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METHOD FOR ASSESSING BENEFITS OF AIRBORNE NOISE ISOLATION
REQUIREMENTS IN RESIDENTIAL AND EDUCATIONAL BUILDINGS

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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 provided 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.

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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 research leading to this 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
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1.0 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 (2,3). Unique to the MNCC are the variable 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 (4). As

described in the MNCC documentation, 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 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 indicates 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.

2.0 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

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 high-rise, low-rise, and townhouse buildings.
    E = All educational buildings.

[b] also applies to single family dwellings

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)	
$\geq$	<	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.

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

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.

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

These 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 effect
five different building components.[1] 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 assembles
are affected only by the Acoutical 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.[2]
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. It this provision were implemented it would
primarily affect multifamily residential buildings.

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[1] 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 high-rise building is likely to be minimal. Further, the
increment in benefits may not be significant.

[2] For justification of the use of prescriptive rather than performance require-
ments for Impact Noise Isolation see Reference 2, p. 45.

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

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.

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	X	
Windows	X	X
Doors	X	X
Interior Walls (Partitions)		X
Floor/Ceiling Assemblies		X

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3.0 OVERVIEW OF METHODOLOGY

The 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 detailed
steps that are influenced by local conditions a detailed example is presented
in Section 5.

3.1 Definition of Benefit

This model attempts to quantify non-economic 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 "defacto" 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. This estimate is, however, an approximation.

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.

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 multi-family residential and educational

construction. The code requirements specify an increased interior wall noise

isolation performance for decreasing 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 <u>Impact Noise</u>. The MNCC uses a prescriptive rather than a performance

requirement for impact noise isolation (see Sec. 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

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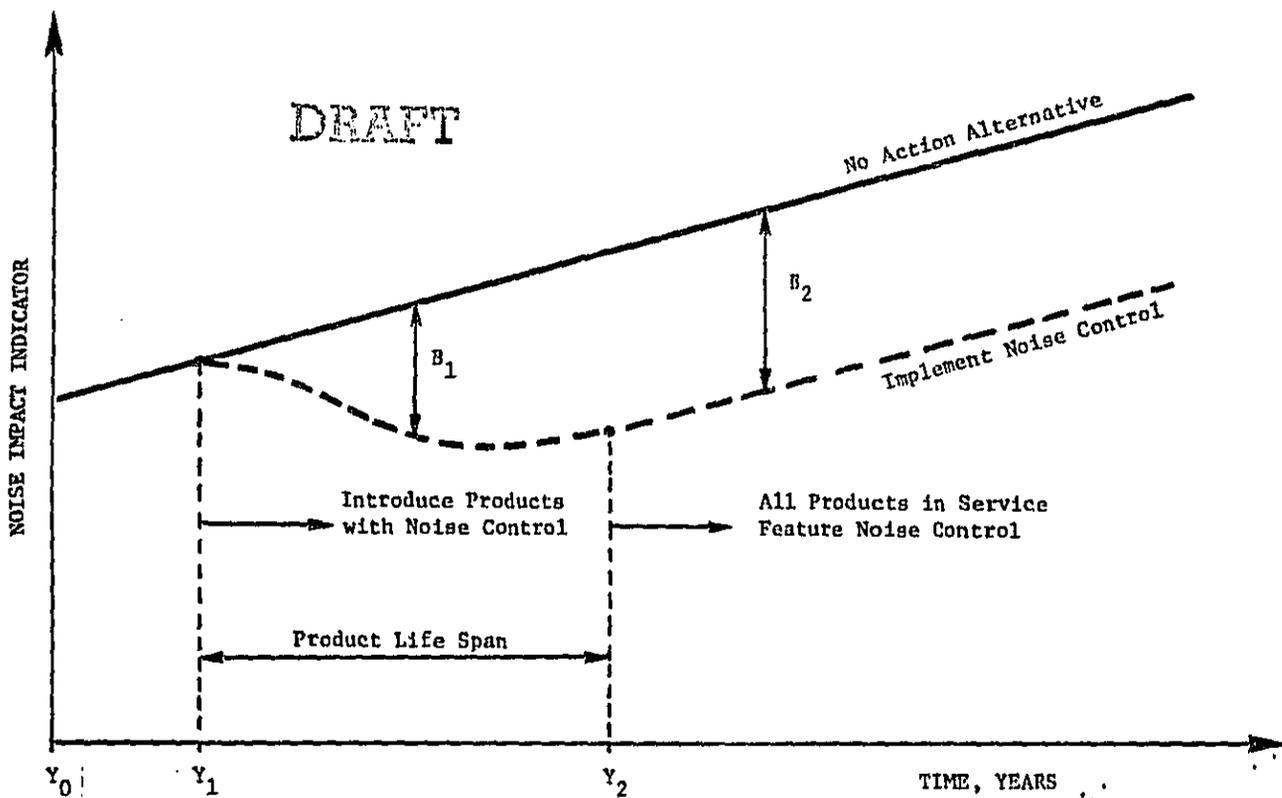
Figure 3.1 General Characteristics of a Noise Impact Assessment for
Implementing Noise Control Requirements on a Product.

