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Method for Assessing Benefits of Airborne Noise Isolation Requirements in Residential and Educational Buildings

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
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Final Report

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Prepared for:
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

This report presents a method for estimating benefits accruing from implementation of acoustical performance requirements for new buildings. The method can be applied to a wide range of environmental noise conditions and noise isolation requirements for building envelopes. Benefits are estimated based upon the distribution of population with outdoor noise level and the noise isolation provided by the building envelope. A method is described for estimating noise isolation performance of existing construction based upon local conditions.

Key words: acoustical design; benefit analysis; building codes; model code; noise control; noise impact; outdoor-indoor noise isolation.

PREFACE

This report is one of two NBS research reports describing models for assessing the cost and the benefits of implementation of noise control requirements in building codes. The cost model is described in NBSIR 81-2366, "Method for Assessing Costs of Noise Control Requirements in Multifamily Residential and Educational Buildings." The research leading to the present report was conducted by the Building Acoustics Group in the Center for Building Technology, National Engineering Laboratory of the National Bureau of Standards. This research was sponsored by the U.S. Environmental Protection Agency, Office of Noise Abatement and Control (ONAC) under Interagency Agreement No. AD-13-F-1-507-0, "Model Building Code Benefits Study" dated February 1981.

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1. INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this report is to present a uniform method for estimating benefits of incorporating noise control requirements for new residential and educational buildings. The primary benefits that may be estimated using this model are those accruing from noise-isolation requirements for the building envelope. Benefits related to noise isolation requirements for interior partitions and floor/ceiling assemblies and mechanical equipment noise can only be addressed in general terms.

The costs related to achieving the benefits described in this report are not addressed. These costs may be estimated using the methodology described in reference [1].

To illustrate the use of the benefit model, a particular noise-control code, called the Model Noise Control Code (MNCC), is used. This proposed model code was developed under the sponsorship of the U.S. Environmental Protection Agency (references [2] and [3]). Unique to the MNCC are the varisble performance requirements based upon expected noise levels surrounding the buildings in question. In contrast, current building noise-control provisions in the Appendix of the Uniform Building Code are fixed performance requirements independent of the outdoor noise surrounding the building, reference [4]. As described in the MNCC document, the MNCC provisions could be substituted for the current building noise-control provisions contained in the Appendix, chapter 35, "Sound Transmission Control," of the Uniform Building Code. The performance requirements of the MNCC are restricted to residential and educational buildings.

The benefit model described in this report may be used to assess alternative noise-isolation requirements for any proposed level of isolation. The model requires input data based upon local conditions at a future point in time. These data define the distribution of population with outdoor noise levels and the noise-isolation performance of existing local construction. If noise-isolation data are not available, a method is described for estimating the required data based upon local considerations.

1.2 ORGANIZATION

Section 2 of this report begins with an overview of the specific provisions of the acoustical performance code used to illustrate the model, the MNCC, and identifies the types of buildings affected by each provision. The detailed acoustical performance requirements specified by the MNCC provisions are presented in tabular form and interpreted.

Section 3 is an overview of the benefit model. A benefit, as defined for this model, is a decrease in noise impact. The decrease is measured relative to continued use of existing construction and is attributable to the noise-control provisions being considered. The data requirements to use the model are described and the classification of the benefits are discussed. Since the reader may not be familiar with noise impact assessments, the necessary considerations are presented.

Section 4 is a guideline to the steps necessary to conduct a benefit analysis using the model. These guidelines are necessarily general since the model's format allows the user to incorporate local data at various levels of detail.

Section 5 is a very detailed example of a benefit analysis using the model and the MNCC provisions. The example is an estimate of benefits for the United States' population resulting from implementing the MNCC requirements. This example considers only highway traffic noise. However, the detailed discussions in the example indicate tabular formats and data summaries that apply to all local conditions.

There are three appendixes to this report. Appendix A is a brief discussion of the methodology used to conduct a noise impact estimate. Appendix B presents a method for estimating the noise isolation performance of existing construction incorporating local conditions. This method may be used if local data are not available. Appendix C is a blank copy of a worksheet that is useful in conducting the benefit analysis.

2. MODEL NOISE CONTROL CODE PROVISIONS

This section reviews the provisions of the MNCC used to illustrate the benefit assessment method and identifies the building types and major building envelope components affected by those provisions. The purpose here is to provide the reader with a brief description of the MNCC sections which are specifically addressed by the methodology. For more elaborate details on these MNCC provisions, the reports prepared for the Environmental Protection Agency should be consulted [2,3].

2.1 OUTDOOR NOISE ISOLATION AND ACOUSTICAL PRIVACY

Table 2.1 presents the titles of the four MNCC provisions and indicates the building types affected by each. The first two provisions, Outdoor Noise Isolation and Acoustical Privacy, both govern the transmission of airborne noise into and within buildings. It is expected that these provisions would account for most of the benefits resulting from widespread adoption of the MNCC. The acoustical provisions contained in building codes today are generally presented in terms of a fixed acoustical performance requirement [5]. In contrast, the airborne noise requirements of the MNCC vary as a function of the outdoor acoustical environment. This acoustical environment is measured in decibels of outdoor day-night sound level which is defined as "...the equivalent A-weighted sound level during a 24-hour period with 10 decibels added to the equivalent A-weighted sound level during the nighttime hours (10:00 p.m. to 7:00 a.m.)" [6].

The Outdoor Noise Isolation provision (section 3507) imposes outdoor noise isolation requirements on the exterior shell of the building. It affects both residential and educational buildings exposed to outdoor day-night sound

Table 2.1. Model Noise Control Provisions Developed by Bolt, Beranek, and Newman, Inc.

Provision	Buildings Affected[a]	
Outdoor Noise Isolation (sec. 3507)	R[b]	E
Acoustical Privacy (sec. 3504)	R	E
Impact Noise Isolation (sec. 3505)	R	
Mechanical Equipment Noise (sec. 3506)	R	E

[a] Key: R = Multifamily highrise, lowrise, and townhouse buildings.
E = All educational buildings.

[b] Also applies to single family dwellings.

levels[1] greater than 60 dB. As indicated in table 2.2, the outdoor noise isolation requirements vary directly with changes in the outdoor sound levels.

The Acoustical Privacy provision (section 3504) imposes performance requirements for airborne noise transmission reductions for multifamily residential and educational buildings. These noise transmission reduction requirements distinguish two types of acoustical privacy by building separations (e.g., floors/ceilings or interior walls): 1) interior private to private dwelling unit separations (party walls); and 2) interior public to private dwelling unit separations.

The Acoustical Privacy requirements vary inversely with changes in the outdoor sound level within a range from 60 dB and lower. These requirements, however, become constant above 60 dB.

The predominant construction cost impacts of the performance requirements for Outdoor Noise Isolation and Acoustical Privacy given in table 2.2 affect five different building components[2]. Table 2.3 lists these components and indicates which provisions affect each component. The exterior walls are affected by the Outdoor Noise Isolation provision. Windows and doors are affected by both provisions. Interior walls and floor/ceiling assemblies are affected only by the Acoustical Privacy provision [1]. The benefits accruing from the Outdoor Noise Isolation provisions may be quantified using the model described in this report.

2.2 IMPACT NOISE ISOLATION AND MECHANICAL EQUIPMENT NOISE

The other two provisions listed on table 2.1 are Impact Noise Isolation and Mechanical Equipment Noise. The Impact Noise Isolation provision (section 3505) calls for prescriptive compliance with a Construction Handbook of approved designs for impact noise reduction[3]. This provision could not be addressed by the methodology presented in this report because the proposed Construction Handbook of acceptable designs has not yet been prepared. If this provision were implemented it would primarily affect multifamily residential buildings.

The fourth provision addresses Mechanical Equipment Noise (section 3506). This provision requires that both multifamily residential and educational buildings control the noise transmission from various building machinery and appliances.

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[1] The term "levels" refers to the 24-hour day-night sound level.

[2] The Outdoor Noise Isolation requirement may also affect the construction cost of roofs. This component is not included in the analysis since its impact on the entire cost of a highrise building is likely to be minimal. Further, the increment in benefits may not be significant. For single family dwellings construction costs related to roofing may be important, however.

[3] For justification of the use of prescriptive, rather than performance, requirements for Impact Noise Isolation, see reference [2], p. 45.

Table 2.2. Model Noise Control Code Specifications (Decibels) for Outdoor Noise Isolation and Acoustical Privacy

If Outdoor Day- Night Sound Level		Outdoor Noise Isolation (sec. 3507)	Acoustical Privacy (sec. 3504)	
≥	<	Outside to Inside[a]	Public to Private[b]	Private to Private[b]
	50	-	55	60
50	55	-	50	55
55	60	-	45	50
60	65	20	40	45
65	70	25	40	45
70	75	30	40	45
75	80	35	40	45
80		***********CONSTRUCTION PROHIBITED***********		

[a] The difference, in decibels, between the outdoor equivalent A-weighted sound level and the corresponding equivalent A-weighted sound level in the receiving space. Denoted by ΔL_A in this report.

[b] The Normalized Sound Level Difference as defined in reference [2], p. 29. The MNCC recommends that these values be increased 5 dB when using STC as the design requirement.

Table 2.3. Major Building Components Affected by the Outdoor Noise Isolation and Acoustical Privacy Provisions of the MNCC

Building Component	Outdoor Noise Isolation Provision	Acoustical Privacy Provision
Exterior Walls and Roof	X	
Windows	X	X
Doors	X	X
Interior Walls (Partitions)		X
Floor/Ceiling Assemblies		X

The Mechanical Equipment Noise provision specifies that the A-weighted sound levels produced by the operation of mechanical equipment be no greater than 45 dB in any dwelling unit or guest room. It also specifies that operation of appliances produce an A-weighted sound level no more than 70 dB and food waste disposals no more than 88 dB.

3. OVERVIEW OF METHODOLOGY

The method or model described in this report attempts to quantify benefits attributable to implementation of noise control requirements in building codes. This section describes an overview of the model and the type of benefits addressed. The following section presents more detail concerning the application of the model to local conditions. Since the model incorporates many specific steps that are influenced by local conditions a comprehensive example is presented in section 5.

3.1 DEFINITION OF BENEFIT

The benefit model described in this report attempts to quantify noneconomic benefits that may be assigned to a segment of the population within a community. The population considered in the analysis is the population residing in new construction at future points in time. The model is based upon the recognition that noise can cause an adverse environmental impact on this population [7]. As a result, a "benefit" estimated using this model is defined as a mitigation of adverse environmental noise impact. This definition establishes the framework of the model -- the estimation of environmental noise impact on a segment of the population.

Accepted techniques are available for conducting environmental noise impact assessments [6]. These techniques are applied in this model. The application, however, required an extension of these techniques to incorporate the effect of noise isolation provided by the building construction. The basic steps in the noise impact analysis are quite simple: 1) determine the population affected by the proposed action, 2) determine the noise exposure of this population, and 3) estimate the noise impact. To evaluate the benefits or reduction in the noise impact, it is necessary to establish a bench-mark for comparisons. The bench-mark is the no-action alternative and for this model corresponds to no change in the building codes to incorporate noise control requirements. Appendix A briefly describes the accepted methodology for conducting noise impact assessments.

3.2 DATA REQUIRED

As stated above, three steps are required to determine the noise impact for both the no-action alternative and the alternative of implementing noise control requirements. To obtain a quantitative estimate of either noise impact or benefits, it is necessary to obtain local data for input into the model. These data correspond to population projections, future noise environment, and the noise isolation performance of existing construction. The aggregation of these local data is the most important and time-consuming task for any benefit assessment. Much of the data will be available through local planning activities, however, and it is only necessary to aggregate the data in the format required by the model. Based upon the available information, the data format is dictated by the noise isolation performance of the existing construction.

3.2.1 Building Envelope Noise Isolation Performance

One very important aspect of noise control requirements for building construction is the specification of the outdoor-to-indoor noise isolation of the building envelope. One measure of the envelope noise isolation performance is the A-weighted sound level difference. This is a single number characterizing the envelope performance and is the requirement used in the Model Noise Control Code (MNCC) described in section 2 (see table 2.2). This requirement is based upon the outdoor day-night sound level expected at the building site. However, the de facto building envelope noise level reduction or noise isolation performance, as measured by the A-weighted sound level difference, depends upon the dominant source of outdoor environmental noise. The technical basis for this distinction is discussed in Appendix B.

One characteristic of this benefit model is that it allows the consideration of different sources of outdoor noise to be incorporated into the assessment of benefits. This is achieved by attributing different noise isolation performance estimates for the building envelope on the basis of the dominant source of outdoor noise. These performance estimates apply to existing construction and are described in Appendix B. The three dominant outdoor noise source categories addressed in Appendix B are: 1) aircraft noise, 2) highway traffic noise, and 3) urban noise.

As a result, the model may incorporate an assessment of benefits accruing to three population categories: 1) population exposed mainly to aircraft noise, 2) population exposed mainly to highway traffic noise, and 3) population exposed to "urban noise."

As described in the example benefit analysis in section 5, the model requires an estimate of the distribution of the building envelope noise level reduction for existing construction. This distribution may be based upon available local data. In the absence of local data, the methodology of Appendix B may be used to obtain an estimate appropriate to the local conditions. The method is, however, an approximation technique.

