.AND.FACTAR.LT.32.0) GO TO 363
ISN 0052      IF(FACTAR.GE.32.0) GO TO 364
ISN 0054      362 ADJDER=0
ISN 0055      GO TO 365
ISN 0056      363 ADJDER=-10.1548*(1.0+DERLOG)+10.0+0.5
ISN 0057      GO TO 365
ISN 0058      364 ADJDER=-15
ISN 0059      365 CONTINUE
ISN 0060      RETURN
ISN 0061      END

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ISN 0002      SUBROUTINE BARL (HTBARL,DSBARL,WILANE,DOTCNL,DOTCEL,ADJBAL,OBSHGT)
ISN 0003      INTEGER ADJBAL
ISN 0004      IF(DOTCEL.LE.DSBARL) GO TO 405
ISN 0006      DTBARL=DOTCNL-(1.0/2.0)*WILANE-DSBARL
ISN 0007      IF(OBSHGT.GT.HTBARL) GO TO 498
ISN 0009      IF(OBSHGT.EQ.0.0) GO TO 496
ISN 0011      RATIO=(((DOTCEL-DTBARL)/(HTBARL))/((DOTCEL)/(OBSHGT)))
ISN 0012      IF(RATIO.GT.1.0) RATIO=1.0
ISN 0014      HTBARL=HTBARL-(HTBARL*RATIO)
ISN 0015      IF(HTBARL.EQ.0.0) GO TO 405
ISN 0017      GO TO 496
ISN 0018      498 OBSHGT=OBSHGT-HTBARL
ISN 0019      DEPTH=HTBARL
ISN 0020      WSHOLL=DSBARL
ISN 0021      CALL DEPL (DEPTH,WSHOLL,WILANE,DOTCNL,DOTCEL,ADJDEL,OBSHGT)
ISN 0022      ADJBAL=ADJDEL
ISN 0023      GO TO 415
ISN 0024      496 BARRIL=(HTBARL**2.0)/DTBARL
ISN 0025      BALLOG=ALOG10((HTBARL**2.0)/(DOTCEL-DTBARL))
ISN 0026      IF(BARRIL.GT.0.0.AND.BARRIL.LT.0.3) GO TO 401
ISN 0028      IF(BARRIL.GE.0.3.AND.BARRIL.LT.1.0) GO TO 402
ISN 0030      IF(BARRIL.GE.1.0.AND.BARRIL.LT.4.0) GO TO 403
ISN 0032      IF(BARRIL.GE.4.0) GO TO 404
ISN 0034      401 FACTEL=(HTBARL**2.0)/(DOTCEL-DTBARL)
ISN 0035      IF(FACTEL.LT.0.1) GO TO 405
ISN 0037      IF(FACTEL.GE.0.1.AND.FACTEL.LT.2.7) GO TO 406
ISN 0039      IF(FACTEL.GE.2.7) GO TO 407
ISN 0041      405 ADJBAL=0.
C      ADJBAL IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL FOR A
C      BARRIER ON THE LEFT SIDE OF THE ROADWAY.
ISN 0042      GO TO 415
ISN 0043      406 ADJBAL=-10.48*(1.0+BALLOG)-1.0+0.5
ISN 0044      GO TO 415
ISN 0045      407 ADJBAL=-15
ISN 0046      GO TO 415
ISN 0047      402 FACTEL=(HTBARL**2.0)/(DOTCEL-DTBARL)
ISN 0048      IF(FACTEL.LT.0.15) GO TO 409
ISN 0050      IF(FACTEL.GE.0.15.AND.FACTEL.LT.2.2) GO TO 410
ISN 0052      IF(FACTEL.GE.2.2) GO TO 411
ISN 0054      409 ADJBAL=-5
ISN 0055      GO TO 415
ISN 0056      410 ADJBAL=-8.145*(1.0+BALLOG)-4.0+0.5
ISN 0057      GO TO 415
ISN 0058      411 ADJBAL=-15
ISN 0059      GO TO 415
ISN 0060      403 FACTEL=(HTBARL**2.0)/(DOTCEL-DTBARL)
ISN 0061      IF(FACTEL.LT.0.3) GO TO 413
ISN 0063      IF(FACTEL.GE.0.3.AND.FACTEL.LT.1.7) GO TO 414
ISN 0065      IF(FACTEL.GE.1.7) GO TO 416
ISN 0067      413 ADJBAL=-10
ISN 0068      GO TO 415
ISN 0069      414 ADJBAL=-6.64*(1.0+BALLOG)-7.0+0.5
ISN 0070      GO TO 415
ISN 0071      416 ADJBAL=-15
ISN 0072      GO TO 415
ISN 0073      404 ADJBAL=-15
ISN 0074      415 CONTINUE
ISN 0075      RETURN
ISN 0076      END

```

```

ISN 0002      SUBROUTINE BARR (HTBARR,DSBARR,WILANE,DOTCNL,DOTCEL,ADJBAR,OBSHGT)
ISN 0003      INTEGER ADJBAR
ISN 0004      IF(DOTCEL.LE.DSBARR) GO TO 455
ISN 0006      DTBARR=DOTCNL-(1.0/2.0)*WILANE-DSBARR
