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NOISE IMPACT REVIEW MANUAL

HIGHWAY NOISE IMPACT

May 1977

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16. ABSTRACT

A manual has been prepared which presents a procedure for reviewing noise impact of proposed highway projects. The manual reviews Federal Highway Administration policy for noise impact, and includes specific steps for reviewing environmental impact statements and noise study reports prepared for proposed highway projects. The noise policy of the Department of Housing and Urban Development and noise levels identified by the Environmental Protection Agency are also reviewed, so that a complete assessment of the impact of expected noise may be made. A noise prediction model, consisting of charts, nomograms, and simple equations, is presented so as to enable an independent check of predicted levels presented in an EIS. The noise model (which includes barriers) is itself suitable for predicting roadside noise levels.

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1.0 INTRODUCTION

More people in this country are exposed to noise from highways than from any other single source of noise. It is not surprising, therefore, that adverse impact from highway noise is of major concern to land-use planners, regulatory agencies, and impacted or potentially impacted persons. In order to gauge the adverse impact of noise and limit its encroachment, federal policies now require that an environmental impact statement (EIS) be prepared for proposed highway construction and for significant changes in intended use of existing highway systems. The noise section required in an environmental impact statement must quantify the existing noise climate, define the additional noise exposure associated with the proposed alternatives, estimate the impact resulting from the additional noise exposure, and demonstrate that all reasonable measures have been taken to minimize this impact. For reasons of conciseness and format, an EIS often contains only major conclusions and data summaries with regard to noise. In such cases, complete supporting data and documentation are contained in a separate noise study report. This information is required for a comprehensive evaluation of the noise section of an EIS. Therefore, within the context of this review manual, the terminology "environmental impact statement" will be taken to include the noise study report.

It should also be noted that an EIS is rarely devoted to noise alone. The noise section often utilizes data presented in other sections. Within the context of this review manual, "noise section of an EIS" will be taken to include data presented elsewhere in the EIS, but utilized in the section specifically dealing with noise.

The evaluation of an environmental noise impact assessment for proposed or existing highways can be complicated and should be performed by means of a uniform methodology to ensure that all necessary concerns are consistently addressed. This manual provides the user with the methodological approach necessary for the review of environmental impact statements for highway noise and for evaluating the effectiveness of further actions that may be necessary in the highway design.

The underlying philosophy evident throughout this manual is one of satisfying local needs for noise abatement rather than merely ensuring compliance with fixed noise standards. This reflects the federal policy on highway noise and ensures that noise abatement measures are consistent with local social, economic and environmental considerations. Moreover, it is stressed that federal policies relating to housing development and overall community noise control must be considered together with that relating solely to highway noise.

The manual itself has been designed so that it can be used by people not necessarily trained in the field of acoustics. It does assume that the reader is familiar with some of the terminology, but does not require computational capability other than the use of charts, tables and nomograms.

The manual is divided into three main parts. Section 2 contains the step-by-step approach to be followed in the review of an EIS; Section 3 describes methods for assessing the impact of highway noise; and Section 4 introduces available methods of noise abatement that should be considered in highway design. Also included is a method for independently checking the noise level computations using a series of simple nomograms.

2.0 THE REVIEW OF ENVIRONMENTAL IMPACT STATEMENTS

This section of the manual describes the procedure for reviewing an EIS prepared specifically for a highway project. The project may involve noise control for an existing highway or it may consist of the construction or reconstruction of a section of highway. The purpose of the review procedure is to determine the adequacy of both the noise impact predictions and the proposed measures for noise abatement. The major steps in the procedure are as follows:

- Review and evaluate the data used.
- Check the predicted noise levels by means of an independent calculation.
- Assess the predicted noise impact.
- Evaluate the proposed noise abatement measures.
- Identify additional abatement measures that might be required or might be desirable.
- Make recommendations for action required.

The details involved in each step of the procedure are described in the following sections.

2.1 Review of Input Data

To a large extent, the accuracy of the noise predictions will depend on the validity of the data used in the calculations. It is necessary as a first step to review the data used in the preparation of the EIS. The approach towards the review should be critical and should attempt to answer the following types of questions:

- Is the source of the data identified, and is that source reputable?
- Which portion (if any) of the data is based upon forecasts, and what are the assumptions used in such forecasts?
- Was data requested from all local transportation, planning and housing agencies — in other words, have all local future plans been considered?

The input data required for an assessment of an EIS are as follows:

Definition of the Highway

The highway data used in the calculation of highway noise levels are as follows:

- The width of the roadway
- The number of lanes in each direction
- The width of the median strip
- Road grade
- Elevation of the roadway
- Location of entrance and exit ramps
- Posted speed limits for automobiles and trucks

Definition of Local Topography

This information can be provided in a variety of forms ranging from aerial photographs and topographical maps of the area to cross-sections of the local terrain. The essential data to be provided under this heading includes changes of ground elevation over the study area, and location and height of natural or man-made perturbations of the terrain which may serve as barriers to acoustic propagation. Where there are barriers, the required information is as follows:

- The height of the barrier top above the roadway
- The length of the barrier
- The distance from the highway to the barrier
- The distance from the barrier to the receiver
- The elevation of the receiver relative to the highway

Traffic Flow

Traffic data are a necessary input to calculate noise levels associated with the operation of the highway. Current traffic volume and vehicle mix data are required to estimate the noise impact of existing highways or to verify noise level measurements. Future traffic data are similarly required to calculate noise levels associated with future operation of the highway. The specific data required are as follows:

- Present Day:
  a. Volume (total vehicles/hour)
  b. Mix (percent trucks)
  c. Speed
- Design Year:
  a. Volume
  b. Mix
  c. Speed

Present-day traffic data will consist of measured traffic flow. These data are maintained by state and local highway authorities. Estimates of future traffic for the design year, a time generally considered to be 10 to 20 years after construction, will consist of estimates provided by the state and federal highway authorities. Sources and assumptions for these data will be required.

Land-Use Data

- Present-Day Land-Use Data: In order to evaluate the importance of the noise levels predicted in the evaluation of an EIS, information on land use within the study area is necessary. This information may be acquired through aerial photographs, examination of the local zoning codes applicable to the study area, from U.S. Census Bureau data, or from a visual examination of the study area. Since these data are to represent present-day conditions, zoning information must be used with discretion — undeveloped land will have no present-day noise impact associated with it, except, of course, for the case of parks or public access land used for recreational purposes. It is convenient to present land-use data for parcels of land coinciding with the local zoning system. The specific data required for each land parcel are as follows:
  - Area
  - Frontage length along highway

- Depth from highway
- Zoning
- Building type
- Population density (where applicable)
- Distance to nearest dwelling
- Height of dwellings

Examples of land-use input data are shown below:

a) Land Parcel A, consisting of 4.86 square miles, fronting the proposed new highway route is used (and zoned) for multi-family apartments, with an average population density of 287 persons per square mile. This parcel has 1500 feet frontage on the proposed new highway route and the dwelling structures are evenly distributed along this frontage, average 225 feet from the highway route, with the nearest dwelling 57 feet from the highway.

b) Land Parcel B, consisting of 2.5 square miles, is used for industrial manufacturing and is zoned for heavy industry. This parcel is adjacent to the proposed route, spanning 1.4 miles of frontage with an average depth of 1.8 miles. No residential dwellings are located on this tract, which is used by seven manufacturing concerns.

c) Land Parcel C, consisting of 7.6 square miles, is used (and zoned) for single-family residential purposes. This tract has an average depth of 350 feet from the proposed highway route, with the nearest house 45 feet from the highway, and extends along 4.7 miles of frontage. Tract C has an average population density of 98 persons per square mile, according to the latest census survey. Houses are one- or two-stories high.

- Projected Future Land-Use Data: The projected land-use patterns throughout the study area are based upon present-day demands for various categories of land, as well as projected growth in and near the study area. These projections are provided by land-use planners, and this data will routinely be provided in an EIS. This data allows the noise standards of Section 3.0 to be applied to specific tracts within the study area for evaluation of the future noise impact, as indicated by the future noise level predictions.

2.2 Check the Noise Levels Presented in the EIS

The next step in the procedure is to assess the validity of the noise levels given in the EIS. In the case of an existing highway, these levels may represent measurements or estimates of highway noise. For a proposed highway, these levels will have to be predicted, but measurements of the existing noise levels may be provided.

Measured Noise Levels

Measured noise data are subject to a number of errors which may be introduced at any stage between the acquisition and presentation. The following factors should be considered in the assessment of such data.

- The data must have been taken during a period which may be validly adjusted to design hour conditions. Adjustments for volume may be applied, provided speed and traffic mix are similar to those for the design hour.
- Traffic (total volume and number of trucks) must be counted during the measurement period.
- Full details of the measurements should be provided, including the following:
  - Date and time
  - Traffic flow and mix
  - Duration of measurements

- Measurement locations
- Site descriptions
- Presence of nearby reflecting obstacles
- Weather conditions
- Equipment used
- Sampling rate
- Presence of other noise sources
- Calibration sequence

If the conditions appear suspect, then the persons involved in the measurement should be contacted, or the site should be examined. The data supplied should be reviewed critically to provide answers to the following questions:

- What was the rationale for selecting the measurement locations?
- Are there sufficient measurements to adequately define the noise environment?
- Were the noise levels influenced by nearby buildings, unusual sources of noise, changes in the weather, etc.?

- The traffic conditions should be carefully checked to ensure that they were unaffected by temporary local events, such as sports meetings, accidents, route closure, or construction. Existing traffic data can usually be obtained from the local or State Department of Highways or its equivalent.

In all cases, measured highway noise levels should be checked by comparison to levels predicted, using the Nomogram Method described in detail in Appendix A. There is no general method for predicting the background noise levels existing prior to highway construction and so the assessment must be made solely on the adequacy of the description of the measurement procedure.

Predicted Noise Levels

The predicted noise levels presented in the EIS should always be checked for accuracy. The procedure is as follows:

1. Perform a detailed analysis of the noise levels using the Nomogram Procedure of Appendix A. If the site is very complex then it may be necessary to use one of the computer prediction models described in Appendix C. In the EIS, noise levels should be provided for every section of the highway which may be considered "different" in terms of the factors described in Section 2.1. If it is not possible to estimate noise levels at points not analyzed by reasonable interpolation from levels provided, then not enough points have been analyzed. In some cases, the noise levels at additional locations may be required for a full assessment.

2. If the predicted levels differ from those presented in the EIS, proceed to Step 3. Otherwise, proceed to Section 3.0.

3. Identify and attempt to resolve any discrepancies between the predicted levels and those presented in the EIS. This may require contact with the person responsible for the preparation of the EIS and use of the data in Appendix C which show differences to be expected from using alternative prediction models and alternative assumptions.

4. Proceed to Section 3.0.

3.0 ASSESSMENT OF NOISE IMPACT

Noise impact can be expected under either of the following two conditions:

- If the noise levels approach or exceed the noise standards given in Table 1.
- If the noise levels are substantially higher than the existing levels, even if they are below the standards given in Table 1.

It is important to recognize that noise impact can occur for this second condition. Therefore, all EIS reviews should include an assessment of whether abatement measures need to be considered, even if the standards of Table 1 are satisfied.

The evaluation of noise levels in areas adjacent to highways should be undertaken with a full knowledge of the guidelines laid down by various federal agencies. The FHWA has developed highway noise standards to minimize adverse noise impacts in the location and design of highways. HUD has adopted a policy that incorporates interim noise standards to prevent the location of HUD-assisted development in noise-exposed areas. HUD pays particular attention to fostering land-utilization patterns for housing and other municipal needs that will separate uncontrollable noise sources from residential and other noise-sensitive areas. Finally, the EPA has identified noise levels requisite to protect public health and welfare with an adequate margin of safety. The levels specified by these three agencies differ significantly due to emphasis on different aspects of noise impact. The quantitative and qualitative aspects of each of these programs are discussed in this section.

3.1 FHWA Noise Standards

Background

The Federal Aid Highway Act of 1970 contained a requirement that noise regulations be developed for the planning and design of federal-aid highways. The Act required that the regulations assign noise standards compatible with different land uses: It further provided that the plans and specifications for a highway project could not be approved unless they included measures adequate to comply with the standards. Interim

Table 1

Design Noise Level/Activity Relationships*

Activity Category	Design Noise Levels–dBA[1]		Description of Activity Category
	$L_{eq}(h)$	$L_{10}(h)$	
A[2]	57 (Exterior)	60 (Exterior)	Tracts of land which serenity and quiet 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, open spaces, or historic districts which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet.
B[2]	67 (Exterior)	70 (Exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, and parks which are not included in Category A and residences, motels, hotels, public meeting rooms, schools, churches, libraries, and hospitals.
C	72 (Exterior)	75 (Exterior)	Developed lands, properties or activities not included in Categories A and B above.
D	--	--	For requirements on undeveloped lands, see Paragraph 11.a, and c.*
E	52 (Interior)	55 (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

1 Either L_{eq} or L_{10} design noise levels may be used.

2 Parks in Categories A and B include all such lands (public or private) which are actually used as parks as well as those public lands officially set aside or designated by a governmental agency as parks on the date of public knowledge of the proposed highway project.

* Federal-Aid Highway Program Manual, Vol. 7, Chapter 7, Section 3.

standards were adopted in April 1972, and an environmental statement on the standards was circulated and reviewed. After consideration of the review comments, the final standards were promulgated initially as Policy and Procedure Memorandum (PPM) 90-2 in February 1973, and revised as Federal Highway Program Manual (FHPM), Volume 7, Chapter 7, Section 3, "Procedures for Abatement of Highway Traffic Noise and Construction Noise" (FHPM 7-7-3), 1976. In addition, FHWA has prepared a manual (The Audible Landscape: Manual for Highway Noise and Land Use) for local officials to use to assist in compatible development in the vicinity of noisy highways. The manual describes the administrative measures which local governments can use to control future development. It also describes the physical measures which builders, architects, and developers can use to comply with the local administrative controls.