3.2.2. Population Noise Exposure

The most important input for a noise impact assessment is the estimation of population noise exposure. This estimate is a data aggregation that assigns or distributes the population to the range of environmental noise in the community. This estimate requires a knowledge of the noise exposure of land areas and the population residing in these land areas. Since this benefit model addresses new construction at a future point in time, the population noise exposure estimates are based upon future land development and the future noise levels. The MNCC requirements specify that the noise control requirements be established on the basis of future noise levels and provide methods for predicting these levels [2,3].

The format of the population noise exposure data required by the benefit model is illustrated in tables 5.2 through 5.7 in the example benefit analysis. Such data may be obtained, for example, from local authorities or federal agencies.

The recently enacted Part 150 of the Federal Aviation Administration regulations require airport operators to determine the aircraft noise impact for land areas surrounding airports [8]. These data will be in a format directly applicable to this benefit model. Estimates of land exposure to future levels of highway traffic noise may be obtained from environmental impact statements of major highway projects.

The benefit model requires an estimate of future population noise exposure at levels of environmental noise equal to or greater than a day-night sound level of 55 dB. These data are aggregated into intervals of noise exposure. The intervals used by the model are 5 dB intervals as recommended for noise impact estimates (see Appendix A and reference [6]).

Since the model allows the consideration of different outdoor noise sources, the population noise exposure data should be aggregated on this basis. The envelope noise reduction levels for aircraft noise are appropriate for land areas around airports. The envelope noise reduction levels for highway traffic noise are appropriate for land areas adjacent to interstate highways and major arterials. The envelope noise reduction levels for urban noise environments is appropriate to land areas on local streets away from other major noise sources. The extent of detail to incorporate into the local benefit analysis using the present model is entirely a local decision. It is essential, however, to understand that the population noise exposure data are aggregated on the basis of the expected noise environment and dominant noise source.

3.3 CLASSIFICATION OF BENEFITS

The benefits accruing from implementation of noise control requirements may be classified according to the interior noise environment in the living unit. The interior noise environment is comprised of three components: 1) interior noise due to outdoor noise, 2) interior noise due to sources in other living units, and 3) interior noise generated within the living unit. These components are discussed in relation to the MNCC requirements.

3.3.1 Envelope Noise Isolation

The envelope noise isolation performance applies to all residential and educational construction and determines the interior noise due to outdoor noise sources. This component of the interior noise environment may be quantified using existing measures of noise impact and is the component of interior noise used in this benefit model. For higher levels of outdoor noise, the MNCC requires increased envelope noise isolation performance (see table 2.2).

3.3.2 Interior Wall Noise Isolation

The interior wall noise isolation performance of the MNCC applies to multifamily residential and educational construction. The code requirements specify an increased interior wall noise isolation performance for <u>decreasing</u> levels of outdoor noise (see table 2.2). This requirement is the most important aspect of the MNCC specifications and is the most difficult to evaluate quantitatively on the basis of potential benefits. For a benefit analysis one must quantify the noise sources on a consistent basis. Hence, it is necessary to assess the levels of interior noise generated by neighbors. Only a very limited data base exists for estimating these levels [7,9]. Further, the interior wall noise isolation requirements apply mainly to the population exposed to outdoor day-night sound levels below 60 dB. This is a very large segment of the total population. As a result, even a small change in interior noise attributable to sources in other living units would result in a large noise impact estimate. Hence, any inaccuracies in estimating the level of interior noise would result in, perhaps, meaningless benefit estimates. For these reasons, the present model cannot address benefits -- which may be substantial -- attributable to the interior wall noise isolation requirements.

3.3.3 Internal Noise

The MNCC provisions specify levels of interior noise attributable to mechanical equipment and appliances. The considerations for conducting a benefit analysis attributable to this requirement are identical to those described in section 3.3.2 and are not addressed by the present model.

3.3.4 Impact Noise

The MNCC uses a prescriptive, rather than a performance, requirement for impact noise isolation (see section 2.2). Further, with present-day knowledge, it is difficult to assess benefits attributable to abatement of impact noise [10]. For these reasons this model does not attempt to assess these benefits. The significance of impact noise reduction is, however, very great in relation to occupant's satisfaction with their living environment [10].

3.4 BENEFIT TIME-STREAM ANALYSIS

Noise impacts and benefits will vary from year-to-year. For example, a fixed population exposed to increasing levels of environmental noise represents an increasing noise impact. Similarly, an increasing population exposed to a constant level of environmental noise represents an increasing noise impact. The first situation may correspond to a residential development adjacent to a highway that experiences an ever-increasing traffic flow with the attendant increasing noise levels. The second example corresponds to development of land for residential use adjacent to a major highway carrying a constant traffic flow. A noise impact assessment must account for these long-term time-varying characteristics. Since the benefits depend upon the noise impacts for the no-action and the implementation alternatives, the estimated benefits will also vary with time. These considerations are discussed in this section. The benefit model may be used to estimate these time-varying effects at future points in time.

Figure 3.1 illustrates the general characteristics of a noise impact estimate with time. The vertical scale is a "noise impact indicator" which is a numerical value that establishes the noise impact [6,7,11]. The horizontal scale is time measured in years. Two noise impact curves are indicated in figure 3.1: the no-action alternative and an alternative representing the implementation of noise control requirements on a product. The no-action alternative simulates the continued production and use of the product in the present-day condition. In figure 3.1, the "present day" is a point in time before the year Y_1. In relation to implementing noise control requirements in buildings, the "product" is, of course, building construction.

The solid line represents the noise impact related to the no-action alternative and is shown increasing with time. The slope of this line represents the rate of increase of the noise impact. In relation to the present model, this rate of increase corresponds to both the population in a community moving into new construction and increased exposure to environmental noise.

The dashed line represents the noise impact related to implementing noise control. The difference between these two lines is the "benefit" of noise control. The numbers B_1 and B_2 in figure 3.1 are benefit estimates at future points in time. Since the dashed line is below the solid line, these benefits are positive numbers indicating a positive benefit of implementing noise control. The benefit model described in this report is simply a method of computing points on the lines corresponding to the no-action alternative and the implementation of noise control requirements for building construction.

In figure 3.1, the year Y_1 represents the future point in time at which products featuring noise control enter service. The year Y_2 represents the future point in time at which all products in service feature noise control. Beyond the year Y_2 the noise control requirements are fully effective since they apply to all products either in service or entering service.

In relation to implementing noise control requirements in building codes, the time span between initiating the requirements, year Y_1 in figure 3.1, and achieving total effectiveness, year Y_2, is the time required to totally replace all buildings in a community. Obviously, this time span is beyond the life of the population. Hence, the benefits that may be estimated at a future point in time within the planning framework of a community will always be less than the ultimate benefits that can be expected to accrue to future generations.

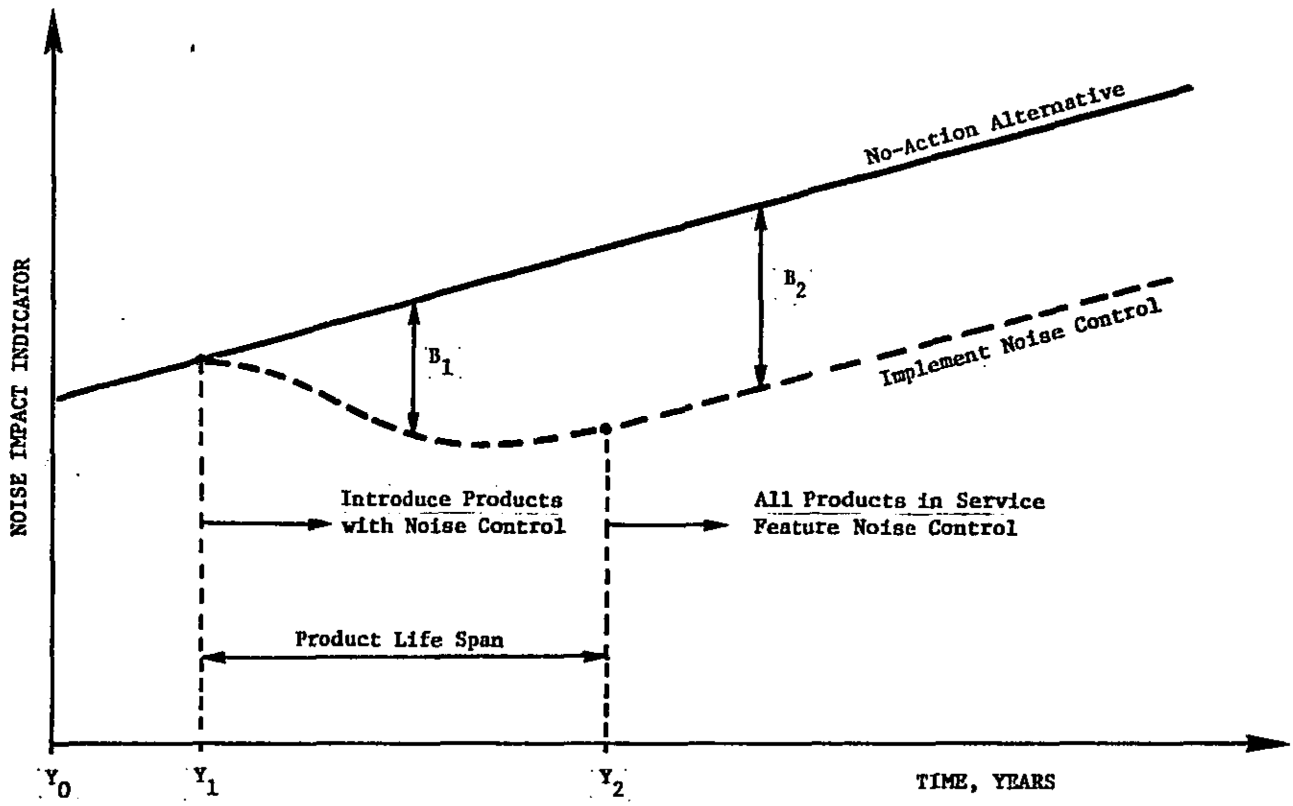

Figure 3.1 General Characteristics of a Noise Impact Assessment for Implementing Noise Control Requirements on a Product.

4. ESTIMATION OF BENEFITS

This section is a guideline for estimating benefits of implementing noise control requirements for building codes using local data. A detailed discussion is not presented in this section but is included in the following section relative to an example benefit analysis. In order to estimate a benefit it is not necessary to conduct a complete time-stream analysis as indicated in figure 3.1. It is only necessary to estimate, at a selected future point in time, the proportion of population residing in new construction built under existing code requirements and population residing in new construction built under the code provisions corresponding to implementation of noise control requirements.

4.1 SELECTING THE TIME FRAME

As recommended by the implementation manual for the MNCC, a 20 year future point in time may be used to estimate the noise impact [3]. This 20 year time is measured from the time at which the noise control requirements are initiated (year Y_1, in figure 3.1). From this point in time it is necessary to estimate the population that will eventually occupy the new construction and the distribution of this population with the outdoor day-night sound level. Since the noise impact assessment must include all population exposed to indoor noise levels above 42.5 dB, it is necessary to estimate the proportion of the population that resides in buildings exempted from the noise isolation requirement and the population in buildings requiring a specified level of noise control. (The 42.5 dB indoor criterion for determining noise impact is discussed in Appendix A.)

4.2 POPULATION NOISE EXPOSURE DISTRIBUTIONS

As discussed in section 3.2.2 it is necessary to aggregate population data by the estimated level of noise exposure, and if required, the aggregation may be further refined by the dominant source of outdoor noise (see section 3.2.1).

4.3 NOISE ISOLATION PERFORMANCE OF EXISTING CONSTRUCTION

The noise isolation performance of existing construction may be estimated using the methodology in Appendix B or may be based upon available local data. As described in section 3.2.1, these data are in the form of a distribution and may be further refined by categories of dominant outdoor noise source.

4.4 WORKSHEET FORMAT

A worksheet has been developed to assist in conducting the noise impact estimate. A blank sample of this worksheet is presented in Appendix C. A worksheet must be filled out for each population distribution described in section 4.1 and 4.2, the appropriate noise isolation distribution described in section 4.3, and the noise control requirements being implemented. (The example in section 5 illustrates this process.) The required calculations are then conducted using the worksheet.

4.5 NOISE IMPACT ESTIMATES

The baseline or no-action alternative noise impact estimate is determined from the worksheets by the combination of population distributions to outdoor noise and the envelope noise level reduction distributions for existing construction. Two noise impact estimates are obtained from each worksheet: impact due to population exposure at outdoor noise levels and impact due to population exposure at indoor noise levels. The final noise impact estimates are obtained by summing the outdoor noise impacts for all categories of outdoor noise sources and by summing the indoor noise impacts for all categories of outdoor noise sources.

For the noise control alternative, an identical set of calculations is performed with the only extension being that impacts must be estimated separately for the population residing in new construction exempted from noise control (outdoor levels below 60 dB) and the population residing in new construction requiring noise control (outdoor levels above 60 dB). The 60 dB limit referred to is the limit specified by the MNCC and is used here to denote the separation of population categories. The model allows the user to select other limits if so desired.

