6. DETAILED NOISE ANALYSIS

This chapter describes the detailed computation of both project and existing noise levels for a comprehensive assessment of project noise impact. The main purpose of this chapter is to provide a procedure that allows prediction of impact and assessment of the effectiveness of mitigation with greater precision than can be achieved with the General Assessment. In some cases, decisions on appropriate mitigation measures can be made based on the results of the General Assessment. When a more detailed evaluation of mitigation measures is needed, the procedures in this chapter should be followed.

It is important to recognize that use of the Detailed Analysis methods will not provide more accurate results than the General Assessment unless more detailed and specific input data are used. In the case of a transit center for example, the General Assessment provides a source level at a reference distance from the center of the site based on the number of buses at the facility during each hour. Thus, the only information needed for a General Assessment of the transit center is the site location and hourly bus volumes. However, a Detailed Analysis would require specific information on the locations, reference levels, traffic volumes and duration of operations for individual sources that contribute to the total noise output of the transit center. Such information would include a detailed design plan for the facility, the locations of idling buses and the idling durations, as well as the bus and automobile traffic patterns and volumes. A Detailed Analysis cannot be done until such information is available.

Detailed Noise Analysis is appropriate in two main circumstances: first, for major fixed-guideway projects after a preferred alignment has been selected; and second, for any other transit project where potentially severe impacts are identified at an early stage. For fixed-guideway projects, once the preferred mode and alignment are established, the project sponsor begins preliminary engineering and preparation of the environmental document (usually an Environmental Impact Statement). Information required for the Detailed Noise Analysis is generally available at the preliminary engineering stage; such information includes hourly operational schedules during day and night, speed profiles, plan and profiles of guideways, locations of access roads, and landform topography including terrain and building features.

Even for relatively minor transit projects, noise impacts are likely to occur whenever the project is in close proximity to noise-sensitive sites, particularly residences. Some examples are: (1) a terminal or station sited adjacent to a residential neighborhood; (2) a maintenance facility located near a school; (3) a storage yard adjacent to residences; and (4) an electric substation located adjacent to a hospital. As with the larger fixed guideway projects mentioned above, detailed noise analysis for these projects will require information normally developed at the preliminary design stage.

The procedures of this chapter include everything needed for a fully detailed transit noise analysis. They are aimed at major transit projects that have enough lead time for thorough environmental analysis. They need not be followed to the letter; they can be tempered by competent engineering judgment and adapted somewhat to specific project constraints.

This chapter employs equations as the primary mode of computation, rather than graphs or tables of numbers, in order to facilitate the use of spreadsheets and/or programmable calculators. Moreover, these equations and their supporting text have been streamlined to provide as concise a view of the Detailed Noise Analysis as possible. As a result, basic noise concepts are not repeated in this chapter.

The steps in the procedure appear in Figure 6-1 and are described below. They parallel the steps for the General Noise Assessment, though they are more refined in the prediction of project noise and subsequent evaluation of mitigation measures.

1. Receivers of Interest: Select receivers of interest, guided by Section 6.1. The number of receivers will depend upon the land use in the vicinity of the proposed project and the extent of the study area defined by the Screening Procedure. If a General Assessment has been done, this will give a good indication of the extent of potential impacts.

2. Project Noise: Determine whether the project is primarily a fixed-guideway transit, highway/transit, or stationary facility. Note that a major fixed guideway system will have stationary facilities associated with it, and that a stationary facility may have highway/transit elements associated with it. Identify the project noise sources that are in the vicinity of receivers of interest. For these sources, determine the source reference noise in terms of SEL from the tables in Section 6.2. Each reference SEL pertains to reference operating conditions for stationary sources or to one vehicle passby under reference operating conditions for fixed-guideway and highway/transit sources. These reference levels should incorporate source-noise mitigation only if such mitigation will be incorporated into the system specifications. For example, if the specifications include vehicle noise limits, these limits should be used to determine the reference level, and this level should be used in the analysis rather than the standard, tabulated reference level. Convert each source SEL to noise exposure (L_{dn} or L_{eq} (h)) at 50 feet, for the appropriate project operating parameters, using additional equations in Section 6.2.

3. Propagation and Summation of Project Noise at Receivers of Interest: Draw a noise exposure vs. distance curve for each relevant source, using the equations in Section 6.3. This curve will show source noise as a function of distance, accounting for shielding along the path, as well as any propagation-path mitigation that will be included in the project. From these curves, determine the total

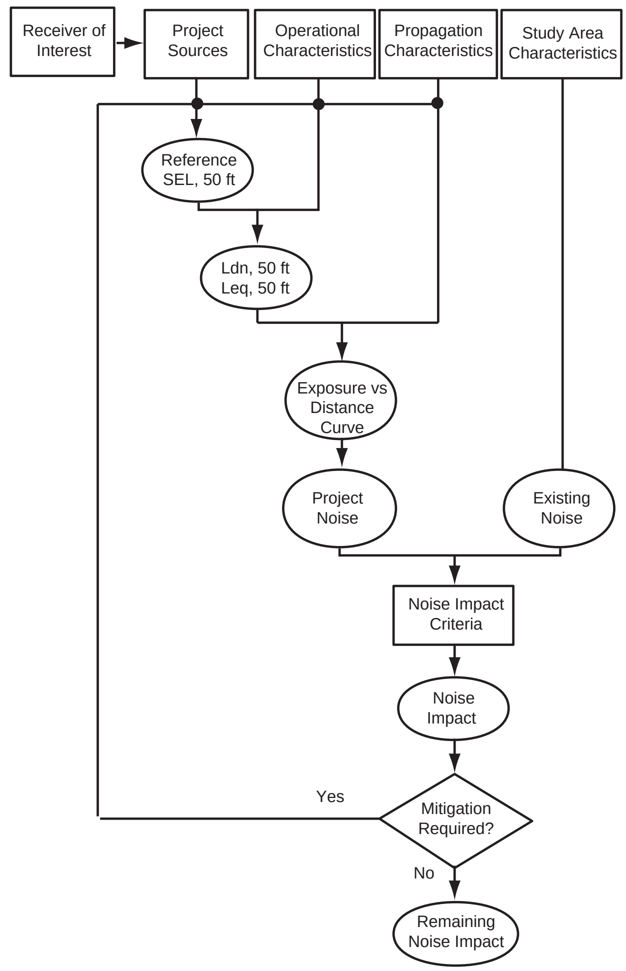


Figure 6-1 Procedure for Detailed Analysis

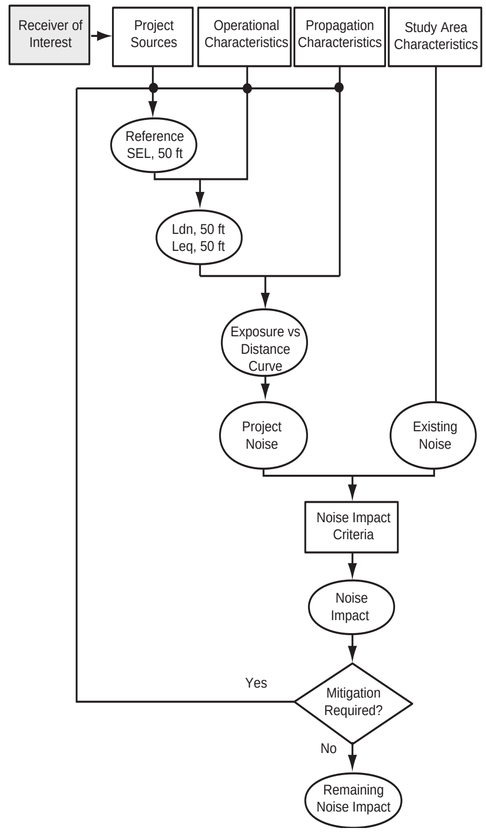
project noise exposure at all receivers of interest by combining the levels from all relevant sources (Section 6.4).

4. Existing Noise in the Study Area: Estimate the existing noise exposure at each receiver of interest, using the methods in Section 6.5.

5. Noise Impact Assessment: Assess noise impact at each receiver of interest using the procedures in Section 6.6 which incorporate the noise impact criteria of Chapter 3.

6. Mitigation of Noise Impact: Where the assessment shows either Severe Impact or Impact, evaluate alternative mitigation measures referring to Section 6.7. Then loop back to modify the project-noise computations, thereby accounting for the adopted mitigation, and reassess the remaining noise impact.

6.1 RECEIVERS OF INTEREST



The steps in identifying the receivers of interest, both the number of receivers needed and their locations, are shown in Figure 6-2. Later sections discuss the measurement/computation of ambient noise, the computation of project noise, and the resulting assessment of noise impact that is done for each receiver. The basic steps, which are discussed in the following subsections, are:

1. Identify all noise-sensitive land uses.
2. Find individual receivers of interest. Examples are isolated residences and institutional resources such as schools.
3. Cluster residential neighborhoods and other relatively large noise-sensitive areas.

6.1.1 Identifying Noise-Sensitive Land Uses

A Detailed Noise Analysis should usually be performed on all noise-sensitive land uses where impact is identified by the General Noise Assessment. If a General Noise Assessment has not been done, but there appears to be potential for noise impacts, all noise-sensitive sites within the area defined by the noise screening procedure should be included. In areas where ambient noise is low, the assessment will include land uses that are farther from the proposed project than for areas with higher ambient levels.

Some of the land-use materials and methods that can be helpful in locating noise-sensitive land uses in the vicinity of the proposed project include:

- **Land-use maps**, prepared by regional or local planning agencies or by the project staff. Area-wide maps often do not have sufficient detail to be of much use. However, they can provide broad guidance and may suggest residential pockets hidden within otherwise commercial zones. Of more use are project-specific maps which provide building-by-building detail on the land nearest the proposed project.
- **USGS maps,** prepared by the United States Geological Survey generally at 2000-foot scale. These maps contain details of house placement, except in highly urbanized areas, and generally show the location of all schools and places of worship, plus many other public-use buildings. In addition, the topographic contours on these maps may be useful later during noise computation.
- **Road and town maps**. These can supplement the USGS maps, are generally more up-to-date, and may be of larger scale.

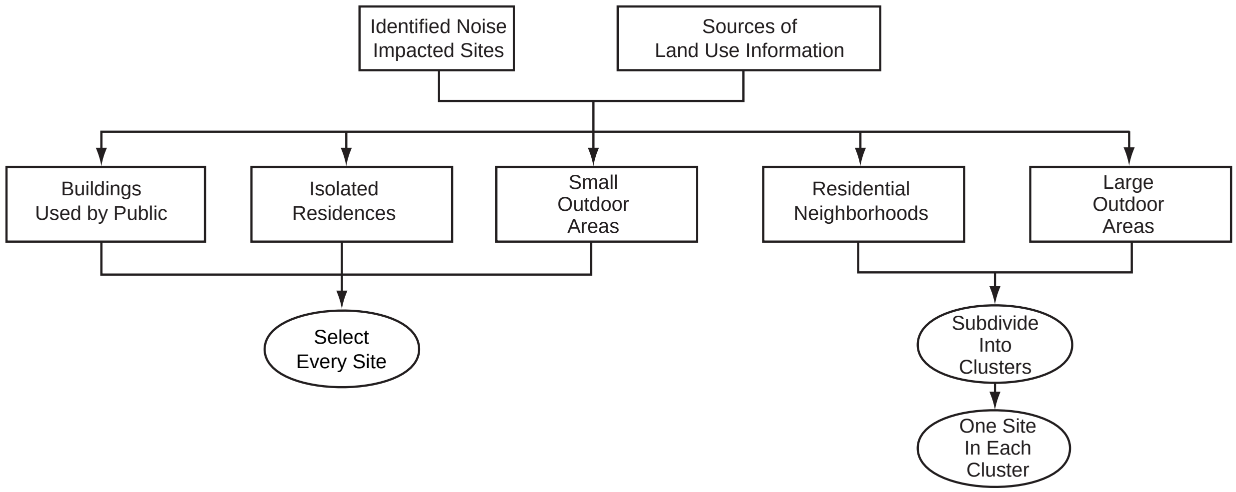


Figure 6-2 Guide to Selecting Receivers of Interest

- **Aerial photographs,** especially those of 400-foot scale or better. When current, aerial photos are valuable in locating all potential noise-sensitive land uses close to the proposed project. In addition, they can be useful in determining the distances between receivers and the project.

- **Windshield survey** of the corridor. Definitive identification of noise-sensitive sites is accomplished by a windshield survey in which the corridor is driven and land uses are annotated on base maps. The windshield survey, supplemented by footwork where needed, is especially useful in identifying newly-constructed sites and in confirming land uses very close to the proposed project.