Standards

The regulations require that a noise analysis be conducted for each highway project. Noise-sensitive land uses and activities in the vicinity of highway projects must be identified, and anticipated noise levels computed in L_{10} or L_{eq} for the noise-sensitive areas on the basis of the worst noise situation expected to occur from the highway in question. The standards contain design noise levels of L_{10} or L_{eq} values considered by FHWA to be the upper limits of acceptable noise levels for exterior land uses and outdoor activities and for certain interior uses. These design levels are given in Table 1.

Noise level predictions are to be compared with the appropriate design noise levels to determine the need for noise abatement measures for existing developed land. Such measures are to be taken on all projects to meet the design noise levels to the extent that reasonable opportunities exist to control noise. However, there are projects for which abatement measures cannot feasibly achieve the design noise levels, and the policy includes provisions for handling these exceptions.

It is important to recognize several factors associated with these design levels.

- FHWA authorizes the use of federal funds for noise abatement wherever a traffic noise impact can be identified provided only that the measures reduce the noise impact and the overall benefits exceed the overall adverse social, economic and environmental effects. (Para. 12, FHPM 7-7-3.)
- A noise impact can exist when:
  (1) The predicted traffic noise levels approach or exceed the design noise levels; or
  (2) The predicted traffic noise levels substantially exceed the existing noise levels. (Para. 4, FHPM 7-7-3.)
- The design noise levels in the standards represent a balancing of that which is desirable and that which may be achievable, and noise impacts can occur even though the design noise levels are achieved.
- The values in Table 1 should be viewed as maximum acceptable values, with the recognition that in many cases the achievement of lower noise levels would result in even greater benefits to the community. Highway agencies are urged by FHWA to strive for noise levels below those listed in Table 1 where they can be achieved at reasonable cost and without undue difficulty, and where the benefits appear to clearly outweigh the costs and efforts required. (Para. 8, FHPM 7-7-3.)
- While the design noise levels apply only to lands which are developed on the date of public knowledge of the highway, the standards indicate that highway agencies may consider the desirability of applying them to undeveloped lands which are subject to development. In addition, highway agencies are to furnish local officials with approximate generalized noise

levels for various distances from the highway improvement and other information to assist and encourage local governments to develop and implement programs (such as zoning or subdivision control) to protect against future development which is incompatible with the expected noise levels along the highway.

The above conditions do not apply to areas that have, or are expected to have, limited human use, or where lower noise levels would result in little benefit. The exterior design noise levels apply to outdoor areas that have regular human use and where a lowered noise level would be of benefit to the public. The values do not apply to an entire tract upon which the activity is based, but only to that portion of which such activity normally occurs.

The interior design noise levels apply to:

1. Indoor activities for those parcels where no exterior noise-sensitive land use or activity is identified.

2. Those situations where the exterior activities on a tract are either remote from the highway or shielded in some manner so that the exterior activities will not be significantly affected by the noise, but the interior activities will.

The interior design noise level may be considered as a basis for "soundproofing" public-use institutional structures in special situations when, in the judgment of the highway agency and concurred in by the FHWA, such consideration is in the best interest of the public. Interior noise level predictions may be computed by subtracting from the predicted exterior levels the noise reduction factors for the building in question. If field measurements of these noise reduction factors are obtained (or if the factors are calculated from detailed acoustical analyses), the measured (or calculated) values shall be used. In the absence of field measurements, the noise reduction factors may be obtained from the following table:

Noise Reduction Factors For Interior Noise Level Predictions*

Building Type	Window Condition	Noise Reduction Due to Exterior of the Structure
All	Open	10 dB
Light Frame	Ordinary Sash (Closed)	20
	With Storm Windows	25
Masonry	Single Glazed	25
Masonry	Double Glazed	35

* Federal-Aid Highway Program Manual, Vol. 7, Chapter 7, Section 3

Note: Recent work performed by Wyle Laboratories ("Insulation of Buildings Against Highway Noise," FHWA Manual FHWA-TS-77-202) validates these values for their intended purpose.

Structures in climates where windows are open only a few days a year and structures with air conditioning will normally be considered as a closed-window condition. Situations where the open-window period does not coincide with a high noise level from the highway may qualify as a closed-window condition.

The standards do not guarantee the elimination of annoyance or disturbance from traffic noise even in those situations where the design noise levels are met. The standards are those noise levels established for various activities or land uses which represent the upper limit of acceptable traffic noise level conditions. These levels are used to determine the degree of noise impact on human activities. Occasional peak noises, such as those which occur from the passage of a few trucks per hour, will not be controlled. The reduction of these occasional noise peaks (and concurrent reduction of annoyance) will come when the appropriate governmental agencies provide for reduction of vehicle source noise levels, both through improved vehicle noise standards and enforcement of maximum operating noise limits. However, the standards of Table 1, if applied, can ensure that noise is given proper consideration in the development of highway projects.

Eligible Noise Abatement Projects

FHWA permits federal funds to be used on federal-aid highway projects for the abatement of traffic noise. The basis for the policy is to minimize adverse noise impacts. It is recognized that these impacts are often difficult to quantify, but their reduction is often justified in terms of the money spent.

Federal funds may be used for the construction of noise barriers and for the associated acquisition of necessary land or land rights. Federal funds may also be used to acquire lands (primarily undeveloped) as a preemptive buffer zone. Traffic operational measures such as truck routes and restriction of hours of operation are often feasible noise abatement measures. The increased costs of such measures are also eligible for federal funding. In special situations, the "soundproofing" of public-use institutional buildings may be incorporated in federal-aid highway projects to abate traffic noise. Current FHWA policy regarding the use of federal funds for private dwellings is that federal funds may be approved under the National Experimental and Evaluation Program (NEEP) Project No. 21 – Noise Insulation for Private Dwellings – based on the criteria established in FHPM 7-7-3, Paragraph 12a; i.e., "a traffic noise impact has been identified, the noise abatement measures will reduce the noise impact, and the overall noise abatement benefits are determined to outweigh the overall adverse social, economic, and environmental effects of the noise abatement measures. The requirements of Paragraph 12e need not be met; i.e., noise insulation may be implemented even if noise impact is not especially severe and other abatement measures are feasible."

3.2 HUD Building and Development Site Noise Standards

Background

In August of 1971, HUD published an innovative policy on noise abatement and control which indicated the Department's intent to deal in a new manner with the noise pollution problem. As set forth in HUD Circular 1390.2, this policy is directed toward

- Encouraging land utilization patterns for housing and other municipal needs that will separate uncontrollable noise sources from residential and other noise-sensitive areas; and
- Restricting HUD support for the construction of noise-sensitive development, particularly housing on new sites which are adversely exposed to noise.

HUD's policy is not to stop the building of needed housing, but rather to encourage construction in areas which constitute good residential environments. The focus of this policy lies in HUD's power to stop or alter plans for HUD-assisted housing construction wherever noise levels are high.

Standards

In discouraging the construction of new dwelling units on sites having excessive noise exposure, HUD has implemented the exterior noise standards which were established in the 1971 Circular. The standards set forth four noise level categories which are applied to the site of the proposed construction. The four categories are: Acceptable, Discretionary-Normally Acceptable, Discretionary-Normally Unacceptable, and Unacceptable. As set forth in the 1971 Circular, the Acceptable category represents an ideal goal. In actual practice, the Discretionary-Normally Acceptable category is used for acceptability criteria and is combined with the Acceptable category.

Approval of sites in the Unacceptable noise zone is strongly discouraged; only the Secretary of HUD can approve such sites after an Environmental Impact Statement has been filed. At the other extreme, there are no special requirements associated with the Acceptable noise zone, since sites in that zone are not considered to have a noise problem. In the Discretionary-Normally Unacceptable zone, approval requires noise attenuation measures, the Regional Administrator's concurrence, and a detailed environmental statement as defined by Section 102(2)C of PL 91-190 and implementing guidelines of the Council on Environmental Quality and HUD.

HUD realizes that in densely developed urban areas in particular, land available for development is scarce or is subject to a variety of constraints in development, so that the total housing needs of an area often cannot be accommodated without some development in areas impacted by noise. In such circumstances, approvals in Discretionary-Normally Unacceptable areas are authorized, but only to the extent that the area's housing needs cannot be reasonably accommodated in areas not exposed to noise.

The rules of discretion, as applied to HUD's noise policy, are designed to accommodate the Department's mandate to provide both a "decent home" and a "suitable environment" to American families. If it is truly a choice between housing with some noise, or no housing at all, then it is HUD's policy to assist the housing and to minimize the noise impact through noise attenuation measures. HUD only requires that the true extent of the trade-off between housing and noise be established.

Noise Reduction Features

In the past four years, since implementation of the noise policy, many instances have occurred in which noise attenuation measures have resulted in basic project design modifications and the incorporation of double-glazed windows, solid wood doors, air conditioning, and other acoustical features necessary to reduce and prevent the encroachment of noise upon the potential homeowner or apartment dweller. The additional cost of the noise reduction features is absorbed by the developer and ultimately by the buyer. Such costs can often be avoided or reduced by planning for noise and taking it into consideration in the earlier site selection and site planning stages of the project.

Clearly, this policy has made it advisable for local and area-wide agencies responsible for housing and land-use planning to conduct studies to establish a strategy for the location of housing in a land-use plan which accounts for noise as well as other environmental concerns. In the absence of a planning strategy which addresses noise, developers must document the need for the proposed noise-sensitive development in order to obtain HUD assistance. This can be a time-consuming process resulting in the rejection of some projects in areas exposed to noise, if alternative and less exposed sites exist or the lack of such sites has not been adequately established.

3.3 EPA Identified Levels

In March of 1974, EPA published a document entitled Information on Levels of Environmental Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety. The levels identified in this document are based solely upon public health and welfare considerations and are presented in Table 2. It is important to note that these levels were established without consideration of cost or feasibility, and hence they do not represent an agency standard. Unlike an agency standard, levels which are in excess of those identified may be appropriate in individual cases and no special procedures or exemptions are necessarily recommended. On the other hand, an adverse impact on the public health and welfare does exist for levels in excess of those identified and it is this impact which must be traded-off against the cost, feasibility of achievement, and the attainment of other objectives in making final decisions. These levels are therefore considered by the EPA as goals to be strived for, with the recognition that the time for actual achievement in individual cases will depend on a variety of other considerations.

Table 2

Summary of Noise Levels Identified As Requisite To Protect Public Health and Welfare With An Adequate Margin of Safety*

Effect	Level	Area
Hearing Loss	$L_{eq(24)} \leq 70$ dB	All areas
Outdoor Activity Interference and Annoyance	$L_{dn} \leq 55$ dB	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq(24)} \leq 55$ dB	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds, etc.
Indoor Activity Interference and Annoyance	$L_{dn} \leq 45$ dB	Indoor residential areas
	$L_{eq(24)} \leq 45$ dB	Other indoor areas with human activities such as schools, etc.

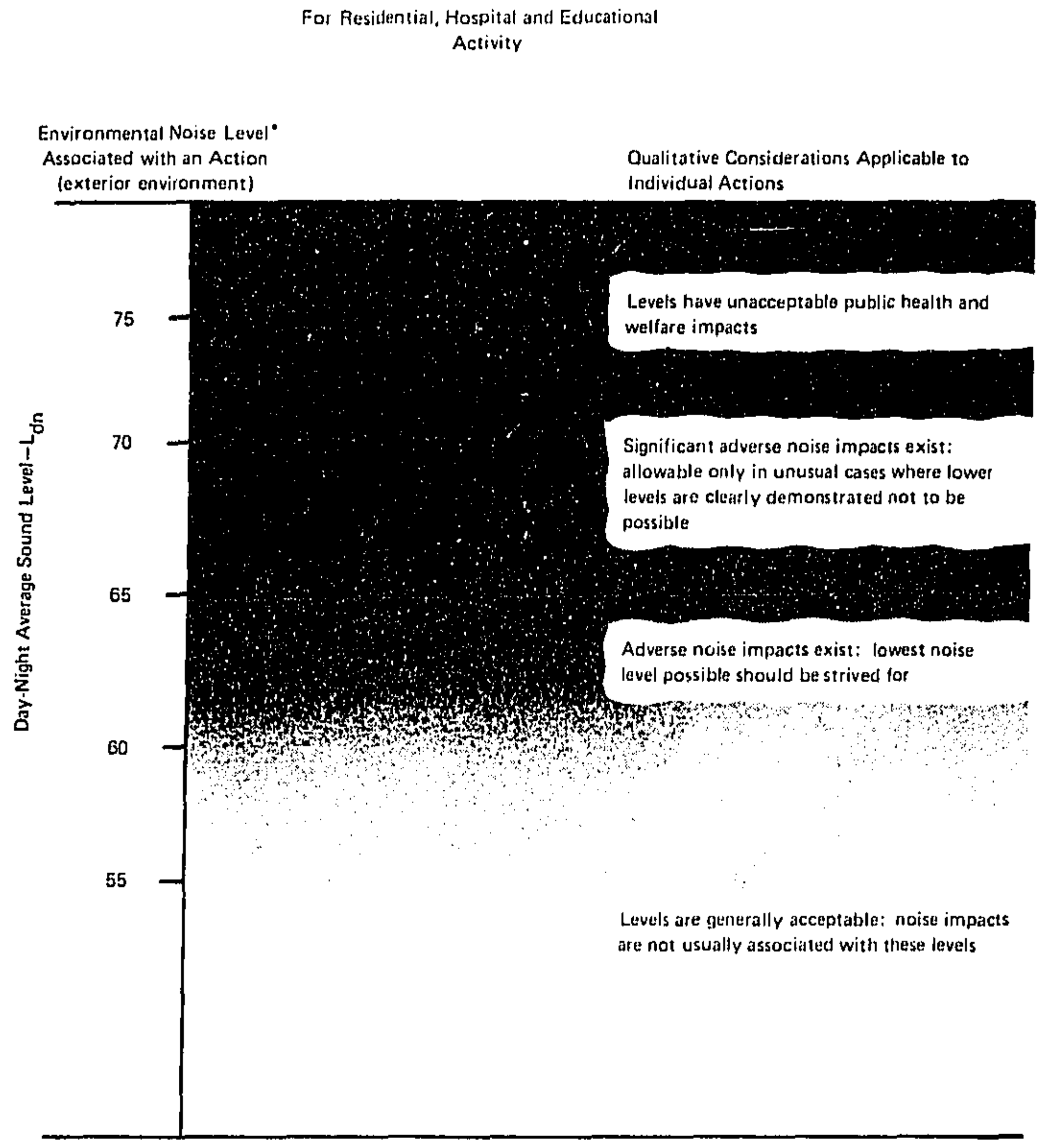
* "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety", Report No. 550/9-74-004, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, March 1974.