4.6 DETERMINATION OF NET BENEFITS

The result of the calculations described in Section 4.5 is two sets of numbers that estimate the noise impact in a future year. One set of numbers represents the noise impact based upon population exposure at outdoor levels for the no-action and the noise control alternative. The difference between these two numbers (no-action value less noise control value) represents the benefit to the population based upon exposure at outdoor noise levels. This estimate is required since the MNCC provisions prohibit construction in land areas exposed to outdoor day-night levels exceeding 80 dB.

The other set of numbers represents the noise impact based upon population exposure at indoor noise levels for the no-action and the noise control alternative. The difference between these two numbers represents the benefit to the population based upon exposure at indoor noise levels. This benefit is expected to be the major benefit resulting from implementation of the outdoor noise isolation requirements of the MNCC.

4.7 EVALUATION OF BENEFITS FOR ALTERNATIVE LEVELS OF ENVELOPE NOISE ISOLATION

The benefit model may be used to estimate alternative levels of building envelope noise isolation than the levels prescribed by the Model Noise Control Code described in Section 2. The brief guidelines in this section are the general steps required to conduct a benefit analysis. The following section presents a detailed example illustrating the many considerations and steps described above using the MNCC provisions as the example of noise control requirements.

5. EXAMPLE OF A BENEFIT ANALYSIS

This section presents an example of a benefit analysis of implementing noise isolation requirements for building envelopes. The outdoor noise isolation provisions (sec. 3507) of the MNCC are used as the example requirements. An estimate of the national population exposure to highway traffic noise is used as the basis for determining expected benefits. A time-stream benefit analysis is used to illustrate the time effects of implementing the noise isolation provisions.

Each step in this example is discussed so that the basic considerations may be clearly understood. These steps are identical to those required to conduct a similar analysis at a local level using data appropriate to the community.

5.1 POPULATION DISTRIBUTIONS

The first step in the benefit analysis is the estimation of population distribution with respect to the outdoor day-night sound level, L_{dnO}. Table 5.1 presents an estimate for the distribution of the national population noise exposure due to highway traffic noise [12][1]. This estimate assumes that highway traffic noise remains unregulated and that the national population increases at a rate based upon historical trends. It is beyond the scope of this example to further describe the basis for the table 5.1 estimate. However, the format of the data will be described since local data aggregations should follow a similar format.

Each entry in table 5.1 is a population estimate with the columns representing years. In this example, five year increments are used beginning with the reference year 1980 through the year 2010. The first six rows of table 5.1 indicate intervals of outdoor day-night sound level, L_{dnO}. These intervals cover the range of 55 dB through 85 dB in 5 dB intervals corresponding to the MNCC specifications in table 2.2. The last four rows are summary entries indicating the population distribution to ranges of outdoor day-night sound levels. The last row is the total population estimate.

Since benefits resulting from implementing any building code requirement applying to new construction can only be attributed to the population residing in the new construction, it is necessary to estimate this segment of the population. To do this, the change in population distribution is required. The estimated change in population distribution in future years relative to the reference year (1980) is easily obtained from the table 5.1 data. The result is presented in table 5.2.

The next step is to estimate the proportion of the population that will reside in new construction and the time sequence for implementation of the noise control requirements. Estimates of population increases residing in new construction may be obtained based upon construction trends and averages of

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[1] All tables and figures in this section are included at the end of the section for easy reference with the text.

occupancy per type of living unit. For the purposes of this example, it will be assumed that the total population change resides in new housing. However, based upon local conditions, it may be desirable to adjust the data for distribution between existing construction and new construction. The time sequence for implementing noise control requirements presents a similar consideration and will be emphasized in the present example.

The following implementation scenario is used to illustrate the considerations. First, it is assumed that all new construction through the year 1985 complies with "current building code" requirements. That is, the outdoor-indoor noise isolation corresponds to existing construction performance. Beginning in 1985 through 1990 a transition occurs such that at the end of 1990 half of the population increase for this time period resides in new construction conforming to the MNCC requirements and the other half resides in new constructtion conforming with the "current building code." Finally, it is assumed that all new construction beyond 1990 conforms with the MNCC requirements. (It is emphasized that this implementation scenario is an example and it is recognized that a national implementation based upon consensus standards is difficult -- if not impossible -- to formulate. The example, however, does illustrate the steps required to evaluate benefits based upon local considerations.)

Table 5.3 illustrates the effect of the above scenario on the population distribution with outdoor day-night sound level. Several details in table 5.3 must be mentioned since they reflect the MNCC requirements. First, two segments of the population are identified for each year in the analysis: population residing in new construction complying with current building codes (CBC) and construction complying with the Model Noise Control Code (MNCC). This distinction is necessary since the benefits must be compared to the "baseline" alternative of not adopting the MNCC requirements.

The first note concerning the data entries in table 5.3 is that the segment of the population exposed to outdoor noise in the 55-60 dB interval is allocated to the "current building code" column. The reason for this is that the MNCC allows "existing construction" for these conditions. Next, it should be noted that beginning in 1995 and beyond, no population is allocated to the 80 to 85 dB range other than the population allowed under "current building code" requirements prior to 1990. For the population increases in the 80 to 85 dB range indicated in table 5.2, the changes in population have been allocated to the 75-80 dB range for MNCC requirements in 1995 and beyond. This allocation reflects the "construction prohibited" requirement of the MNCC. Other than the 75-85 dB interval, the total population at all sound levels and ranges for each year is identical for the table 5.2 data and the table 5.3 data.

The table 5.2 data are used to obtain the noise impact estimate associated with the no-action alternative of utilizing existing construction. The table 5.3 data are used to obtain the noise impact estimate associated with the example implementation scenario for the MNCC as described above. To do this it is necessary to estimate the outdoor-to-indoor noise isolation for existing construction.

5.2 BUILDING ENVELOPE NOISE ISOLATION

The building envelope noise isolation must be estimated for existing construction. The noise isolation characteristics are described by a distribution. This distribution represents the fraction of existing construction exhibiting noise isolation characteristics of a given value. The methodology described in Appendix B may be used to obtain estimates based upon local conditions. For this example problem, it is appropriate to use the "national average" noise isolation distribution for highway traffic noise. This distribution is presented in table 5.4 and is derived in Appendix B. It incorporates assumptions concerning open and closed windows and the distribution of population between cold and warm climate conditions. Details are discussed in the Appendix.

Comparing this distribution with the MNCC requirements in table 2.2, it is seen that over 50 percent of existing construction would comply with the minimum MNCC requirement of 20 dB and less than one percent of existing construction is estimated to exceed the maximum MNCC requirement of 35 dB. The significance of this observation is that existing construction will partly mitigate outdoor noise intrusion when compared to the population distribution with outdoor day-night sound level as required by the MNCC.

The basic assumption of this model is that the distribution of noise isolation of existing construction is independent of the outdoor day-night sound level. This assumption is necessary since data are not available to estimate a relationship between outdoor day-night sound level and noise isolation characteristics of existing construction. Since benefits will be estimated on an incremental or relative basis, this assumption may not be expected to be too critical to the final result.

5.3 ESTIMATION OF NOISE IMPACTS

The noise impact estimate must be conducted for two alternatives: 1) the no-action alternative, and 2) the adoption of noise control requirements. The data in table 5.2 are used to estimate the noise impact of the no-action alternative. The data in table 5.3 are used to estimate the noise impacts associated with the adoption of the MNCC requirements as described in section 5.1. Further, since the MNCC requirements prohibit construction in land areas exposed to noise levels greater than 80 dB, it is necessary to estimate noise impacts for both outdoor and indoor conditions. These estimates are calculated for each of the years indicated in tables 5.2 and 5.3 for each segment of the population under consideration. To assist in conducting these calculations, a worksheet has been developed. A blank copy of the worksheet is included in Appendix C. The example data will be used to illustrate the use of the worksheet for conducting noise impact estimates.

5.3.1 No-Action Alternative

The noise impact estimate for the no-action alternative is conducted for each year 1985 through 2010 using the data in table 5.2. Data for the year 1995 will be used to illustrate the data entries for the calculation worksheet.

Table 5.5 is the completed worksheet for the no-action alternative in the year 1995. The columns under the heading "OUTDOOR" apply to the outdoor environment and to the population exposed to the levels of outdoor noise. The columns under the heading "INDOOR" apply to the estimate of population distribution with levels of indoor noise from outdoor sources. The population exposed to indoor noise levels is identical to the population exposed to outdoor noise levels. The worksheet is used to calculate two numbers: the Level Weighted Populations based on outdoor and indoor noise environments for the same population. (The Level Weighted Population or LWP is one type of noise impact indicator. See Appendix A and References 7 & 11.)

The data entries in the column heading ΔP_{exp} are directly transcribed from table 5.2 for the year 1995[1]. The entries under the column heading ΔLWP_O are obtained by multiplying the ΔP_{exp} entries by the weighting factors $W_O(L_{dnO})$ for each interval of outdoor day-night sound level. The weighting factors are described in Appendix A and are evaluated at the mid-point of the outdoor sound level interval. The total Level Weighted Population for the outdoor environment is obtained by summing all entries in the ΔLWP_O column. For the example in table 5.5, this total is 3.5125 million (M) people.

To characterize the indoor environment, it is necessary to estimate the distribution of population exposed to levels of indoor noise at each level of outdoor noise. The columns under the heading "INDOOR" correspond to levels of the building envelope noise level reduction, ΔL_A. At the top of each column, one enters the appropriate fraction of the building envelope noise isolation. Since the example in table 5.5 corresponds to existing construction, the data entries are obtained from the distribution given in table 5.4.

Each cell in the array of table 5.5 corresponds to an indoor noise level due to the outdoor noise environment. The indoor level is predetermined by the worksheet format and is denoted by the entry L_{dnI}. For example, with an outdoor environment in the interval 60-65 dB (center at 62.5 dB) and an envelope noise level reduction in the interval 15-20 dB (center 17.5 dB) the average indoor noise level is estimated to be 45 dB (62.5-17.5). For this cell, the population experiencing this indoor noise level of 45 dB is estimated by multiplying the total population in the outdoor interval (3.21 M) by the fraction of construction exhibiting the level of noise isolation (0.3360) to obtain the estimate 1.0786 M.

This process is repeated for each cell in the array. Since indoor noise exposures less than 45 dB are not considered to impact the population, it is not necessary to completely fill the table. It is only required to calculate the indoor population exposure for levels of indoor noise equal to or greater than 45 dB. The total estimate of population indoor noise exposure is then obtained at each level of indoor noise by summing each entry in the array at each level of indoor noise exposure. In the format of table 5.5, the cells of constant indoor sound level are located on a diagonal running from upper left to lower right.

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[1] A "Δ" prefix is used to denote a quantity based upon a population change.

For each level of indoor day-night sound level, L_{dnI}, the accumulated population exposure is tabulated in the indicated column at the bottom of the worksheet. At each indoor sound level, the exposed population is multiplied by the indicated weighting factor for indoor noise intrusion, $W_I(L_{dnI})$. (This weighting factor is also described in Appendix A.) The resulting term is the Level Weighted Population for indoor noise exposure at the level of indoor noise. Each of these terms is summed to obtain the final estimate of the Level Weighted Population for the indoor noise environment, ΔLWP_I. For the example data in table 5.5, the indoor Level Weighted Population for indoor noise due to outdoor sources is 1.1829 M people.

In summary, the table 5.5 data provides two numbers: 1) the Level Weighted Population based upon the outdoor noise environment, $\Delta LWP_O = 3.5125$ M, and 2) the Level Weighted Population based upon the indoor noise environment due to outdoor noise, $\Delta LWP_I = 1.1829$ M. These estimates are for the year 1995. Similar calculations are conducted for the other years in the time-stream for the no-action alternative.

5.3.2 Implementation Alternative

The noise impact estimate for the implementation alternative is essentially identical to that described for the no-action alternative. However, the calculations involve two population exposure categories for each year of the time-stream: 1) population residing in existing construction, and 2) population residing in new construction complying with the MNCC requirements. The population distributions of table 5.3 are used for these estimates.

For the year 1995 and the population distribution given in table 5.3 for the current building code requirements (existing construction), the worksheet is used to obtain the estimates: $\Delta LWP_O = 1.5575$ M and $\Delta LWP_I = 0.4362$ M. These data entries and calculations are illustrated in table 5.6.

For the year 1995 and the population distribution given in table 5.3 for the MNCC requirements, the worksheet is used to obtain the estimates: $\Delta LWP_O = 1.9525$ M and $\Delta LWP_I = 0.2363$ M. These data entries and calculations are illustrated in table 5.7.

Comparing tables 5.5 through 5.7, it is seen that the outdoor data manipulations are identical. However, the indoor data entries for table 5.7 are different from the entries in tables 5.5 and 5.6. The difference is a recognition -- in an accounting sense -- of the MNCC requirements. For existing construction (tables 5.5 and 5.6) the indoor noise environment is a distribution of population exposure at each level of outdoor noise. For the MNCC requirements, the distribution is condensed into an explicit performance range depending upon the outdoor noise environment. For example, the MNCC requirements specify an envelope noise isolation of 25 dB for outdoor noise in the interval 65 to 70 dB day-night sound level. This requirement is reflected in the worksheet format of table 5.7 by a uniform allocation of the population exposed to 65 to 70 dB outdoor levels to the two cells corresponding to indoor levels of 40 and 45 dB. Indeed, at each outdoor level interval, the MNCC requirements specify an indoor level in the range of 40 to 45 dB (see table 2.2). With this allocation of population, the indoor Level Weighted Population estimates follow in a format identical to that described in section 5.3.1. The significance of the table 5.7 calculations is that the MNCC requirements remove all indoor noise level impact estimates from consideration except for the population exposed to indoor levels centered at 45 dB.