ISN 0007      IF(OBSHGT.GT.HTBARR) GO TO 499
ISN 0009      IF(OBSHGT.EQ.0.0) GO TO 497
ISN 0011      RATIO=(((DOTCEL-DTBARR)/(HTBARR))/((DOTCEL)/(OBSHGT)))
ISN 0012      IF(RATIO.GT.1.0) RATIO=1.0
ISN 0014      HTBARR=HTBARR-(HTBARR*RATIO)
ISN 0015      IF(HTBARR.EQ.0.0) GO TO 455
ISN 0017      GO TO 497
ISN 0018      499 OBSHGT=OBSHGT-HTBARR
ISN 0019      DEPTH=HTBARR
ISN 0020      WSHOLR=DSBARR
ISN 0021      CALL DEPR (DEPTH,WSHOLR,WILANE,DOTCNL,DOTCEL,ADJDER,OBSHGT)
ISN 0022      ADJBAR=ADJDER
ISN 0023      GO TO 470
ISN 0024      497 BARRIR=(HTBARR**2.0)/DTBARR
ISN 0025      BARLOG=ALOG10((HTBARR**2.0)/(DOTCEL-DTBARR))
ISN 0026      IF(BARRIR.GT.0.0.AND.BARRIR.LT.0.3) GO TO 451
ISN 0028      IF(BARRIR.GE.0.3.AND.BARRIR.LT.1.0) GO TO 452
ISN 0030      IF(BARRIR.GE.1.0.AND.BARRIR.LT.4.0) GO TO 453
ISN 0032      IF(BARRIR.GE.4.0) GO TO 454
ISN 0034      451 FACTER=(HTBARR**2.0)/(DOTCEL-DTBARR)
ISN 0035      IF(FACTER.LT.0.1) GO TO 455
ISN 0037      IF(FACTER.GE.0.1.AND.FACTER.LT.2.7) GO TO 456
ISN 0039      IF(FACTER.GE.2.7) GO TO 457
ISN 0041      455 ADJBAR=0
ISN 0042      C ADJBAR IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL FOR A
ISN 0043      C BARRIER ON THE RIGHT SIDE OF THE ROADWAY.
ISN 0044      GO TO 470
ISN 0045      456 ADJBAR=-10.48*(1.0+BARLOG)-1.0+0.5
ISN 0046      GO TO 470
ISN 0047      457 ADJBAR=-15
ISN 0048      GO TO 470
ISN 0049      452 FACTER=(HTBARR**2.0)/(DOTCEL-DTBARR)
ISN 0050      IF(FACTER.LT.0.15) GO TO 459
ISN 0051      IF(FACTER.GE.0.15.AND.FACTER.LT.2.2) GO TO 460
ISN 0052      IF(FACTER.GE.2.2) GO TO 461
ISN 0053      459 ADJBAR=-5
ISN 0054      GO TO 470
ISN 0055      460 ADJBAR=-8.145*(1.0+BARLOG)-4.0+0.5
ISN 0056      GO TO 470
ISN 0057      461 ADJBAR=-15
ISN 0058      GO TO 470
ISN 0059      453 FACTER=(HTBARR**2.0)/(DOTCEL-DTBARR)
ISN 0060      IF(FACTER.LT.0.3) GO TO 463
ISN 0061      IF(FACTER.GE.0.3.AND.FACTER.LT.1.7) GO TO 464
ISN 0062      IF(FACTER.GE.1.7) GO TO 465
ISN 0063      463 ADJBAR=-10
ISN 0064      GO TO 470
ISN 0065      464 ADJBAR=-6.64*(1.0+BARLOG)-7.0+0.5
ISN 0066      GO TO 470
ISN 0067      465 ADJBAR=-15
ISN 0068      GO TO 470
ISN 0069      454 ADJBAR=-15
ISN 0070      470 CONTINUE
ISN 0071      RETURN
ISN 0072      END

```


ISN 0002 SUBROUTINE SUR (SURTYP,ADJSUR)

ISN 0003 INTEGER ADJSUR

ISN 0004 IF(SURTYP.EQ.1.0) GO TO 701

ISN 0006 IF(SURTYP.EQ.2.0) GO TO 702

ISN 0008 IF(SURTYP.EQ.3.0) GO TO 703

ISN 0010 701 ADJSUR=5

C ADJSUR IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL FOR
C THE TYPE OF SURFACE OF ROADWAY.

ISN 0011 GO TO 704

ISN 0012 702 ADJSUR=0

ISN 0013 GO TO 704

ISN 0014 703 ADJSUR=-5

ISN 0015 704 CONTINUE

ISN 0016 RETURN

ISN 0017 END

ISN 0002 SUBROUTINE GRAD (GRADTO,ADJGRA)

ISN 0003 INTEGER ADJGRA

ISN 0004 IF(GRADTO.LE.4) GO TO 102

ISN 0006 IF(GRADTO.LE.6) GO TO 103

ISN 0008 IF(GRADTO.GE.7) GO TO 104

ISN 0010 102 ADJGRA=2

C ADJGRA IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL MADE FOR THE
C GRADIENT OF THE ROADWAY.