Table 6-1 contains the types of land use of most interest to transit projects, separated into three types of land use. If noise impact was identified at other types of buildings/areas with noise-sensitive use by the General Noise Assessment, these should be selected also.

6.1.2 Selecting Individual Receivers of Interest

Select as an individual receiver of interest: (1) every major noise-sensitive building used by the public; (2) every isolated residence; and (3) every relatively small outdoor noise-sensitive area. Use judgment here to avoid analyzing noise where such analysis is obviously not needed. For example, many roadside motels are not particularly sensitive to noise from outdoors. On the other hand, be careful to include buildings used by the public or outdoor areas which are considered to be particularly noise-sensitive by the community. Isolated residences that are particularly close to the project should certainly be included, while those at some distance may often be omitted or "clustered" together with other land uses, as described in the next section. Use judgment also concerning relatively small outdoor noise-sensitive areas. For example, playgrounds can often be omitted unless they directly abut the proposed project, since noise sensitivity in playgrounds is generally low.

Table 6-1 Land Uses of Interest

Land Uses	Specific Use	Selecting Receivers
Outdoor noise-sensitive areas	Parks Historic sites used for interpretation Amphitheaters Recreation areas Playgrounds Cemeteries Other outdoor noise-sensitive areas	For relatively small noise-sensitive areas: same as indoor noise-sensitive sites. For relatively large areas: same as for residential areas.
Residences	Single family residences Multi-family residences (apartment buildings, duplexes,etc.)	Select each isolated residence as a receiver of interest. For residential areas, cluster by proximity to project sources, proximity to ambient-noise sources, and location along project line. Choose one receiver of interest in each cluster.
Indoor noise-sensitive sites	Places of worship Schools Hospitals/nursing homes Libraries Public meeting halls Concert halls/auditoriums/theaters Recording/broadcast studios Museums and certain historic buildings Hotels and motels Other public buildings with noise-sensitive indoor use	Select noise-sensitive buildings as separate receivers of interest.

6.1.3 Clustering Residential Neighborhoods and Outdoor Noise-Sensitive Areas

Residential neighborhoods and relatively large outdoor noise-sensitive areas can often be clustered, simplifying the analysis that is required without compromising the accuracy of the analysis. The goal is to subdivide all such neighborhoods/areas into clusters of approximately uniform noise, each containing a collection of noise-sensitive sites. Attempt to obtain uniformity of both project noise and ambient noise, guided by these considerations:

1. In general, project noise drops off with distance from the project. For this reason, project noise uniformity requires nearly equal distances between the project noise source and all points within the cluster. Such clusters will usually be shaped as long narrow strips parallel to the transit corridor and/or circling project point sources such as a maintenance facility. Suggested are clusters within which the project noise will vary over a range of 5 decibels or less. Be guided here by the fact that project noise will drop off approximately 3 decibels per doubling of distance for line sources and 6 decibels per doubling of distance for point sources over open terrain. Drop off with distance will be faster in areas containing obstacles to sound propagation, such as rows of buildings.

2. Ambient noise usually drops off from non-project sources in the same manner as does noise from project sources. For this reason, clustering for uniform ambient noise will usually result in long narrow

strips parallel to major roadways or circling major point sources of ambient noise, such as a manufacturing facility. Suggested are clusters within which the ambient noise will vary over a range of 5 decibels or less, though this may be hard to judge without measurements. In areas without predominant sources of noise, like highways, ambient noise varies with population density, which is generally uniform along the corridor. In situations where ambient noise tends to be uniform, the clusters can encompass relatively large areas.

After defining the cluster, select one receiver as representative in each cluster. Generally choose the receiver closest to the project and at an intermediate distance from the predominant sources of exising noise. Detailed procedures for clustering appear in Appendix B along with an example of clustering for a segment of rail line. This method will generally result in an adequate selection of receivers along the corridor or surrounding the site.

6.2 PROJECT NOISE

Once receivers have been selected, projections of noise from the project must be developed for each receiver. This section describes the first step, calculating the noise exposure at an equivalent distance of 50 feet from each project noise source. As shown in Figure 6-3, the basic procedures for the computation are: (1) Separate nearby sources into these source-type categories: fixed-guideway sources, highway/transit sources, and stationary sources; (2) Determine the reference SEL for each source.; and (3) Use the projected source operating parameters to convert each reference SEL to noise exposure (either L_{dn} or L_{eq}(h)) at 50 feet.

Table 6-2 lists many of the noise sources that are involved in transit projects. The right-hand column of the table indicates whether or not each source is a major contributor to overall noise impact. Note that some noise sources, such as track maintenance equipment, create high noise levels but are not indicated as "major." Although such sources are loud, they rarely stay in a neighborhood for more than a day or two; therefore, the overall noise exposure is relatively minor. Computations are required for all major noise sources in this table. The computations for the three basic groups – fixed-guideway sources, highway/transit sources, and stationary sources – appear in separate sections below.

6.2.1 Fixed-Guideway Sources

This section describes the computation of project noise at 50 feet from fixed-guideway sources of transit noise, identified in the second column of Table 6-2.

Step 1: Source SELs at 50 feet

For each major fixed-guideway noise source, first determine the reference SEL at 50 feet, either by measurement or by table look-up. Table 6-3 provides guidance on which method is preferred for each source type. A "NO" implies that the source levels are based on a solid and consistent data base; a "YES" means that a solid data base is not available. In general, measurements are preferred for source types that vary significantly from project to project, including any emerging technology sources. Table look-up is adequate for source types that do not vary significantly from project to project. In general, table look-up is adequate

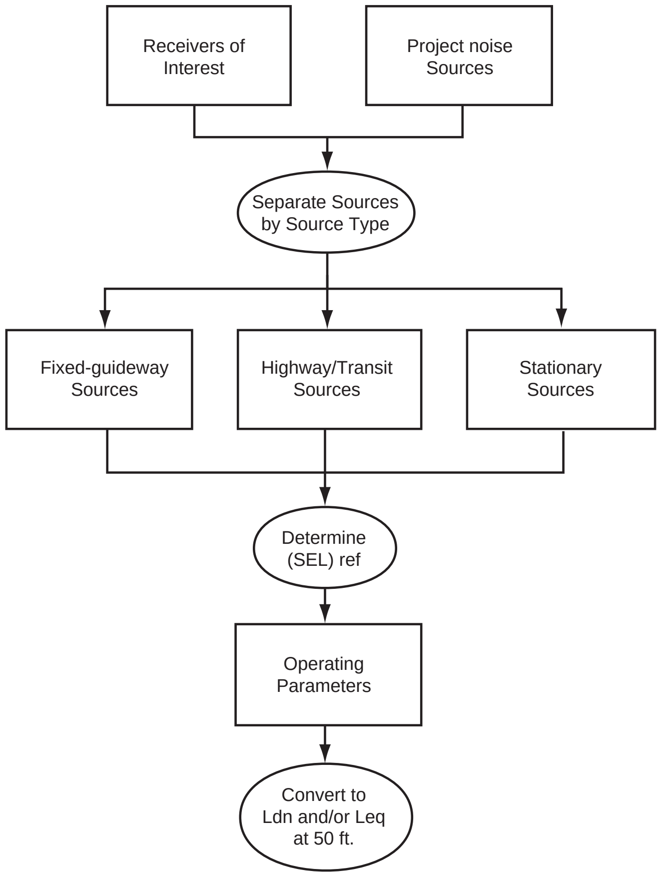


Figure 6-3 Flow Diagram for Determining Project Noise at 50 ft

for fewer source types during Detailed Noise Analysis than during General Noise Assessment where less precision is acceptable.

For sources where measurements are indicated in Table 6-3, Appendix D discusses measurement procedures and conversion of these measurements to the reference conditions of Table 6-3. These procedures have been placed in an appendix because of their relative complexity. For projects where source-noise specifications have been defined (e.g., noise limits are usually included in the specifications for purchase of new transit vehicles), these specifications may be used instead of measurements, after conversion to reference conditions with the equations of Appendix D.

For sources where table look-up is indicated in Table 6-3, the table provides appropriate Source Reference SELs. Approximate L_{max} values also appear in the table for general user information and for comparison with factors such as the noise limits that are included in transit vehicle specifications. As discussed in Chapter 2, L_{max} is not used directly in the evaluation of noise impact.

Table 6-2 Sources of Transit Noise

Project Type	Source Type	Actual Source	Major?
Commuter Rail Light Rail Rail Rapid Transit	Fixed Guideway	Locomotive and rail car passbys	YES
		Horns and whistles	YES
		Crossing signals	YES
		Crossovers/switches	YES
		Squeal on tight curves	YES
		Track-maintenance equipment	NO
	Stationary	Substations	YES
		Chiller plants	NO
Busways Bus Transit Malls	Highway/Transit	Bus passbys	YES
		Buses parking	NO
	Stationary	Buses idling	YES
Automated Guideway Transit Monorail	Fixed Guideway	Vehicle passbys	YES
	Miscellaneous	Line equipment	NO
Terminals Stations Transit Centers	Fixed Guideway	Locomotive and rail car passbys	YES
		Crossovers/switches	YES
		Squeal on tight curves	YES
	Highway/Transit	Bus passbys	YES
		Buses parking	NO
		Automobile passbys	NO
	Stationary	Locomotives idling	YES
		Buses idling	YES
		HVAC equipment	NO
		Cooling towers	NO
		P/A systems	NO
Park-and-Ride Lots	Highway/Transit	Bus passbys	YES
		Buses idling	YES
		Automobile passbys	NO
	Stationary	P/A systems	NO
Traffic Diversion Projects	Highway/Transit	Highway vehicle passbys	YES
Storage Facilities Maintenance Facilities	Fixed Guideway	Locomotive and rail car passbys	YES
		Locomotives idling	YES
		Squeal on tight curves	YES
		Horns, warning signals, coupling/ uncoupling, auxiliary equipment, crossovers/ switches, brake squeal and air release	YES
	Highway/Transit	Bus passbys	YES
	Stationary	Buses idling	YES
		Yard/shop activities	NO
		Car washes	NO
		HVAC Equipment	NO
		P/A Systems	NO

Table 6-3 Source Reference SELs at 50 Feet: Fixed-Guideway Sources

Source	Reference SEL (dBA)	Approximate L_{max} (dBA)	Prefer Measurements?
Rail Cars	82	80	NO
Locomotives - Diesel	92	88	NO
Locomotives - Electric	90	86	NO
AGT - Steel Wheel	80	78	YES
AGT - Rubber Tire	78	75	YES
Monorail	82	80	YES
Maglev	72	70	YES
Locomotive Horns or Whistles	108	105	NO
Transit Car Horns or Whistles	93	90	NO

Step 2: Conversion to Noise Exposure at 50 feet

Step 1 results in reference SELs at 50 feet. Step 2 is to convert from these reference SELs to noise exposure based on operating conditions and parameters such as train consists, speed, and number of trains per hour. The steps are:

1. Identify operating conditions. Trains with different consists require separate conversion since they will produce different noise exposure. The same is true for trains at different speeds, or under different operating conditions. As guidance here, the following percentage changes in operating conditions will produce an approximate 2-decibel change in noise exposure:

   - 40 percent change in number of locomotives or cars per train
   - 40 percent change in number of trains per hour
   - 40 percent change in number of trains per day, or per night (for computation of L_{dn})
   - 15 percent change in train speed
   - change of one notch in diesel locomotive throttle setting (e.g. from notch 5 to notch 6).

   In general, where operating conditions change by these amounts, separate calculations should be made. Without separate conversions, the risk is that the results may not be accurate enough.

2. Establish relevant time periods. For each of these source types/conditions, decide what are the relevant time periods for all receivers that may be affected by this source. For residential receivers, the two time periods of interest for computation of L_{dn} are: daytime (7 am to 10 pm) and nighttime (10 pm to 7 am). If the source will affect non-residential receivers, choose the loudest project hour during noise-sensitive activity. Several different hours may be of interest for non-residential receivers depending on the hours the facility is used.

3. Collect input data.
   - Source reference SELs for locomotives, rail cars, and warning horns.

- N_{cars}, the number of rail cars in the train.
- N_{locos}, the number of locomotives in the train, if any.
- *S*, the train speed, in miles per hour.
- *T*, the average throttle setting of the train's locomotive(s), if it is diesel-electric.* If this input is not available, assume a throttle setting of 8.
- For residential receivers of interest:

  V_d, the average hourly train volume during daytime hours (equals the total number of train passbys between 7 am and 10 pm, divided by 15), and

  V_n, the average hourly train volume during nighttime hours (equals the total number of train passbys between 10 pm and 7 am, divided by 9).