It may be argued that the uniform allocation for the MNCC is simply an accounting scheme and that other allocations may be more representative of reality. This argument is accepted. However, the model allows the user to incorporate his best judgment. For example, if one assumed that buildings designed to meet the MNCC would incorporate a margin so that the requirement was always exceeded, the entire exposed population would be allocated to the 40 dB interior noise level of table 5.7. In this case, one would estimate the minimum noise impact for indoor noise exposure and obtain a maximum benefit estimate. By shifting the indoor population noise exposure to higher levels to simulate less stringent noise isolation requirements than the MNCC, one may still use the model. The point being made is that the model accepts such variations -- made at the users' judgment -- and that variations are incorporated at this stage of the noise impact analysis.

5.3.3 Summary of Estimates

The next step in the analysis is to summarize the noise impact estimates for each year in the time-stream. Based upon the data in tables 5.2 and 5.3, the noise impact estimates are summarized as indicated in table 5.8. This summary indicates the relative significance of the population noise exposure calculations for the two alternatives. The no-action alternative data of table 5.8 represent the baseline conditions for comparing the benefits of implementing the noise control options.

The data in table 5.8 for the MNCC implementation scenario are grouped into three sets: 1) noise impact related to existing construction; 2) noise impact related to new construction; and 3) the total noise impact combining these two impact estimates. The noise impact estimates all increase with time as indicated in table 5.8. However, the increase for each grouping of the population result from different causes. The increases in the ΔLWP values for the no-action alternative result directly from the population increases at all levels of outdoor noise exposure. For the population residing in existing construction under the MNCC implementation, the increases in ΔLWP values result from population increases for people residing in the 55-60 dB outdoor noise exposure interval. For the population residing in new construction, the increases in ΔLWP result directly from population increases.

Comparing the ΔLWP_O values in table 5.8 for the no-action and the total MNCC alternatives, it is seen that there is a slight decrease in noise impact based on the outdoor noise exposure. This is a result of the prohibition of construction in areas exposed to outdoor levels greater than 80 dB as required by the MNCC. The small decrease is attributable to the small fraction of the total population estimated to reside in land areas exposed to levels of highway traffic noise above 80 dB (see table 5.1).

Comparing the ΔLWP_I values in table 5.8 for the no-action and the total MNCC alternatives, it is seen that there is a rather large decrease in noise impact based upon the indoor noise exposure. This decrease is, of course, a result of implementing the MNCC requirements for the outdoor-to-indoor noise isolation.

The ΔLWP values are one format that may be used to estimate the benefits. An LWP value represents an absolute estimate in the sense that it attempts to establish a single number representing an equivalent population. Another format for estimating benefits, is the single number called the Noise Impact Index or NII. The NII value is the ratio of the LWP value to the total population base for the LWP estimate. The NII may be presented as a fraction or a percentage as described in Appendix A.

Table 5.9 presents the summary of the population exposed, the ΔLWP values, and the ΔNII values for the no-action alternative of the example. The table presents both outdoor and indoor noise impact estimates. The population exposed values are obtained from table 5.2. The ΔLWP values are obtained from table 5.8. The ΔNII values are calculated as the percentage of the ΔLWP values relative to the population exposed. It should be noted that the population exposed value represents the total population exposed to outdoor day-night sound levels above 55 dB. This segment of the population encompasses everyone affected by both the outdoor and the indoor noise impact estimates.

At first, the ΔNII estimates in table 5.9 may appear surprising. The are essentially constant for all years of the time-stream! The value of the ΔNII_O, is constant at about 32.5 percent of the population exposed to outdoor sound levels above 55 dB. The value of the ΔNII_I, is constant at about 10.9 percent. One should not, however, be too surprised that these results are constants. This may be anticipated since the total population growth rate in table 5.1 is essentially constant. As a result, the ΔLWP values remain in almost constant proportion to the population exposed values at each year of the time-stream and the ΔNII is simply the proportionality constant.

Table 5.10 presents the ΔNII estimates for the MNCC implementation scenario. The values of ΔNII for the outdoor noise impact estimate are essentially constant at 32.5 percent. The values of the ΔNII for the indoor noise impact estimate, however, are decreasing with years in the time-stream. This decrease in the indoor noise impact, as measured by the Noise Impact Index, represents another measure of the effect of implementing the MNCC requirements.

5.4 ESTIMATION OF BENEFITS

The ΔLWP and ΔNII estimates summarized in tables 5.9 and 5.10 are used to estimate the benefits attributable to implementation of the noise control requirements. As stated in section 3, the term "benefit" is defined as the decrease in the noise impact as a result of implementing the noise control requirements. The decrease is measured relative to the noise impact of the no-action alternative at each year of the time-stream.

5.4.1 Benefit Based on Outdoor Noise Impact

The MNCC requirements prohibit construction in land areas exposed to outdoor day-night sound levels greater than 80 dB. The benefits attributable to this requirement are estimated by subtracting the values for ΔLWP_0 in table 5.10 from the values for ΔLWP_0 in table 5.9 for each year in the time-stream. Similarly, one obtains the benefit in terms of the Noise Impact Index. The results are presented in table 5.11. For this example, the benefits as measured by the change in ΔLWP_0 or ΔNII_0 are too insignificant to warrant any further consideration. The conclusion, then, is that the MNCC requirements do not appear to result in any net benefit based upon outdoor noise exposure. This conclusion, however, applies only to this example. A benefit analysis based upon local conditions may result in a benefit due to the outdoor noise restrictions of the MNCC or similar code requirements.

5.4.2 Benefit Based on Indoor Noise Impact

The benefits resulting from implementing the MNCC requirements based on the indoor noise impacts are estimated as described above for the outdoor benefits. For the example scenario, the estimated benefits are listed in table 5.11 under the columns headed "INDOOR." In this case, the benefits are significant for the years 1995 and beyond. The benefit estimate based upon the Level Weighted Population continually increases as does the estimate based upon the Noise Impact Index. For this example, the net benefit of implementing the MNCC requirements are estimated to be a change in Level Weighted Population of 2.84 M or a change in Noise Impact Index of 6.4 percent for the year 2010.

5.5 INTERPRETATION OF BENEFIT ESTIMATES

The question arises as to the significance of the benefit estimates and the decision to implement the noise control requirements. There is, however, no explicit criterion to apply that will indicate a benefit value above which implementation is clearly warranted. What the benefit estimates do indicate is that a positive benefit does result from the proposed action. These benefits accrue to an ever-increasing segment of the national population. In table 5.11, the column headed "Population Affected" represents the estimated population residing in buildings incorporating the noise control requirements. These data are obtained from table 5.3. Hence, implementation of the noise control requirements, based upon the example scenario, would affect an estimated 21.07 M people by the year 2010 or about 7.1 percent of the national population.

5.6 PRESENTATION OF ESTIMATES

It is appropriate to discuss formats for presenting results of a benefit analysis. Tabulated data are necessary to document the inputs and the outputs of the estimates. It will be noted that tables 5.1 through 5.3 present data with two significant figures to the right of the decimal point. In tables 5.5 through 5.11, estimates are conducted to four places to the right of the decimal point. Carrying four-place decimal numbers does not imply accuracy, however. The number of decimal places indicated in tables 5.5 through 5.11 is necessary to avoid errors introduced by rounding. However, it is appropriate to present rounded numbers in the final presentation of data such as the benefit estimates of table 5.11. Indeed, the benefit summary in the format of table 5.11 may be the only information required for a policy decision. Based upon the example estimates in table 5.11 and the above discussion, table 5.12 is a final presentation of the benefit estimates. The entries in table 5.12 are rounded from the entries in table 5.11 and convey the same message without implication of unwarranted accuracy.

In addition to tabular data, graphical presentation of both the noise impact estimates and the benefit estimates are effective formats. Figure 5.1 illustrates the noise impact estimates based upon the Level Weighted Population. These results are plotted from the data in tables 5.9 and 5.10. Figure 5.2 illustrates the noise impact based upon the Noise Impact Index. These results are also plotted from the data in tables 5.2, 5.9 and 5.10. Figure 5.3 presents the benefit estimates of table 5.11 for the indoor conditions. In figures 5.2 and 5.3 it is necessary to approximate the curves based on the ΔNII index between the three years 1985, 1990, and 1995. This is the transition period for the benefit analysis, and as indicated in these figures and table 5.10, the ΔNII values are significantly affected.

5.7 SINGLE-POINT BENEFIT ESTIMATES

It is instructive to view the benefit estimates on the basis of a single-point benefit estimate as discussed in section 4.1. The term single-point estimate is used to denote a benefit calculation at only one point in the future time frame. In section 4.1, a 20-year single-point benefit estimate was suggested. For the example presented here, the 20-year time interval is measured from 1985 (the year Y_1 in figure 3.1) so that the single-point estimate would be conducted for the year 2005. The question then arises as to the interpretation of the benefits knowing only a single estimate.

From table 5.12, the benefit estimates are "no change" for the outdoor sound exposure, and for the indoor exposure, a change in Level Weighted Population of 2.01 M and a change of Noise Impact Index of 6.2 percent. As mentioned in section 3.4 and indicated in figure 3.1, the 20-year time span is expected to be well within the range for which benefits will continually increase. This statement, however, applies to absolute measures of benefit such as the Level Weighted Population. For the Noise Impact Index benefit measure, we note that this value seems to be approaching a constant with increasing time. This constant, in the example problem, is something slightly above the value of 6 percent of the population exposed to outdoor levels greater that 55 dB.

Hence, as an approximation, if one conducts a single-point estimate, one should state the estimate in terms of the absolute measure of the Level Weighted Population emphasizing that this absolute measure is continually increasing proportional to the rate of change of the benefit estimate based on the Noise Impact Index. One may be more confident, of course, if a complete time-stream analysis is performed.

Table 5.1. Estimated Population Distribution to Highway Traffic Noise (reference 12)

L_{dn0} Interval	YEAR OF TIME STREAM 1980	1985	1990	1995	2000	2005	2010
55-60	42.50	43.73	44.61	47.79	52.79	58.40	64.40
60-65	25.81	26.55	27.09	29.02	32.06	35.49	39.10
65-70	13.14	13.51	13.79	14.77	16.31	18.05	19.90
70-75	4.16	4.28	4.36	4.68	5.16	5.72	6.30
75-80	1.07	1.10	1.12	1.20	1.33	1.47	1.62
80-85	0.12	0.13	0.13	0.14	0.15	0.17	0.18
<55	135.2	145.3	156.2	162.0	164.1	164.8	164.9
≥55	86.8	89.3	91.1	97.6	107.8	119.3	131.5
≥60	44.3	45.57	46.49	49.81	55.01	60.9	67.1
TOTAL	222.00	234.60	247.3	259.6	271.9	284.1	296.4

Table 5.2. Estimated Change in Population Distribution to Highway Traffic Noise (see table 5.1)

L_{dn0} Interval	1980*	1985	1990	1995	2000	2005	2010
			YEAR OF TIME-STREAM				
55-60	42.50	1.23	2.11	5.29	10.29	15.90	21.90
60-65	25.81	0.74	1.28	3.21	6.25	9.68	13.29
65-70	13.14	0.37	0.65	1.63	3.17	4.91	6.76
70-75	4.16	0.12	0.20	0.52	1.00	1.56	2.14
75-80	1.07	0.03	0.05	0.13	0.26	0.40	0.55
80-85	0.12	0.01	0.01	0.02	0.03	0.05	0.06
<55	135.2	10.10	21.00	26.80	28.90	29.60	29.70
≥55	86.8	2.50	4.30	10.80	21.00	32.50	44.70
≥60	44.3	1.27	2.19	5.51	10.71	16.60	22.80
TOTAL	222.0	12.60	25.30	37.60	49.90	62.10	74.40

*Reference Year (Totals)

Table 5.3 Distribution of Population Between Construction Categories Based Upon Example Implementation Scenario

L_{dn0}	1985		1990		1995		2000		2005		2010	
	CBC	MNCC	CBC	MNCC	CBC	MNCC	CBC	MNCC	CBC	MNCC	CBC	MNCC
55-60	1.23	0.0	2.11	0.0	5.29	0.0	10.29	0.0	15.90	0.0	21.90	0.0
60-65	0.74	0.0	1.01	0.27	1.01	2.20	1.01	5.24	1.01	8.67	1.01	12.28
65-70	0.37	0.0	0.51	0.14	0.51	1.12	0.51	2.66	0.51	4.40	0.51	6.25
70-75	0.12	0.0	0.16	0.04	0.16	0.36	0.16	0.84	0.16	1.40	0.16	1.98
75-80	0.03	0.0	0.04	0.01	0.04	0.10	0.04	0.24	0.04	0.40	0.04	0.56
80-85	0.01	0.0	0.01	0.0	0.01	0.0	0.01	0.0	0.01	0.0	0.01	0.0
<55	10.10	0.0	21.00	0.0	26.80	0.0	28.90	0.0	29.60	0.0	29.70	0.0
≥55	2.50	0.0	3.84	0.46	7.02	3.78	12.02	8.98	17.63	14.87	23.63	21.07
≥60	1.27	0.0	1.73	0.46	1.73	3.78	1.73	8.98	1.73	14.87	1.73	21.07
TOTAL	12.60	0.0	24.84	0.46	33.82	3.78	40.92	8.98	47.23	14.87	53.33	21.07