ISN 0011 GO TO 105

ISN 0012 103 ADJGRA=3

ISN 0013 GO TO 105

ISN 0014 104 ADJGRA=5

ISN 0015 105 CONTINUE

ISN 0016 RETURN

ISN 0017 END

ISN 0002 SUBROUTINE PRINT(IPR,IUP,IDN,N,NCL,ICL,IP,IPI)

ISN 0003 DIMENSION IPR(1),IUP(1),IDN(1),ICL(1)

ISN 0004 LIM=N*2

ISN 0005 DO 20 I=1,LIM

ISN 0006 DO 10 J=1,NCL

ISN 0007 M=J

ISN 0008 IF(IPR(I).LE.IUP(J).AND.IPR(I).GE.IDN(J)) GO TO 20

ISN 0010 10 CONTINUE

ISN 0011 20 IPR(I)=M

C IPR NOW CONTAINS CLASS NUMBERS IN PLACE OF ACTUAL VALUES.

ISN 0012 WRITE(6,1004)(ICL(IPR(N-J+1)),J=1,N),IP,IPI,(ICL(IPR(I+N)),I=1,N)

ISN 0013 1004 FORMAT(5X,57A1,A4,A3,57A1)

ISN 0014 RETURN

ISN 0015 END

ISN 0002 SUBROUTINE STRUCL (DOTCEL,XLANE,WMEDIA,WILANE,DSL TN1,DSL TN2,DSL TN3,
1,ADJSL1,ADJSL2,ADJSL3)

ISN 0003 INTEGER ADJSL1,ADJSL2,ADJSL3

ISN 0004 DSLTF1=DSL TN1+(XLANE-1.0)*WILANE+WMEDIA

ISN 0005 DSLTE1=SQRT((DSL TN1)*(DSLTF1))

ISN 0006 IF(DOTCEL.GT.DSLTE1) GO TO 501

ISN 0008 ADJSL1=0

ISN 0009 ADJSL2=0

ISN 0010 ADJSL3=0

ISN 0011 GO TO 551

ISN 0012 531 DSLTF2=DSL TN2+(XLANE-1.0)*WILANE+WMEDIA

ISN 0013 DSLTE2=SQRT((DSL TN2)*(DSLTF2))

ISN 0014 IF(DOTCEL.GT.DSLTE2) GO TO 511

ISN 0016 ADJSL2=0

ISN 0017 ADJSL3=0

ISN 0018 GO TO 551

ISN 0019 541 DSLTF3=DSL TN3+(XLANE-1.0)*WILANE+WMEDIA

ISN 0020 DSLTE3=SQRT((DSL TN3)*(DSLTF3))

ISN 0021 IF(DOTCEL.GT.DSLTE3) GO TO 521

ISN 0023 ADJSL3=0

ISN 0024 GO TO 551

ISN 0025 501 ADJSL1=-3

```

ISN 0026      GO TO 531
ISN 0027      511 ADJSR2=-3
ISN 0028      GO TO 541
ISN 0029      521 ADJSR3=-3
ISN 0030      551 CONTINUE
ISN 0031      RETURN
ISN 0032      END

```

```

ISN 0002      SUBROUTINE STRUCR (DOTCEL,XLANE,WMEDIA,WILANE,DSRTN1,DSRTN2,DSRTN3
1,ADJSR1,ADJSR2,ADJSR3)
ISN 0003      INTEGER ADJSR1,ADJSR2,ADJSR3
ISN 0004      DSRTF1=DSRTN1+(XLANE-1.0)*WILANE+WMEDIA
ISN 0005      DSRTF1= SQRT((DSRTN1)*(DSRTF1))
ISN 0006      IF(DOTCEL.GT.DSRTF1) GO TO 502
ISN 0008      ADJSR1=0
ISN 0009      ADJSR2=0
ISN 0010      ADJSR3=0
ISN 0011      GO TO 552
ISN 0011      C ADJSR1 IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL MADE FOR
C THE STRUCTURES ON THE RIGHT SIDE OF THE ROADWAY.