3.4 Land-Use Compatibility Guide

The use of land for compatibility with various noise environments is illustrated in Figure 1. The choice of the use is governed by the L_{dn} values describing the noise exposure. There is no universal method of rigidly interpreting requirements — this must be done on an individual basis with consideration for local constraints.

For most land uses, the compatibility interpretation for the lower L_{dn} values indicates that there are no special noise insulation requirements for new construction, and that there should be no adverse effects from transportation noise. Corresponding to higher levels of noise exposure, the interpretations generally define a range of noise exposure in which new construction or development should not be undertaken but could be allowed where restrictions are not possible due to local land development constraints. In such cases, an analysis of noise reduction requirements should be made and needed noise reduction features included in the site development and building design.

A major factor to be considered in determining noise requirements for a given land use is the local building construction. The quality and type of wall, window and roof constructions are among the most effective ways of reducing the number of noise leakage paths. This is one of the key areas of control by local authorities through local building and safety codes.



*Interior noise levels will depend on the building structure.

Figure 1. Representation of Land-Use Compatibility With Noise.

4.0 APPROACHES TO NOISE CONTROL

The federal policy requires that every reasonable effort be made to achieve substantial noise reductions when noise impacts are identified. However, any significant reduction in the existing or predicted noise levels will be a benefit, so that the inability to comply with the standards does not imply that noise abatement measures should not be incorporated. Thus, measures to achieve partial reductions in noise level shall be included in the project development where they are consistent with overall social, economic, and environmental considerations.

Furthermore, since the standards represent a balancing of that which is desirable and that which may be achievable, noise impacts can occur even though the standards are achieved. Accordingly, the standards should be viewed as maximum acceptable values recognizing that lower levels will result in an increase in community benefits. It is recommended that measures be introduced to reduce noise levels to values below those of the standards in cases where the benefits appear to outweigh the costs involved.

For a more detailed definition of federal policy, the reader is referred to Section 3 of this manual, or to the Federal Highway Program Manual, Vol. 7, Chapter 7, Section 3.

In order to control highway noise in the most effective manner, it is generally agreed that a three-part approach is needed. The elements of this approach are as follows:

1. Reduction of sound at the source (the motor vehicle).
2. Noise control measures in the planning and design of highway projects.
3. Control of the use of land in the vicinity of highways.

Each of these approaches will be discussed in detail in the following sections.

4.1 Reduction at the Source

The reduction of noise at the source — that is, on the vehicle itself — is potentially the most fruitful way to reduce the problems of motor vehicle noise. Whereas the application of other techniques, such as land planning and increased building insulation, may provide local abatement of noise, a quieter vehicle will produce lower noise levels wherever it travels. Also, quieter vehicles can provide a reduction of noise along existing highways where no other corrective measures are possible.

There are basically two methods available for reducing vehicle noise at the source, namely:

- Operational limits, where existing vehicles are required not to exceed a specified noise level. Vehicles producing levels below the limit would not be affected; those exceeding the limit must be brought into compliance by repair, retrofitting, or eliminating. A certain degree of non-compliance is inevitable and should be included in any assessment of the effectiveness.
- New vehicle limits, where new vehicles are required to meet specified noise standards. The standard for new vehicles can be substantially lower than an operational limit, because new technology is more readily incorporated into new vehicles than into existing ones.

Any realistic strategy must incorporate both types of limits. The operational limit alone does not provide for maximum use of new technology; new vehicle regulations alone do not provide for control of vehicles once they are in service. Strategies may also include lowering both types of limits with time, as noise control technology improves.

The Environmental Protection Agency (EPA) has promulgated noise emission standards for motor carriers currently engaged in interstate commerce, and FHWA/BMCS (Bureau of Motor Carrier Safety) has enforcement responsibility for these standards. EPA has also promulgated noise standards for newly manufactured medium and heavy duty trucks. In states where these laws (or similar prior state laws) have been actively enforced, reduced vehicle noise levels have been observed.

There is one important difference between the two methods for regulating vehicle noise levels. The operational noise limit is a limit to be met by all vehicles, and if properly enforced, will result in an immediate reduction in highway noise. The new vehicle noise standards only apply to the vehicles introduced into the fleet, and even though they might be much quieter than existing vehicles, the full effect is only obtained after many years of attrition of older vehicles. As a result, it might be assumed that the operational noise limit represents the optimum method of vehicle noise control. Unfortunately, it is quite difficult to significantly reduce the noise levels of existing vehicles – some of which may be 10 years old – without considerable expense. Accordingly, the benefits to be obtained from vehicle noise reduction will not be fully realized for many years.

An alternative method of reducing vehicle noise at the source is to modify the operation of the vehicle. Although this is actually a highway design or operating approach, its effect is the same as a source reduction, and is therefore treated here. There are two ways in which this can be achieved:

- Reducing Truck Traffic

  Restricting the number of trucks operating on the highway can be a very effective solution to high noise levels. Table 3 shows the effect for speeds of 35 and 55 miles per hour (mph). For example, a change from 15 to 5 percent truck traffic traveling at 55 mph will result in a decrease of about 4 dB in overall highway noise. Completely eliminating trucks on specific roads through the use of alternate truck routes in compatible areas would result in a decrease of 8.5 dB. Even greater reductions can be obtained in speed zones of 35 mph.

- Reducing Truck Speed

  Highway noise levels can also be reduced by limiting the speed of trucks. This is useful only on high-speed roads where tire noise dominates and is reduced with decreasing speed. The reduction in overall highway noise is given in Table 4.

Tables 3 and 4 can be used to determine the change in highway noise levels resulting from changes in truck flow and speed. For example, if the existing truck percentage is 20%, traveling at 55 mph, the effect of reducing the percentage to 10% and the speed to 35 mph can be obtained as follows:

- Find the reduction in noise level due to a change in truck percentage from 20% to 10% at 55 mph from Table 3 (= 2.5 dB).
- Find the reduction in noise level due to a reduction in truck speed from 55 mph to 45 mph at the new percentage of 10% from Table 4 (= 1 dB).
- Find the total change in highway noise level by direct addition (= 3.5 dB).

Table 3

The Effect on Highway Noise Levels of Reducing Truck Traffic

If the Change in Truck Percentage is from:	Then the Reduction in Highway Noise Level (L_{eq} or L_{dn}) in dB is:*	
	35 mph	55 mph
20% to 15%	1	1
15% to 10%	1.5	1.5
10% to 5%	2.5	2.5
5% to 0%	6.5	4.5

* The reductions in these columns are additive, so that, for example, the reduction in highway noise level resulting from a change in truck percentage from 20% to 5% at 35 mph is 1 + 1.5 + 2.5 = 5 dB

Table 4

The Effect on Highway Noise Levels of Reducing Truck Speed

Change in Truck Speed (mph) From — To	Approximate Reduction in Highway Noise Level (L_{eq} or L_{dn}) dB		
	Truck Mix		
	5%	10%	20%
65 — 55	0.5	1.0	1.5
65 — 45	1.0	1.5	2.0
65 — 35	2.0	3.0	3.0
55 — 45	1.0	1.0	1.0
55 — 35	1.0	2.0	2.0
45 — 35	1.0	1.0	1.0

4.2 Noise Control in Highway Planning and Design

The second part of the three-part approach is the abatement of traffic noise in the planning and design of highway projects. A consideration of this approach is required by the FHWA noise policy before federal funds can be allocated to a highway project. The methods of abatement that are available include the selection of highway location, the depression of the roadway, the introduction of barriers, and the soundproofing of buildings. The effect of each of the road design methods can be determined by the procedures described in Appendices A and B.

In the planning and design phase, the following factors should be considered:

- An effective measure for minimizing noise impact involves adjustment of the alignment to avoid sensitive receptors, such as schools, hospitals, and residential areas.
- Since the topography of an area may be used in some instances to reduce noise, horizontal adjustments may be appropriate in order to take advantage of shielding by existing terrain.
- Adjustments to the profile and cross-section may effectively reduce noise. While elevated facilities generally have a limited ability to contain noise, the knee of the slope may act as a barrier which satisfactorily reduces noise levels at adjacent receptors. However, a more effective vertical adjustment of the alignment involves depression of the roadway. Depressed alignments, particularly those between deep retaining walls or with covers, are effective means of containing noise.
- Other design considerations include the modification of roadway gradients. Steeper gradients will normally increase traffic noise levels.

4.2.1 Barriers

An alternative to either source noise reduction or receiver protection consists of the incorporation of acoustic barriers between the noise and the receiver. Barriers are generally considered to be feasible only along major highways with long, uninterrupted stretches of road. Barriers are not usually considered for local streets due to the many interruptions that would occur for crossing streets.

While much literature is available on the theoretical effectiveness of noise barriers, the basic consideration remains the effective height of the barrier relative to the line of sight between the source and the receiver. Barriers have been designed to provide attenuation over the range from 5 to 15 dBA, with the median value being 10 dBA. The 15 dBA value represents the maximum practical design limit.* The cost of barriers varies greatly not only with the type of material used, but also with the location and the existing ground surface.

The attenuation provided by a barrier is dependent on the geometry of the source-barrier-receiver system, and can be incorporated into the noise assessment by means of the nomogram procedure given in Appendix B.

The material used for constructing the barrier must be selected so that the transmission of sound through the barrier is much less than that diffracted over the top. In general, this can be achieved by ensuring that the mass of the barrier material is at least:

- 1.3 lbs/ft^2 for an attenuation of 5 dB.
- 2.3 lbs/ft^2 for an attenuation of 10 dB.
- 4.0 lbs/ft^2 for an attenuation of 15 dB.

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* Snow, C.H., "Highway Noise Barrier Selection, Design and Construction Experiences, A State-of-the-Art Report – 1975", U.S. Department of Transportation, FHWA Implementation Package 76-8.

4.2.2 Noise Reduction at the Receiver — Dwelling Modifications

For ground transportation noise sources, it may be possible to achieve desired interior noise levels through treatment only of walls facing the source. The soundproofing treatments and the relative effort involved in these modifications are summarized below under the categories of minor, moderate, and major dwelling modifications.

Minor Dwelling Modifications

Through attenuation to details such as minimization of "sound leaks" around doors, windows, and vents and replacement of "acoustically weak" components, outside to inside noise reduction of A-weighted noise levels on the order of 25 to 30 dB is obtainable. These improvements consist primarily of adequate weatherstripping around doors, assurance of snug-fitting doors and windows, elimination of louvered windows and treatment of exterior vents (chimneys and kitchen or bathroom fans, in particular). In addition, exterior hollow-core doors need to be replaced with the solid-core variety. This treatment essentially ensures that the noise reduction provided by the dwelling structure is up to the performance capabilities of the building elements and is not affected by leaks, etc.

Moderate Dwelling Modifications

Moderate modifications would include all of those listed under "minor" plus major attention to the weakest housing components — namely, windows. The most effective window treatments consist of double glazing or sealed windows. In both cases, this usually necessitates the installation of a mechanical ventilating system or air conditioner in the dwelling, if it is not already done. Additional attention is given to the attic by acoustical treatment of attic vents, increased sound absorption material (hence, better heat insulation) in the attic space, and when required, finishing the crawl space areas with gypsumboard. Such treatments will produce overall sound insulation on the order of 30 to 35 dB for A-weighted noise levels.

Major Dwelling Modifications

Major modifications consist of all items under "minor" and "moderate", plus some structural improvements of weak walls and roofs. These changes would include elimination or suitable modification of exposed beam roof/ceiling designs and a general "beefing up" of exterior walls. Sufficient exterior wall improvement may normally be attained by installation of an extra layer of gypsum board on the interior surfaces over sheets of sound-deadening board or by securing it to resilient channels. Where possible, double-entry doors or vestibule entrances could be incorporated. In lieu of these, "acoustic" doors are required. Improvements in sound insulation available from these changes may yield noise reductions on the order of 40 dB for A-weighted noise levels.

The cost of modifying dwellings depends on the construction type, the geographical area and the degree of noise reduction required. For minor and moderate modifications, the noise reduction can be increased by 4 to 9 dB at a cost (in 1976 dollars) of between $3 to $7 per square foot of dwelling area. Major modifications that can increase the noise reduction by up to 15 dB cost about $14 per square foot. These cost figures are intended as a guideline only and must be estimated on an individual basis.

In view of the expense involved, it is recommended that this approach be considered only as a last resort – particularly since the exterior noise environment remains unaffected.

To achieve compatible land use through improved sound insulation in building structures, it is necessary to amend the building code to achieve two objectives:

- Incorporate adequate exterior to interior noise reduction in new construction to abate external noise, and
- Establish minimum requirements for internal noise reduction in multi-family dwellings, hotels, and motels to achieve desired acoustical privacy.

Both of these changes provide a legal basis for noise abatement which is of direct benefit to the people and is not costly to implement.

An important aspect in the application of noise control techniques to houses is the fact that the sound levels at various points around the outside of a house will differ by virtue of the acoustic shielding provided by the house structure itself against the noise source. This is similar to the formation of a shadow in the case of light. It is possible to make use of this effect in soundproofing since the shielding is equivalent to an increase in attenuation of the shielded wall or window. Thus, the shielded elements of a house are not required to provide the same degree of attenuation as are the unshielded walls.

For highway noise sources, this self-shielding will reduce by about 10 dB the noise levels on wall surfaces facing directly away from the traffic. The shielding for the side walls is usually in the neighborhood of 3 dB.

4.3 Land Use

The third part of a balanced attack on highway noise is control over the use of land in the immediate vicinity of the highway. This does not necessarily mean that this land remain vacant. Many commercial and industrial activities can exist within a moderately noisy environment, and many other types of activities can be accommodated through proper site location, building design, and acoustical treatment (soundproofing).