- For non-residential receivers: *V*, the hourly train volume for each hour of interest.
- Track type (continuously welded or jointed) and profile (at-grade or elevated).

4. Calculate L_{eq} at 50 ft for each hour of interest.
   - Compute $L_{eqL}(h)$ for the locomotive(s) using the first equation in Table 6-4.
   - Compute $L_{eqC}(h)$ for the rail car(s) using the second equation in Table 6-4. Use the adjustments indicated in the table, as needed.
   - Compute $L_{eqH}(h)$ for the train horn using the third equation in Table 6-4.
   - Compute the total $L_{eq}(h)$ using the fourth equation in Table 6-4. Two totals may be necessary: one with the warning horn and one without it. These will pertain to different neighborhoods along the corridor, depending upon whether the horn is sounded in that neighborhood or not.

5. Compute L_{dn} at 50 ft. If the project noise will affect any residential receivers, compute the total train L_{dn} from the fifth equation in Table 6-4. Again two totals may be necessary: one with the warning horn and one without it, as explained above.

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* Otherwise, this term is not applicable and should be omitted from the equation in Table 6-4.

Table 6-4 Computation of L_{eq} and L_{dn} at 50 feet: Fixed-Guideway Sources

LOCOMOTIVES[†] Hourly L_{eq} at 50 ft:	$L_{eqL}(h) = SEL_{ref} + 10\log(N_{locos}) + C_T - 10\log\left(\frac{S}{50}\right) + 10\log(V) - 35.6$ where $C_T = \begin{cases} 0 & \text{for } T < 6 \\ 2(T-5) & \text{for } T \geq 6 \end{cases}$
RAIL VEHICLES Hourly L_{eq} at 50 ft:	$L_{eqC}(h) = SEL_{ref} + 10\log(N_{cars}) + 20\log\left(\frac{S}{50}\right) + 10\log(V) - 35.6$ use the following adjustments as applicable: + 5 → JOINTED TRACK + 3 → EMBEDDED TRACK ON GRADE + 4 → AERIAL STRUCTURE WITH SLAB TRACK
WARNING HORNS Hourly L_{eq} at 50 ft:	$L_{eqH}(h) = SEL_{ref} - 10\log\left(\frac{S}{50}\right) + 10\log(V) - 35.6$
COMBINED Hourly L_{eq} at 50 ft:	$L_{eq}(h) = 10\log\left[10^{\left(L_{eqL}/10\right)} + 10^{\left(L_{eqC}/10\right)} + 10^{\left(L_{eqH}/10\right)}\right]$
Daytime L_{eq} at 50 ft:	$L_{eq}(day) = L_{eq}(h)\Big\|_{V=V_d}$
Nighttime L_{eq} at 50 ft:	$L_{eq}(night) = L_{eq}(h)\Big\|_{V=V_n}$
L_{dn} at 50 ft:	$L_{dn} = 10\log\left[(15)\cdot 10^{\left(L_{eq}(day)/10\right)} + (9)\cdot 10^{\left((L_{eq}(night)+10)/10\right)}\right] - 13.8$

N_{locos} = average number of locomotives per train
N_{cars} = average number of cars per train
T = average throttle setting of diesel-electric locomotive
S = train speed, in miles per hour
V = average hourly volume of train traffic, in trains per hour
V_d = average hourly daytime volume of traffic, in trains per hour

$$= \frac{\text{number of trains, 7 am to 10 pm}}{15}$$

V_n = average hourly nighttime volume of train traffic, in trains per hour

$$= \frac{\text{number of trains, 10 pm to 7 am}}{9}$$

† assumes a diesel locomotive power rating of approximately 3000 hp.

Example 6-1. Computation of L_{eq} and L_{dn} at 50 feet for Fixed Guideway Source

A commuter train with 1 diesel locomotive and 6 cars will pass close to a school that is in session from 8 am to 4 pm on weekdays. Within this time period, the hour of greatest activity for this train type is 8 to 9 am. For this project source,

SEL_{ref} = 92 for locomotives,
= 82 for rail cars,
= 108 for warning horns.

In addition,

N_{cars} = 6

N_{locos} = 1

S = 43 mph

T = 8

V = 6 trains from 8am to 9am

The track is also jointed in this vicinity. Using Table 6-4, the resulting hourly L_{eq}'s at 50 feet are as follows:

L_{eqL}(8-9am) = 70.9 for locomotives,

L_{eqC}(8-9am) = 65.7 for cars, and

L_{eqH}(8-9am) = 80.9 for horns.

Total L_{eq}(8-9am) = 81.4 in neighborhoods where the horn is sounded, and
= 72.0 in neighborhoods where it is not.

(Note: Computation results should always be rounded to the nearest decibel at the end of the computation. In all examples of this chapter, however, the first decimal place is retained in case readers wish to precisely match their own computations against the example computations.)

This same commuter train will also pass close to a residential area. For this project source, all SEL_{ref}'s are the same as above -- as are values for N_{cars}, N_{locos}, S, and T. In addition,

V_d = (40 trains)/(15 hours) = 2.67 trains per hour, and

V_n = (2 trains)/(9 hours) = 0.22 trains per hour.

Using Table 6-4, the resulting daytime L_{eq}'s at 50 feet are as follows:

L_{eqL}(day) = 67.4 for locomotives,

L_{eqC}(day) = 62.2 for cars, and

L_{eqH}(day) = 77.4 for horns,

Total L_{eq}(day) = 77.9 with horns, and
= 68.5 without horns.

Using Table 6-4, the resulting nighttime L_{eq}'s at 50 feet are as follows:

L_{eqL}(night) = 56.5 for locomotives,

L_{eqC}(night) = 51.3 for cars, and

L_{eqH}(night) = 66.5 for horns,

Total L_{eq}(night) = 67.0 with horns, and
= 57.6 without horns.

Finally, this total day and night traffic results in:

L_{dn} = 77.6 at 50 ft in neighborhoods where horns are sounded, and
= 68.2 at 50 ft in neighborhoods where they are not.

End of Example 6-1

6.2.2 Highway/Transit Sources

This section describes the computation of project noise at 50 feet for highway/transit sources, identified in the second column of Table 6-2. This method is based on the FHWA highway noise prediction model, including the noise emission levels and mathematics.(1) This model can be used because the vehicle equations are applicable to speeds typical of freely-flowing traffic on city streets and access roads. For highway/transit projects with complex geometry or traffic conditions, it may be more appropriate to use the detailed FHWA computation methods discussed in Section 6.6.2.

Step 1: Source SELs at 50 feet

Determine the source reference SEL at 50 feet for each "major" highway/transit source near a receiver of interest. As indicated in the fourth column of Table 6-5, it is usually adequate to use the standard Reference SELs of Table 6-5 for highway/transit sources. If measurements are chosen, however, Appendix D discusses the measurement procedures, plus procedures for the conversion of these measurements to reference conditions of Table 6-5. These measurement/conversion procedures have been placed in an appendix because of their relative complexity.

Table 6-5 Source Reference SELs at 50 Feet: Highway/Transit Sources

Source	Reference SEL (dBA)	Approximate L_{max} (dBA)	Prefer Measurements?
Automobiles	73	70	No
Two-axle (city) Buses	84	81	No
Three-axle (commuter) Buses	88	85	No

Step 2: Conversion to Noise Exposure

Convert the source reference SELs at 50 feet to actual operating conditions such as actual vehicle speed and number of vehicles per hour. Next convert to noise exposure using the following steps:

1. Identify actual source operating conditions. Noise emission from most transit buses does not depend significantly upon whether the buses are accelerating or cruising. On the other hand, accelerating intercity buses are significantly louder than are cruising intercity buses. For this reason, intercity buses

require separate conversion along roadway stretches where they are accelerating. Separate conversion is also needed for all highway/transit vehicles at different speeds, since speed affects noise emissions. As guidance here, the following percentage changes in operating conditions will produce an approximate 2-decibel change in noise exposure:

- 40 percent change in number of vehicles per hour
- 40 percent change in number of vehicles per day, or per night (for computation of L_{dn})
- 15 percent change in vehicle speed.

In general, where operating conditions change by these amounts, separate conversions should be made.

Note that buses on city streets will have lower speeds than on freeways and will often be accelerating. For these reasons, separate conversions are generally needed on these two types of roadways. No other distinctions are needed besides these two; the computations suffice for both. Note also that idling buses are included with other stationary sources.

2. Establish relevant time periods. For each of these source types/conditions, decide what are the relevant time periods for all receivers that may be affected by this source. If the source will affect residential receivers, two time periods are of interest to compute L_{dn}: daytime (7 am to 10 pm) and nighttime (10 pm to 7 am). In addition, if the source will affect non-residential receivers, choose the loudest facility hour during noise-sensitive activity. Several different hours may be of interest for non-residential receivers, depending on the hours the facility is used.

3. Collect input data. Gather the following information:

- Source reference SELs for the vehicle types of concern.
- *S*, the average running speed in miles per hour.
- For residential receivers of interest:

  V_d, the average hourly vehicle volume during daytime hours (equals the total number of vehicle passbys between 7 am and 10 pm, divided by 15), and

  V_n, the average hourly vehicle volume during nighttime hours (equals the total number of vehicle passbys between 10 pm and 7 am the next day, divided by 9).
- For non-residential receivers of interest: *V*, the hourly vehicle volume for each hour of interest, in vehicles per hour.

4. Calculate L_{eq} at 50 ft for each hour of interest. Compute $L_{eq}(h)$ for the vehicle type using the first equation in Table 6-6.

5. Compute L_{dn} at 50 ft. If this vehicle type will affect any residential receivers, compute the total L_{dn} for the vehicle type using the fourth equation in Table 6-6.

Table 6-6 Computation of L_{eq} and L_{dn} at 50 feet: Highway/Transit Sources

Hourly L_{eq} at 50 ft:	$L_{eq}(h) = SEL_{ref} + 10\log(V) + C_{emissions} - 10\log\left(\frac{S}{50}\right) - 35.6$
Daytime L_{eq} at 50 ft:	$L_{eq}(day) = L_{eq}(h)\Big\|_{V=V_d}$
Nighttime L_{eq} at 50 ft:	$L_{eq}(night) = L_{eq}(h)\Big\|_{V=V_n}$
L_{dn} at 50 ft:	$L_{dn} = 10\log\left[(15)\times 10^{\left(L_{eq}(day)/10\right)} + (9)\times 10^{\left(L_{eq}(night)+10/10\right)}\right] - 13.8$
Noise Emissions:	$C_{emissions} = 1.6$ → 3-axle commuter buses, accelerating $= 24.6 \times \log\left(\frac{S}{50}\right)$ → 3-axle commuter buses, not accelerating $= 33.9 \times \log\left(\frac{S}{50}\right)$ → 2-axle city buses $= 38.1 \times \log\left(\frac{S}{50}\right)$ → automobiles
Other adjustments	− 3 → automobiles, open-graded asphalt + 3 → automobiles, grooved pavement

V = hourly volume of vehicles of this type, in vehicles per hour

V_d = average hourly daytime volume of vehicles of this type, in vehicles per hour

$= \frac{\text{total vehicle volume, 7am to 10pm}}{15}$

V_n = average hourly nighttime volume of vehicles of this type, in vehicles per hour

$= \frac{\text{total vehicle volume, 10pm to 7am}}{9}$

S = average vehicle speed in miles per hour (distance divided by time, excluding stop time at red lights)

Note: Idling buses appear under Stationary Sources.

Example 6-2. Computation of L_{eq} and L_{dn} at 50 feet for Highway/Transit Source

A bus route with 2-axle buses will pass close to a school that is in session from 8 am to 4 pm on weekdays. Within this time period, the hour of greatest activity for this bus route is 8 am to 9 am. For this project source,

SEL_{ref} = 84 dB

S = 40 mph, and

V = 30 buses per hour

Using Table 6-6, the resulting hourly L_{eq} at 50 ft = 60.9 dB. (Note: Computation results should always be rounded to the nearest decibel at the end of the computation.)

Continuing the example, this same bus also passes close to a residential area. For this project source, SEL_{ref} is the same as above, as is S. In addition,

V_d = (200 buses)/(15 hours) = 13.33 buses per hour, and
V_n = (20 buses)/(9 hours) = 2.22 buses per hour.

Using Table 6-6, the resulting L_{eq}'s at 50 ft are as follows:

L_{eq}(day) = 57.3 dB and

L_{eq}(night) = 49.5 dB.

Finally, the total day and night traffic results in L_{dn} at 50 ft = 58.3 dB.