ISN 0012      532 DSRTF2=DSRTN2+(XLANE-1.0)*WILANE+WMEDIA
ISN 0013      DSRTF2= SQRT((DSRTN2)*(DSRTF2))
ISN 0014      IF(DOTCEL.GT.DSRTF2) GO TO 512
ISN 0016      ADJSR2=0
ISN 0017      ADJSR3=0
ISN 0018      GO TO 552
ISN 0019      542 DSRTF3=DSRTN3+(XLANE-1.0)*WILANE+WMEDIA
ISN 0020      DSRTF3= SQRT((DSRTN3)*(DSRTF3))
ISN 0021      IF(DOTCEL.GT.DSRTF3) GO TO 522
ISN 0023      ADJSR3=0
ISN 0024      GO TO 552
ISN 0025      502 ADJSR1=-3
ISN 0026      GO TO 532
ISN 0027      512 ADJSR2=-3
ISN 0028      GO TO 542
ISN 0029      522 ADJSR3=-3
ISN 0030      552 CONTINUE
ISN 0031      RETURN
ISN 0032      END

```

```

ISN 0002      SUBROUTINE LANDSL (DOTCEL,XLANE,WMEDIA,WILANE,DLN1,DLN2,ADJLL1
1,ADJLL2)
ISN 0003      INTEGER ADJLL1,ADJLL2
ISN 0004      DLLTF1=DLN1+(XLANE-1.0)*WILANE+WMEDIA
ISN 0005      DLLTE1= SQRT((DLLTF1)*(DLN1))
ISN 0006      IF(DOTCEL.GT.DLLTE1) GO TO 601
ISN 0008      ADJLL1=0
ISN 0009      ADJLL2=0
ISN 0009      C ADJLL1 IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL MADE
C FOR THE LANDSCAPING ON THE LEFT SIDE OF THE ROADWAY.
ISN 0010      GO TO 651
ISN 0011      621 DLLTF2=DLN2+(XLANE-1.0)*WILANE+WMEDIA
ISN 0012      DLLTE2= SQRT((DLLTF2)*(DLN2))
ISN 0013      IF(DOTCEL.GT.DLLTE2) GO TO 611
ISN 0015      ADJLL2=0
ISN 0016      GO TO 651
ISN 0017      601 ADJLL1=-5
ISN 0018      GO TO 621
ISN 0019      611 ADJLL2=-5
ISN 0020      651 CONTINUE
ISN 0021      RETURN
ISN 0022      END

```

ISN 0002		SUBROUTINE LANDSR (DOTCEL,XLANE,WMEDIA,WILANE,DLRTN1,DLRTN2,ADJLR1 1,ADJLR2)
ISN 0003		INTEGER ADJLR1,ADJLR2
ISN 0004		DLRTF1=DLRTN1+(XLANE-1.0)*WILANE+WMEDIA
ISN 0005		DLRTE1= SQRT((DLRTN1)*(DLRTF1))
ISN 0006		IF(DOTCEL.GT.DLRTE1) GO TO 602
ISN 0008		ADJLR1=0
ISN 0009		ADJLR2=0
	C	ADJLR1 IS THE ADJUSTMENT TO THE PREDICTED NOISE LEVEL MADE
	C	FOR THE LANDSCAPING ON THE RIGHT SIDE OF THE ROADWAY.
ISN 0010		GO TO 652
ISN 0011	622	DLRTF2=DLRTN2+(XLANE-1.0)*WILANE+WMEDIA
ISN 0012		DLRTE2= SQRT((DLRTN2)*(DLRTF2))
ISN 0013		IF(DOTCEL.GT.DLRTE2) GO TO 612
ISN 0015		ADJLR2=0
ISN 0016		GO TO 652
ISN 0017	602	ADJLR1=-5
ISN 0018		GO TO 622
ISN 0019	612	ADJLR2=-5
ISN 0020	652	CONTINUE
ISN 0021		RETURN
ISN 0022		END

USER'S MANUAL

This manual is provided to describe the types of format statements and the data deck that are required by ENOISE. When applying the predictive noise model to a highway, this manual should be used in conjunction with Appendix B, which gives a detailed description of the required input variables.

CARD 1 (6A4)

<u>Variable</u>	<u>Column</u>
RDNAME	1-24

CARD 2 (5I7)

<u>Variable</u>	<u>Column</u>
NPT	1-7
NDROAD	8-14
NCL	15-21
NI	22-28
NOOBHT	29-35

CARD 3 (5I7)

<u>Variable</u>	<u>Column</u>
NO	1-7
NNO	8-14
INCN	15-21
INCNN	22-28
INCDNL	29-35

CARD 4 (NF7.0)

<u>Variable</u>	<u>Column</u>
OBSHGT (N)	1-7

The number of OBSHGT that will be read in is equal to NOOBHT. In other words, $N = \text{NOOBHT}$.

CARD 5 (NI7)

<u>Variable</u>	<u>Column</u>
LL(N)	1-7

The number of LL that will be read in is equal to NOOBHT. Again, $N = \text{NOOBHT}$.

CARDS 6 to I (11F7.0)

<u>Variables</u>	<u>Column</u>
WIDROW	1-7
XLANE	
WILANE	
WMEDIA	
VAUTOS	
VTRUCK	
SAUTOS	
STRUCK	
HEIGHT	
WSHODL	
WSHODR	
DEPTI1	
WSHOLL	
WSHOLR	
HTBARL	
HTBARR	
DSBARR	
DSBARL	
DSLTN1	
DSLTN2	
DSLTN3	
DSRTN1	
DSRTN2	
DSRTN3	
DLRTN1	
DLRTN2	
DLRTN1	
DLRTN2	
SURTYP	

The first variable on the sixth data card is WIDROW. This variable and the next 28 variables are reals, and are read in with a F7.0 format. For each segment of the highway (the total number of segments given by NPT), there is a value for WIDROW. All of the values for WIDROW (a total of NPT) will be punched before going on to the next variable. Once this is completed, all of the values for the variable XLANE (a total of NPT) are punched. This is repeated until all of the values for SURTYP, which is the last of the total of 29 real variables, have been punched. Each data card will contain 11 values, each value being placed within a 7 column space.