Often, complaints about highway traffic noise come from residents occupying homes built adjacent to a highway after the highway was already built. Many of these highways were originally constructed through undeveloped lands. Even though highway agencies may be knowledgeable about existing zoning and planning, they are not able to control when and where future development will occur, what such development will be, and the degree of "soundproofing" that will be built into future buildings. Moreover, there are existing highways which are bordered by vacant land which will someday be developed. Sensible land use control implemented at an early stage can help prevent future traffic noise conflicts in these areas. Such controls need not prohibit development; rather, they should utilize reasonable setback distances, appropriate zoning, or other previously discussed abatement measures to avoid future noise disturbances.

Federal funds may be used in the acquisition of real property or interests therein (predominantly unimproved property) to serve as a buffer zone to preempt development which would be adversely impacted by traffic noise and for other noise abatement purposes. Acquisition of a few improved parcels may be included in such buffer zone acquisitions to provide a uniform treatment. Further, it is preferred that buffer zone acquisition be performed in conjunction with local zoning, land use controls, or other local government controls imposed or exercised in accordance with a comprehensive plan. Additional details regarding FHWA land acquisition policy may be found in the FHWA Federal-Aid Highway Program Manual 7-7-3, Paragraph 12b(5).

4.4 Evaluation of Proposed Measures

The steps involved in the evaluation of noise abatement methods are as follows:

1. Determine the amount of noise reduction required to satisfy the noise standards.

2. Assess the noise reduction that can be achieved by the methods proposed in the EIS. For this purpose, calculation methods are contained in Appendices A and B and earlier parts of Section 4.0. Appendices A and B contain the basic method for calculating highway noise levels; Section 4.0 contains information suitable for determining the effectiveness of abatement methods. Discrepancies between the predicted amounts of reduction should be resolved with the persons responsible for preparing the EIS.

3. Evaluate the methods proposed against the reduction required.

4. Identify alternative or additional measures that are suitable for implementing the federal policy of noise abatement.

APPENDIX A

Highway Noise Nomogram Procedure*

The procedure for computing highway noise levels involves the use of nomograms, which, when entered and read properly, allow easy use of the relationships between highway noise variables to determine values of L_{eq}. The step-by-step procedure involves a determination of L_{eq} for a straight roadway segment at a single observer position.

- The procedure is directly applicable to straight road elements. A curved road may be considered to be straight if it deviates from straight by less than 10 percent of the observer distance, D, for a distance ±5D (or the section length if less) from the nearest point. This tolerance is illustrated in Figure A-1. Treatment of roads with greater curvature is discussed later.

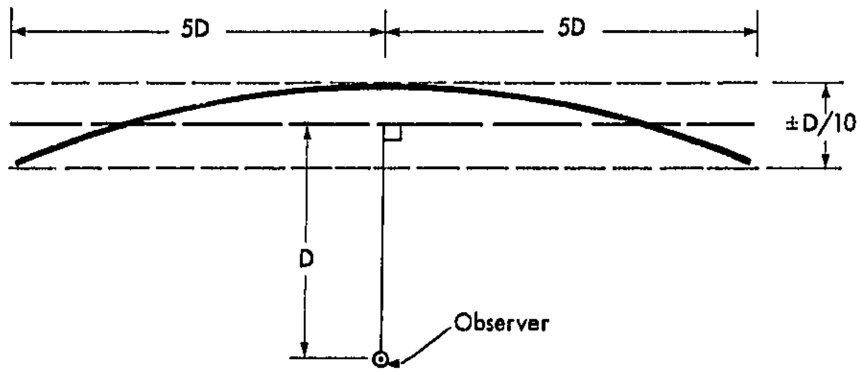


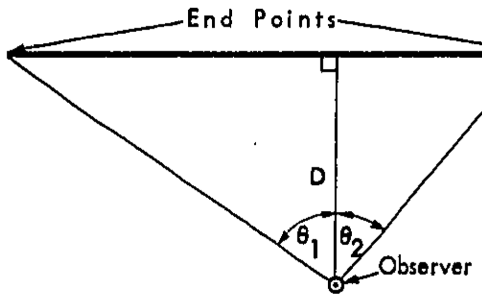
Figure A-1. Permissible Curvature for Approximately Straight Roads.

- If more than one roadway is present, then the noise level from each roadway must be computed separately by using the nomogram procedure. The perpendicular distance from the observer to each roadway must always be taken.

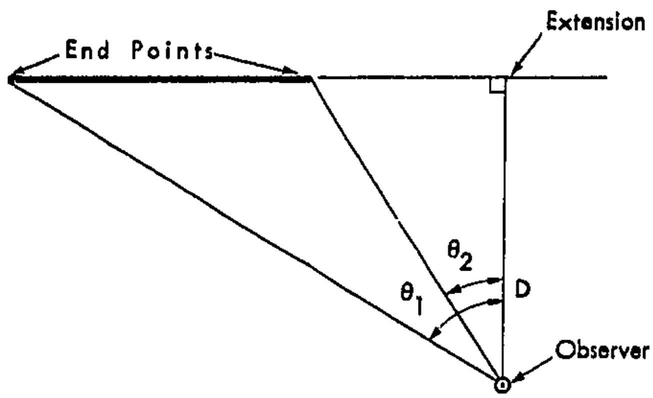
---

* See Appendix C for documentation and validation of this procedure.

- Finite road elements are defined by the angles θ_1 and θ_2, as shown in Figure A-2. If the observer does not lie between the end points, the observer distance D is measured perpendicular to an extension of the section, as shown in Figure A-2b.



a. Observer Between End Points.



b. Observer Not Between End Points. The smaller of the angles (θ_2 in this case) is given a minus sign.

Figure A-2. Geometry and Angle Definitions for Finite Road Elements.

- A curved road may be divided into two or more approximately straight elements, each with tolerances as shown in Figure A-1. An example is shown in Figure A-3. For each section, the observer distance, D, is measured perpendicular to the section or its extension.

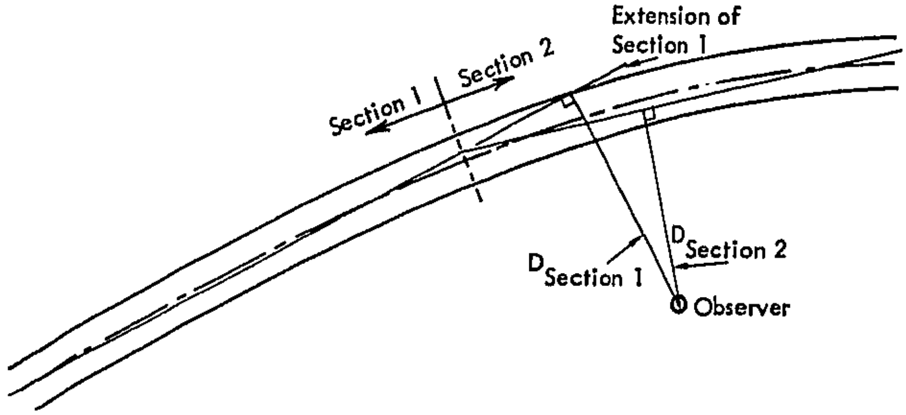


Figure A-3. Curved Roadway Approximated by Two Straight Sections

- After all of the roadways and/or sections have been accounted for and the resulting L_{eq}'s have been tabulated, the total L_{eq} is obtained by combining the individual values, using Nomogram A5, as shown in the procedure.

- If L_{dn} is being calculated for a highway section or sections, then separate L_{eq}'s must be determined for the daytime hours (L_d, 0700-2200) and the nighttime hours (L_n, 2200-0700). L_{dn} can then be obtained from Tables A1 and A2.

- If L_{eq} is desired at more than one single observation point, then the entire step-by-step procedure must be repeated for each additional observer position. (The user will note, however, that a good number of the steps are independent of observer position, so the procedure is not as complicated as it may initially seem.)

Table A1

Method for Calculating L_{dn} from L_d and L_n

If the Value of $L_d - L_n$ is:	Then Add this Number to L_d to Determine L_{dn}:
-4 dB	10 dB
-2	8
0	6.5
2	5
4	3.5
6	2
8	1
10	0
12	-0.5
14	-1
16	-1.5

Table A2

Method of Calculating L_{dn} from L_{eq} When the Day/Night Traffic Percentage is Known

If the Percentage of 24-Hour Traffic Passing During Daytime Hours Is:	Then Add this Number to $L_{eq\ (24)}$ to Determine L_{dn}:
100 %	0 dB
95	1.5
90	3
85	3.5
80	4.5
70	5.5
60	6.5
50	7.5
40	8

Table A3 lists required input data, and specifies units. Table A4 defines symbols used in the calculation procedure, and indicates the step in which they are defined. Figure A4 shows the dimensions defined in Table A3.

The procedure in this appendix is to be used only if a clear line-of-sight exists between the observer and the road surface. If this line-of-sight data does not exist, then the barrier procedure given in Appendix B must be followed.

The nomogram calculation procedure consists of the following steps, with a running numerical example following each of the steps. Worksheet A, shown on page A7, may be used to record the input data and the values obtained along each step of the nomogram procedure.

If a calculator with common logarithm, antilogarithm, and square root functions is available, some users may find it more convenient to calculate quantities. Where a simple equation exists, it is shown on the nomogram.

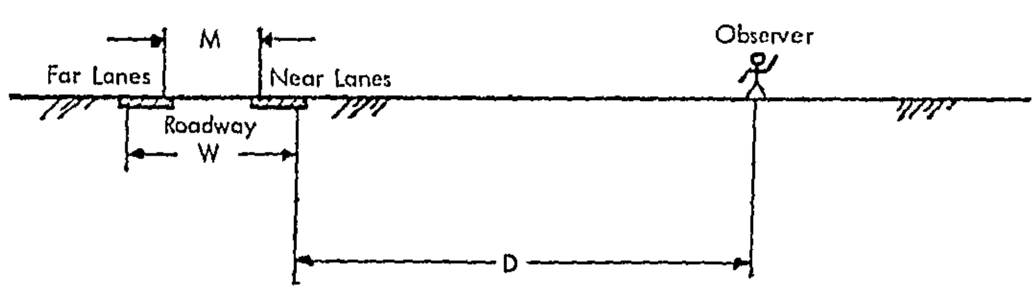


Figure A4. Roadway Dimensions

Table A3

Input Quantities Used in the Nomogram Procedure for Computing Highway Noise Levels

Variable	Meaning	Units
S	Average speed (if not available, use posted limit)	mph
Q	Total vehicle flow [1]	vehicles/hr
T	Truck flow [1]	trucks/hr
M	Distance between centerlines of inner (left) lanes	feet
W	Distance between centerlines of outer (right) lanes	feet
D	Distance from point of measurement to centerline of nearest lane	feet
G	Roadway grade	percent
θ_1, θ_2	Angles defining road section ends	degrees

[1] If L_{dn} is being calculated, separate values are needed for the hours of 7AM to 10 PM, and 10PM to 7AM.

Table A4

Symbols Used in the Highway Noise Nomogram Method

Variable	Meaning	Units	Step Number In Which Variable Is Defined
L	Base Noise Level	dB	1
t	Percentage of Trucks	percent	2
GF	Grade Factor	---	2
E	Effective Truck Percentage	percent	2
Δ_T	Truck Noise Increment	dB	3
Δ_D	Distance Adjustment	dB	4
Δ_W	Road Width Correction	dB	5

WORKSHEET A

NOMOGRAM PROCEDURE FOR COMPUTING HIGHWAY NOISE LEVELS
(See Text for Step-by-Step Instructions)

REQUIRED DATA

Average Speed,	S =	______ mph
Total Vehicles Per Hour,	Q =	______ per hour
Trucks Per Hour,	T =	______ per hour
Distance Between Centerlines of Inner Lanes,	M =	______ ft
Distance Between Centerlines of Outer Lanes,	W =	______ ft
Distance from Observer to Centerline of Nearest Lane,	D =	______ ft
Roadway Grade,	G =	______ %
Angles Defining Road Section Ends,	θ_1 =	______ degrees
	θ_2 =	______ degrees

STEP 1

L = ______ dBA

STEP 2

$t = \frac{T}{Q} \times 100 =$ ______ %

E = t x (GF = ______) = ______ %

STEP 3

Δ_T = ______ dB

STEP 4

Δ_D = ______ dB

STEP 5

$\frac{M}{W}$ = ______

$\frac{W}{D}$ = ______

Δ_W = ______ dB

STEP 6

L_{eq} = (Δ_T = ______) + (Δ_D = ______) + (Δ_W = ______) = ______ dB
(from STEP 3) (from STEP 4) (from STEP 5)

STEP 7 If $\theta_1 = \theta_2 = 90°$, use L_{eq} from STEP 6 and terminate procedure.

θ_1 = ______ Δ_{A_1} = ______ dB

θ_2 = ______ Δ_{A_2} = ______ dB

L_{eq_1} = (L_{eq} = ______) -3 + Δ_{A_1} = ______ dB
(from STEP 6)

L_{eq_2} = (L_{eq} = ______) -3 + Δ_{A_2} = ______ dB
(from STEP 6)

STEP 8

(L_{eq_1} = ______) + (L_{eq_2} = ______) = ______ dB
(from STEP 7) (from STEP 7)

(NOTE: L_{eq_1} must be larger than L_{eq_2}; if not, reverse them.)

Combined L_{eq} = ______ dB

STEP 1 Enter Nomogram A1 with Q and S to obtain the base noise level, L.

(Example: For Q = 6000/hour and S = 55 mph, L = 75.5 dBA)

STEP 2 Calculate the truck percentage, t, by dividing Q into T and then multiplying by 100. Enter Table A5 with the roadway grade, G, to obtain the grade factor GF. Multiply the truck percentage, t, by the grade factor, GF, to determine the effective truck percentage, E.

(Example: For T = 300/hour, t = 5%. For G = 2%, GF = 1.4 or that E = 7.0)

Table A5

Roadway Grade and Grade Factors

Roadway Grade, G	Grade Factor, GF
< 2%	1
2 to 6%	1.4
> 6%	2

STEP 3 Enter Nomogram A2 with S and E to obtain the truck noise increment Δ_T.