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 then the ultimate benefits that can be expected to accrue to

future generations.

4.0   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 Fig. 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 porportion of the population that resides in buildings exempted from the

noise isolation requirement and the population residing 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 refered 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.

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    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.

5.0 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.

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

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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 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 construction 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 concensus 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

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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 $\Delta P'_{exp}$ are directly transcribed

from Table 5.2 for the year 1995.[1] The entries under the column heading

ΔLWP_0 are obtained by multiplying the ΔP_{exp} entries by the weighting factors

$W_0(L_{dnO})$ 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_0

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 pre-determined

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

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
(3.21M) by the fraction of construction exhibiting the level of noise
isolation (0.3360) to obtain the estimate 1.0786M.

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.

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 that 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 provide two numbers: the Level
Weighted Population based upon the outdoor noise environment, $\Delta LWP_O =$
3.5125M, and the Level Weighted Population based upon the indoor noise
environment due to outdoor noise, $\Delta LWP_I = 1.1829M$. 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 indentical to that described for
the no-action alternative. However, the calculations involve two population
exposure categories for each year of the time-stream: population residing
in existing construction and 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: $\Delta LWP_O = 1.5575M$ and $\Delta LWP_I =$
0.4362M. 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
manunipulations are identical.. However, the indoor data entries for

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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' judgement - 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: noise impact related to existing construction;
noise impact related to new construction; and 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_0 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 above 80 dB (See Table 5.1).

Comparing the ΔLWP_I values in Table 5.8 for the "no action" and the
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 suprising. They are essentially constant for all years of the time-stream! The value of the ΔNII for the outdoor impact, ΔNII$_0$, is constant at about 32.5 percent of the population exposed to outdoor sound levels above 55 dB. The value of the ΔNII for the indoor impact, ΔNII$_I$, is constant at about 10.9 percent. One should not, however, be too suprised 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 Impacts. 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 Impacts. 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

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of 2.84M 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 21.07M 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 un-
warranted 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 estimates based upon the Noise
Impact Index. These results are also plotted from the data in Tables
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 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.

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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 than 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 the benefit estimate based on the

Noise Impact Index. One may be more confident, of course, if they conduct

a complete time-stream analysis.