End of Example 6-2

6.2.3 Stationary Sources

This section describes the computation of project noise at 50 feet for stationary sources of transit noise, identified in the second column of Table 6-2.

Step 1: Source SELs at 50 feet

Determine the reference SEL at 50 feet for each major source, either by measurement or by table look-up. Table 6-7 provides guidance on which method is preferred for each source type. In general, measurements are preferred for source types that vary significantly from project to project. Table look-up is adequate for source types that do not vary significantly from project to project (crossing signals, for example).

Table 6-7 Source Reference SELs at 50 Feet: Stationary Sources

Source	Reference SEL (dBA)	Approximate L_{max} (dBA)	Prefer Measurements?
Auxiliary Equipment	101	65	YES
Locomotive Idling	116	80	NO
Rail Transit Idling	106	70	NO
Buses Idling	111	75	NO
Curve Squeal	136	100	YES
Car Washes	111	75	YES
Crossing Signals	109	73	NO
Substations	99	63	NO

For sources where measurements are indicated in Table 6-7, Appendix D discusses the measurement procedures, plus procedures for the conversion of these measurements to the reference conditions of Table 6-7.

For sources where table look-up is indicated in Table 6-7, the table provides appropriate reference SELs for one typical noise event at 50 feet and of 1-hour duration (3600 seconds). Approximate L_{max} values are also given in the table for general user information.

Step 2: Conversion to Noise Exposure at 50 feet

Step 1 results in reference SELs at 50 feet. Step 2 is to convert from these reference SELs to actual operating conditions, such as actual event durations and numbers of events, and calculate noise exposure at 50 ft. The steps are:

1. Identify actual source durations and numbers of events. The following percentage changes in durations/numbers will produce an approximate 2-decibel change in noise exposure:

   - 40 percent change in event duration (e.g. from 30 to 42 minutes)

   - 40 percent change in number of events per hour (e.g. from 10 to 14 events per hour).

   In general, where durations/numbers change by these amounts, separate conversions should be made.

2. Establish relevant time periods. For each source, determine the relevant time periods for all receivers that may be affected by the source. For residential receivers, the two time periods of interest to compute L_{dn} are: daytime (7 am to 10 pm) and nighttime (10 pm to 7 am). If the source will affect non-residential receivers, choose the loudest facility hour during noise-sensitive activity.

3. Collect input data. Gather the following input information:

   - Source reference SELs for each relevant source.

   - E, the average duration of one event, in seconds.

   - For residential receivers of interest:

     N_d, the average number of events per hour that occur during the daytime (equals the total number of events between 7 am and 10 pm, divided by 15), and

     N_n, the average number of events per hour that occur during the nighttime (equals the total number of events between 10 pm and 7 am, divided by 9).

   - For non-residential receivers of interest: N, the number of events that occur during each hour of interest, in events per hour.

4. Compute L_{eq} at 50 ft. For each hour of interest, compute the L_{eq} for the source using the first equation in Table 6-8.

5. Compute L_{dn} at 50 ft. If this source will affect any residential receivers of interest, compute the total L_{dn} for the source using the fourth equation in Table 6-8.

Table 6-8 Computation of L_{eq} and L_{dn} at 50 feet: Stationary Sources

Hourly L_{eq} at 50 ft:	$L_{eq}(h) = SEL_{ref} + 10\log(N) + 10\log\left(\frac{E}{3600}\right) - 35.6$
Daytime Leq at 50 ft:	$L_{eq}(day) = L_{eq}(h)\Big\vert_{N=N_d}$
Nighttime Leq at 50 ft:	$L_{eq}(night) = L_{eq}(h)\Big\vert_{N=N_n}$
Ldn at 50 ft:	$L_{dn} = 10\log\left[(15)\times 10^{\left(L_{eq}(day)/10\right)} + (9)\times 10^{\left(L_{eq}(night)+10/10\right)}\right] - 13.8$

E = duration of one event, in seconds
N = number of events of this type that occur during one hour
N_d = hourly average number of events of this type that occur during daytime (7am to 10pm)
$= \frac{\text{number that occur between 7am and 10pm}}{15}$
N_n = hourly average number of events of this type that occur during nighttime (10pm to 7am)
$= \frac{\text{number that occur between 10pm and 7am}}{9}$

Example 6-3. Computation of L_{eq} and L_{dn} at 50 feet for Stationary Source

A signal crossing lies close to a school that is in session from 8 am to 4 pm on weekdays. Within this time period, the hour of greatest activity for the signal crossing is 8am to 9am. For this project source,

SEL_{ref} = 109 dB
E = 25 seconds (counting both cycles of the signal), and
N = 22.

Using Table 6-8. the resulting L_{eq}(h) = 65.2 from 8 to 9 am. (Computation results should always be rounded to the nearest decibel at the end of the computation.)

This same signal crossing lies close to a residential area. For this project source, SEL_{ref} is the same as above, as is E. In addition,

N_d = (200)/(15 hours) = 13.3 events per hour, and
N_n = (12)/(9 hours) = 1.33 events per hour.

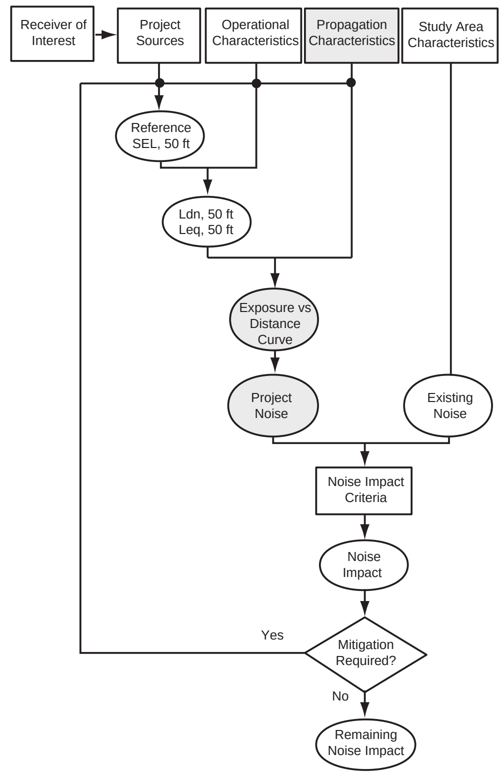
Using Table 6-8, the resulting daytime and nighttime L_{eq}'s are:

L_{eq}(day) = 63.0 and
L_{eq}(night) = 53.0.

Finally, using the fourth equation in Table 6-8, the resulting L_{dn} at 50 feet = 63.0 dB.

End of Example 6-3

6.3 PROPAGATION CHARACTERISTICS



Once estimates of noise exposure at 50 feet from each source are available, then propagation characteristics must be taken into account to compute the noise exposure at receivers of interest. The steps, shown in Figure 6-4, for this are: 1) determine the propagation characteristics between each source and the receiver of interest; 2) then, draw a noise exposure vs. distance curve outward from each relevant source as a function of distance; and 3) add a final adjustment using the appropriate shielding term based on intervening barriers between source and receiver.

6.3.1 Noise Exposure vs. Distance

The following steps result in a noise exposure vs. distance curve for each project source:

1. Draw several approximate topographic sections, each perpendicular to the path of moving sources or outward from point sources, similar to those shown in Figure 6-5. Draw separate sections, if necessary, to account for significant changes in topography. Use judgment here to prevent an extreme number of different topographic sections. Often, several typical sections will suffice throughout the transit corridor.

2. For each topographic section, use the relationship illustrated in Figure 6-5 to determine the effective path height, H_{eff}, and from it the Ground Factor, G. Larger Ground Factors mean larger amounts of ground attenuation with increasing distance from the source. As shown in the figure, the effective path height depends upon source heights, which are standardized at the bottom of the figure, and upon receiver heights, which can often be taken as 5 feet for both outdoor receivers and first-floor receivers. With these standard heights, only one H_{eff} (and therefore one Ground Factor) results from each cross section. For acoustically "hard" (i.e. non-absorptive) ground conditions, G should be taken to be zero.

3. Then for each L_{dn} and each L_{eq} at 50 feet developed earlier in the analysis, plot a noise exposure vs. distance curve with L_{dn} or L_{eq} represented on the

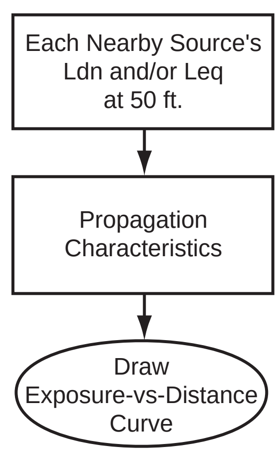


Figure 6-4 Flow Diagram for Determining Project Noise at Receiver Location

vertical axis and distance on the horizontal axis using one of the following equations:

$$L_{dn} \text{ or } L_{eq} = (L_{dn} \text{ or } L_{eq})\Big|_{\text{at 50 ft}} - 20\log\left(\frac{D}{50}\right) - 10\,G\log\left(\frac{D}{50}\right)$$ for stationary sources

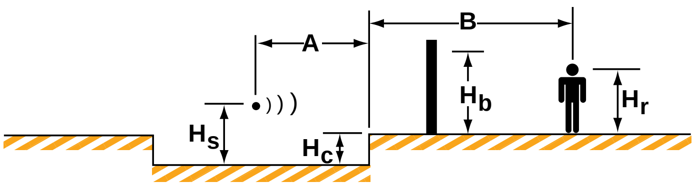
$$= (L_{dn} \text{ or } L_{eq})\Big|_{\text{at 50 ft}} - 10\log\left(\frac{D}{50}\right) - 10\,G\log\left(\frac{D}{42}\right)$$ for fixed-guideway rail car passbys

$$= (L_{dn} \text{ or } L_{eq})\Big|_{\text{at 50 ft}} - 10\log\left(\frac{D}{50}\right) - 10\,G\log\left(\frac{D}{29}\right)$$ for fixed-guideway locomotive and rubber-tired passbys, highway vehicle passbys and horns

IN GENERAL: H_{eff} = sum of average path heights on either side of barrier

$$H_{eff} = \frac{H_s + 2H_b + H_r}{2} \qquad (1)$$

Example 1: Source in shallow cut

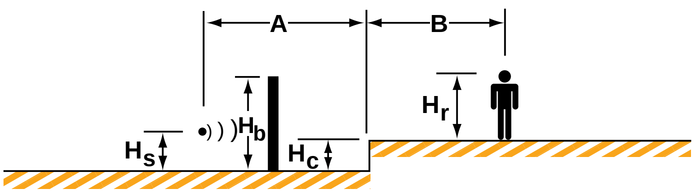


For $B < A/2$,

$$H_{eff} = \frac{H_s + 2H_b + H_c + H_r}{2}$$

* Otherwise use Equation (1)

Example 2: Receiver elevated



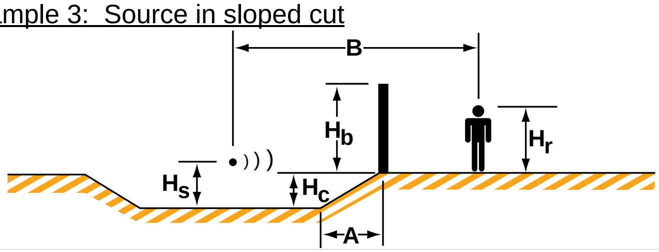
For $H_b > H_c$,

$$H_{eff} = \frac{H_s + 2H_b - H_c + H_r}{2}$$

For $H_b < H_c$,

$$H_{eff} = \frac{H_s + H_c + H_r}{2}$$

Example 3: Source in sloped cut

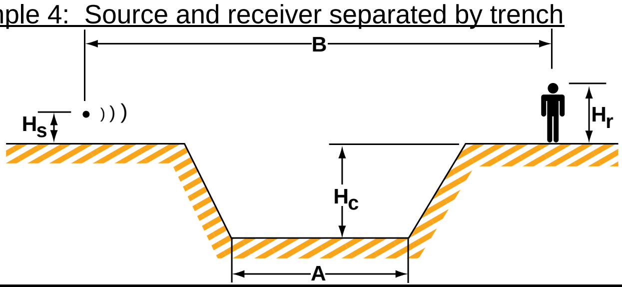


For $A < B/2$,
use Equation (1)

For $A > B/2$,

$$H_{eff} = \frac{H_s + 2H_b + H_c + H_r}{2}$$

Example 4: Source and receiver separated by trench



For $A > B/2$,

$$H_{eff} = \frac{H_s + 2H_c + H_r}{2}$$

For $A < B/2$,

$$H_{eff} = \frac{H_s + H_r}{2}$$

Source Heights:

H_s = 8 ft, trains **with** diesel-electric locomotives
2 ft, trains **without** diesel-electric locomotives
0 ft, automobiles
3 ft, 2-axle city buses
8 ft, 3-axle commuter buses

Note: Equations for H_{eff} remain valid even when $H_b = 0$.