CARDS I + 1 to J (11I7)

<u>Variable</u>	<u>Column</u>
BEGELE	1-7
ENDELE	
GRADTO	

The first variable on the I + 1 card is BEGELE. All of the values for BEGELE (a total of NPT) will be punched before going on to the next variable. The values for ENDELE and then GRADTO are punched. These three variables are integers, and therefore an I7 format is used. A maximum of 11 values are placed on each card.

CARDS J + 1 and J + 2 (11I7)

<u>Variable</u>	<u>Column</u>
IUP	1-7

There are 14 values of IUP in the present program.

CARDS J + 3 and J + 4 (11I7)

<u>Variable</u>	<u>Column</u>
IDN	1-7

There are 14 values of IDN in the present program.

In the subroutine PRINT, the numerical values in the format statement (1004) are dependent upon the value chosen by the user for NI. Presently, ENOISE inputs a value of 57 for NI in the example problem. Therefore, the value of 57A1 is used in the format statement in PRINT, along with the value 5X. The total of these two values must be 62 (57 + 5), while the value for A1 must be equal to NI. As an example, if only 10 noise levels were desired for each side of the highway, NI would equal 10 and the format statement would be:

```
FORMAT(52X,10A1,A4,A3,10A1)
```

The structure of the complete program ENOISE is shown in Figure C.1 for use on the IBM 360/195 computer system at Argonne National Laboratory.

Figure C.1. Physical structure of deck of Program ENOISE

DATA FOR TEST RUN

RDNAME = Hypothetical Expressway
 NPT = 4
 NROAD = 43000
 NCL = 14
 NI = 57
 NOOBHT = 6
 NO = 12100
 NNO = 150
 INCN = 100
 INCNN = 50
 INCDNL = 50
 ODSIGHT = 0., 0., 10., 10., 20., 20.
 LL = 50, 10, 50, 10, 50, 10

Variable Name	Segment Number			
	1	2	3	4
WIDROW	200.	200.	200.	200.
XLANE	6.	6.	6.	6.
WILANE	12.	12.	12.	12.
WMEDIA	20.	20.	20.	20.
VAUTOS	6000.	6000.	6000.	6000.
VTRUCK	1200.	1200.	1200.	1200.
SAUTOS	60.	60.	60.	60.
STRUCK	55.	55.	55.	55.
HEIGHT	15.	0.	0.	0.
WSHODL	25.	0.	0.	0.
WSHODR	25.	0.	0.	0.
DEPTH	0.	15.	0.	0.
WSHOLL	0.	35.	0.	0.
WSHOLR	0.	35.	0.	0.
HTBARL	0.	0.	15.	0.
HTBARR	0.	0.	15.	0.
DSBARR	0.	0.	35.	0.
DSBARL	0.	0.	35.	0.
DSLTN1	200.	0.	200.	0.
DSLTN2	350.	0.	350.	0.
DSLTN3	500.	0.	500.	0.
DSRTN1	200.	0.	200.	0.
DSRTN2	350.	0.	350.	0.
DSRTN3	500.	0.	500.	0.
DLLTN1	0.	200.	0.	200.
DLLTN2	0.	400.	0.	400.
DLRTN1	0.	200.	0.	200.
DLRTN2	0.	400.	0.	400.
SURTYP	1.	2.	3.	2.
BEGELE	0	20500	28000	35500
ENDELE	20499	27999	35499	56000
GRADTO	3	6	8	4

Symbol	IUP	IDN
A	100 dBA	79 dBA
B	78 dBA	77 dBA
C	76 dBA	75 dBA
D	74 dBA	73 dBA
E	72 dBA	71 dBA
F	70 dBA	69 dBA
G	68 dBA	67 dBA
H	66 dBA	65 dBA
I	64 dBA	63 dBA
J	62 dBA	61 dBA
K	60 dBA	59 dBA
L	58 dBA	57 dBA
M	56 dBA	55 dBA
N	54 dBA	0 dBA

APPENDIX D

AIRCRAFT NOISE EXPOSURE CONTOUR MODEL

AIRCRAFT NOISE EXPOSURE CONTOUR MODEL

Basically, the Airport Noise Exposure Contour Model, developed by the U.S. Department of Transportation, calculates the noise levels generated by an airport, based upon the physical characteristics of the runways and the flights using the facility.¹¹⁸ For each runway, data are required that describe its geographic location and its physical use, including a description of the types of aircraft in use, their operations, and the location of takeoff and touchdown points. In the outline on the following pages, a detailed description of the required input variables is given.