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

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YEAR OF TIME STREAM

L_{dnO} Interval	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
$\geq$55	86.8	89.3	91.1	97.6	107.8	119.3	131.5
$\geq$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)

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L_{dn0} Interval	YEAR OF TIME-STREAM						
	1980*	1985	1990	1995	2000	2005	2010
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
$\geq$55	86.8	2.50	4.30	10.80	21.00	32.50	44.70
$\geq$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

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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	0.00	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

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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						
L_{dnO} interval	ΔP_{exp} M	$W_O(L_{dnO})$	ΔLWP_O M	Row	Distribution of Envelope Noise Level Reduction, ΔL_A, dB						
					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	—

	40 dB	45 dB	50 dB	55 dB	60 dB	65 dB	70 dB	Row Total
Indoor Day-Night Sound Level, L_{dnI}, dB	40 dB	45 dB	50 dB	55 dB	60 dB	65 dB	70 dB	
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$45dB)	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

L_{dnO} interval	ΔP_{exp} M	$W_0(L_{dnO})$	ΔLWP_0 M	Row	Distribution of Envelope Noise Level Reduction, ΔL_A, dB						
					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_0 M			1.5575	ΔP_{exp}	0.0014	0.0034	0.0036	0.0014	0.0002	—	—

	40 dB	45 dB	50 dB	55 dB	60 dB	65 dB	70 dB	Row Total
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 (≥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

L_{dnO} interval	ΔP_{exp} M	$W_O(L_{dnO})$	ΔLHP_O M	Row	Distribution of Envelope Noise Level Reduction, ΔL_A, dB						
					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 ΔLHP_O M			1.9525	ΔP_{exp}	-	-	-	-	-	0	0

	40 dB	45 dB	50 dB	55 dB	60 dB	65 dB	70 dB	Row Total
Indoor Day-Night Sound Level, L_{dnI}, dB	40 dB	45 dB	50 dB	55 dB	60 dB	65 dB	70 dB	
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(≥45dB)	1.8900	1.8900	0	0	0	0	0	1.8900
Indoor Level Weighted Population, ΔLHP_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 | | | | ALL CONSTR. | |
| | | | EXISTING CONSTR. | | NEW CONSTR. | | | |
	$\Delta LWP_O / M$	$\Delta LWP_I / M$	$\Delta LWP_O / M$	$\Delta LWP_I / M$	$\Delta LWP_O / M$	$\Delta LWP_I / M$	$\Delta LWP_O / M$	$\Delta LWP_I / M$
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

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Table 5.9   Noise Impact Estimate for the No Action Alternative

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YEAR	ΔP_{exp} ≥ 55 dB M	OUTDOOR		INDOOR	
		ΔLWP_O M	ΔNII_O %	ΔLWP_I M	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

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YEAR	ΔP_{exp} ≥ 55 dB M	OUTDOOR ΔLWP_O M	ΔNII_O %	INDOOR ΔLWP_I .M	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

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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)

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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

(a) Population Exposed to Outdoor Day-Night
     Sound Levels Greater Than 55 dB.