Ground Factor

For soft ground:

$$G = \begin{cases} 0.66 & H_{eff} < 5 \\ 0.75\left(1 - \frac{H_{eff}}{42}\right) & 5 < H_{eff} < 42 \\ 0 & H_{eff} > 42 \end{cases}$$

For hard ground:

$$G = 0$$

Figure 6-5 Computation of Ground Factor G for Ground Attenuation

Example 6-4. Computing Exposure-vs-Distance Curve for Fixed Guideway Source

A commuter train, under the operating conditions in the previous examples, will produce the following levels without horn blowing at 50 feet:

$L_{eq}(8\text{-}9am) = 72$ decibels
$L_{dn} = 68$ decibels.

For sound propagation over grassland with a flat cross-sectional geometry without a noise barrier, and $H_R = 5$ feet:

$H_{eff} = 6.5$ feet

and from Figure 6-5 the resulting Ground Factor is

$G = 0.63$

Hence the relevant equations from above become:

$L_{eq}(8\text{-}9am) = 72 - 10 \log(D/50) - 6.3 \log(D/42)$
$L_{dn} = 68 - 10 \log(D/50) - 6.3 \log(D/42)$

Plots of these two equations appear in Figure 6-6. From these curves, the noise levels due to this train operation can be determined for a receiver of interest at any distance. The only factor not accounted for is the effect of shielding between source and receiver, which is the subject of the next section.

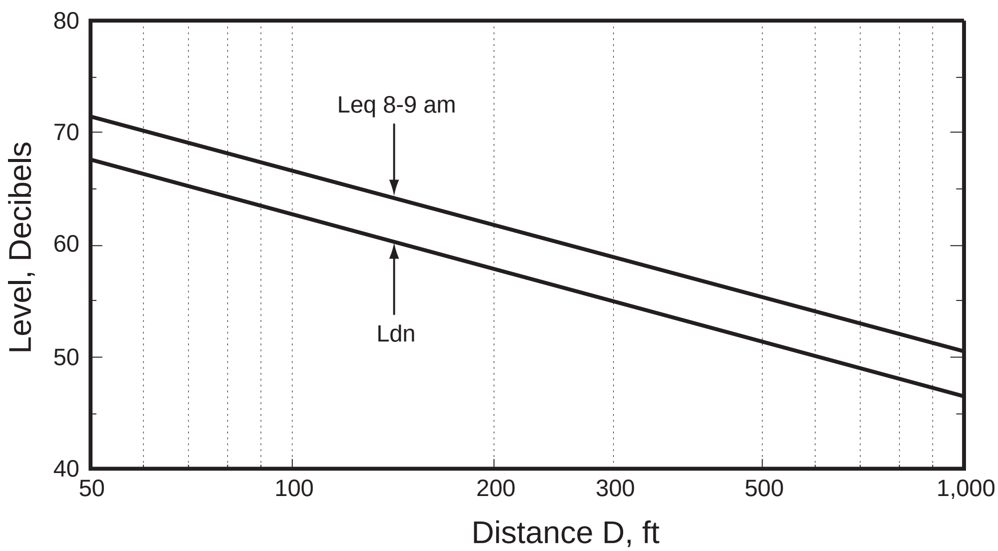


Figure 6-6 Example Exposure vs Distance Curves

End of Example 6-4

6.3.2 Shielding at each Receiver

The resulting L_{eq}'s and L_{dn}'s from the previous section do not include shielding between source and receiver. Such shielding can be due to intervening noise barriers, terrain features, rows of buildings, and dense tree zones. The individual attenuations are computed using the equations from Table 6-9 for barriers and terrain, or from Table 6-10 for rows of buildings and dense tree zones.

The results are attenuation values which are applied to the previously determined project noise at receiver locations (Figure 6-4).

Table 6-9 Computation of Shielding: Barriers and Terrain

Condition	Equation†
For ***non-absorptive*** transit barriers within 5 feet of the track:	$A_{barrier} = \min\{12 \text{ or } [5.3\times\log(P)+6.7]\}$
For ***absorptive*** transit barriers within 5 feet of the track:	$A_{barrier} = \min\{15 \text{ or } [5.3\times\log(P)+9.7]\}$
For all other barriers, and for protrusion of terrain above the line of sight:	$A_{barrier} = \min\left\{15 \text{ or } \left[20\times\log\left(\frac{2.51\sqrt{P}}{\tanh\left[4.46\sqrt{P}\right]}\right)+5\right]\right\}$
Barrier Insertion Loss	$IL_{barrier} = A_{barrier} - 10\,(G_{NB} - G_B)\log\left(\frac{D}{50}\right)$
Net Attenuation	$A_{shielding} = \max\{IL_{barrier} \text{ or } A_{barrier} \text{ or } A_{trees}\}$

D = closest distance between the receiver and the source, in feet
P = path length difference, in feet (see figure below)
G_{NB} = Ground factor G computed *without barrier* (see Figure 6-5)
G_B = Ground factor G computed *with barrier* (see Figure 6-5)

† The term "tanh(variable)" stands for hyperbolic tangent, available on many scientific calculators. If "tanh" is not available, then compute E = exp(variable), and set tanh(variable) = (E - 1/E) / (E + 1/E), where exp(variable) is the "exponential" function, also written as e^x on calculator keypads.

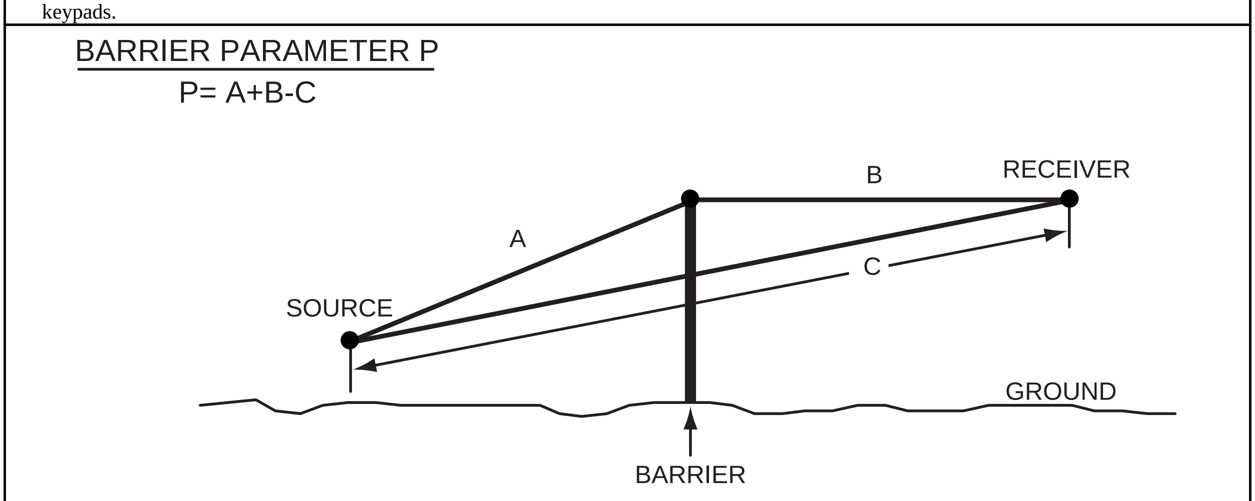


Table 6-10 Computation of Shielding: Rows of Buildings and Dense Tree Zones

Condition	Equation
If gaps in the row of buildings constitute less than 35 percent of the length of the row:	$A_{buildings} = \min\{10 \text{ or } [1.5(R-1)+5]\}$
If gaps in the row of buildings constitute between 35 and 65 percent of the length of the row:	$= \min\{10 \text{ or } [1.5(R-1)+3]\}$
If gaps in the row of buildings constitute more than 65 percent of the length of the row:	$= 0$
Where at least 100 feet of trees intervene between source and receiver, *and* if no clear line-of-sight exists between source and receiver, *and* if the trees extend 15 feet or more above the line-of-sight:	$A_{trees} = \min\left\{10 \text{ or } \dfrac{W}{20}\right\}$ I
If above conditions do not occur:	$= 0$
NET ATTENUATION	$A_{shielding} = \max\{IL_{barrier} \text{ or } A_{buildings} \text{ or } A_{trees}\}$

R = number of rows of houses that intervene between source and receiver
W = width of the tree zone along the line-of-site between source and receiver, in feet

Example 6-5. Computation of Shielding

Intervening between the rail corridor and a receiver of interest is the following shielding:

(1) a 15-foot high noise barrier, 40 feet from the closest track and 130 feet from the 5-foot-high receiver, and

(2) a dense tree zone 100 feet thick. The source height H_S = 8 feet, per Figure 6-5.

For the barrier: A = 40.61 feet, B = 130.38 feet, C = 170.03 feet, and therefore P = 0.96 feet, according to Table 6-9.

From Figure 6-5,

H_{eff} (no barrier) = 6.5 feet and

H_{eff} (with barrier) = 21.5 feet,

which result in

G_{NB} = 0.63, and

G_B = 0.37.

From Table 6-9, the resulting barrier attenuation is

$A_{barrier}$ = min{15 *or* 20×log[2.45/tanh(4.37)]+5}

= min{15 *or* 12.8}

= 12.8 dB

and the resulting barrier Insertion Loss is

$IL_{barrier}$ = 12.8 - 10(0.63-0.37)×log(170/50)

```
= 12.8 - 1.4
= 11.4 decibels.
```

For the tree zone: The attenuation is estimated to be 5 decibels using Table 6-10. The total shielding is the maximum of the barrier and tree zone shielding, i.e. 11.4 decibels. (Computation results should always be rounded to the nearest decibel at the end of the calculation.)

End of Example 6-5

6.3.3 Combined Propagation Characteristics

The result of combining shielding with geometrical spreading and ground effects involves subtracting the attenuation values obtained from Tables 6-9 and 6-10 from the noise exposure values obtained in Section 6.3.1 at the receiver location.

$L_{dn} \text{ or } L_{eq} = (L_{dn} \text{ or } L_{eq})\Big|_{\text{at 50 ft}} - 20\log\left(\frac{D}{50}\right) - 10G\log\left(\frac{D}{50}\right) - A_{shielding}$	→ for stationary sources
$= (L_{dn} \text{ or } L_{eq})\Big|_{\text{at 50 ft}} - 10\log\left(\frac{D}{50}\right) - 10G\log\left(\frac{D}{42}\right) - A_{shielding}$	→ for fixed-guideway rail car passbys
$= (L_{dn} \text{ or } L_{eq})\Big|_{\text{at 50 ft}} - 10\log\left(\frac{D}{50}\right) - 10G\log\left(\frac{D}{29}\right) - A_{shielding}$	→ for fixed-guideway locomotive and rubber-tired passbys, highway vehicle passbys and horns

6.4 COMBINED NOISE EXPOSURE FROM ALL SOURCES

Once propagation adjustments have been made for the noise exposure from each source separately, then the sources must be combined to predict the total project noise at the receivers. Table 6-11 contains the equations for combining sources. Total noise exposure is used in Section 6.6 to assess the transit noise at each receiver of interest. Note that in the table a 5 dB penalty is assigned to sources with pure tones that can be particularly annoying to people, such as bells on crossing signals, whistles, and wheel squeal on sharp curves. These sources have noise energy confined to a narrow range of frequency which makes them especially noticeable compared with the ambient, even at relatively low levels. The 5 dB penalty is applied at this point in the procedure when noise levels from individual noise sources are combined as the total project noise. It is important to note that if there is a pure-tone penalty applied, the calculated project noise levels will not correspond to actual measured levels.

Table 6-11 Computing Total Noise Exposure

Total L_{eq} from All Sources Combined, for the hour of interest:	$L_{eq}(total) = 10\log\left(\sum_{\text{all sources}} 10^{L_{eq}/10}\right)$
Total L_{dn} from All sources Combined:	$L_{dn}(total) = 10\log\left(\sum_{\text{all sources}} 10^{L_{dn}/10}\right)$
Pure Tone Adjustment:	C_{adj} = + 5 when pure tones are present (e.g., crossing bells, horns, wheel squeal.)

Example 6-6. Computation of Total Exposure from Combined Sources

A commuter train operation produces the following levels at a certain receiver of interest:

L_{eq}(8-9am) = 72 decibels, and
L_{dn} = 68 decibels.