The program provides the user with three output options. The first is the Contour Output, which provides a list of coordinates that give the location of a specified Noise Exposure Level. Also given is the area enclosed by these points. The second output, the Grid Output, provides the Noise Exposure Level for each set of coordinates specified by the user. Finally, the Diagnostic Output provides a subtotal, the Effective Perceived Noise Level, which includes the present flight considered plus all previous flights. This output also gives a complete description of the present flight being considered, including such other information as aircraft type, percent thrust, and elevation. The details of the three outputs are provided in the outline on the following pages.

The program has been constructed to give the flexibility needed to incorporate new relationships. The data statements, which contain the present noise levels versus slant height, percent thrust, and distance, may easily be changed when new relationships become available. The model has the capability to calculate not only Noise Exposure Levels, but also Effective Perceived Noise Levels and Noise Exposure Forecasts.

AIRCRAFT NOISE EXPOSURE CONTOUR MODEL OUTLINE

A. Input Requirements of Model

1. Number of runways, and for each runway:
 - (a) Runway coordinates - Cartesian coordinates of runway end points;
 - (b) Distance from the end of runway to the start of takeoff roll;
 - (c) Distance from the end of runway to the touchdown point; and
 - (d) Number of flights on each runway (a flight is a given aircraft type on a given flight path), and for each flight:
 - (1) Type of flight - takeoff or landing;
 - (2) Type of aircraft;
 - (3) Number of operations; and
 - (4) Number of segments composing each operation, and for each segment:
 - a) Segment length;
 - b) Flight path climb angle;
 - c) Thrust level of aircraft; and
 - d) Radius of curved segment.

B. Output Options of Model

1. Contour Output

- (a) Required inputs:
 - (1) Noise exposure (NE) level;
 - (2) Tolerance of NE Level; and
 - (3) Estimate of X and Y coordinates of location of first point with given NE level.
- (b) Output:
 - (1) X and Y coordinates of locations of specified NE level; and
 - (2) Area enclosed by points on line connecting the prescribed NE level.

2. Grid output

(a) Required inputs:

- (1) X and Y coordinates of the starting point on grid;
- (2) Increments for X and Y; and
- (3) Number of points on X and Y axis.

(b) Output:

- (1) NE levels for each set of coordinates specified.

3. Diagnostic output

(a) Required inputs:

Sames as one required for grid output.

(b) Output:

- (1) Flight number;
- (2) Aircraft type;
- (3) Slant range to observer;
- (4) Elevation angle to observer;
- (5) Percent thrust;
- (6) EPNL (Effective Perceived Noise Level of aircraft at slant range H);
- (7) Corrections for
 - a) Shielding;
 - b) Excess ground attenuation; and
 - c) Number of operations.
- (8) Net EPNL; and
- (9) Subtotal EPNL - includes present flight plus all preceding ones.

C. Flexibility of Model

1. Has been converted for use on the IBM 360/195. (The original program was written for the CDC 6400.)

2. Program has been designed to generate NE levels, but it can easily be modified to produce

(a) EPNL:

$$NE = EPNL + 10 \log NOPS - 88$$

(NOPS = number of observations)

(b) NEF:

$$NOPS = NOPS_{\text{day}} + 16.67 NOPS_{\text{night}}$$

3. Program presently has:

- (a) 24 noise curves - EPNL vs Slant Height - one curve for takeoff and one for landing for each of 12 aircraft types;
- (b) 6 thrust correction curves - EPNL vs Percent Thrust; and
- (c) 2 excess ground attenuation curves - EPNL vs Distance.

4. Finally, new relationships developed for both new and existing aircraft may be easily incorporated into the program as data statements.

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REFERENCES

1. "The Economic Impact of Noise," U.S. Environmental Protection Agency, Washington, D.C., December 31, 1971, p. 4.
2. V. O. Knudson, "Noise, The Bane of Hearing," Noise Control, Vol. 1, No. 3, May, 1955, p. 11.
3. C. R. Bragdon, Noise Pollution, The Unquiet Crisis, University of Pennsylvania Press, Philadelphia, Pennsylvania, 1971, pp. 5-9.
4. "Vieux Carre Historic District Study: An Evaluation of the Effects of the Proposed Riverfront Expressway on the Vieux Carre," Bureau of Government Research, New Orleans, Louisiana, December, 1968, pp. 57-70.
5. "National Environmental Policy Act," Public Law No. 91-190, January 1, 1970.
6. "Guidelines for Implementing Section 102 (2) (6) of the National Environmental Policy Act of 1969," PPM 90-1, U.S. Department of Transportation, Washington, D.C., August, 1971.
7. "Noise Standards and Procedures," PPM 90-2, U.S. Department of Transportation, Washington, D.C., February 8, 1973.
8. "Noise Standards and Procedures," Federal Highway Administration, Federal Register, Vol. 38, No. 117, pp. 15953-15956, June 19, 1973.
9. G. Bugliarello, Noise Pollution: A Review of its Techno-Sociological and Health Aspects, Biotechnology Program, Carnegie-Mellon University, Pittsburgh, Pennsylvania, February 1, 1968.