(b) Outdoor Noise Impact

No Action Alternative
MNCC Alternative

Curves Overlay Each Other

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(c) Indoor Noise Impact

No Action Alternative
MNCC Alternative
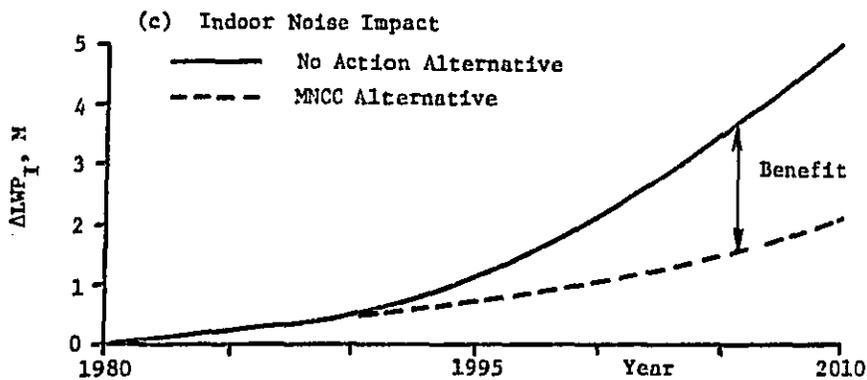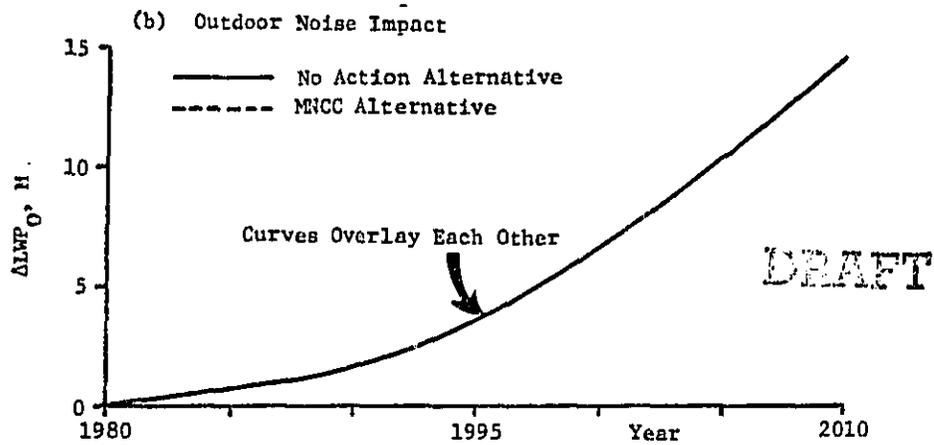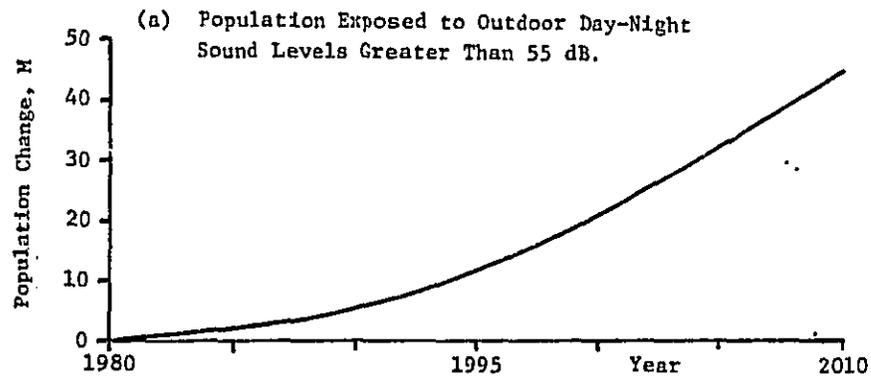
Benefit

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

(a) Population Exposed to Outdoor Day-Night Sound Levels Greater than 55 dB.