(Example: Δ_T = +6 dB)

STEP 4 Enter Nomogram A3 with D to obtain the distance correction Δ_D. In typical cases where propagation is over the ground, the scale marked "Over Ground" is to be used. This scale includes normal ground absorption. Where the geometry is such that ground absorption does not occur (as described on the nomogram), the scale marked "Free Space" is used. The free space scale is also used in the barrier calculation described in Appendix B.

(Example: For D = 200 ft, Δ_D = -8.3 dB)

STEP 5 Enter Nomogram A4 with M/W and W/D to obtain the road width correction factor, Δ_W.

(Example: For M = 32 ft and W = 80 ft, M/W = 0.4 and W/D = 0.4 From Nomogram A4, $\Delta_W = -1$ dB)

STEP 6 Determine the equivalent noise level, L_{eq}, by adding the three corrections to L:

$$L_{eq} = L + \Delta_T + \Delta_D + \Delta_W$$

Note: The correction factors Δ_D and Δ_W are always zero or negative.

(Example: $L_{eq} = 75.5 + 6 - 8 - 1 = 72.5$ dBA)

Note: As a result of vehicle noise regulations, the individual noise levels of vehicles will decrease with time. The effect of this reduction can be taken into account by correction factors applied to L_{eq}, as described in Appendix D.

STEP 7 If θ_1 and θ_2 are not each 90° (an assumed infinite road), a correction Δ_A must be applied. Table A6 gives this correction for a symmetric road with half angle $\theta = \theta_1 = \theta_2$. For $\theta_1 \neq \theta_2$, divide the road into two parts at $\theta = 0$. Subtract 3 dB from L_{eq} to get the noise for each half, add Δ_A from Table A6 to the resulting levels for each half, then combine the sections as per STEP 8.

(Example: $\theta_1 = \theta_2 = 90°$, $\Delta_{A_1} = \Delta_{A_2} = 0$. Use L_{eq} from STEP 6 and terminate procedure)

(Example: $\theta_1 = 60°$, $\Delta_{A_1} = -1.2$,
$\theta_2 = 40°$, $\Delta_{A_2} = -2.8$,
$L_{eq} = 72.5 - 3\text{ dB} = 69.5$
$L_{eq_1} = 69.5 + (-1.2) = 68.3$
$L_{eq_2} = 69.5 + (-2.8) = 66.7$)

Table A6

Half Angle θ and Correction Factor Δ_A

If the Half Angle θ is:	Then the Value of Δ_A in dB is:
10°	-8.7
20°	-5.7
30°	-4.0
40°	-2.8
50°	-1.9
60°	-1.2
70°	-0.7
80°	-0.3
90°	0

STEP 8 If the highway is divided into sections, or if there is more than one highway, then the noise levels associated with each are combined. Enter Nomogram 5 with L_{eq_1} and $L_{eq_1} - L_{eq_2}$. If there are more than two sections and/or highways, Nomogram A5 is repeatedly applied to combine each L_{eq} to a running total. This completes the nomogram procedure.

(Example: $L_{eq_1} = 73$, $L_{eq_2} = 68$, $L_{eq_3} = 70$. Combine L_{eq_1} and L_{eq_2} to obtain 74.2; combine this with L_{eq_3} to obtain 75.6)

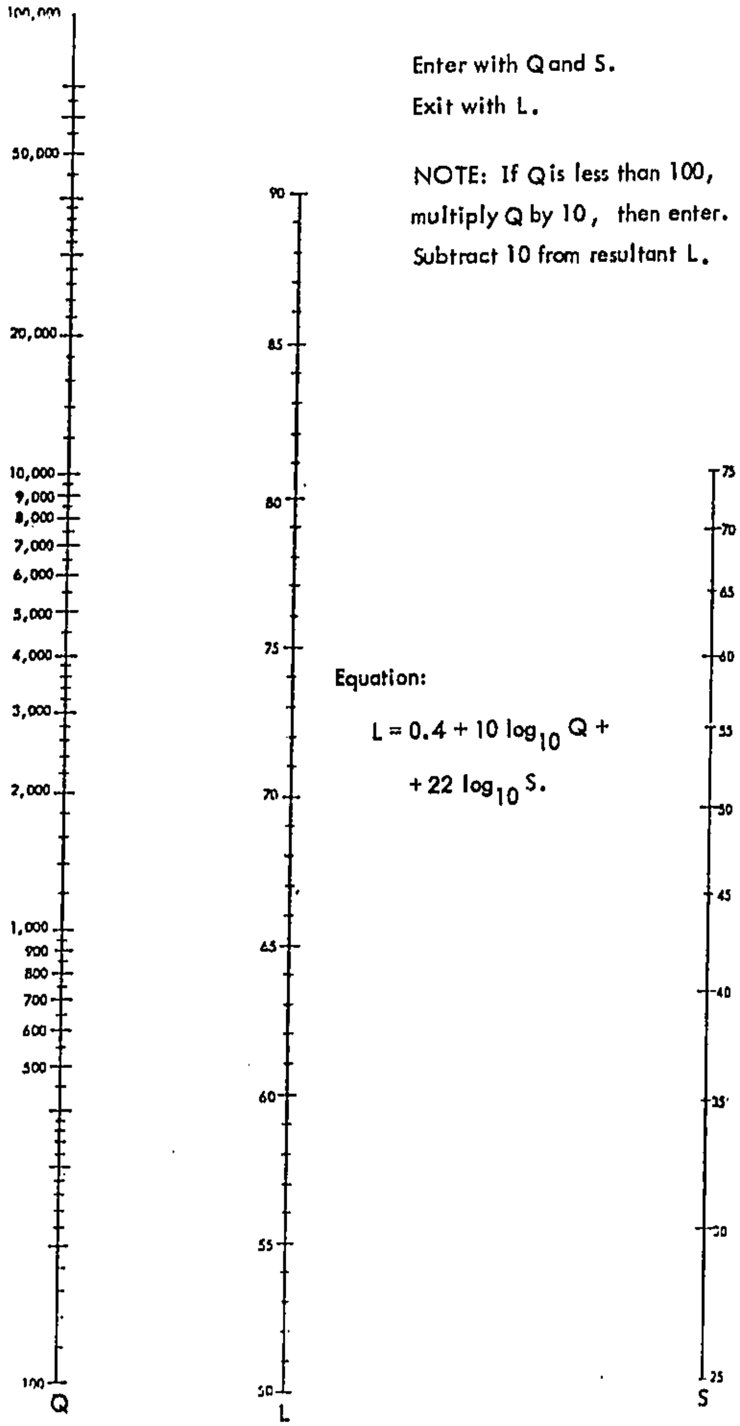
If the geometry of a finite road element is such that one angle is negative (as in Figure A-2b), Nomogram A5 must be used "backwards" to subtract the negative portion. Considering $\theta_1 > \theta_2$, and denoting the respective L_{eq}'s by L'_{eq_1} and L'_{eq_2}, there are two cases:

1. $L'_{eq_1} - L'_{eq_2} > 3$ dB. Enter Nomogram A5 with L'_{eq_1} on the $L_{eq_{total}}$ scale, and adjust the straightedge such that $L'_{eq_2} + \Delta$ equals the value on the L_{eq_2} scale. This value on the L_{eq_2} scale is the answer.

2. $L'_{eq_1} - L'_{eq_2} < 3$ dB. Enter Nomogram A5 with L'_{eq_1} on the $L_{eq_{total}}$ scale, and L'_{eq_2} on the L_{eq_1} scale. Subtract the resultant Δ from L'_{eq_2} to obtain the answer.

Alternately, the equation may be used replacing the plus sign with a minus sign.

In some cases, the highway or the local terrain may be too complex to be treated by the simple nomogram method which can only handle fairly orthodox configurations. It will therefore be necessary to resort to a computerized method of calculation that can account for these situations. Available methods are described in Appendix C.



Nomogram A1. Calculation of Base Noise Level, L.

Equation:

$$\Delta_T = 10\log_{10}\left[\left(1-\frac{E}{100}\right)+\frac{E}{100}\,a\left(\frac{S}{65}\right)^{-b}\right]$$

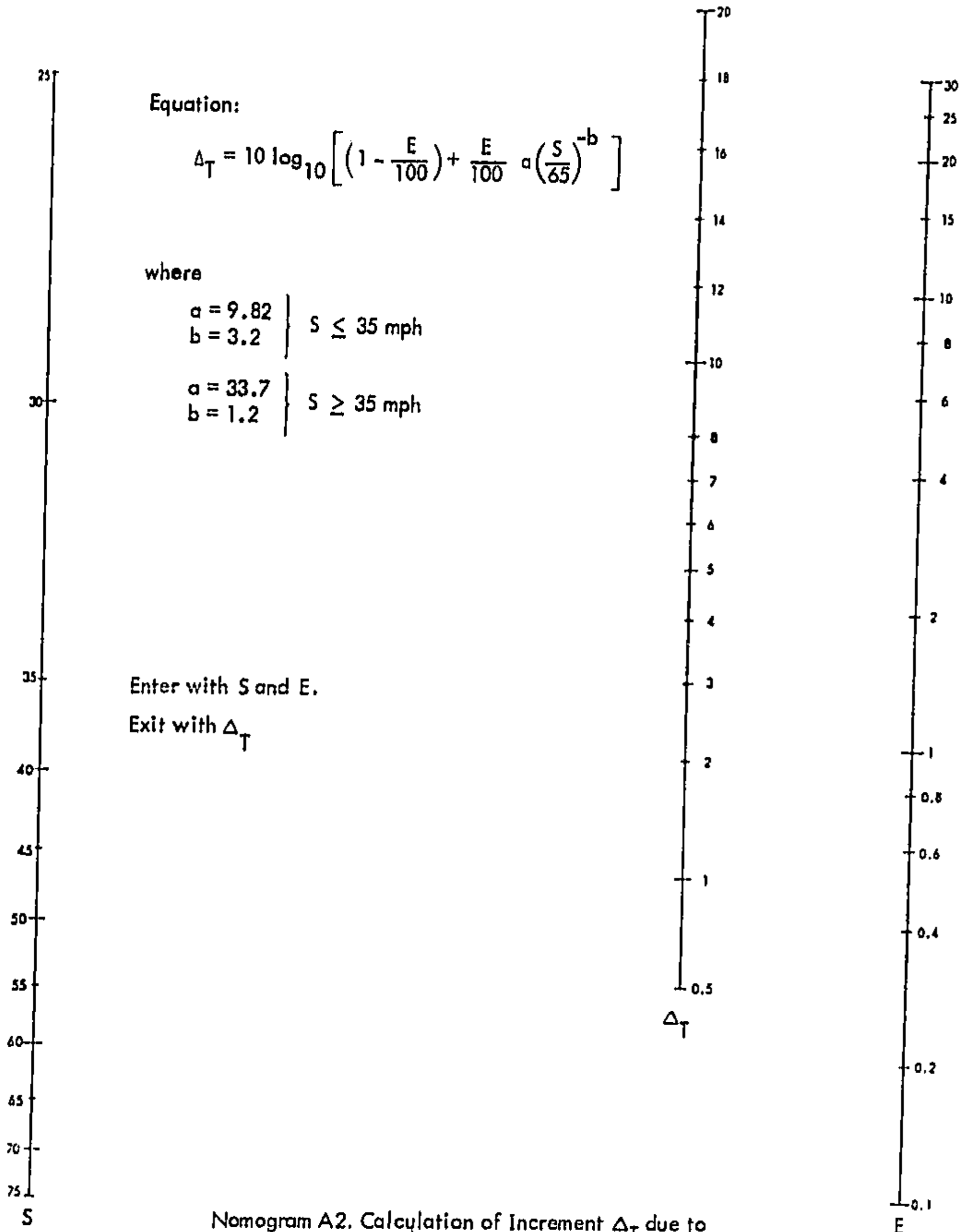
where

$$\left.\begin{array}{l} a = 9.82 \\ b = 3.2 \end{array}\right\} \; S \le 35 \text{ mph}$$

$$\left.\begin{array}{l} a = 33.7 \\ b = 1.2 \end{array}\right\} \; S \ge 35 \text{ mph}$$

Enter with S and E.

Exit with Δ_T

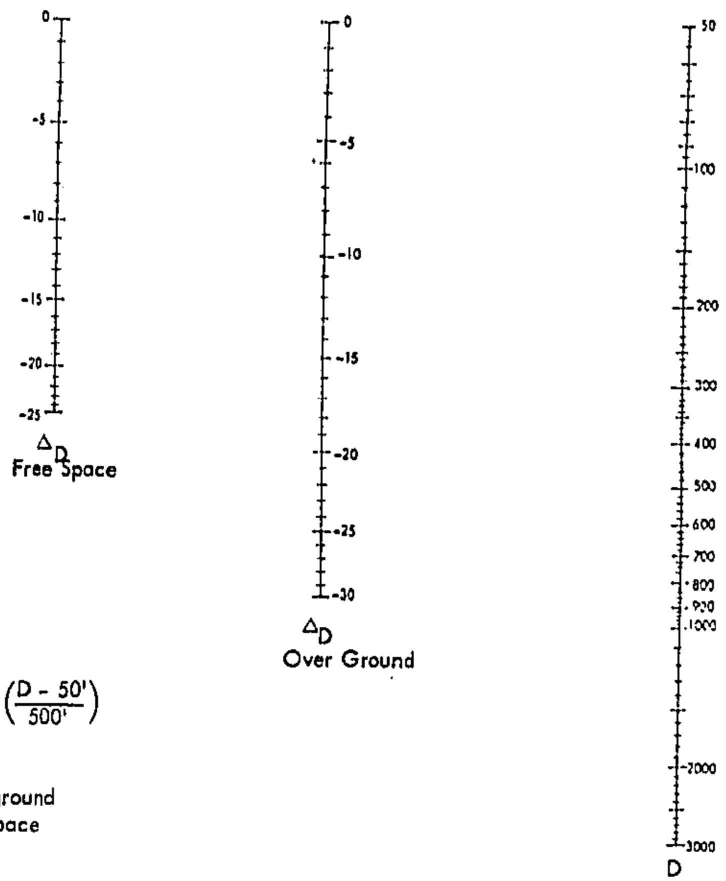


Nomogram A2. Calculation of Increment Δ_T due to Truck Traffic.