10. See Ref. 1, pp. 18-31.
11. Ibid., p. 31.
12. Ibid., p. 32.
13. "Papers and Proceedings: Volume III," Commission on the Third London Airport, London, 1970, pp. 365-424.
14. See Ref. 3, p. 13.
15. Ibid., p. 12.
16. See Ref. 1, pp. 55-57.
17. "The Social Impact of Noise," U.S. Environmental Protection Agency, Washington, D.C., December 31, 1971, p. 2.

18. A. Cohen, "Noise Effects on Health, Productivity, and Well Being," Transactions of New York Academy of Science, Series II, Vol. 30, 1968.
19. See Ref. 17, p. 7.
20. Ibid., p. 6.
21. D. Lipscomb, Environmental Protection Agency Hearings, Washington, D.C., 1971.
22. G. Jansen, "Effects of Noise on Health," German Medical Monthly, Vol. 13, 1968.
23. N. N. Shatalov, "Some Hemodynamic Changes Provided by Industrial Noise," U.S. Army Intelligence Report, 1965.
24. A. Suter, Environmental Protection Agency Hearings, Atlanta, Georgia, 1971.
25. "Effects of Noise on People," U.S. Environmental Protection Agency, Washington, D.C., December 31, 1971, p. 15.
26. Ibid., p. 22.
27. Ibid., p. 20.
28. A. Glorig, "Industrial Noise and the Worker," Noise as a Public Health Hazard, American Speech and Hearing Association, Washington, D.C., 1969, pp. 105-109.
29. K. D. Kryter, G. Jansen, D. Parker, H. O. Parrack, G. Thiessen and H. L. Williams, "Non-Auditory Effects of Noise," Washington, D.C., 1971.
30. P. Michael, "Noise in the News," American Industrial Hygiene Association, Vol. 26, No. 6, November-December, 1965, pp. 615-668.
31. See Ref. 3, pp. 70-71.
32. R. C. Davis, Electromyographic Factors in Aircraft Control: Muscular Activity During Steady Noise and its Relation to Instructed Responses Evoked by Auditory Signals, School of Aviation Medicine, Randolph Field, Texas, 1956.
33. See Ref. 22.
34. "Effects of Noise on Wildlife and Other Animals," U. S. Environmental Protection Agency, Washington, D.C., December 31, 1971.
35. Ibid., p. 12.

36. A. Anthony and J. E. Harclerpe, "Noise Stress in Laboratory Rodents; Effects of Chronic Noise Exposures on Sexual Performance and Reproductive Function of Guinea Pigs," Journal of Acoustical Society of America, Vol. 31, 1959, pp. 1437-1440.
37. See Ref. 25, p. 131.
38. See Ref. 34, p. 44.
39. H. O. Parrack, "Community Response to Noise," Handbook of Noise Control, McGraw Hill, New York, New York, 1957.
40. P. N. Borsky, "Community Reaction to Sonic Booms in the Oklahoma City Area," AMRL Technical Report 65-37, Ohio, 1965.
41. D. C. Glass, J. E. Singer and I. N. Friedman, "Psychic Cost of Adaptation to an Environmental Stressor," Journal of Personality and Social Psychology, Vol. 12, 1969.
42. H. A. Denzel, "Noise and Health," Science, Vol. 143, 1964.
43. G. Thiessen, "Effects of Noise During Sleep," Psychological Effects of Noise, Plenum Press, New York, New York, 1970, p. 271.
44. See Ref. 25, p. 73.
45. L. E. Farr, "Medical Consequences of Environmental Home Noise," Journal of American Medical Association, Vol. 202, 1967.
46. E. E. Lieber, Occupational Health, Business Publications, London, 1954.
47. See Ref. 25, p. 49.
48. "Community Reaction to Airport Noise Vol. 1," National Aeronautics and Space Administration, Washington, D.C., 1971.
49. W. A. Rosenblith and K. N. Stevens, Handbook of Acoustic Noise Control, Vol. II: Noise and Man, Bolt, Beranek, and Newman, Inc., 1953.
50. See Ref. 3, pp. 68-69.
51. Ibid., p. 67.
52. Ibid., p. 88.
53. Report of the Secretary of the Interior of the Special Study Group Noise and Sonic Boom in Relation to Man, U.S. Department of Interior, November, 1968.
54. "Correlation of Public Reaction to Sonic-Boom-Induced Property Damage," Citizens League Against Sonic Boom, May, 1968.
55. See Ref. 25, pp. 118-119.

56. See Ref. 3, p. 82.
57. See Ref. 25, p. 119.
58. P. B. Ostergaard, "Background Noise Levels in Suburban Communities," Journal of Acoustical Society of America, Vol. 36, 1969, pp. 435-439.
59. See Ref. 17, p. 14.
60. M. C. Branch and R. D. Beland, "Outdoor Noise and the Metropolitan Environment - Case Study of Los Angeles with Special Reference to Aircraft," Los Angeles Planning Department, Los Angeles, California, July, 1970.