Population Change, M

50
40
30
20
10
0

1980 — 1995 — Year — 2010

(b) Outdoor Noise Impact

ΔNII_O, %

Curves Overlay Each Other

40
20
0

——— No Action Alternative
- - - - MNCC Alternative

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1980 — 1995 — Year — 2010

(c) Indoor Noise Impact

ΔNII_I, %

12
10
8
6
4
2
0

Benefit

——— No Action Alternative
- - - - MNCC Alternative

1980 — 1995 — Year — 2010
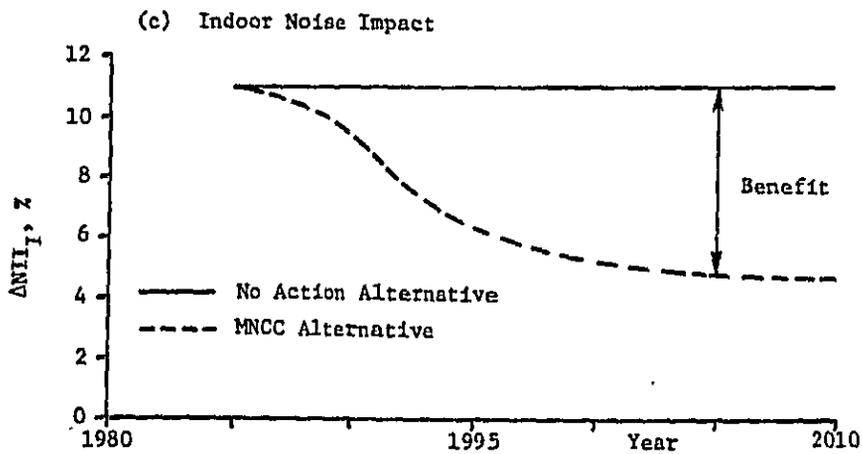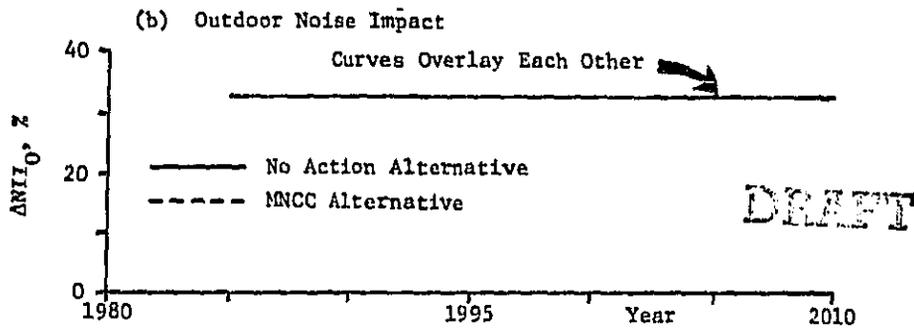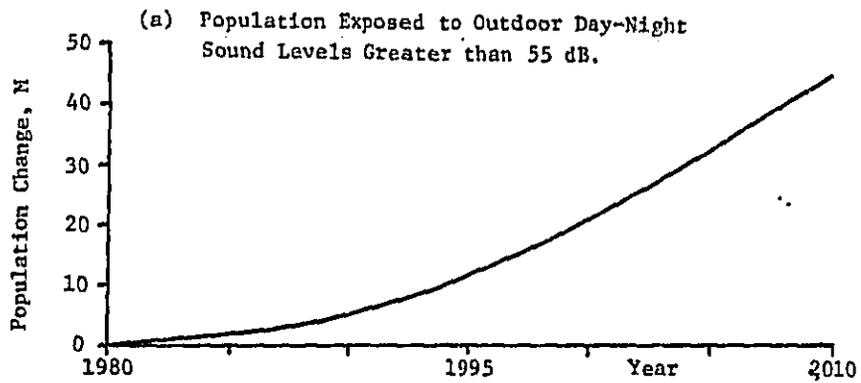
Figure 5.2   Population Change and Noise Impact Index
for Years in the Time Stream.