P

Enter with D, using Pivot Point P
Exit with Δ_D

Use "Free Space" Δ_D scale if the angle between the line of sight from the road surface to the observer and the terrain is 10 degrees or greater. This scale is also used for barrier calculations. (See Appendix B).



Equation:

$$\Delta_D = -a \log_{10}\left(\frac{D}{50'}\right) - \left(\frac{D - 50'}{500'}\right)$$

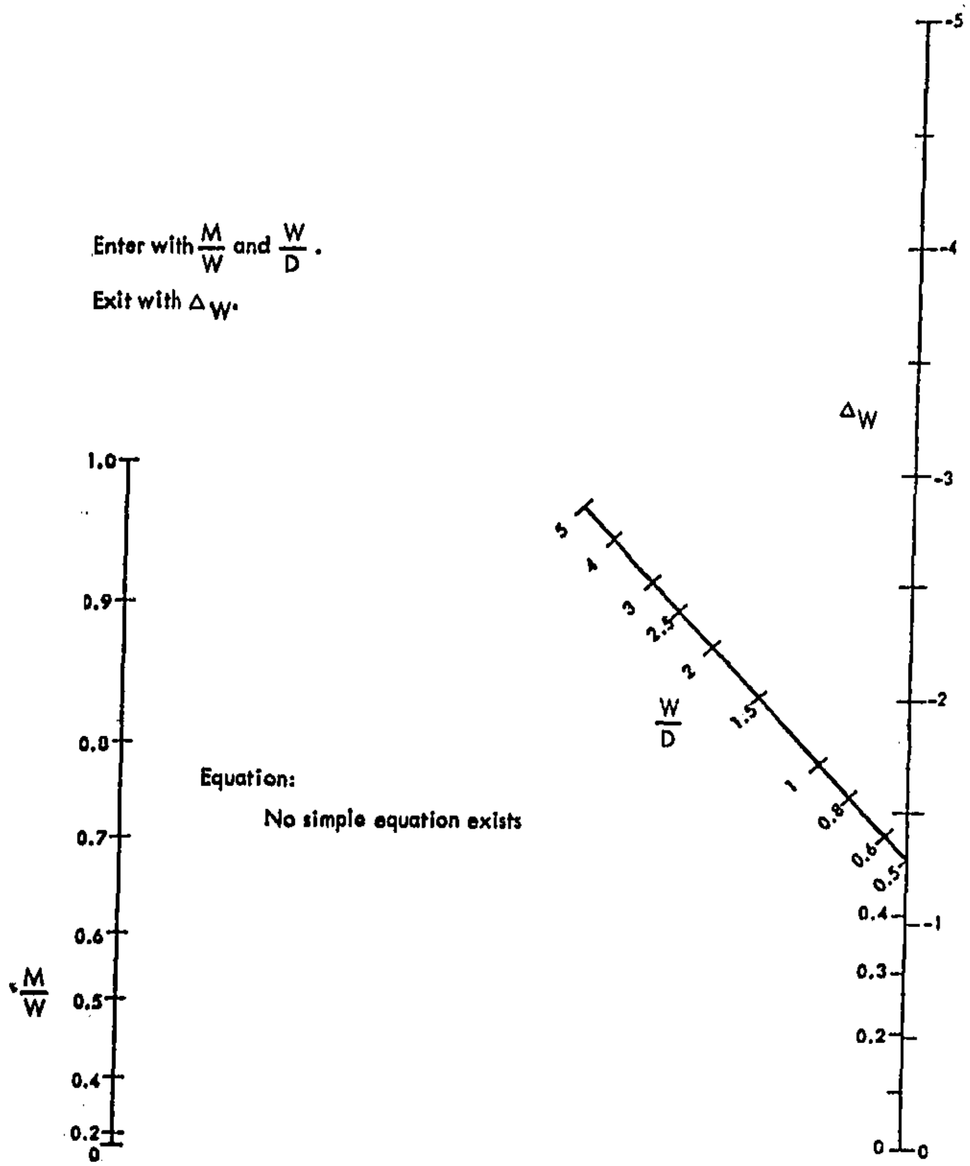
where

$$a = \begin{cases} 13.3, & \text{over ground} \\ 10.0, & \text{free space} \end{cases}$$

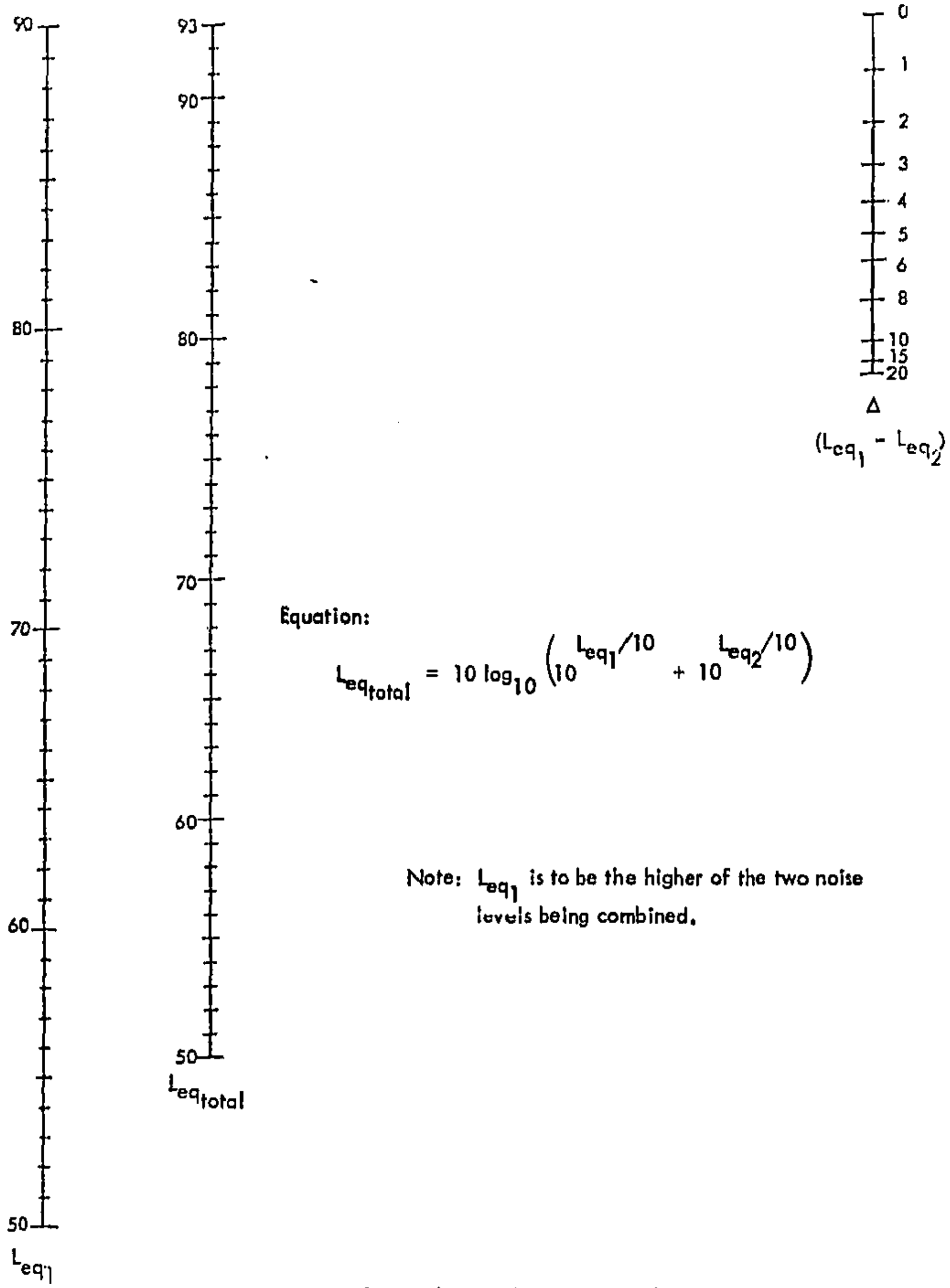
Nomogram A3. Calculation of Correction Δ_D for Distance.

Enter with $\frac{M}{W}$ and $\frac{W}{D}$.
Exit with Δ_W.

Equation:
No simple equation exists



Nomogram A4. Calculation of Correction Factor Δ_W for Road Geometry.



Equation:

$$L_{eq_{total}} = 10 \log_{10} \left(10^{L_{eq_1}/10} + 10^{L_{eq_2}/10} \right)$$

Note: L_{eq_1} is to be the higher of the two noise levels being combined.

Nomogram A5. Nomogram for Combining the Noise Levels from Two Highways

APPENDIX B

Barrier Nomogram Procedure

If there is a barrier alongside the highway, or if the highway is depressed, the result will generally be a reduction in noise level. The effect of the barrier will be different for cars and trucks because of the different noise characteristics and noise source locations and the two types of vehicles. The barrier effect is incorporated into the highway noise nomogram procedure presented in Appendix A by the mechanism of modifying the actual number of cars and trucks in order to achieve the applicable noise reduction. If there is more than one traffic lane, the following procedure must be applied to adjust the car and truck volumes in each lane. If many lanes are involved, the calculation can be lengthy. Simplifications in the procedure are not feasible, however, because shielding is very dependent on the geometry. Unacceptably large errors could result if lanes were grouped.

Data required for the barrier calculation, in addition to that specified in Appendix A, are listed in Table B1. Additional quantities used in the procedure are listed in Table B2. Figure B-1 illustrates a highway-barrier situation and the symbols used in the nomogram procedure.

Table B1

Input Data Items Required For
Barrier Nomogram Procedure

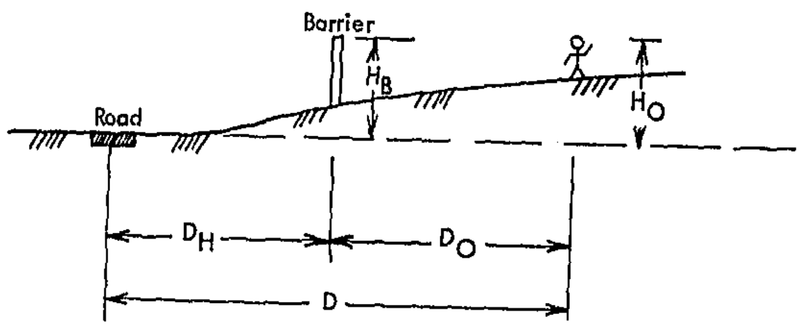
Variable	Meaning	Unit
D_O	Horizontal distance from observer to barrier.	feet
D_H	Horizontal distance from barrier to center of lane.	feet
D	Total distance from observer to center of lane.	feet
H_B	Barrier height, relative to road surface.	feet
H_O	Observer height, relative to road surface.	feet
θ_B	Barrier included half-angle.	degrees

Table B2

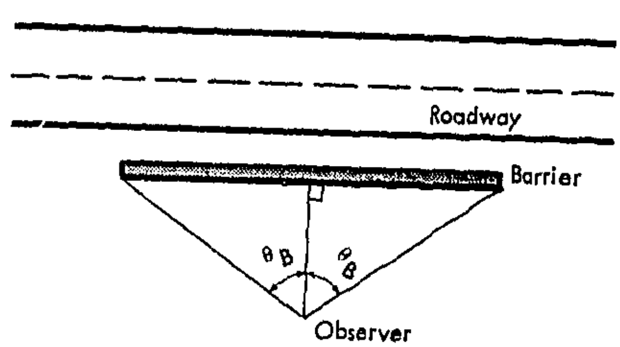
Symbols Used in Barrier Nomogram Procedure

Variable	Meaning	Step Number In Which Variable Is Defined
a,b,c	Intermediate quantities used in finding path length difference	1,2,3, respectively
δ	Path length difference	4
H_{crit}	Critical barrier height	4
Barrier Factor	"Adjustment" to traffic flow volumes due to barrier	5
Q'	Adjusted vehicle flow for cars	6
T'	Adjusted vehicle flow for trucks	6

Note: The quantities a,b,c,δ, and Barrier Factor are elsewhere referred to with subscripts C and T denoting cars and trucks, respectively.



a) Roadway and Barrier Cross-Section. Heights are Measured From Road Elevation.



b) Roadway Plan

Figure B-1. Dimensions for Barrier Procedure.

The following points should be noted with regard to these data:

- The barrier height, H_B, and the observer height, H_O, are always measured relative to the roadway. Thus, in the case of an elevated highway section with no side barrier, the barrier height would be the same as the roadway (typically) which yields a barrier height, $H_B = 0$. The observer height would then have (typically) some negative value.
- For a depressed highway, the barrier height would be equal to the height of the ground level above the depression. The observer height would be greater than the barrier height.
- θ_B, the barrier-included half-angle, is one-half of the angle subtended by lines of sight from the observer to the ends of the barrier. For an infinite barrier, $\theta_B = 90^{\circ}$. If the barrier does not cross the closest line of sight to the road, shielding will be less than 3 dB, and is not of any useful benefit.

The bulk of the barrier calculation involves finding the path length difference δ as defined as:

$$\delta = A + B - C$$

where A, B and C are defined in Figure B-2.

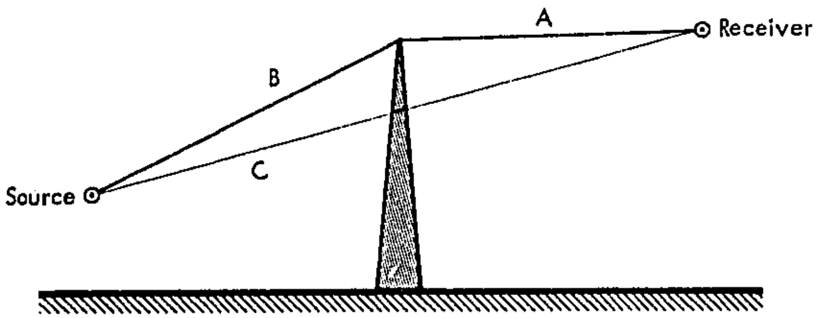


Figure B-2. Illustration of Path Length Difference ($\delta = A + B - C$).