At this same receiver, a light rail system produces the following levels:

L_{eq}(8-9am) = 69 decibels, and
L_{dn} = 70 decibels.

No other project sources affect this receiver. Using Table 6-11, the receiver's total noise exposures are therefore:

L_{eq}(8-9am, total) = 73.8 decibels, and
L_{dn}(total) = 72.1 decibels.

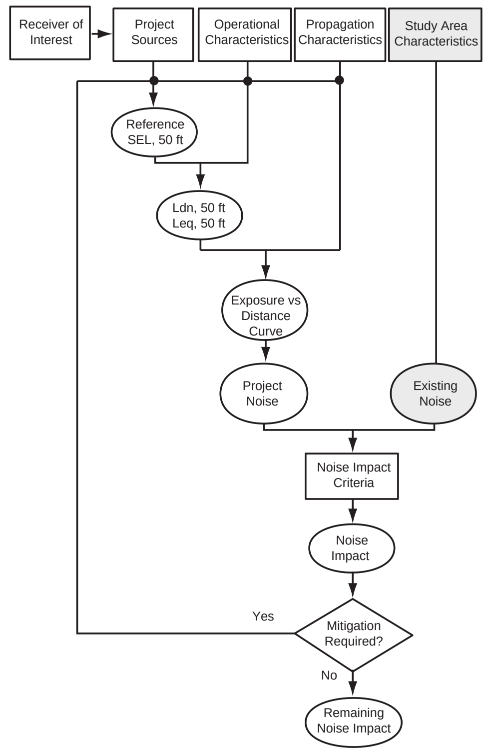
(Computation results should always be rounded to the nearest decibel at the end of the calculation.)

End of Example 6-6

6.5 MAXIMUM NOISE LEVEL FOR FIXED-GUIDEWAY SOURCES

The assessment of noise impact in this manual utilizes either the L_{dn} or the L_{eq} descriptor. As such, in determining impact it is not necessary to determine and tabulate the maximum levels (L_{max}). However, it is often desirable to include computations of L_{max} because it is representative of what people hear at any particular instant and can be measured with a sound level meter. The L_{max} is also the descriptor used in vehicle specifications. Because L_{max} represents the sound level heard during a transportation vehicle passby, people can relate this metric with other noise experienced in the environment. Particularly with rail transit projects, the noise from an individual train passby is quite distinguishable from the existing background noise. A comparison of L_{max} with other sources can be made by referring to Figure 2-8. Thus, although L_{max} is not used in this manual as a basis for assessing noise impact, it can provide people with a more complete description of the noise effects of a proposed project.. Equations for computing L_{max} from SEL are given in Appendix E.

6.6 STUDY AREA CHARACTERISTICS



This section contains procedures to estimate existing noise exposure at each receiver of interest identified previously for use in assessing noise impact. Figure 6-7 shows the flow diagram for estimating ambient noise. First decide whether to measure noise exposure, to compute it from partial measurements, or to estimate it from the table provided in this chapter. Different methods may be used at different receivers along the project. Finally, make the measurements, computations or estimates of the ambient noise at each receiver of interest.

6.6.1 Deciding Whether to Measure, Compute, or Estimate

In general, it is better to measure existing noise than to compute or estimate it. Measurements are more precise than computations and estimates and therefore lead to more precise conclusions concerning noise impact. However, measurements are expensive, are often thwarted by weather, and take significant time in the field. So the choice between measurements and computations/estimates is a choice between the precision of measurements and the convenience of computations/estimates. A mixture of these is generally selected, relying on measurements where the greatest precision is needed.

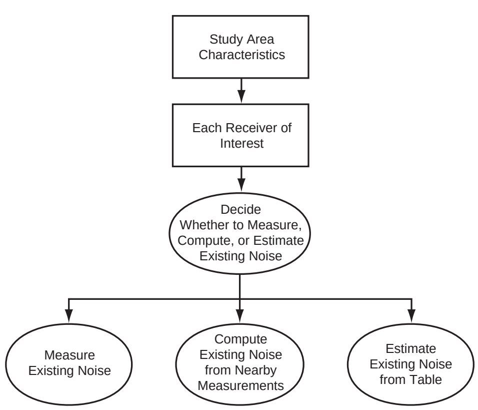


Figure 6-7 Flow Diagram for Determining Existing Noise

A penalty comes along with the convenience of computations and especially of tabular estimates. Because computations/estimates are less precise than measurements, the procedures for them (in Appendix C) are purposely conservative. They are designed to underpredict the ambient noise somewhat, and thereby overpredict relative noise impact. When more precise impact projections are desired, measurements should be chosen instead.

The choice among measurements, computations, or estimates depends partly upon the type of land use. For non-residential land uses with daytime use only, it is usually adequate to measure only one hour's ambient L_{eq}, preferably during the hour when project activity is likely to cause the greatest impact. This is relatively easy to measure. On the other hand, in residential areas that are not near major roadways, a full day's ambient L_{dn} is usually required. The following sections describe the approaches to be taken in each case and how to combine the results to characterize the existing ambient conditions.

6.6.2 Noise Exposure Measurements

Full one-hour measurements are the most precise way to determine ambient noise exposure for non-residential receivers. For residential receivers, full 24-hour measurements are most precise. Such full-duration measurements are preferred over other options, where time and study funds allow. The following procedures apply to full-duration measurements:

- For non-residential land uses, measure a full hour's L_{eq} at the receiver of interest, on at least two non-successive weekdays (generally between noon Monday and noon Friday). Select the hour of the day when the maximum project activity is expected to occur.
- For residential land uses, measure a full 24-hour's L_{dn} at the receiver of interest, for a single weekday (generally between noon Monday and noon Friday).
- Use judgment in positioning the measurement microphone. Location of the microphone at the receiver depends upon the proposed location of the transit noise source. If, for example, a new rail line will be in front of the house, do not locate the microphone in the back yard. Figure 6-8 illustrates recommended measurement positions for various locations of the project, with respect to the house and the existing source of ambient noise.
- Undertake all measurements in accordance with good engineering practice following guidelines given in ASTM and ANSI Standards.(2)(3)

6.6.3 Noise Exposure Computations from Partial Measurements

Often measurements can be made at some of the receivers of interest and then these measurements can be used to estimate noise exposure at nearby receivers. In other situations, several hourly L_{eq}'s can be measured at a receiver and then the L_{dn} computed from these. Both of these options require experience and knowledge of acoustics to select representative measurement sites.

Measurements at one receiver can be used to represent the noise environment at other sites, but only when proximity to major noise sources is similar among the sites. For example, a residential neighborhood with otherwise similar homes may have greatly varying noise environments: one part of the neighborhood may be located where the ambient noise is clearly due to highway traffic; a second part, toward the interior of the neighborhood, may have highway noise as a factor but also a significant contribution from other community noise; and a third part located deep into the residential area will have local street traffic and other community activities dominate the ambient noise. In this example, three or more measurement sites would be required to represent the varying ambient noise conditions in a single neighborhood.

Typical situations where representative measurement sites can be used to estimate noise levels at other sites occur when both share the following characteristics:

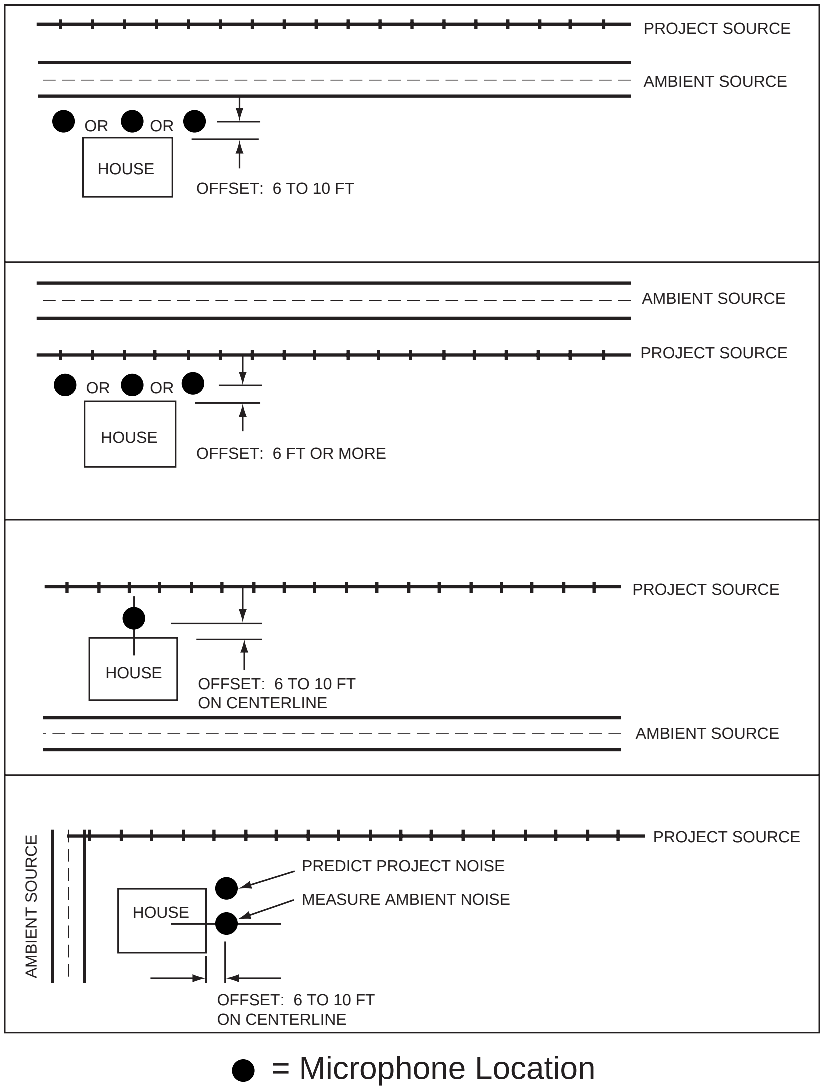


Figure 6-8 Recommended Microphone Locations for Existing Noise Measurements

- proximity to the same major transportation noise sources, such as highways, rail lines and aircraft flight patterns;
- proximity to the same major stationary noise sources, such as power plants, industrial facilities, rail yards and airports;
- similar type and density of housing, such as single-family homes on quarter-acre lots and multi-family housing in apartment complexes.

Acoustical professionals are often adept at such computations from partial data and are encouraged here to use their experience and judgment in fully utilizing the measurements in their computations. Required here is an attempt to somewhat underestimate ambient noise in the process, to account for reduced precision compared to full noise measurements.

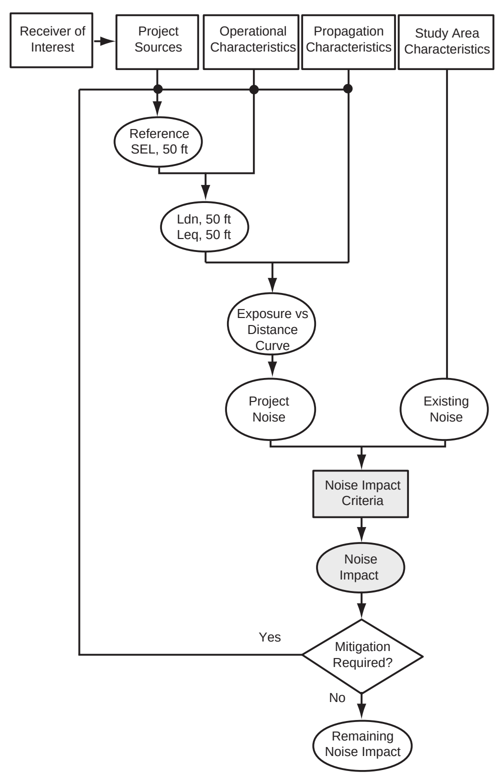
On the other hand, people lacking the background in acoustics are encouraged to use the procedures in Appendix C to accomplish this same aim. These procedures are an attempt to systematize such computations from partial measurements. The methods in Appendix C are designed with a safety factor to underestimate ambient noise to account for reduced precision compared to full noise measurements.

6.6.4 Estimating Existing Noise Exposure

The least precise way to determine noise exposure is to estimate it from a table. This method is appropriate for the General Noise Assessment. The tabular estimate is not generally recommended for a detailed noise analysis. However, it can be used in the absence of better data for locations where roadways or railroads are the predominant ambient noise source. Table 5-7 presents these ambient levels. In general, the tabulated values of noise exposure are underestimates. As explained above, underestimates here are intended to compensate for the reduced precision of the estimated ambient levels compared to the options that incorporate full or partial measurements.