(a) Population Affected by MNCC Example Scenario
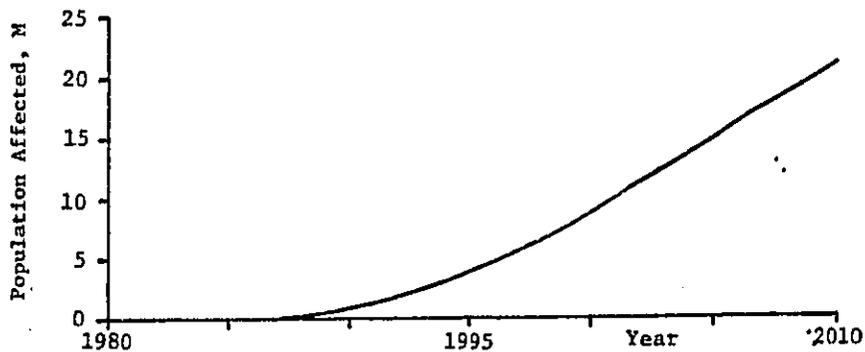
(b) Benefit of MNCC Based on Noise Impact Index
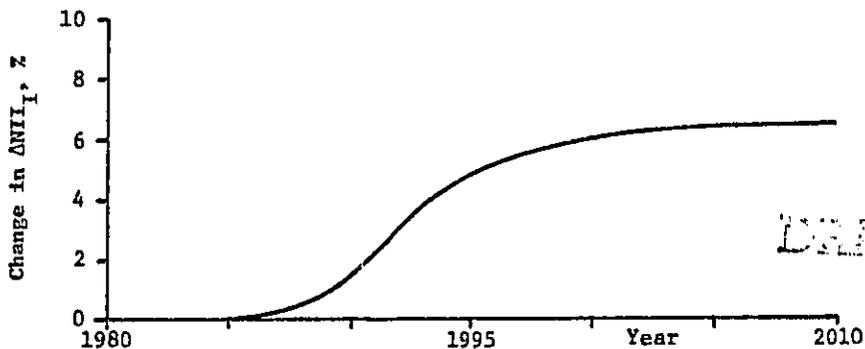
(c) Benefit of MNCC Based on Level Weighted Population
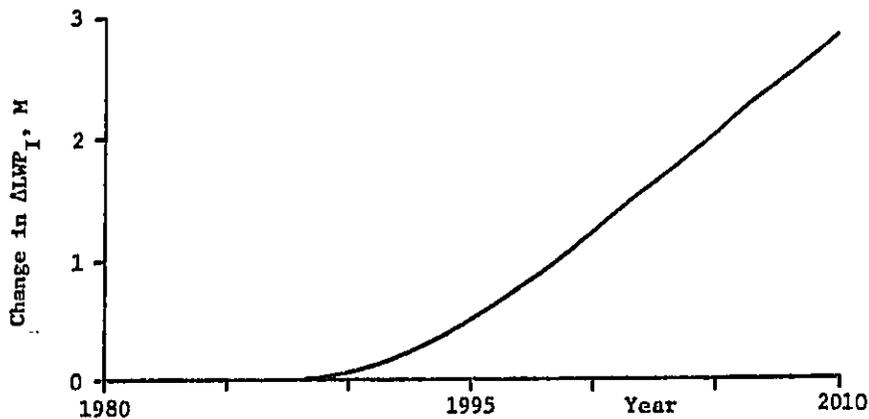
Figure 5.3 Population Affected, Change in Indoor Noise Impact Index, and Change in Indoor Level Weighted Population for Years in the Time Stream.

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6.0 CONCLUSION

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 with the format of the benefit model.

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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 is 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: the Level Weighted Population (LWP) and 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 $p_\ell(L)$ and provides the
estimate of the population exposed at a given outdoor day-night sound
level, L_{dn0}. 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 their 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:

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

where i denotes an interval of L_{dn0}

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

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

The form of Equation (A-1) is the most readily useable for practical

applications. For constant intervals, the above result is simplified to:

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

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):

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

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

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

where L_{dnO} is the <u>outdoor</u> day night sound level.

To evaluate the effect of noise <u>indoors</u> 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 $L_{dnO} = 55$ dB would correspond to an acceptable condition with windows open.

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

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

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

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

where L_{dnI} is the <u>indoor</u> 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:

$$\Delta L_A = L_{dn0} - L_{dnI}, \text{ dB.} \tag{A-5}$$

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 Eqn (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:

$$NII = LWP/P_{exposed}.$$
<div align="right">(A-7)</div>

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 changes 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
change in population exposure, the notation ΔLWP and ΔNII is used.
The values of ΔLWP and ΔNII are not changes in these quantities but
denote LWP or NII estimates for the change in population noise exposure,
ΔP_{exp}.

APPENDIX B   DRAFT

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 distri-
butions 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 both the noise source, the envelope construction, and the receiving room sound absorption.