Because cars and trucks have different effective source heights, δ must be computed separately for each.

Path length difference may be computed either of two ways, depending on whether a calculator is available.

1. If a calculator with square root function is available, use the following equation:

$$\delta = \left[(H_B - H_O)^2 + D_O^2\right]^{\frac{1}{2}} + \left[(H_B - H_S)^2 + D_H^2\right]^{\frac{1}{2}} - \left[(H_O - H_S)^2 + D^2\right]^{\frac{1}{2}}$$

where H_S is the source height:

$$H_S = \begin{cases} 2 \text{ feet for cars} \\ 8 \text{ feet for trucks} \end{cases}$$

2. If a calculator is not available, use Nomograms B1 and B2. Worksheet B may be used to record the procedure, which is as follows:

STEP 1 Enter Nomogram B1 with D_O and H_B-H_O to obtain the quantity a.

STEP 2 Enter Nomogram B2 with D_H and H_B to obtain the quantity b. Obtain separate values for cars and trucks. Note that H_S is not needed, as it is built into the nomogram, and that there are separate scales for cars and trucks.

STEP 3 Enter Nomogram B2 with D and H_O to obtain the quantity c. Obtain separate values for cars and trucks.

STEP 4 Compute δ for cars and trucks:

$$\delta = a + b - c$$

Note that a, b and c are related to, but not the same as, the distances A, B and C.

The calculated value of δ is always positive. However, because shielding for a given value of δ depends on whether the direct line of sight (C in Figure B-2) is broken, the following sign convention is adopted:

- δ is positive if line of sight C is broken by the barrier.
- δ is negative if line of sight C is not blocked by the barrier.

Whether or not line of sight is blocked may be determined from the geometry. Alternatively, Nomogram B3 may be entered with H_O and D_O/D_H to obtain H_{crit}, the critical barrier height which just touches the line of sight. If $H_B > H_{crit}$, δ is positive. If $H_B < H_{crit}$, δ is negative.

STEP 5 Enter Nomogram B4 with the barrier half angle θ_B and each value of δ to obtain the barrier factors.

If a finite barrier is not symmetric, divide the road into two segments at $\theta_B = 0$ and treat as two separate roads.

STEP 6 Multiply the car and truck volumes in each lane by the corresponding barrier factors. Add these over all lanes to obtain the adjusted traffic volume Q'. Sum the values (volume times barrier factor) for trucks to obtain the adjusted truck volume T'.

STEP 7 Follow the procedure of Appendix A, using Q' and T' in place of Q and T. When obtaining Δ_D from Nomogram A3, use the "free space" scale.

WORKSHEET B

BARRIER NOMOGRAM PROCEDURE
(See Text for Step-by-Step Instructions)

REQUIRED DATA

Horizontal Distance from Observer to Barrier,	D_O =	________ ft
Horizontal Distance from Barrier to Center of Nearest Lane	D_H =	________ ft
Total Distance from Observer to Center of Nearest Lane ($D_O + D_H$)	D =	________ ft
Barrier Height, Relative to Road Surface,	H_B =	________ ft
Observer Height, Relative to Road Surface,	H_O =	________ ft
Barrier Included Half-Angle	θ_B =	________ degrees

STEP 1

$H_B - H_O$ = ________ ft

a = ________

STEP 2

b_C = ________

b_T = ________

STEP 3

c_C = ________

c_T = ________

STEP 4

δ_C = (a = ________ (from STEP 1)) + (b_C = ________ (from STEP 2)) - (c_C = ________ (from STEP 3)) = ________ ft

δ_T = (a = ________ (from STEP 1)) + (b_T = ________ (from STEP 2)) - (c_T = ________ (from STEP 3)) = ________ ft

$\frac{D_O}{D_H}$ = ________ $H_{crit_{CAR}}$ = ________ $H_{crit_{TRUCK}}$ = ________

If $H_B > H_{crit_{CAR}}$, then δ_C is positive; else δ_C is negative

If $H_B > H_{crit_{TRUCK}}$, then δ_T is positive; else δ_T is negative

$\delta_C = \pm$ ________ $\delta_T = \pm$ ________ Circle the Appropriate Signs

STEP 5

Barrier Factor_C = ________

Barrier Factor_T = ________

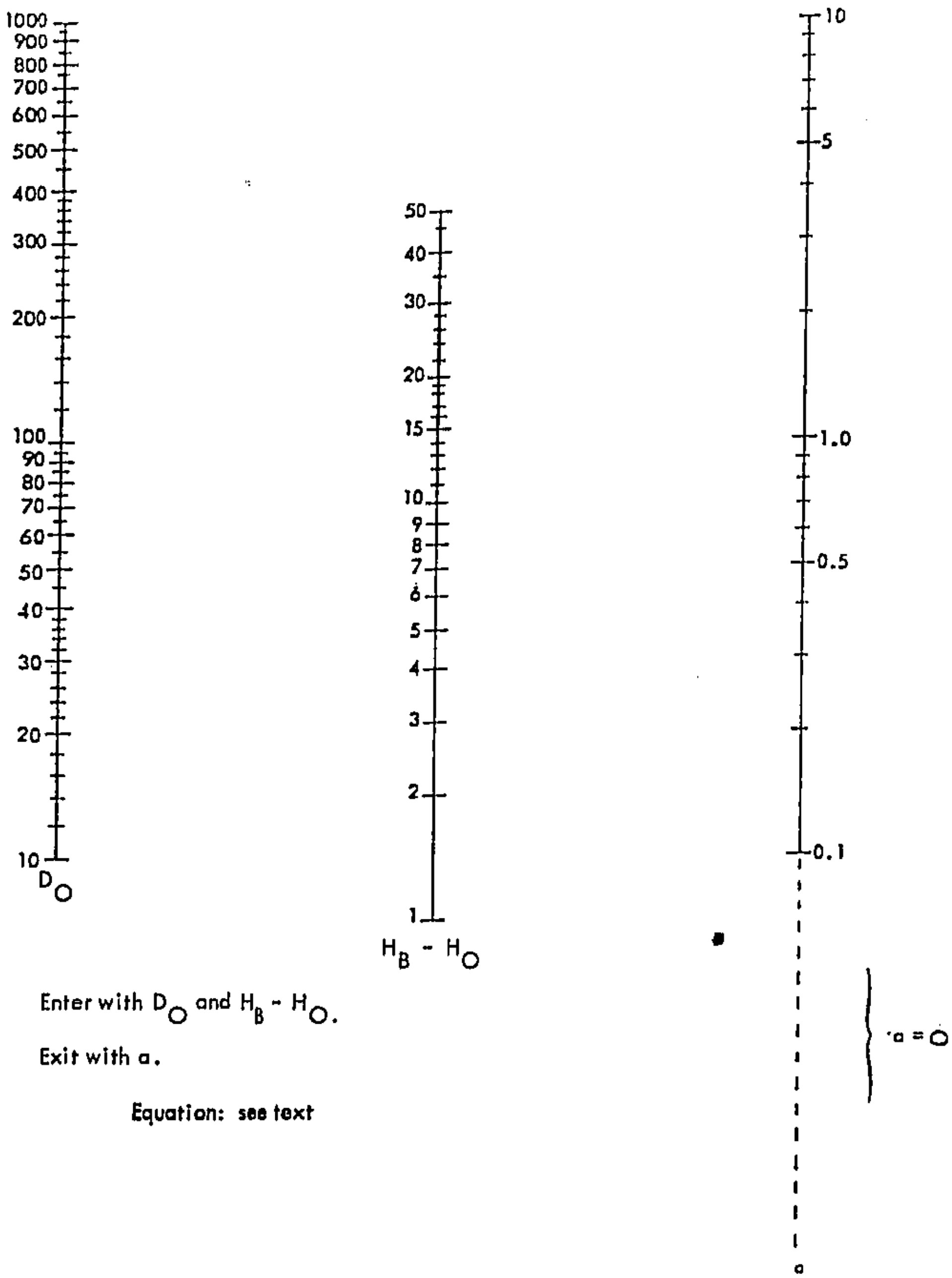
STEP 6

Q' = (Q = ________ (total vehicles/hr)) × (Barrier Factor_C = ________ (from STEP 5)) = ________ /hr

T' = (T = ________ (trucks/hour)) × (Barrier Factor_T = ________ (from STEP 5)) = ________ /hr

STEP 7

Proceed to Nomogram Procedure in Appendix A using Q' and T' for Q and T, respectively.

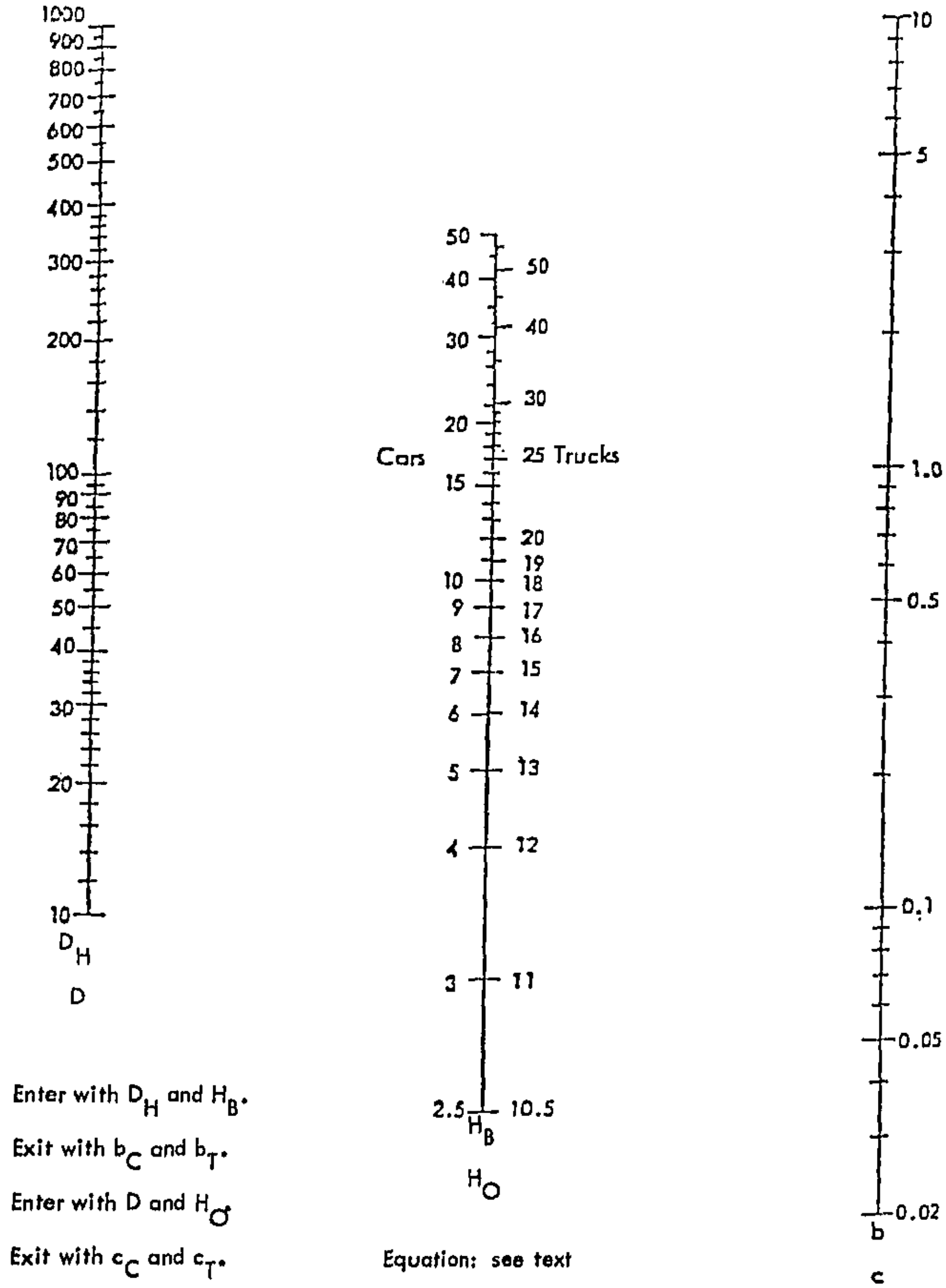


Enter with D_O and $H_B - H_O$.

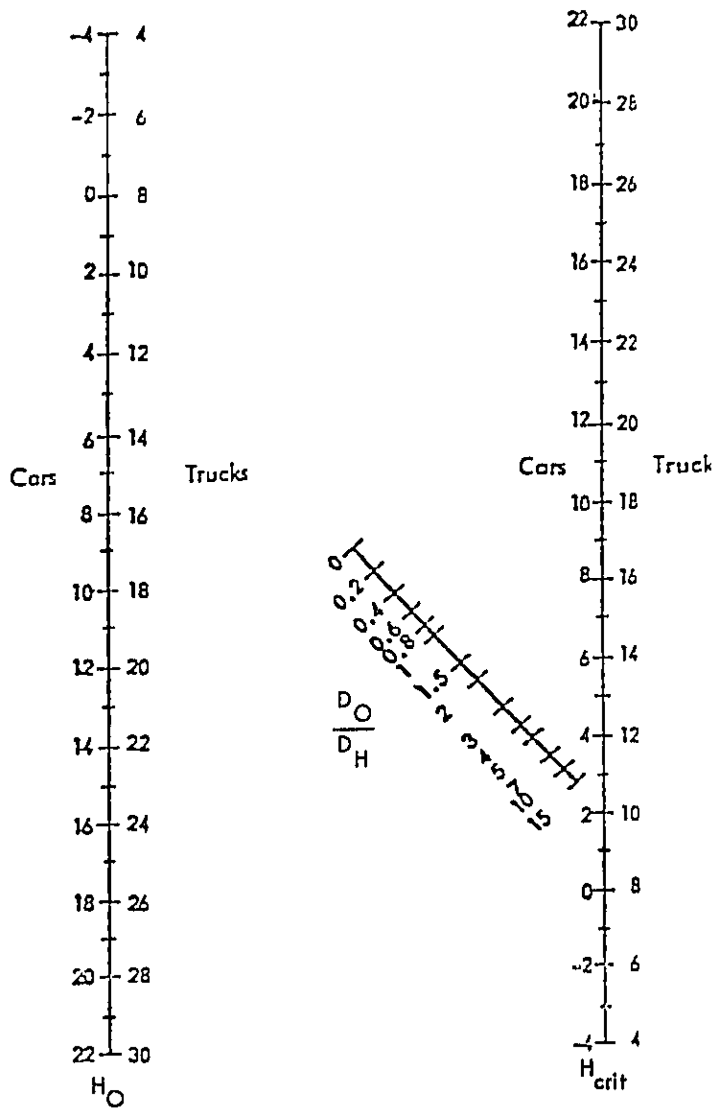
Exit with a.