61. Automobile Manufacturing Association, Inc., 1971 Automobile Facts and Figures, Washington, D.C., 1971, pp. 18-19.
62. Ibid., p. 55.
63. W. J. Galloway, W. E. Clark and J. S. Kerrick "Highway Noise: Measurement, Simulation, and Mixed Reactions," National Cooperative Highway Research Program Report No. 78, Bolt, Beranek, and Newman, Inc., Washington, D.C., 1969, pp. 5-6.
64. D. C. Colony, Study of the Effect, If Any, of an Urban Freeway Upon Residential Properties Contiguous to the Right of Way, Research Foundation, University of Toledo, Toledo, Ohio, 1967.
65. An Investigation of the Effects of Freeway Traffic Noise on Apartment Rents, Robin M. Town and Associates, Inc., Seattle, Washington, October, 1965.
66. G. B. Bartholomaeus, "Impacts of Elevated Rapid Transit Facilities on Commercial Activities: A Case Study of Noise in the Chicago Loop," Northwestern University, Evanston, Illinois (Master Thesis), August, 1972.
67. See Ref. 1, p. 43.
68. See Ref. 39.
69. See Ref. 25, pp. 70-71.
70. See Ref. 48.
71. See Ref. 63, pp. 9-10.

72. S. S. Stevens, "Procedures for Calculating Loudness: Mark VI," Journal of Acoustical Society of America, Vol. 33, No. 11, 1961, pp. 1577-1585.
73. See Ref. 63, pp. 4-5, 22-29.
74. 1970 Society of Automotive Engineers Handbook, Society of Automotive Engineers, Inc., New York, New York, 1970, pp. 970-973.
75. J. J. Kaufman, "The Legal Aspects of Noise Control," Congressional Record, House of Representatives, Vol. 115, No. 176, October 29, 1969, E 9031-E9112.
76. "Chicago Urban Noise Study, Phase 1: Noise in the Urban Environment," Bolt, Beranek, and Newman, Inc., Chicago, Illinois, November, 1970, pp. 40-51.
77. "Municipal Code of Chicago," Art. 4, Sec. 17-4.7 (b), Chicago, Illinois, March 10, 1971.
78. Ibid., Sec. 17-4.7 (c).
79. 1970 Society of Automotive Engineers Handbook, pp. 971, 973-974.
80. Ibid.
81. See Ref. 7.
82. Ibid., Appendix B, Table 1, p. 4.
83. K. E. Nelson, "Predictive Model for Highway Noise Levels and Its Application to Transportation Planning," Northwestern University, Evanston, Illinois, (Master Thesis), October, 1972.
84. C. G. Gordon, W. J. Galloway, B. A. Kugler and D. L. Nelson, "Highway Noise: A Design Guide for Engineers," National Cooperative Highway Research Program Report No. 117, Bolt, Beranek, and Newman, Inc., Washington, D.C., 1971.
85. See Ref. 63.
86. K. E. Nelson, "Hand Method for the Calculation of Highway Noise Levels," Center for Environmental Studies, Argonne National Laboratory, Argonne, Illinois, August, 1973.
87. See Ref. 84, pp. 8, 42.
88. Ibid., p. 13.

89. See Ref. 83, pp. 43-53.
90. Ibid., p. 47.
91. Ibid., an insert in rear cover.
92. See Ref. 7.
93. A. Horowitz, and W. Meisel, "Freeway Noise in Simi Valley: A Status Report and Future Projection," Technology Service Corporation, Santa Monica, California, May, 1973.
94. See Ref. 84, pp. 8 and 42.
95. Ibid., p. 11.
96. Ibid., p. 14.
97. Ibid., p. 67.
98. Ibid., p. 9.
99. Ibid., p. 8.
100. Ibid., p. 10.
101. Ibid., p. 13.
102. See Ref. 63, p. 13.
103. See Ref. 84, p. 15.
104. Z. E. Maekawa, "Noise Reduction by Screens," Applied Acoustics, No. 1, 1968, pp. 157-173.
105. See Ref. 63, p. 15.
106. See Ref. 84, p. 16.
107. Ibid., p. 15.
108. Ibid., p. 16.
109. Ibid., p. 17.
110. See Ref. 63, p. 3.
111. See Ref. 84, p. 18.
112. D. R. Johnson and E. G. Saunders, "The Evaluation of Noise from Freely Flowing Road Traffic," J. Sound and Vibration, Vol. 7, 1968, pp. 287-309.

113. R. J. Stephenson and G. H. Vullan, "Traffic Noise," J. Sound and Vibration, Vol. 7, 1968, pp. 247-262.
114. See Ref. 84, p. 14.
115. R. J. Sawley and C. G. Gordon, "A Comprehensive Survey of the Noise in Communities Around Boeing Field, Seattle," Report 1709, Bolt, Beranek and Newman, Inc., 1969.
116. See Ref. 84, p. 18.
117. Ibid., pp. 41-44.
118. H. B. Safeer, Airport Noise Exposure Contour Model: User Manual, U.S. Department of Transportation, Office of Noise Abatement, Washington, D.C., August 24, 1972.