The two broad 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 source 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 assuumed 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 six 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 duration are obtained using the following expressions:

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

$$\sigma_{avg} = \sigma_{closed} \tag{B-2}$$

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

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	σ	Windows Open ΔL_A	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

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:

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

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

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 completly 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

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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:

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

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

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:

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

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:

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

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

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 $\Delta P(\ell)$ 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

Table B.2

Example Calculation of Distribution
of Envelope Noise Level Reduction

$(\Delta L_A)_{avg}$ = 17.8; σ_{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			

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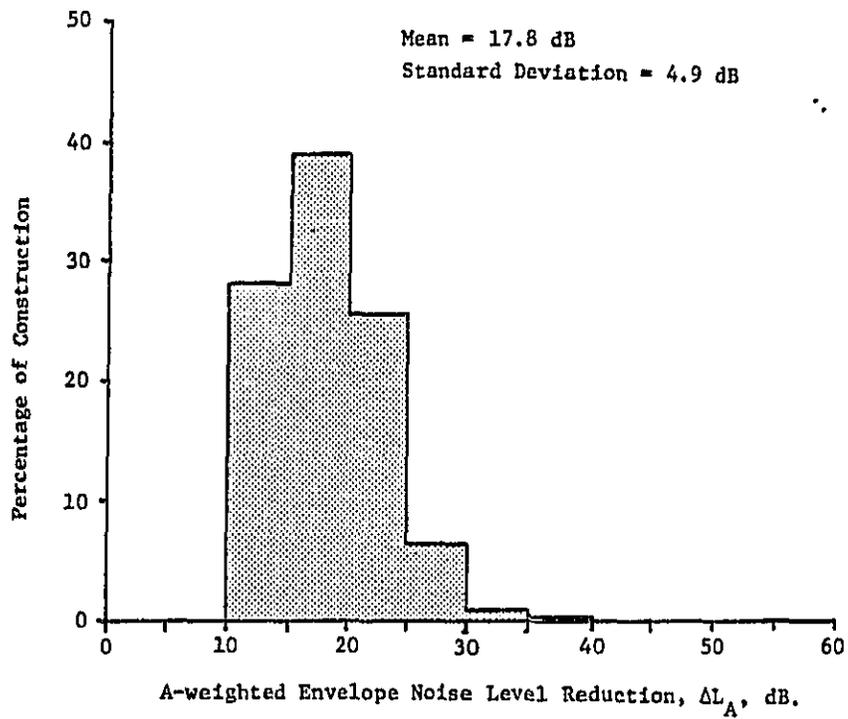
Figure B.1   Envelope Noise Level Reduction Distribution for Data in Table B.2

Table B.3

Percentage Distribution of Envelope Noise Level Reduction for

Existing Construction

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WINDOWS CLOSED

ΔL_A Internal	Aircraft Noise Climate		Highway Noise Climate		Urban Noise Climate	
	Cold	Warm	Cold	Warm	Cold	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.

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, Eqn (B-1), and the

standard deviation, Eqn (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 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.

Table B.4

Percentage Distribution of Envelope Noise Level Reduction
National Averages for Existing Construction

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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.

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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						
L_{dnO} interval	ΔP_{exp}	$W_O(L_{dnO})$	ΔLWP_O	Row	Distribution of Envelope Noise Level Reduction, ΔL_A, dB						
					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	Entry							
55-60 dB		0.1250		L_{dnI} / ΔP_{exp}	45 dB	40 dB	35 dB	30 dB	25 dB	20 dB	15 dB
60-65 dB		0.3750		L_{dnI} / ΔP_{exp}	50 dB	45 dB	40 dB	35 dB	30 dB	25 dB	20 dB
65-70 dB		0.6250		L_{dnI} / ΔP_{exp}	55 dB	50 dB	45 dB	40 dB	35 dB	30 dB	25 dB
70-75 dB		0.8750		L_{dnI} / ΔP_{exp}	60 dB	55 dB	50 dB	45 dB	40 dB	35 dB	30 dB
75-80 dB		1.1250		L_{dnI} / ΔP_{exp}	65 dB	60 dB	55 dB	50 dB	45 dB	40 dB	35 dB
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							