6.7 NOISE IMPACT ASSESSMENT

This section contains procedures for the assessment of project noise impact, utilizing the ambient noise and project noise results from the previous analysis. Figure 6-9 is the flow diagram for the steps in the assessment process. Two assessment methods are included:



- Rail and Bus Facilities: This category includes all rail projects (e.g., rail rapid transit, light rail transit, commuter rail, and automated guideway transit), including rail transit projects built within a highway or railroad corridor. Also included are fixed facilities such as storage and maintenance yards, passenger stations and terminals, parking facilities, substations, etc. Bus facilities include separate roadways built exclusively for buses. Bus operations on local streets and highways are included where the project does not significantly change the roadway capacity.
- Highway/Transit Projects: Projects in this category involve bus facilities with either modifications to

existing roadways or construction of new roadways, resulting in a significant change of highway capacity. Included are lane additions or lane reconfigurations on existing highways to accommodate buses and/or HOV's. Also included are newly-constructed highways incorporating a transit or HOV component, such as dedicated bus/HOV lanes.

6.7.1 Assessment for Rail and Bus Facilities

For these types of projects, noise impact is assessed at each receiver of interest using the criteria for transit projects described in Chapter 3. The assessment procedure is as follows:

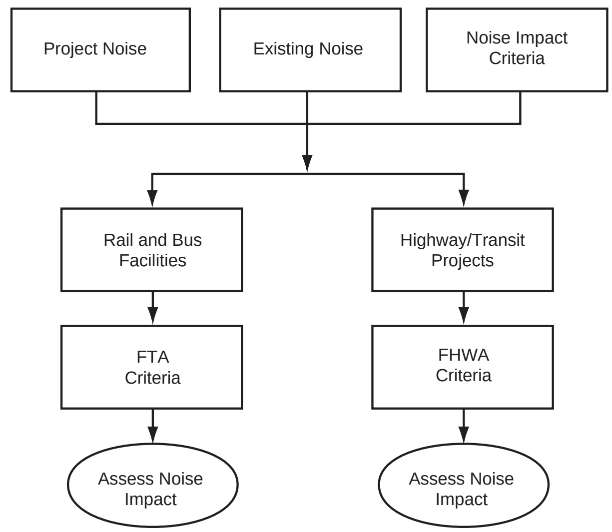


Figure 6-9 Flow Diagram for Noise Impact Assessment

1. Tabulate existing ambient noise exposure (rounded to the nearest whole decibel) at all receivers of interest from earlier in the analysis.
2. Tabulate project noise exposure at these receivers from the analytical procedures described in this chapter.
3. Determine the level of noise impact (No Impact, Impact or Severe Impact) following the procedures in Chapter 3.
4. Document the results in noise-assessment inventory tables. These tables should include the following types of information:

   - Receiver identification and location
   - Land-use description
   - Number of noise-sensitive sites represented (number of dwelling units in residences or acres of outdoor noise-sensitive land)
   - Closest distance to the project
   - Existing noise exposure
   - Project noise exposure
   - Level of noise impact (No Impact, Impact or Severe Impact)

   In addition, these tables should also indicate the total number of receivers, especially numbers of dwelling units, predicted to experience Impact or Severe Impact.

5. Illustrate the areas of Impact and Severe Impact on maps or aerial photographs. This could consist of project noise contours on the maps or aerial photographs, along with the impact areas. This is done by delineating two impact lines: one between the areas of No Impact and Impact and the second between Impact and Severe Impact. Such impact contours would be similar to those estimated in the General Assessment of Chapter 5, but with greater precision. If desired to conform with the practices of another

agency, the contouring may perhaps include several contour lines of constant project noise, such as L_{dn} 65, L_{dn} 70 and L_{dn} 75.

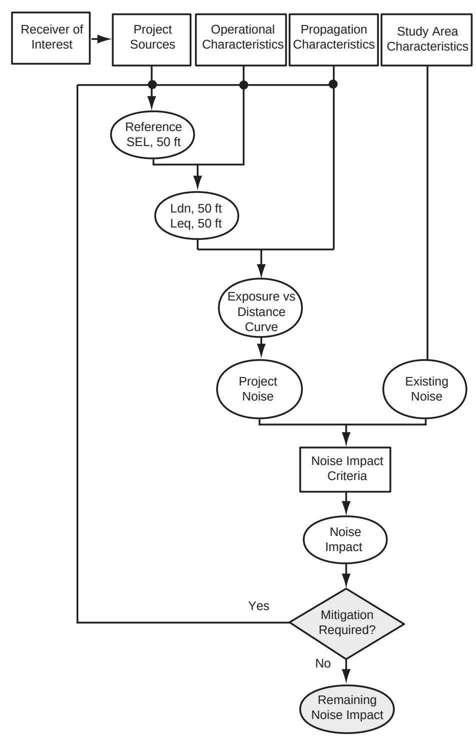
6. Discussion of the magnitude of the impacts is an essential part of the assessment. The magnitude of noise impact is defined by the two threshold curves delineating onset of Impact and Severe Impact. Interpretation of the two impact regimes is discussed in Chapter 3.

6.7.2 Assessment for Highway/Transit Projects

For highway/transit projects, the FHWA procedures and Noise Abatement Criteria should be used.[4][5][6] FHWA's current computation method resides within its computer program Stamina 2.0/OPTIMA.[7] This computation method is now being substantially revised. The revised method is scheduled to be promulgated by FHWA in late 1995 or early 1996, in the form of a new computer program, FHWA TNS (Traffic Noise Software).

6.8 MITIGATION OF NOISE IMPACT

Where the noise impact assessment shows either Severe Impact or Impact, this section provides guidance on considering and implementing noise reduction measures. The following sub-sections discuss the factors considered in determining the need for noise mitigation. Figure 6-10 contains the corresponding flow diagram.



6.8.1 Determining the Need for Noise Mitigation

Because intrusive noise is frequently among the most significant environmental concerns of planned mass transit projects, FTA, working with the project sponsor, makes every reasonable effort to reduce predicted noise to levels deemed acceptable for affected noise-sensitive land uses. The Noise Impact Criteria in Chapter 3 provide the framework for identifying the magnitude of the impact. Then, the need for noise mitigation is determined based on the magnitude and consideration of factors specifically related to the proposed project and affected land uses.

Given the statutory basis for planning and designing mass transit projects which are environmentally compatible, noise impacts in the Severe range represent the most compelling need for mitigation. However, mitigation is not the first-order concern when Severe impacts are predicted. First, the project sponsor should evaluate alternative locations/alignments to determine whether it is feasible to avoid Severe impacts altogether. In densely populated urban areas, this evaluation of alternative locations may reveal a trade-off of one group of impacted noise-sensitive sites for another – especially for surface rail alignments passing through built-up

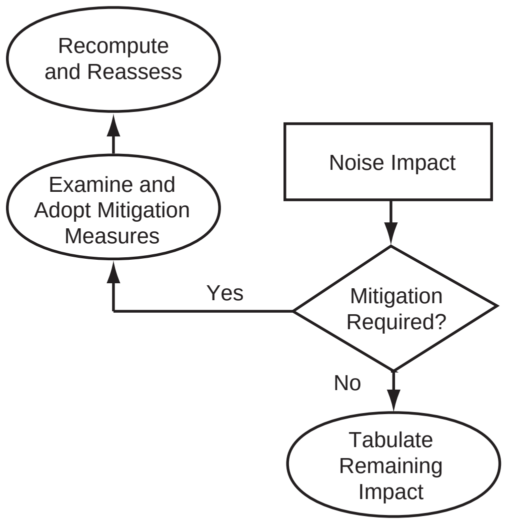


Figure 6-10 Flow Diagram for Mitigation

areas. However, this is not always the case; projects which are characterized more as point sources of noise than line sources often present a greater opportunity for selecting alternative sites. Note that this guidance manual and FTA's environmental impact regulation both attempt to encourage the selection of project sites which are compatible with surrounding development. The regulation designates certain projects as categorical exclusions when located in areas with compatible land use. In this manual, the list of noise-sensitive land uses in Chapter 3 does not include most commercial and industrial land uses, thus obviating the need to consider noise mitigation in areas with predominantly commercial or industrial use.

Predicted impacts in the Severe range are considered to be significant adverse effects in the context of NEPA and will trigger the requirement for an environmental impact statement, irrespective of any other environmental effects associated with the project. Severe impacts are also considered to be an "adverse effect" as this term is used in the regulations governing Section 106 of the National Historic Preservation Act (36 CFR 800). In addition, impacts of this magnitude would normally constitute a "constructive use" of properties afforded protection by Section 4(f) of the DOT Act and implementing regulations (23 CFR 771.135 (p)). The examination of alternatives that would avoid, minimize, or mitigate impacts of this magnitude is explicitly required in the compliance process for all of these statutes.

Only when it has been demonstrated that avoidance is not practical does the study progress to measures which would minimize the adverse affect. Where Severe impacts are predicted, the goal is to gain substantial noise reduction through the use of mitigation measures; it is not simply to reduce the predicted levels to just below the Severe impact threshold. Since FTA must make a judgment on whether the proposed mitigation is feasible and prudent, the study must include the noise reduction potential of the options as well as the effects on transit service, capital and operating costs and any other relevant factors, for example, new environmental impacts originating from the change.

Though of a lesser magnitude, projected noise levels in the Impact range will still require consideration and adoption of mitigation measures when it is considered reasonable. While it might be simpler conceptually to establish a definitive level dictating the need for mitigation, from a practical standpoint there should be an area where professional judgment comes into play. The range of Impact delineates an area where project planners are alerted to the potential for adverse impacts and complaints from the community and must then carefully consider project specifics as well as details concerning the affected properties in determining the need for mitigation.

The following considerations will help project planners and FTA staff in reaching these determinations:

- The number of noise-sensitive sites affected at this level. A row or cluster of residences adjacent to a rail transit line establishes a greater need for mitigation than one or several isolated residences in a mixed-use area.

- The increase over existing noise levels. Since the noise impact criteria are delineated as bands or ranges, project noise can vary 5-7 decibels within the band of Impact at any specific ambient noise level. If the project and ambient noise plot falls just below the Severe range (in Figure 3-1), the need for mitigation is strongest. Similarly, if the plot falls just above the No Impact threshold, the need for mitigation is lessened.

- The noise sensitivity of the property. Table 3-2 gives a comprehensive list of noise-sensitive land uses; yet there can be differences in noise sensitivity depending on individual circumstances. For example, parks and recreational areas vary in their sensitivity depending on the type of use they experience (active vs. passive recreation) and the settings in which they are located.

- Effectiveness of the mitigation measure(s). What is the magnitude of the noise reduction that can be achieved? Are there conditions which limit effectiveness, for example, noise barrier effectiveness for a multi-story apartment building?

- The potential to reduce high preexisting noise exposure due to transportation sources. Sometimes, an existing transportation facility causes intrusive noise and a proposed project sharing the same right-of-way presents the opportunity to lower cumulative noise levels. When a shared right-of-way situation occurs, this type of environmental enhancement is strongly encouraged.

- Community views. This manual provides the methodology to make an objective assessment of the need for noise mitigation. However, the views of the community cannot be overlooked. The NEPA compliance process provides the framework for hearing the community's concerns about a proposed project and then making a good-faith effort to address those concerns. Many projects can be expected to have projected noise levels within the Impact range and decisions regarding mitigation should be made only after considering input from the affected public, relevant government agencies and community organizations. There have been cases where the solution to the noise problem – a sound barrier – was rejected by community members because of perceived adverse visual effects.

- Special protection provided by law. Section 4(f) of the DOT Act and Section 106 of the Historic Preservation Act come into play frequently during the environmental review of transit projects. Section 4(f) protects historic sites and publicly-owned parks, recreation areas and wildlife refuges. Section 106 protects historic and archeological resources. No blanket statement can be made about whether project noise within the Impact range constitutes "constructive use" under Section 4(f) or "adverse effect" under Section 106. Nor can it be said that mitigation is always required when protected resources are impacted at this level. As previously noted, some historic properties are not noise-sensitive at all. It is clear, though, that the regulatory processes stemming from these statutes require coordination and consultation with relevant agencies and organizations. Their views on the project's impact on protected resources are given careful consideration by FTA and the project sponsor, and their recommendations may influence the decision to adopt noise reduction measures.

The decision to include noise mitigation in a project is made by FTA after public review of the environmental document. It is reached in consultation with the project sponsor. If mitigation measures are deemed necessary to satisfy the statutory requirements, they will be incorporated as an integral part of the project, and subsequent grant documents will reference these measures as contractual obligations on the part of the project sponsor.