Key: CBC = Current Building Code
MNCC = Model Noise Control Code

Table 5.4. Building Envelope Noise Isolation: National Average for Highway Traffic Noise (see Appendix B)

Noise Isolation ΔL_A	Percent of Existing Construction	Percent of Existing Construction Exceeding Lower Limit
10-15	14.01	100.00
15-20	33.60	85.99
20-25	35.54	52.39
25-30	14.46	16.85
30-35	2.26	2.39
35-40	0.13	0.13
40-45	0.0	0.0

Table 5.5. Completed Work Sheet for Noise-Impact Analysis: No-Action Alternative for 1995

OUTDOOR				INDOOR							
					Distribution of Envelope Noise Level Reduction, ΔL_A, dB						
L_{dnO} interval	ΔP_{exp} M	$W_O(L_{dnO})$	ΔLWP_O M	Row	10-15 dB	15-20 dB	20-25 dB	25-30 dB	30-35 dB	35-40 dB	40-45 dB
<55 dB	26.8	0	0	Entry	0.1401	0.3360	0.3554	0.1446	0.0226	0.0013	0.0
55-60 dB	5.29	0.1250	0.6613	L_{dnI}	45 dB	40 dB	35 dB	30 dB	25 dB	20 dB	15 dB
				ΔP_{exp}	0.7411	1.7774					
60-65 dB	3.21	0.3750	1.2038	L_{dnI}	50 dB	45 dB	40 dB	35 dB	30 dB	25 dB	20 dB
				ΔP_{exp}	0.4497	1.0786	1.1408				
65-70 dB	1.63	0.6250	1.0188	L_{dnI}	55 dB	50 dB	45 dB	40 dB	35 dB	30 dB	25 dB
				ΔP_{exp}	0.2284	0.5477	0.5793	0.2357			
70-75 dB	0.52	0.8750	0.4550	L_{dnI}	60 dB	55 dB	50 dB	45 dB	40 dB	35 dB	30 dB
				ΔP_{exp}	0.0729	0.1747	0.1848	0.0752	0.0118		
75-80 dB	0.13	1.1250	0.1463	L_{dnI}	65 dB	60 dB	55 dB	50 dB	45 dB	40 dB	35 dB
				ΔP_{exp}	0.0182	0.0437	0.0462	0.0188	0.0029	0.0002	
80-85 dB	0.02	1.3750	0.0275	L_{dnI}	70 dB	65 dB	60 dB	55 dB	50 dB	45 dB	40 dB
Total ΔLWP_O M			3.5125	ΔP_{exp}	0.0028	0.0067	0.0071	0.0029	0.0005	0.0000	—

Indoor Day-Night Sound Level, L_{dnI}, dB	40 dB	45 dB	50 dB	55 dB	60 dB	65 dB	70 dB	Row Total
Indoor Weighting Factor, $W_I(L_{dnI})$	0	0.1250	0.3750	0.6250	0.8750	1.1250	1.3750	
Indoor Population Exposed, ΔP_{exp} M ($\geq$45 dB)	3.1659	2.4771	1.2015	0.4522	0.1237	0.0249	0.0028	4.2822
Indoor Level Weighted Population, ΔLWP_I M	0	0.3096	0.4506	0.2826	0.1082	0.0280	0.0039	1.1829

Table 5.6. Completed Work Sheet for Noise-Impact Analysis: Existing Construction for 1995

OUTDOOR				INDOOR							
					Distribution of Envelope Noise Level Reduction, ΔL_A, dB						
L_{dnO} interval	ΔP_{exp} M	$W_O(L_{dnO})$	ΔLWP_O M	Row	10-15 dB	15-20 dB	20-25 dB	25-30 dB	30-35 dB	35-40 dB	40-45 dB
<55 dB	26.80	0.	0	Entry	0.1401	0.3360	0.3554	0.1446	0.0226	0.0013	0.0
55-60 dB	5.29	0.1250	0.6613	L_{dnI}	45 dB	40 dB	35 dB	30 dB	25 dB	20 dB	15 dB
				ΔP_{exp}	0.7411	1.7774					
60-65 dB	1.01	0.3750	0.3788	L_{dnI}	50 dB	45 dB	40 dB	35 dB	30 dB	25 dB	20 dB
				ΔP_{exp}	0.1415	0.3394	0.3590				
65-70 dB	0.51	0.6250	0.3188	L_{dnI}	55 dB	50 dB	45 dB	40 dB	35 dB	30 dB	25 dB
				ΔP_{exp}	0.0715	0.1714	0.1813	0.0737			
70-75 dB	0.16	0.8750	0.1400	L_{dnI}	60 dB	55 dB	50 dB	45 dB	40 dB	35 dB	30 dB
				ΔP_{exp}	0.0224	0.0538	0.0569	0.0231	0.0036		
75-80 dB	0.04	1.1250	0.0450	L_{dnI}	65 dB	60 dB	55 dB	50 dB	45 dB	40 dB	35 dB
				ΔP_{exp}	0.0056	0.0134	0.0142	0.0058	0.0009	0.0001	
80-85 dB	0.01	1.3750	0.0138	L_{dnI}	70 dB	65 dB	60 dB	55 dB	50 dB	45 dB	40 dB
Total ΔLWP_O M			1.5575	ΔP_{exp}	0.0014	0.0034	0.0036	0.0014	0.0002	—	—

Indoor Day-Night Sound Level, L_{dnI}, dB	40 dB	45 dB	50 dB	55 dB	60 dB	65 dB	70 dB	Row
Indoor Weighting Factor, $W_I(L_{dnI})$	0	0.1250	0.3750	0.6250	0.8750	1.1250	1.3750	Total
Indoor Population Exposed, ΔP_{exp} M($\geq$45dB)	2.2138	1.2858	0.3758	0.1409	0.0394	0.0090	0.0014	1.8523
Indoor Level Weighted Population, ΔLWP_I	0	0.1607	0.1409	0.0881	0.0345	0.0101	0.0019	0.4362

Table 5.7. Completed Work Sheet for Noise-Impact Analysis: Construction Conforming to MNCC Provisions for 1995

OUTDOOR				INDOOR							
					Distribution of Envelope Noise Level Reduction, ΔL_{A}, dB						
L_{dnO} interval	ΔP_{exp} M	$W_O(L_{dnO})$	ΔLWP_O M	Row	10-15 dB	15-20 dB	20-25 dB	25-30 dB	30-35 dB	35-40 dB	40-45 dB
<55 dB	0	0.	0	Entry	—	—	—	—	—	—	—
55-60 dB	0	0.1250	0	L_{dnI}	45 dB	40 dB	35 dB	30 dB	25 dB	20 dB	15 dB
				ΔP_{exp}	0	0					
60-65 dB	2.20	0.3750	0.8250	L_{dnI}	50 dB	45 dB	40 dB	35 dB	30 dB	25 dB	20 dB
				ΔP_{exp}	—	1.1000	1.1000				
65-70 dB	1.12	0.6250	0.7000	L_{dnI}	55 dB	50 dB	45 dB	40 dB	35 dB	30 dB	25 dB
				ΔP_{exp}	—	—	0.5600	0.5600			
70-75 dB	0.36	0.8750	0.3150	L_{dnI}	60 dB	55 dB	50 dB	45 dB	40 dB	35 dB	30 dB
				ΔP_{exp}	—	—	—	0.1800	0.1800		
75-80 dB	0.10	1.1250	0.1125	L_{dnI}	65 dB	60 dB	55 dB	50 dB	45 dB	40 dB	35 dB
				ΔP_{exp}	—	—	—	—	0.0500	0.0500	
80-85 dB	0	1.3750	0	L_{dnI}	70 dB	65 dB	60 dB	55 dB	50 dB	45 dB	40 dB
	Total ΔLWP_O M		1.9525	ΔP_{exp}	—	—	—	—	—	0	0

Indoor Day-Night Sound Level, L_{dnI}, dB	40 dB	45 dB	50 dB	55 dB	60 dB	65 dB	70 dB	Row
Indoor Weighting Factor, $W_I(L_{dnI})$	0	0.1250	0.3750	0.6250	0.8750	1.1250	1.3750	Total
Indoor Population Exposed, ΔP_{exp} M($\geq$45dB)	1.8900	1.8900	0	0	0	0	0	1.8900
Indoor Level Weighted Population, ΔLWP_I	0	0.2363	0	0	0	0	0	0.2363

Table 5.8. Summary of Level Weighted Population Changes for Example Benefit Analysis

YEAR	NO ACTION ALTERNATIVE		MNCC IMPLEMENTATION SCENARIO: EXISTING CONSTR.		MNCC IMPLEMENTATION SCENARIO: NEW CONSTR.		MNCC IMPLEMENTATION SCENARIO: ALL CONSTR.	
	ΔLWP_O M	ΔLWP_I M	ΔLWP_O M	ΔLWP_I M	ΔLWP_O M	ΔLWP_I M	ΔLWP_O M	ΔLWP_I M
1985	0.8150	0.2768	0.8150	0.2768	0.0	0.0	0.8150	0.2768
1990	1.3950	0.4664	1.1600	0.3806	0.2350	0.0288	1.3950	0.4094
1995	3.5125	1.1829	1.5575	0.4362	1.9525	0.2363	3.5100	0.6725
2000	6.8200	2.2923	2.1825	0.5238	4.6325	0.5613	6.8150	1.0851
2005	10.5700	3.5566	2.8838	0.6221	7.6763	0.9294	10.5601	1.5515
2010	14.5200	4.8804	3.6338	0.7271	10.8738	1.3169	14.5076	2.0440

Table 5.9. Noise-Impact Estimate for the No-Action Alternative

YEAR	ΔP_{exp} $\geq$55 dB M	OUTDOOR ΔLWP_O M	OUTDOOR ΔNII_O %	INDOOR ΔLWP_I M	INDOOR ΔNII_I %
1985	2.50	0.8150	32.60	0.2768	11.07
1990	4.30	1.3950	32.44	0.4664	10.85
1995	10.80	3.5125	32.52	1.1829	10.95
2000	21.00	6.8200	32.48	2.2923	10.92
2005	32.50	10.5700	32.52	3.5566	10.94
2010	44.70	14.5200	32.48	4.8804	10.92

Table 5.10. Noise-Impact Estimate for the Example Implementation Scenario for the MNCC

YEAR	ΔP_{exp} $\geq$55 dB M	OUTDOOR ΔLWP_O M	OUTDOOR ΔNII_O %	INDOOR ΔLWP_I M	INDOOR ΔNII_I %
1985	2.50	0.8150	32.60	0.2768	11.07
1990	4.30	1.3950	32.44	0.4094	9.52
1995	10.80	3.5100	32.50	0.6725	6.23
2000	21.00	6.8150	32.45	1.0851	5.17
2005	32.50	10.5601	32.49	1.5515	4.77
2010	44.70	14.5076	32.46	2.0440	4.56

Table 5.11. Benefit Estimates for the Example Implementation Scenario for the MNCC

YEAR	OUTDOOR Change in ΔLWP_O M	Change in ΔNII_O %	INDOOR Change in ΔLWP_I M	Change in ΔNII_I %	Population Affected (Table 5.3) M
1985	0.0000	0.00	0.0000	0.00	0.00
1990	0.0000	0.00	0.0570	1.33	0.46
1995	0.0025	0.02	0.5104	4.72	3.78
2000	0.0050	0.03	1.2072	5.75	8.98
2005	0.0099	0.03	2.0051	6.17	14.87
2010	0.0124	0.02	2.8364	6.36	21.07

Table 5.12. Presentation Format for Final Benefit Estimates (Data Rounded from Table 5.11 Estimates)

YEAR	Change in ΔLWP_O M	Change in ΔNII_O %	Change in ΔLWP_I M	Change in ΔNII_I %	Population Affected (Table 5.3) M
1985	0.00	0.0	0.00	0.0	0.00
1990	0.00	0.0	0.06	1.3	0.46
1995	0.00	0.0	0.51	4.7	3.78
2000	0.00	0.0	1.21	5.8	8.98
2005	0.01	0.0	2.01	6.2	14.87
2010	0.01	0.0	2.84	6.4	21.07