Equation: see text

Barrier Nomogram B1. Calculation of the Quantity "a".



Barrier Nomogram B2. Calculation of the Quantities "b" and "c".



Enter with H_O (on car scale) and $\frac{D_O}{D_H}$.

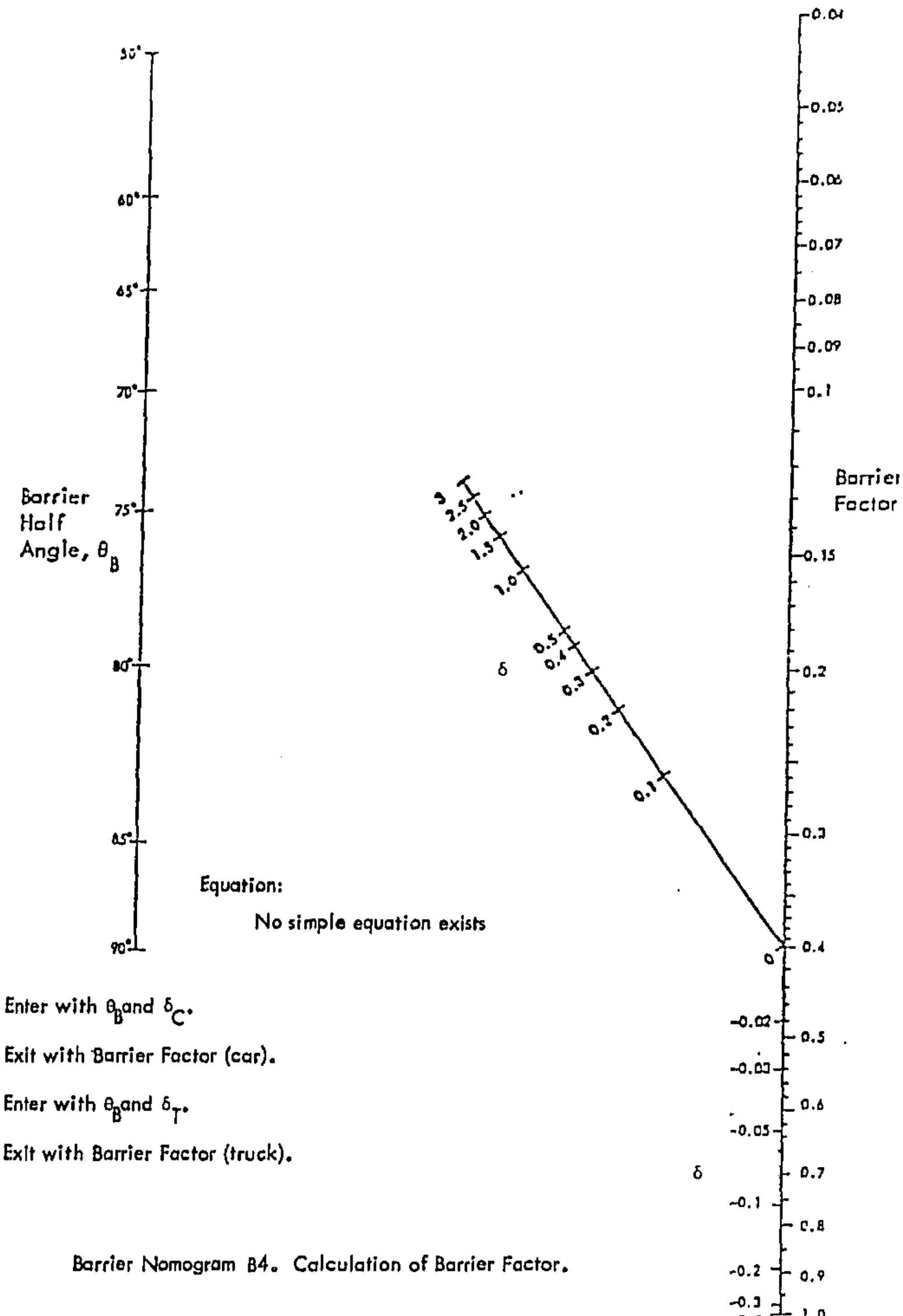
Exit with H_{crit} for cars.

Enter with H_O (on truck scale) and $\frac{D_O}{D_H}$.

Exit with H_{crit} for trucks.

Equation: see text

Barrier Nomogram B3. Calculation of the Quantity H_{crit}.



Enter with θ_B and δ_C.

Exit with Barrier Factor (car).

Enter with θ_B and δ_T.

Exit with Barrier Factor (truck).

Barrier Nomogram B4. Calculation of Barrier Factor.

APPENDIX C

Computerized Highway Noise Models

There are presently three highway noise models available as computer programs which are employed by Federal agencies. These are the NCHRP,[C1] TSC[C2] and RDG[C3] models, used by the Federal Highway Administration (FHWA). In addition, Wyle Laboratories has developed a computerized highway noise model for use in environmental planning which we will call the Wyle model.[C4]

NCHRP Model

This model was originally designed as a series of nomograms and charts;[C5,C6] however, a computerized version is currently available from FHWA. The model predicts L_{50} and L_{10} noise levels, at a given point, due to one or several highways. The levels are based on calculations from a semi-empirical traffic noise model. Data requirements for this model are:

- Traffic volume, speed, and percentage of heavy vehicles.
- Highway locations, elevations and/or depressions, and gradients.
- Highway surface roughness.
- Location of traffic controls.
- Highway width (number of lanes).
- Receiver locations.
- Barrier locations and geometry.

The basic calculation of the program is for L_{50} from each highway. L_{10} is then obtained from L_{50} by applying adjustments based on the statistics and geometry of the traffic flow. Due to limitations in the statistical model, calculations for low truck volumes or interrupted flow may be of questionable accuracy. The combination of several highways of similar noise output, or the presence of barriers, in certain cases, may also reduce the reliability of the L_{10} calculation.

TSC Model

This model can handle the same multiple road and complex barrier configurations as the NCHRP model. The basic calculation is in terms of L_{eq}, however, which allows predictions to be accurate for low traffic volumes and complex road configurations. In addition to L_{eq}, the program also computes L_{10}, L_{50}, L_{90}, L_{NP}*, and A-weighted octave band levels. The statistical metrics are obtained by applying theoretical adjustments to L_{eq}. The accuracy of the statistical metrics is decreased in complex situations, although not so much as with the NCHRP model because of the reliability of the basic L_{eq} calculation. The basic input data is similar to that for the NCHRP model, with the addition of topography and ground surface acoustical properties. All locations must be specified in three-dimensional Cartesian coordinates, which can make input data quite lengthy.

This model allows for reflection of sound from surfaces, and includes a calculation of ground attenuation. The ground attenuation model is extremely crude, however, and must be regarded as approximate. Individual vehicle noise levels form the basis of the L_{eq} calculation. The user has the option of specifying vehicle noise levels other than those provided with the program.

Revised Design Guide (RDG) Method

The Revised Design Guide is a composite product of the NCHRP and the TSC prediction methods — the two methods authorized by the Federal Highway Administration for use on federal-aid highway projects. The Revised Design Guide (RDG) supplements these two authorized methods with experimental data and additional mathematical structuring to extend the prediction validity to low-volume traffic situations.

In brief, the RDG structure consists of an L_{10} nomogram (similar to the TSC nomogram but with revised vehicle source data and revised distance correction), a barrier nomogram, and a series of worksheets — all leading to a hand-method calculation for simple roadway geometrics. As a partner to the hand method, the RDG includes a computer program (similar to the TSC program but with revised source levels, variable propagation drop-off, revised low-volume mathematics, segment adjustment and many other factors) for the detailed prediction of roadway noise levels, both for complex roadway geometrics

*Noise Pollution Level

and for detailed barrier design. In addition, this computer program contains a diagnosis capability that pinpoints "hot spots" along the roadway and enables the user to balance any barrier design up and down the roadway, to avoid under- or over-design of expensive roadway barriers.

Wyle Model

This program takes a different approach from the NCHRP and TSC models in that only one straight road is considered, but detailed lane and traffic information may be specified.[C4] Curved and/or multiple roads can be accounted for through usage of the nomogram method described in Appendix A. The program is written in Super Basic, a conversational language, and is designed to be used with a minimum of instruction. Taking advantage of the conversational format, "full" and "simple" versions are incorporated into the same program. After requesting the number of lanes, lane width, and median strip width, the program requests traffic information. The following data may be supplied in either a full or a short form:

- Traffic flow and truck mix: lane by lane, or one total for each direction.
- Speeds: by lane and vehicle type, or one speed for each direction.
- Vehicle noise levels: values may be specified for up to four vehicle types, or use values for cars and trucks in program.

The noise level is calculated in terms of L_{eq} for specified distances from the highway. The ground attenuation may be specified in terms of a number of dB per doubling of distance from the highway. This form of ground attenuation loss is a good approximation for distances up to several hundred feet. After running the program, any or all of the input data may be changed at the user's option to test different cases.

Comparison of the Models

In using the noise models described above, it may be found that different models often provide different values of the noise level. This is due to differences in the way the computation is performed. There is no simple factor that can be applied to relate the noise levels computed by the various models because the differences are strongly dependent on the highway conditions. A detailed comparison of the three models has been made in Reference C7. A series of charts are presented which may be used to estimate differences among the three models for any specific case.

REFERENCES FOR APPENDIX C

C1. Grove, G.H., "Traffic Noise Level Predictor Computer Program," Research Report No. R-942, Michigan State Highway Commission. October 1974.

C2. Kurze, U.J., Levison, W.H., and Serben, S., "User's Manual for the Prediction of Road Traffic Noise Computer Programs," U.S. Department of Transportation Report DOT-TSC-315-1, May 1972.

C3. Revised Design Guide: ref: Kugler, B.A., Commins, D.E., and Galloway, W.J., "Design Guide for Highway Noise Prediction and Control," Bolt, Beranek and Newman, Inc., Report 2739 (to be published).

C4. Plotkin, K.J., "A Model for the Prediction of Highway Noise and Assessment of Strategies for Its Abatement Through Vehicle Noise Control," Wyle Research Report No. WR 74-5, for the U.S. Environmental Protection Agency, September 1974.

C5. Gordon, C.G., Galloway, W.J., Kugler, B.A., and Nelson, D.L., "Highway Noise – A Design Guide for Engineers," NCHRP Report 117 (1971).

C6. Kugler, B.A. and Pierson, A.G., "Highway Noise – A Field Evaluation of Traffic Noise Reduction Measures," NCHRP Report 144 (1973).

C7. Plotkin, K.J. and Kunicki, R.G., "Comparison of Highway Noise Models," Wyle Research Report No. WR 76-25, for the U.S. Environmental Protection Agency, May 1977. Also, EPA Report 550/9-77-355.

APPENDIX D

The Effect of Motor Vehicle Noise Regulations On Highway Noise Levels

The method of computation described in Appendix A is based upon the existing noise levels produced by automobiles and trucks. In the future, these levels will undergo a change as a result of vehicle emission regulations promulgated by EPA. At the moment, there are two such regulations, both relating to medium and heavy trucks. The first limits the noise produced by trucks as they operate on the highway, and is expected to have the effect of reducing the average 50-foot pass-by truck noise level about 2 dB by mid-1977, assuming 95 percent compliance with the regulation.[D1] The second regulation limits the noise emissions of newly manufactured trucks, and will result in gradual reductions as older trucks are retired from service and replaced with new ones.

The effect of these changes on highway noise levels can be estimated. At the moment, 50-foot pass-by truck noise levels are between 15 and 19 dB greater than automobile noise levels.[D2] Due to this dominance of truck noise, the reduction in highway noise levels due to reduced truck vehicle noise levels will be approximately as shown in Table D1 for speeds less than 35 mph.

Table D1

Reduction in Highway Noise Level
Versus Reduction in 50-foot Passby Level

Reduction in Average 50-foot Passby Truck Noise Level from January 1976 Level (dB)	Approximate Reduction In Highway Noise Level (L_{eq} or L_{dn}) (dB) Truck Mix		
	5%	10%	20%
2	1.5	2	2
4	2	3.5	3.5
6	4	5	5.5

The appropriate U.S. Environmental Protection Agency Regional Office should be consulted — prior to the use of Table D1 — to determine the proper 50-foot noise level reduction achieved at the time. At higher speeds, the reduction in average noise level is generally 1 dB or less. Thus, by maintaining current information on average truck noise levels, one can develop an additional negative correction accounting for quieter future vehicles which will allow use of the nomogram and screening methods well into the future.

It should be noted that as highway noise levels are reduced through more stringent regulations, FHWA is expected to revise their design level standards accordingly. Thus, the necessity for noise abatement measures will, in the future, remain of vital importance in the planning and design of our nation's highways.

REFERENCES FOR APPENDIX D

D1. Plotkin, K.J., "A Model for the Prediction of Highway Noise and Assessment of Strategies for its Abatement Through Vehicle Noise Control", Wyle Research Report WR 74-5, for the U.S. Environmental Protection Agency, September 1974.

D2. Plotkin, K.J., and Sharp, B.H., "Assessment of Highway Vehicle Noise Control Strategies", presented at Inter-Noise 74, Washington, D.C., October 1974.

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