6.8.2 Noise Mitigation Measures

In general, mitigation options are chosen from those below, and then portions of the project noise are recomputed and reassessed to account for this mitigation. This allows an accurate prediction of the level of noise reduction. It is important to emphasize that the source levels used in this manual are typical of systems designed according to current engineering practice, but they do not include special noise control features that could be incorporated in the specifications at extra cost. This approach provides a reasonable analysis of conditions without mitigation measures. If special features that result in noise reductions are included in any of the predictions, then the Federal environmental document must include a commitment by the project sponsor to adopt such treatments before the project is approved for construction.

Mitigation of noise impact from transit projects may involve treatments at the three fundamental components of the noise problem: (1) at the noise source, (2) along the source-to-receiver propagation path or (3) at the receiver. Generally, the transit property has authority to treat the source and some elements of the propagation path, but may have little or no authority to modify anything nearby the receiver.

A list of practical noise mitigation measures that should be considered by project sponsors is summarized in Table 6-12 and discussion of the measures follows. This table is organized according to whether the treatment applies to the source, path or receiver, and includes estimates of the acoustical effectiveness of each treatment.

6.8.3 Source Treatments

Vehicle Noise Specifications (Rail and Bus)

Among the most effective noise mitigation treatments is noise control at the outset, during the specification and design of the transit vehicle. Such source treatments apply to all transit modes. By developing and enforcing stringent but achievable noise specifications, the transit property takes a major step in controlling noise everywhere on the system. It is important to ensure that the noise levels quoted in the specifications are achievable with the application of best available technology during the development of the vehicle and reasonable in light of the noise reduction benefits and costs.

Effective enforcement includes significant penalties for non-compliance with the specifications. The noise mitigation achieved by source treatment depends on the quality of installation and maintenance. In the past,

Table 6-12 Transit Noise Mitigation Measures

Application	Mitigation Measure		Effectiveness
SOURCE	Stringent Vehicle & Equipment Noise Specifications		Varied
	Operational Restrictions		Varied
	Resilient or Damped Wheels*	For Rolling Noise on Tangent Track:	2 dB
		For Wheel Squeal on Curved Track:	10-20 dB
	Vehicle Skirts*		6-10 dB
	Undercar Absorption*		5 dB
	Spin-slide control (prevents flats)*		**
	Wheel Truing (eliminates wheel flats)*		**
	Rail Grinding (eliminates corrugations)*		**
	Turn Radii greater than 1000 ft*		(Avoids Squeal)
	Rail Lubrication on Sharp Curves*		(Reduces Squeal)
	Movable-Point Frogs (reduce rail gaps at crossovers)*		(Reduces Impact Noise)
	Engine Compartment Treatments (Buses)		6-10 dB
PATH	Sound Barriers close to Vehicles		6-10 dB
	Sound Barriers at ROW Line		3-5 dB
	Alteration of Horiz. & Vert. Alignments		Varied
	Acquisition of Buffer Zones		Varied
	Ballast on At-Grade Guideway*		3 dB
	Ballast on Aerial Guideway*		5 dB
	Resilient Track Support on Aerial Guideway		Varied
RECEIVER	Acquisition of Property Rights for Construction of Sound Barriers		5-10 dB
	Building Noise Insulation		5-20 dB

* Applies to Rail Projects Only
** These mitigation measures work to maintain a rail system in its as-new condition. Without incorporating them into the system, noise levels could increase up to 10 dB.

transit vehicles have been delivered that did not meet a noise specification, causing complaints from the public and requiring additional noise mitigation measures applied to the wayside.

Stationary Source Noise Specifications

Stringent but achievable noise specifications also represent an effective approach for mitigating noise impact from stationary sources associated with a transit system. Such equipment includes fixed plant equipment (for example, transformers and mechanical equipment) as well as grade-crossing signals. For example, noise impact from grade-crossing signals can be mitigated by specifying equipment that sets the level of the warning signal lower where ambient noise is lower, that minimizes the signal duration, and that minimizes signal noise in the direction of noise-sensitive receivers.

Wheel Treatments (Rail)

A major source of noise from steel-wheel/steel-rail systems is the wheel/rail interaction which has three components: roar, impact and squeal. Roar is the rolling noise caused by small-scale roughness on the wheel tread and rail running surface. Impacts are caused by discontinuities in the running surface of the rail or by a flat spots on the wheels. Squeal occurs when a steel-wheel tread or its flange rubs across the rail, setting up resonant vibrations in the wheel which cause it to radiate a screeching sound. Various wheel designs and other mitigation measures exist to reduce the noise from each of these three mechanisms.

- **Resilient and damped wheels** serve to reduce rolling noise, but only slightly. A typical reduction is 2 decibels on tangent track. This treatment is more effective in eliminating wheel squeal on tight turns; reductions of 10 to 20 decibels for high frequency squeal noise is typical.

- **Spin-slide control systems,** similar to anti-locking brake systems (ABS) on automobiles, reduce the incidence of wheel flats, a major contributor of impact noise. Trains with smooth wheel treads can be up to 20 decibels quieter than those with wheel flats. To be effective, the anti-locking feature should be in operation during all braking phases, including emergency braking. Wheel flats are more likely to occur during emergency braking than during dynamic braking.

- **Maintenance** of wheels by truing eliminates wheel flats from the treads and restores the wheel profile. As discussed above, wheel flats are a major source of impact noise. A good maintenance program includes the installation of equipment to detect and correct wheel flats on a continuing basis.

Vehicle Treatments (Rail and Bus)

Vehicle noise mitigation measures are applied to the various mechanical systems associated with propulsion, ventilation and passenger comfort.

- **Propulsion systems** of transit vehicles include diesel engines, electric motors and diesel-electric combinations. Noise from the propulsion system depends on the type of unit and how much noise mitigation is built into the design. Mufflers on diesel engines are generally required to meet noise specifications; however, mufflers are generally practical only on buses, not on locomotives. Control of noise from engine casings may require shielding the engine by body panels without louvers, dictating other means of cooling and ventilation.

- **Ventilation** requirements for vehicle systems are related to the noise generated by a vehicle. Fan noise often remains a major noise source after other mitigation measures have been instituted, because of the need to have direct access to cooling air. This applies to heat exchangers for electric traction motors, diesel engines and air-conditioning systems. Fan quieting can be accomplished by installation of one of several new designs of quiet, efficient fans. Forced-air cooling on electric traction motors can be quieter than self-cooled motors at operating speeds. Placement of fans on the vehicle can make a significant difference in the noise radiated to the wayside, or to patrons on the station platforms.

- The **vehicle body** design can provide shielding and absorption of the noise generated by the vehicle components. Acoustical absorption under the car has been demonstrated to provide up to 5 decibels of mitigation for wheel/rail noise and propulsion-system noise on rapid transit trains. Similarly, vehicle skirts over the wheels can provide more than 5 decibels of mitigation. By carrying their own noise barriers, vehicles with these features can provide cost-effective noise reduction.

Guideway Support (Bus and Rail)

The smoothness of the running surface is critical in the mitigation of noise from a moving vehicle. Smooth roadways for buses and smooth rail running surfaces for rail systems are required. In either case, roughness of the street, roadway and rail surfaces can be eliminated by resurfacing roads or grinding rails, thereby reducing noise levels by up to 10 decibels. Bridge expansion joints are also a source of noise for rubber-tire vehicles. This source of noise can be reduced by placing expansion joints on an angle or by specifying the serrated type rather than joints with right-angle edges.

In the case of steel-wheel/steel-rail systems with non-steerable trucks and sharp turns, squeal can be mitigated by installation of rail lubricators. Squeal in such systems can usually be eliminated altogether by designing all turn radii to be greater than 1000 feet, or 100 times the truck wheelbase, whichever is less.

Operational Restrictions (Rail and Bus)

Two changes in operations that can mitigate noise are the lowering of speed and the reduction of nighttime (10 pm to 7 am) operations. Because noise from most transit vehicles depends on speed, a reduction of speed results in lower noise levels. The effect can be considerable. For example, the speed dependency of steel-wheel/steel-rail systems for L_{eq} and L_{dn} (see Table 6-4) results in a 6 dB reduction for a halving of the speed. Complete elimination of nighttime operations has a strong effect on reducing the L_{dn}, because nighttime noise is increased by 10 decibels when calculating L_{dn}. Restrictions on operations are usually not feasible because of service demands. However, if early morning idling can be curtailed to the mimimum necessary, this can have a measurable effect on L_{dn}.

Other operational restrictions that can reduce noise impact for light rail and commuter rail systems include minimizing or eliminating horn blowing and other types of warning signals at grade crossings. However, these mitigation options are often limited by safety considerations.

6.8.4 Path Treatments

Sound Barriers

Sound barriers are effective in mitigating noise when they break the line-of-sight between source and receiver. The mechanism of sound shielding is described in Chapter 2. The necessary height of a barrier depends on such factors as the source height and the distance from the source to the barrier. For example, if a barrier is located very close to a rapid transit train, it need only be 3 to 4 feet above the top of rail to be effective. Barriers close to vehicles can provide noise reductions of 6 to 10 decibels. For barriers further away, such as on the right-of-way line or for trains on the far track, the height must be increased to provide equivalent effectiveness. Otherwise, the effectiveness can drop to 5 decibels or less, even if the barrier breaks the line of sight. Where the barrier is very close to the transit vehicle or where the vehicles travel between sets of parallel barriers, barrier effectiveness can be increased by as much as 5 decibels by applying sound-absorbing material to the inner surface of the barrier.

Similarly, the length of the barrier wall is important to its effectiveness. The barrier must be long enough to screen out a moving train along most of its visible path. This is necessary so that train noise from beyond the ends of the barrier will not severely compromise noise-barrier performance at sensitive locations.

Noise barriers can be made of any outdoor weather-resistant solid material that meets a minimum sound transmission loss requirement. The sound requirements are not particularly strict; they can be met by many commonly available materials, such as 16-gauge steel, 1-inch thick plywood, and any reasonable thickness of concrete. The normal minimum requirement is a surface density of 4 pounds per square foot. To hold up under wind loads, structural requirements are more stringent. Achieving the maximum possible noise reduction requires careful sealing of gaps between barrier panels and between the barrier and the ground or elevated guideway deck.

Costs for noise barriers, based on highway installations, range from $15 to $25 per square foot of installed noise barrier at-grade, not counting design and inspection costs. Installation on aerial structure may be a factor of two greater, especially if the structure has to be strengthened to accommodate the added weight and wind load.

Location of a transit alignment in cut, as part of grade separation, can accomplish the same result as installation of a noise barrier at-grade or on aerial structure. The walls of the cut serve the same function as barrier walls in breaking the line-of-sight between source and receiver.

Noise Buffers

Because noise levels attenuate with distance, one noise mitigation measure is to increase the distance between noise sources and the closest sensitive receivers. This can be accomplished by locating alignments away from sensitive sites. Acquisition of land or purchasing easements for noise buffer zones is an option that may be considered if impacts due to the project are severe enough.

Ground Absorption

Propagation of noise over ground is affected by whether the ground surface is absorptive or reflective. Noise from vehicles on the surface is strongly affected by the character of the ground in the immediate vicinity of the vehicle. Roads and streets for buses are hard and reflective, but the ground at the side of a road has a significant effect on the propagation of noise to greater distance. This effect is described in Chapter 2 and taken into account in the computations of this chapter. Guideways for rail systems can be either reflective or absorptive, depending on whether they are concrete or ballast. Ballast on a guideway can reduce train noise 3 decibels at-grade and up to 5 decibels on aerial structure.

6.8.5 Receiver Treatments

Sound Barriers

In certain cases it may be possible to acquire limited property rights for the construction of sound barriers at the receiver. As discussed above, barriers need to break the line-of-sight between the noise source and the receiver to be effective and are most effective when they are closest to either the source or the receiver. Computational procedures for estimating barrier effectiveness are given earlier in this chapter.

Building Insulation

In cases where rights-of-way are tight, the only practical noise mitigation measure may be to provide sound insulation for the building. The most effective treatments are to caulk and seal gaps in the building envelope and to install new windows that are specially designed to meet acoustical transmission-loss requirements. Such windows are usually made of multiple layers of glass and are beneficial for heat insulation as well as for sound insulation. Depending on the quality of the original windows, such treatments can provide noise reductions of 5 to 20 decibels. These windows are usually non-operable so that central ventilation or air conditioning is needed.

Additional building sound insulation, if needed, can be provided by sealing vents and ventilation openings and relocating them to a side of the building away from the noise source. Much practical experience with sound insulation of buildings has been gained through grants for noise mitigation to local airport authorities by the Federal Aviation Administration.

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