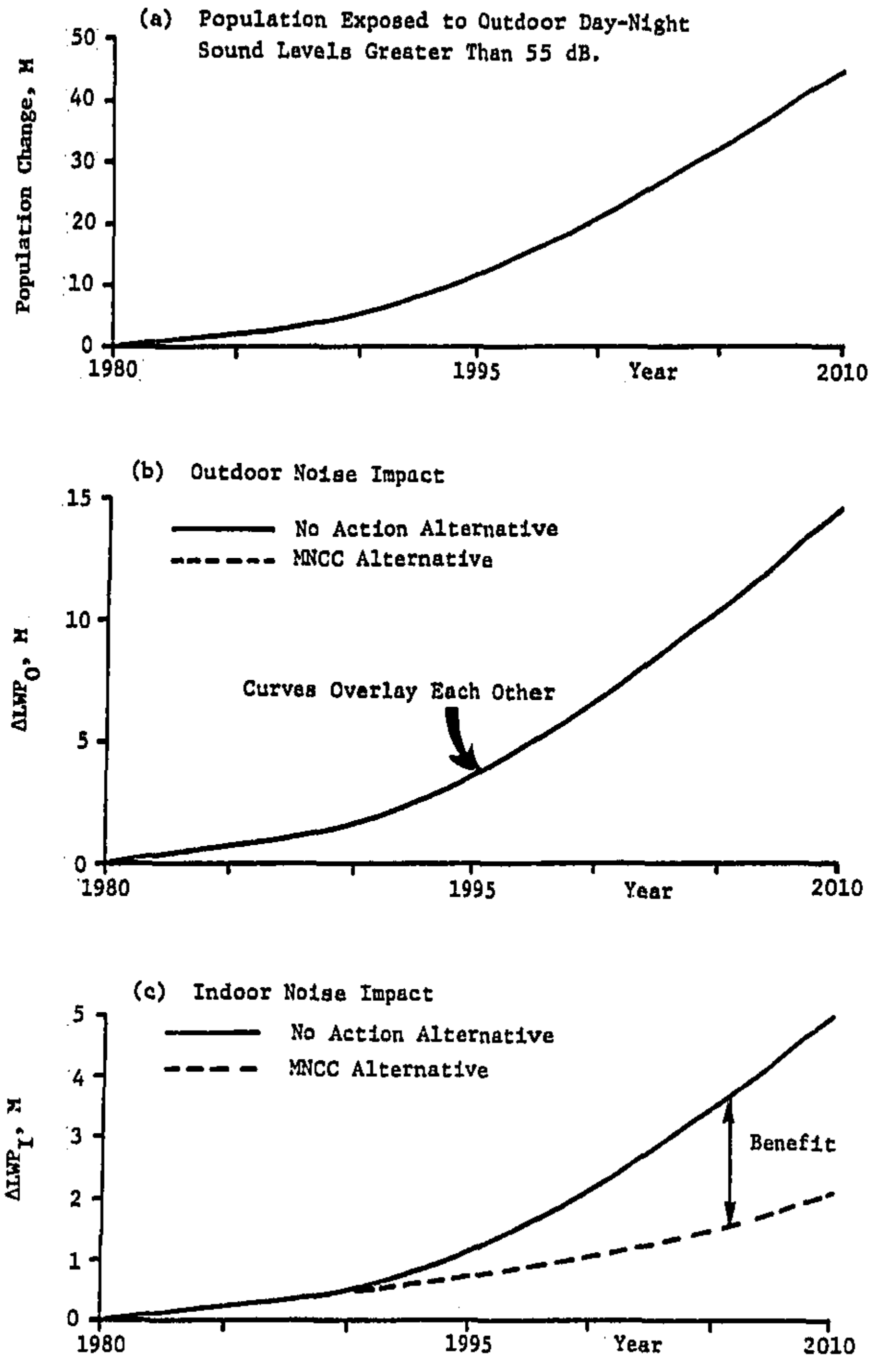

Figure 5.1 Population Change and Level Weighted Population for Years in the Time-Stream.

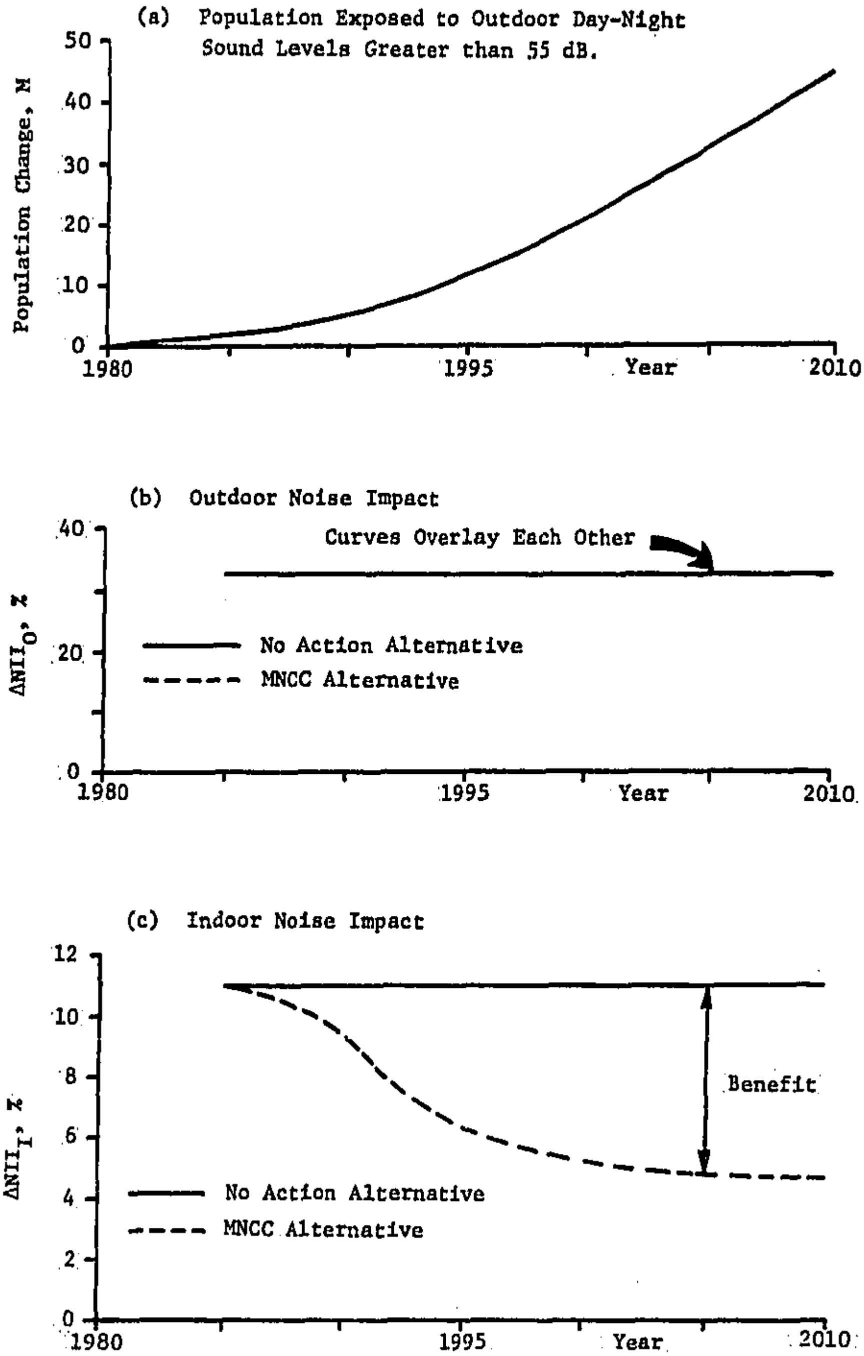

Figure 5.2 Population Change and Noise Impact Index for Years in the Time-Stream.

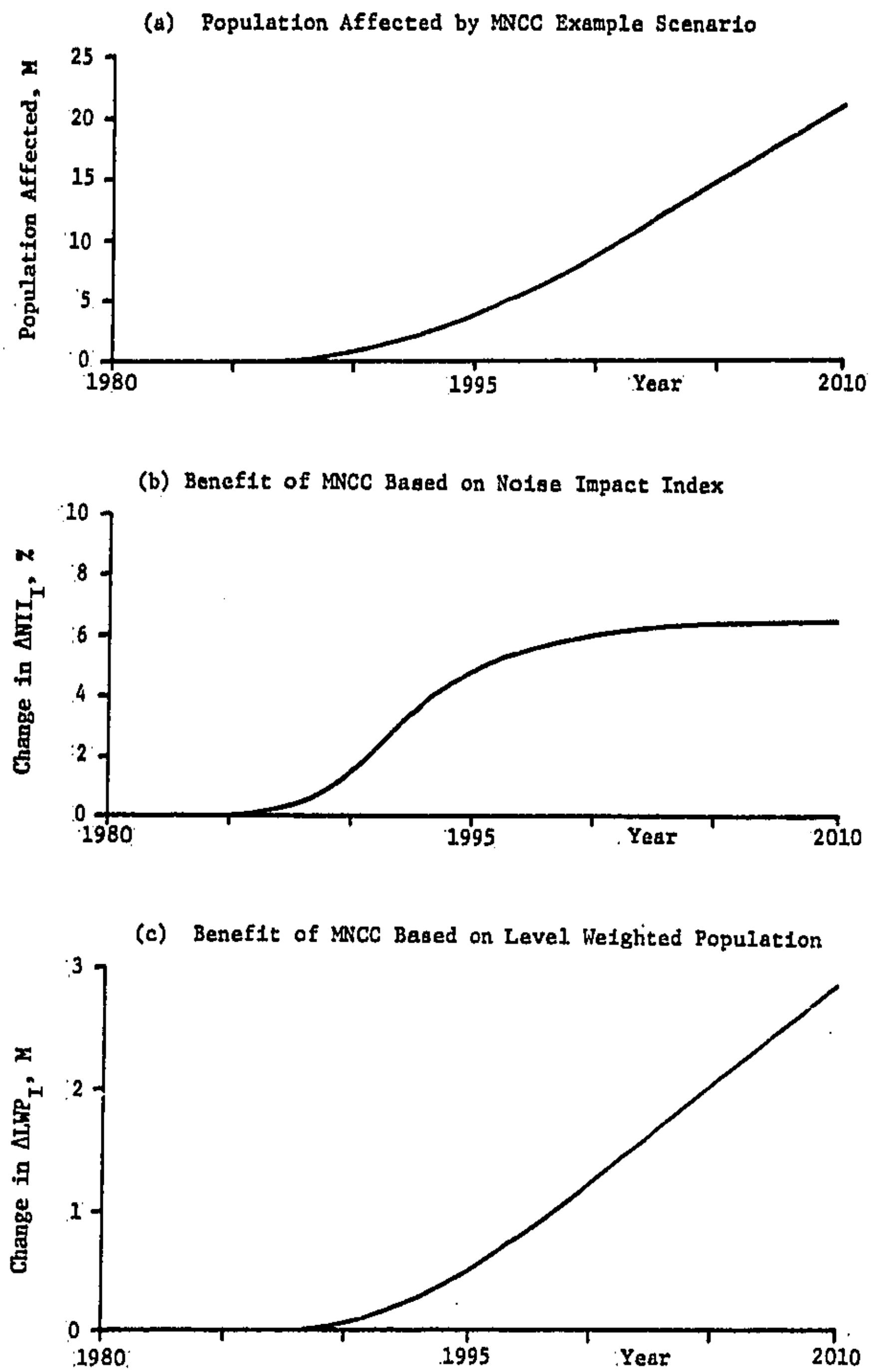

Figure 5.3 Population Affected, Change in Indoor Noise Impact Index, and Change in Indoor Level Weighted Population for Years in the Time-Stream.

6. CONCLUSIONS

A method is presented for estimating "benefits" related to implementing noise control requirements in building codes. The model applies only to the benefits resulting from the implementation of outdoor-to-indoor noise isolation. These benefits may be directly related to costs estimated using a related model (1).

The benefit model allows the user to incorporate local data and alternative noise isolation requirements appropriate to local conditions. Appendixes are included that describe the basic considerations for conducting the noise impact estimates, estimation of noise isolation for existing construction, and a worksheet that is useful in conducting the noise impact estimates.

A detailed example is presented in section 5 that illustrates the steps and considerations necessary to determine the benefits. For this example, a Model Noise Control Code developed for the U.S. Environmental Protection Agency is used to illustrate how one might incorporate the varied provisions of a candidate noise control code within the format of the benefit model.

7. REFERENCES

1. Weber, S. F., Rudder, F. F., and Boehm, M. J., Method for Assessing Costs of Noise Control Requirements in Multi-family Residential and Educational Buildings, U. S. Department of Commerce, National Bureau of Standards, Report NBSIR 81-2366 (1981).

2. Miller, N. P. and Schultz, T. J., Noise Control for Building Codes: Model Noise Control Provisions, Bolt, Beranek, and Newman Report No. 3759, prepared for U. S. Environmental Protection Agency, Office of Noise Abatement and Control (1978).

3. Harris, A. S., Keast, D. N., and Miller, N. P., Noise Control for Building Codes: Implementation Manual, Bolt, Beranek, and Newman Report No. 3837, prepared for U. S. Environmental Protection Agency, Office of Noise Abatement and Control (1978).

4. International Conference of Building Officials, Uniform Building Code, Whittier, CA (1979): Appendix, Chapter 35, Sound Transmission Control, pp. 668-669.

5. Schultz, T. J., Miller, N. P., and Miller, R. L., Interim Report, Task I: Development of Noise Control Requirements for Model Building Code, Bolt, Beranek, and Newman Report No. 3547, prepared for U.S. Environmental Protection Agency, Office of Noise Abatement and Control (1977).

6. Anon., Guidelines for Preparing Environmental Impact Statements on Noise, Report of Working Group 69 on Evaluation of Environmental Impact of Noise, Committee on Hearing, Bioacoustics, and Biomechanics, Assembly of Behavioral and Social Sciences, National Research Council, National Academy of Sciences, Washington, D.C. (1977).

7. Anon., Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, Report 550/9-74-004, U.S. Environmental Protection Agency, Office of Noise Abatement and Control (1974).

8. Part 150 - Airport Noise Compatibility Planning, U.S. Department of Transportation, Federal Aviation Administration, Federal Register/Vol. 46, No. 161, Monday, January 26, 1981/Rules and Regulations.

9. Yaniv, S. L. and Flynn, D. R., Noise Criteria for Buildings: A Critical Review, U.S. Department of Commerce, National Bureau of Standards Special Publication 499 (1978).

10. Schultz, T. J., Impact Noise Testing and Rating - 1980, Report No. NBS-GCR-80-249, U.S. Department of Commerce, National Bureau of Standards, (1981).

11. Maurin, M., Community Noise Impact Indicators: A Framework with Examples, Journal of Sound and Vibration, Vol. 79, No. 4, pp. 479-499 (1981).

12. Rudder, F. F., Ronk, L., and Hutcheson, B., National Roadway Traffic Noise Exposure Model. Prepared for U.S. Environmental Protection Agency, Office of Noise Abatement and Control (1979).

13. von Gierke, H. E., Guidelines for Environmental Impact Statements with Respect to Noise, Proceedings Noise-Con 77, NASA, Langley Research Center, Hampton, Virginia, pp. 61-78 (1977)

14. Goldstein, J., Assessing the Impact of Transportation Noise: Human Response Measures, Proceedings Noise-Con 77, NASA, Langley Research Center, Hampton, Virginia, pp. 79-98 (1977).

15. Sutherland, L. C., Indoor Noise Environments Due to Outdoor Noise Sources, Noise Control Engineering, Vol. 11, No. 3, (November-December 1978).

16. AIR 1081, House Noise Reduction Measurements for Use in Studies of Aircraft Flyover Noise, Society of Automotive Engineers (1971).

17. Anon., Home Sound Proofing Pilot Project for the Los Angeles Department of Airports, Report No. WCR 70-1, Wyle Laboratories, El Segundo, CA (1970).

18. Sabine, H. J., et al, Acoustical and Thermal Performance of Exterior Residential Walls, Doors and Windows, U.S. Department of Commerce, National Bureau of Standards, Report NBS-BSS-77 (1975).

19. Abramowitz, M. and Stegun, I. A., Eds., Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables, U.S. Department of Commerce, National Bureau of Standards, Applied Mathematics Series 55; Chapter 26, Table 26.1 (1965).

20. Burington, R. S., Handbook of Mathematical Tables and Formulas, Fifth Edition, McGraw-Hill Book Company New York, Table 18, pp. 424-427 (1973).

APPENDIX A

ESTIMATION OF NOISE IMPACT

This appendix describes the accepted methodology for estimating the impact of noise on a population [6,7]. The methodology requires that the distribution of population residing in a land area be known in terms of the average annual day-night sound level. The methodology determines single number ratings that are used to characterize the level of noise impact. In the United States, two common single number ratings are used for this purpose: 1) the Level Weighted Population (LWP) and, 2) the Noise Impact Index (NII). Reference 6 is a detailed description of the recommended documentation and methodology required to determine the environmental impact of noise. This appendix includes sufficient detail to quantify the noise impact as required for the benefit model.

A.1 POPULATION DISTRIBUTION WITH SOUND LEVEL

The most difficult data accumulation task is the estimation of the distribution of population in terms of the average annual outdoor day-night sound level. This distribution is denoted as p_ℓ and provides the estimate of the population exposed at a given outdoor day-night sound level, L_{dnO}. The methodology is based upon the average annual day-night sound level at a person's place of residence [6,7] even though a person will not spend the entire day at their place of residence. These considerations are incorporated into the weighting functions described in the following section.

For a population exposed to a range of day-night sound levels, the total population exposed is determined from the population distribution, $p_\ell(L)$, using the expression:

$$P_{exposed} = \sum_{i=1}^{N} p_\ell(L_{ci})\Delta L_i \qquad \text{(A-1)}$$

where i denotes an interval of L_{dnO}

$\Delta L_i = L_{i+1} - L_i$, dB

$L_{ci} = (L_{i+1} + L_i)/2$, dB.

The form of Equation (A-1) is the most readily usable for practical applications. For constant intervals, the above result is simplified to:

$$P_{exposed} = \sum_{i=1}^{N} p_\ell(L_{ci})\Delta L \qquad \text{(A-2)}$$

where ΔL is a constant.

The maximum value of ΔL recommended for evaluation of environmental noise impacts is 5 dB [6]. If the entire range of sound levels used in equations (A-1) or (A-2) encompasses the entire population, then the exposed population equals the total population.

A.2 WEIGHTING FUNCTIONS

Since the population under consideration is exposed to a range of day-night sound levels, it is necessary to incorporate this variation into the noise impact analysis. This is done by introducing weighting functions that attempt to determine an equivalent effect of noise at various levels. Considerable effort has gone into developing weighting functions appropriate to different categories of noise exposure [6,11,13,14].

For the purposes of the present model, a simplified weighting function is utilized. This simplified weighting function is defined by the relationships [6]:

$$W_0(L_{dn0}) = 0 \qquad L_{dn0} \leq 55 \qquad \text{(A-3a)}$$

$$W_0(L_{dn0}) = (L_{dn0} - 55)/20, \qquad 55 \leq L_{dn0} \leq 85 \qquad \text{(A-3b)}$$

$$W_0(L_{dn0}) = 1.5 \qquad L_{dn0} \geq 85 \qquad \text{(A-3c)}$$

where L_{dn0} is the outdoor day-night sound level.

To evaluate the effect of noise indoors due to outdoor sources, it is necessary to shift the description of the outdoor L_{dn} scale to a scale of indoor L_{dn} values. As described in Appendix B, it appears reasonable to assume a shift of 12.5 dBA corresponding to the center of the 10 to 15 dBA interval of building envelope noise isolation. Physically, this means that a residence located in an outdoor environment of $L_{dn0} = 55$ dB would correspond to an acceptable condition with windows open for both outdoor and indoor noise impact estimates.

Denoting the indoor weighting function by $W_I(L)$, the appropriate form for the indoor environment due to outdoor noise sources is:

$$W_I(L_{dnI}) = 0 \qquad L_{dnI} \leq 42.5 \qquad \text{(A-4a)}$$

$$W_I(L_{dnI}) = (L_{dnI} - 42.5)/20, \qquad 42.5 \leq L_{dnI} \leq 72.5 \qquad \text{(A-4b)}$$

$$W_I(L_{dnI}) = 1.5 \qquad L_{dnI} \geq 72.5 \qquad \text{(A-4c)}$$

where L_{dnI} is the indoor day-night sound level due to outdoor noise.

The relationship between the outdoor day-night sound level and the indoor day-night sound level due to outdoor noise is:

$$\Delta L_A = L_{dnO} - L_{dnI}, \text{ dB} \tag{A-5}$$

where ΔL_A is the noise level reduction provided by the building envelope.

A.3 LEVEL WEIGHTED POPULATION

The Level Weighted Population or LWP is a single number defining the equivalent or effective population exposed to a range of environmental noise levels. The functional definition of LWP is [6,7]:

$$LWP = \sum_{i=1}^{N} p_\ell(L_{ci}) W(L_{ci}) \Delta L \tag{A-6}$$

where $p_\ell(L_{ci})$ is the distribution of population exposed to day-night sound levels in the interval $L_{i+1} - L_i$ (see equation (A-2)),

$W(L_{ci})$ is the weighting function,

$L_{ci} = (L_{i+1} + L_i)/2$.

The form of equation (A-6) assumes a constant interval, ΔL, of day-night sound level. If outdoor day-night sound levels are appropriate, one uses the weighting function given by equation (A-3). For indoor day-night sound levels, one uses equation (A-4) for the weighting function to determine the LWP.

A.4 NOISE IMPACT INDEX

The Noise Impact Index or NII is a relative single number index useful in comparing one noise environment to another [6]. The NII is defined in terms of the LWP and the population exposed as:

$$NII = LWP/P_{exposed}. \tag{A-7}$$

The NII value may be expressed either as a fraction or as a percentage.

A.5 OBSERVATIONS

Formally, the distribution of population exposed at a given level of environmental noise, $p_\ell(L)$, has dimensions of "people per dB" as seen from equation (A-2). For constant intervals of noise exposure, it is common practice to aggregate data on the basis of the term $p_\ell(L_{ci})\Delta L$ which has units of people. Similarly, the dimension of the Level Weighted Population is "people" since the weighting functions are dimensionless. The Noise Impact Index is a dimensionless number since it is the ratio of the LWP estimate to the population exposed.

One additional comment concerning notation is necessary. The benefit model utilizes <u>changes</u> in population noise exposure to estimate benefits. In the report, the notation ΔP_{exp} is used to denote the change in population noise exposure. To denote the LWP and NII estimates for the <u>change</u> in population exposure, the notation ΔLWP and ΔNII is used. The values of ΔLWP and ΔNII are <u>not</u> changes in these quantities but denote LWP or NII estimates for the change in population noise exposure, ΔP_{exp}.

APPENDIX B

ESTIMATION OF OUTDOOR-TO-INDOOR NOISE ISOLATION OF EXISTING CONSTRUCTION

This appendix describes the basis for estimating the noise isolation of existing construction. First, the method used to develop the distributions of envelope noise isolation required for the noise impact worksheet is presented. These distributions, or available local data, may then be used to estimate an annual average or composite noise isolation distribution. The composite or average distribution represents the weighting of the envelope noise isolation on the basis of time to account for variations between the "closed window" and the "open window" conditions.

B.1 CLASSIFICATION OF SITE CONDITIONS

The noise isolation distributions developed for this model are based upon the data of reference 15 and the assumption of a normal distribution of the A-weighted noise isolation. Sutherland has developed the estimates for the mean value and the standard deviation of the A-weighted noise isolation provided by building envelopes [15]. These empirical data are divided into three groupings according to the dominant exterior noise source, the climatic region, and the window condition. The groupings are as follows:

(1) Dominant Exterior Noise Source

- (a) aircraft
- (b) highway traffic
- (c) average urban noise

(2) Climatic Region

- (a) cold (Average January temperature below 2°C (36°F))
- (b) warm (Average January temperature above 2°C (36°F))

(3) Window Condition

- (a) closed
- (b) open

The technical basis for this classification is the recognition that the envelope A-weighted noise isolation depends upon the noise source (spectral effects), the building construction, and the extent to which the shell is open to the environment [15,16,17].

The dominant source of exterior noise given above recognizes the differences in frequency content among different noise source categories. This grouping accounts for the frequency dependence of the noise source, the envelope construction, and the receiving room sound absorption.

The two categories for climatic region attempt to account for construction differences attributable to the thermal performance of the envelope. These differences may be attributed to both the thermal insulation (cavity filling, storm windows, etc.) and to the sealing of gaps and cracks (air infiltration). Both of these broad considerations affect the noise insulation of the envelope [18]. The available data allow the estimation of the average noise isolation only for the two categories of climate indicated. The term "cold" refers to geographic areas for which the average January temperature is below 2°C (36°F). The term "warm" refers to geographic areas for which the average January temperature is above 2°C (36°F).

The effect of an open window or a closed window on the noise isolation of the building envelope is obvious. Open windows in a room represent a lower limit to the degree of noise isolation that may be experienced by the occupant. It is necessary to include open window conditions since it cannot be assumed that the envelope will be sealed on an annual basis.

The first step in estimating the average noise isolation of existing construction is to determine the dominant noise for the land area under consideration. Once this is done, the next step is to determine the mean value and the standard deviation of the noise isolation-weighted for climatic conditions and assumed open/closed window conditions appropriate to the local environment.

B.2 MEAN VALUE AND STANDARD DEVIATION

Table B.1 lists the mean value and the standard deviation for each of the site conditions described above. These values must then be adjusted to account for the climatic conditions and the open/closed window condition. Based upon the average January temperature for the locality, the mean value and the standard deviation for the envelope noise level reduction is selected. It is now necessary to estimate the percentage of time that windows are open and closed for the locality for the entire year. This percentage of time is a local consideration.

With these data, the average values of the mean noise isolation and the standard deviation are obtained using the following expressions:

$$(\Delta L_A)_{avg} = P_{open}\,(\Delta L_A)_{open} + (1 - P_{open})\,(\Delta L_A)_{closed} \qquad \text{(B-1)}$$

$$\sigma_{avg} = \sigma_{closed} \qquad \text{(B-2)}$$

where P_{open} is the fraction of time that the windows are estimated to be open during the year.

For example, assume that the site is exposed dominantly to highway noise and that the appropriate climatic condition is cold. Further, it is estimated that open window conditions exist for 50 percent of the year (closed conditions apply to both heating and cooling time periods). From table B.1, the data are:

Table B.1. Mean Value and Standard Deviation of Envelope Noise Level Reduction: Existing Construction (reference 15, and as noted)

Dominant Exterior Noise Source	Climatic Condition	Windows Closed ΔL_A	Windows Closed σ	Windows Open ΔL_A	Windows Open σ
Aircraft	Cold	27.6	5.2	18.4	5.1
Aircraft	Warm	26.4	4.8	12.1	4.4
Highway	Cold	23.0	4.9	12.6	4.1
Highway	Warm	25.0	4.7	10.5*	4.0*
Urban	Cold	24.5	5.0*	12.0	4.0*
Urban	Warm	23.0	5.0*	10.0	3.0*

* Assumed Value

$(\Delta L_A)_{open} = 12.6$ dB

$(\Delta L_A)_{closed} = 23.0$ dB, $\sigma_{closed} = 4.9$

Then, the annual average mean value and standard deviation are:

$$(\Delta L_A)_{avg} = (0.50)(12.6) + (0.50)(23.0) = 17.8, \text{ dB.}$$

$$\sigma_{avg} = 4.9, \text{ dB.}$$

The reason for holding the standard deviation for the average annual condition constant at the closed-window value will be discussed below in relation to the estimate for the distribution of envelope noise level reduction.

B.3 DISTRIBUTION OF ENVELOPE NOISE LEVEL REDUCTION

It is assumed that the distribution of the values of the building envelope noise level reduction is described by a Gaussian or Normal Distribution (19,20). This distribution is completely described by the mean value and the standard deviation. Further, the necessary numerical values are extensively tabulated. The next step in determining the distribution is to aggregate the data in intervals of A-weighted noise level reduction consistent with the intervals used to define the distribution of population to outdoor day-night sound levels. For the present model and consistent with recommended practice [6], the intervals selected are 5 dB intervals.

For this data aggregation, it is necessary to recognize that the open window condition represents a lower limit to the envelope noise level reduction. This consideration is incorporated by assuming that the lower tail of the normal distribution is totally aggregated in the interval 10-15 dB. Physically, this attempts to approximate the lower limiting condition for the average noise level reduction of the envelope with open windows.

The procedure used to aggregate data is best described by an example. First, it is appropriate to define the terminology used. The normal distribution of the envelope noise level reduction is defined as:

$$p(\Delta L) = \text{EXP}\,[-\ell^2(\Delta L)/2]/\sqrt{2\pi}\,\sigma_{avg} \qquad \text{(B-3a)}$$

where $$\ell(\Delta L) = [\Delta L - (\Delta L_A)_{avg}]/\sigma_{avg}. \qquad \text{(B-3b)}$$

The aggregate or fraction of the distribution between two values of ΔL is determined by the area under the $p(\Delta L)$ curve between the two values. The functional expression is:

$$\Delta P = \int_{\ell_1}^{\ell_2} p(x)dx, \qquad \text{(B-4)}$$

where $p(x)$ is given by equation (B-3a), ℓ_1, ℓ_2 are the limits on the interval.

For the normal distribution, the values of ΔP are determined using tabulated values of $P(\ell)$ as:

$$\Delta P = P(\ell_2) - P(\ell_1) \qquad \text{(B-5)}$$

where $P(\ell) = \int_{-\infty}^{\ell} p(x)dx$.

Values of $P(\ell)$ are extensively tabulated (19,20). The above procedure is, again, best illustrated by an example. The previous example estimated the average annual mean noise level reduction as 17.8 dB with a standard deviation of 4.9 dB. Table B.2 illustrates the steps necessary to obtain the distribution of the A-weighted envelope noise level reduction for this example. The values of ℓ are calculated using the definition in equation (B-3b) and the values of $(\Delta L_A)_{avg}$ and σ_{avg}. The values of $P(\ell)$ are obtained from tabulations [20]. The remaining calculations are simple aggregations of the data. The only special note to make is that the value of $P(\ell)$ corresponding to $\Delta L_A = 15$ is totally aggregated into the interval of 10-15 dB. The distribution obtained in table B.2 is illustrated in figure B.1.

B.4 ESTIMATES OF NATIONAL AVERAGE DISTRIBUTION

The data in table B.1 for the mean values and the standard deviation for the six site conditions were used to develop distributions for the closed window condition. The procedure described above was used to obtain these estimates. The results are presented in table B.3. Further, distributions corresponding to "national average" noise level reduction were also estimated. These estimates are based upon the methodology suggested by Sutherland [15]. To obtain these estimates, it is assumed that 80 percent of the population lives in a cold climate with windows open 20 percent of the time and that 20 percent of the population lives in a warm climate with windows open 50 percent of the time. This population allocation and fraction of time for open windows is suggested by Sutherland to be representative of the national conditions [15].

Equations (B-1) and (B-2) are used with the data in table B.1 to estimate the composite mean noise level reduction, equation (B-1), and the standard deviation, equation (B-2), for aircraft noise, highway noise, and urban noise. The methodology described in section B.3 is then used to obtain the distribution for each category of outdoor noise. The results are presented in table B.4. For the urban noise environment, Sutherland used an average mean noise level reduction of 21 dB with a standard deviation of 7 in his development. The distribution corresponding to these data are also presented in table B.4.

One may use the distributions presented in this appendix to estimate the indoor noise impact for existing construction or develop distributions based upon

Table B.2. Example Calculation of Distribution of Envelope Noise Level Reduction

$(\Delta L_A)_{avg} = 17.8; \qquad \sigma_{avg} = 4.9$

L_i	ℓ_i	$P(\ell_i)$	ΔP	ΔL_A Interval	$100\Delta P$
-5	-4.65	0.0000			
			0.0001		
0	-3.63	0.0001			
			0.0044		
5	-2.61	0.0045			
			0.0514		
10	-1.59	0.0559			
			0.2284	10-15	28.43
15	-0.57	0.2843			
			0.2157		
17.8	0	0.5000		15-20	38.93
			0.1736		
20	+0.45	0.6736			
			0.2556	20-25	25.56
25	+1.47	0.9292			
			0.0644	25-30	6.44
30	+2.49	0.9936			
			0.0062	30-35	0.62
35	+3.51	0.9998			
			0.0002	35-40	0.02
40	+4.53	1.0000			
			0.0000	40-45	0.00
45	+5.55	1.0000			

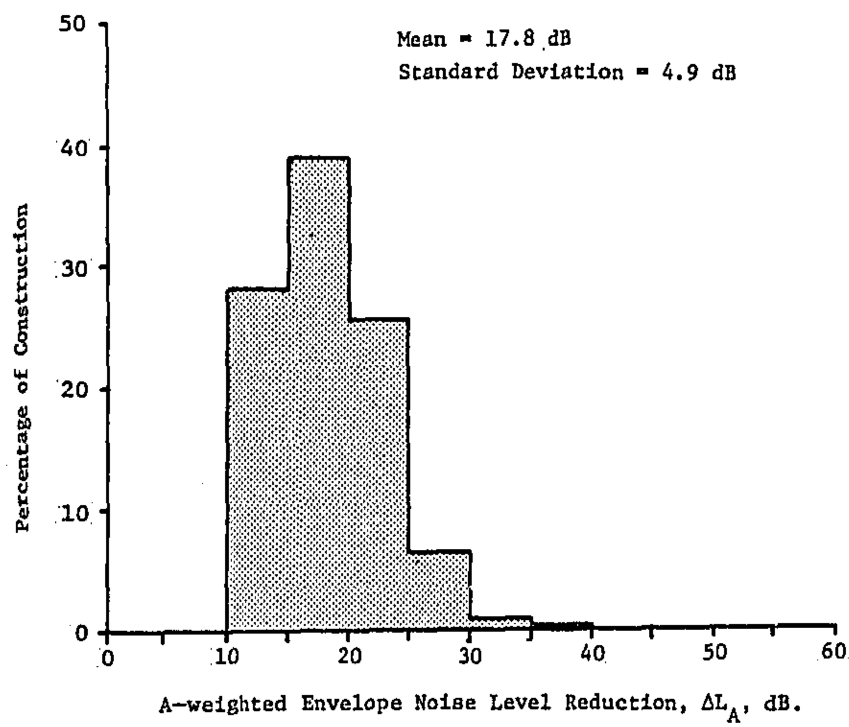

Figure B.1. Envelope noise level reduction for data in table B.2

Table B.3. Percentage Distribution of Envelope Noise Level Reduction for Existing Construction

WINDOWS CLOSED

ΔL_A Internal	Aircraft Noise Climate Cold	Aircraft Noise Climate Warm	Highway Noise Climate Cold	Highway Noise Climate Warm	Urban Noise Climate Cold	Urban Noise Climate Warm
10-15	0.78	0.87	5.16	1.66	2.87	5.57
15-20	6.43	8.31	21.93	12.80	15.54	21.95
20-25	23.64	29.41	38.82	35.54	35.57	38.11
25-30	36.87	38.75	26.45	35.54	32.45	26.38
30-35	24.50	18.99	6.93	12.80	11.78	7.26
35-40	6.91	3.44	0.68	1.59	1.69	0.79
40-45	0.87	0.23	0.03	0.07	0.10	0.03
Mean	27.6	26.4	23.0	25.0	24.5	23.0
Std Deviation	5.2	4.8	4.9	4.7	5.0*	5.0*

* Assumed values.

Table B.4. Percentage Distribution of Envelope Noise Level Reduction: National Averages for Existing Construction

ΔL_A Interval	Aircraft Noise	Highway Noise	Urban Noise	Urban Noise (1)
10-15	3.14	14.01	11.90	19.49
15-20	15.80	33.60	30.96	24.94
20-25	40.93	35.54	36.53	27.14
25-30	26.12	14.46	17.17	18.58
30-35	12.04	2.26	3.20	7.57
35-40	1.85	0.13	0.23	1.94
40-45	0.12	0.00	0.01	0.34
Mean	24.5	20.3	20.9	21.0
Std. Dev.	5.1	4.9	5.0	7.0

(1) Sutherland's estimate - Reference 15.

local conditions. The national highway traffic noise distribution in table B.4 is used in section 5 for the example benefit analysis. If the closed window conditions are used rather than a composite of open/closed conditions, one is assuming that the existing construction provides the maximum possible noise level reduction on an annual basis. The baseline noise impact estimate for this condition will be less than an estimate assuming an open/closed condition. As a result, the benefit (decrease in impact) of implementing noise control requirements in the building code will also decrease.

APPENDIX C

WORKSHEET FOR NOISE-IMPACT ANALYSIS

Tables 5.5 through 5.7 illustrate a worksheet format for conducting the noise impact analysis required to estimate the benefits of implementing noise control requirements for the building envelope. This appendix is a blank copy of this worksheet for users that desire to follow the format illustrated in section 5. The worksheet format was first suggested by Sutherland [15].

Table C.1 Blank Work Sheet for Noise-Impact Estimates

OUTDOOR				INDOOR								
					Distribution of Envelope Noise Level Reduction, ΔL_A, dB							
L_{dnO} interval	ΔP_{exp}	$W_O(L_{dnO})$	ΔLWP_O	Row Entry	10-15 dB	15-20 dB	20-25 dB	25-30 dB	30-35 dB	35-40 dB	40-45 dB	
<55 dB		0	0									
55-60 dB		0.1250		L_{dnI}	45 dB	40 dB	35 dB	30 dB	25 dB	20 dB	15 dB	
				ΔP_{exp}								
60-65 dB		0.3750		L_{dnI}	50 dB	45 dB	40 dB	35 dB	30 dB	25 dB	20 dB	
				ΔP_{exp}								
65-70 dB		0.6250		L_{dnI}	55 dB	50 dB	45 dB	40 dB	35 dB	30 dB	25 dB	
				ΔP_{exp}								
70-75 dB		0.8750		L_{dnI}	60 dB	55 dB	50 dB	45 dB	40 dB	35 dB	30 dB	
				ΔP_{exp}								
75-80 dB		1.1250		L_{dnI}	65 dB	60 dB	55 dB	50 dB	45 dB	40 dB	35 dB	
				ΔP_{exp}								
80-85 dB		1.3750		L_{dnI}	70 dB	65 dB	60 dB	55 dB	50 dB	45 dB	40 dB	
Total ΔLWP_O				ΔP_{exp}								
Indoor Day-Night Sound Level, L_{dnI}, dB					40 dB	45 dB	50 dB	55 dB	60 dB	65 dB	70 dB	Row
Indoor Weighting Factor, $W_I(L_{dnI})$					0	0.1250	0.3750	0.6250	0.8750	1.1250	1.3750	Total
Indoor Population Exposed, ΔP_{exp}												
Indoor Level Weighted Population, ΔLWP_I					0							

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This report presents a method for estimating benefits accruing from implementing acoustical performance requirements for new buildings. The method can be applied to a wide range of environmental noise conditions and noise isolation requirements for building envelopes. Benefits are estimated based upon the distribution of population with outdoor noise level and the noise isolation provided by the building envelope. A method is described for estimating noise isolation performance of existing construction based upon local conditions.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

acoustical design; benefit analysis; building codes; model code; noise control; noise impact; outdoor-indoor noise isolation.

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