Appendices

Appendix FEIR-1

Draft EIR Comment Letters

DEPARTMENT OF TRANSPORTATION
DISTRICT 7- OFFICE OF REGIONAL PLANNING
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Making Conservation
a California Way of Life.

August 10, 2023

Rey Fukuda
City of Los Angeles, Department of City Planning
221 N. Figueroa Street, Suite 1350
Los Angeles, CA 90012

RE: Violet Street Office Campus Project – Draft
Environmental Impact Report (DEIR)
SCH# 2021110015
GTS# 07-LA-2021-04263
Vic. LA-101 PM S0.085
LA-10 PM 17.702
LA-10 PM 17.604

Dear Rey Fukuda:

Thank you for including the California Department of Transportation (Caltrans) in the environmental review process for the above referenced project. The Violet Street Creative Office Campus Project (Project) is a new creative office campus with uses spanning existing and proposed buildings on an approximately 6.3-acre site. Construction of the Project would require the demolition of the existing warehouse uses, office uses, and associated surface parking located on the southwest portion of the Project Site. The remainder of the Project Site is developed with the existing Warner Music Group building and a five-story parking garage, which would be retained as part of the Project. The Project proposes a 13-story building featuring office uses, ground floor retail and/or restaurant uses, and 1,264 automobile parking spaces located in a seven-story parking garage, comprised of one at-grade, two above-grade, and four below-grade levels. Approximately 74,018 square feet of outdoor areas would be provided. The Applicant is requesting a General Plan Amendment to designate a portion of the Project Site's land use from Heavy Manufacturing to Regional Center Commercial and a Vesting Zone Change from the M3-1-RIO zone to C2-2-RIO zone. If approved, the Project's maximum floor area ratio (FAR) would be 6:1, permitting 661,800 square feet of development. The Project also includes a Future Campus Expansion Phase which encompasses a potential expansion opportunity for additional office use to be developed within the Project Site at the corner of Violet Street and Santa Fe Avenue. Construction of the Future Campus Expansion Phase would require the demolition of an existing 21,880-square-foot building containing office uses. For purposes of this analysis, this Future Campus Expansion Phase would be comprised of office and restaurant uses, but this portion of the Project Site could be utilized for any uses consistent with the existing M3-1-RIO zone.

The nearest State facilities to the proposed project are US 101 and I-10. After reviewing the DEIR, Caltrans has the following comments:

As stated in section 3.2 of the Transportation Assessment (Appendix M) of the DEIR, the Project will not result in a significant VMT impact. However, section 3.4 covers the conducted Freeway Safety Analysis and identifies impacts and mitigations at the following locations:

US-101 Southbound Off-ramp & 7th Street

The queue on the US-101 Southbound Off-ramp to 7th Street is projected to add six car lengths to the queue in the AM peak hour. The PeMS data showed that the average mainline speed on the US-101 South near the 7th Street off-ramp during the AM peak hour is approximately 57 mph. Assuming the traffic queued on the ramp is traveling at zero miles per hour since the vehicles extend past the ramp length, this constitutes a potential safety issue during the AM peak hour at the US-101 Southbound Off-ramp to 7th Street.

The following mitigation measure was identified:

- The Project applicant shall work with the City of Los Angeles and Caltrans to signalize the intersection of the US-101 Southbound Off-ramp & 7th Street. This would require complying with the Caltrans project development process as a local agency-sponsored project.

I-10 Eastbound Off-ramp & Porter Street

The queue on the I-10 Eastbound Off-ramp to Porter Street is projected to add three car lengths to the queue in the AM peak hour. The PeMS data showed that the average mainline speed on the I-10 East near the Porter Street off-ramp during the AM peak hour is approximately 66 mph. Assuming the traffic queued on the ramp is traveling at zero miles per hour since the vehicles extend past the ramp length, this constitutes a potential safety issue during the AM peak hour at the I-10 Eastbound Off-ramp to Porter Street.

The following mitigation measure was identified:

- The Project applicant shall work with the City of Los Angeles and Caltrans to signalize the intersection of the I-10 Eastbound Off-ramp to Porter Street. This would require complying with the Caltrans project development process as a local agency-sponsored project. Given this intersection's proximity to other intersections, close signal coordination is recommended with nearby intersections.

I-10 Westbound Off-ramp & Mateo Street/Enterprise Street

The queue on the I-10 Westbound Off-ramp to Mateo Street/Enterprise Street is projected to add five car lengths to the queue in the AM peak hour. The PeMS data showed that the average mainline speed on the I-10 West near the Mateo Street/Enterprise Street off-ramp is approximately 54 mph during the AM peak hour. Assuming the traffic queued on the ramp is traveling at zero miles per hour since the vehicles extend past the ramp length, this constitutes a potential safety issue at I-10 Westbound Off-ramp to Mateo Street/Enterprise Street.

The following mitigation measure was identified:

- The Project applicant shall work with the City of Los Angeles and Caltrans to signalize the intersection of the I-10 Westbound Off-ramp to Mateo Street/Enterprise Street. This would require complying with the Caltrans project development process as a local agency-sponsored project.

Caltrans concurs with the proposed mitigations to signalize the identified impacted locations so long as the designs meet all applicable standards and actively improve safety for all modes. Some additional recommendations are:

- Where possible, form a square 4-leg intersection. Slip lanes cause excessive vehicle speeds and increase pedestrian crossing distance.
- Additional analysis may be justified at the Northbound Route 5 off-ramp to Westbound 7th Street, due to it being approximately 250 feet from the Southbound Route 101 off-ramp to 7th Street.
- Implementing Leading Pedestrian Intervals (LPIs) and curb extensions at as many intersection locations as possible, to improve pedestrian visibility and reduce overall crossing distance.

Since these projects will be sponsored and lead by the local agency (City of Los Angeles) they will primarily be working with Caltrans District 7's Office of Permits once the permit application is complete. Before the Lead Agency develops the permit application package, please be aware of the following requirements and recommendations:

- Conduct a signal warrants analysis for all proposed intersections. Note: that the design at this intersection should also enhance pedestrian crossing safety to the greatest extent possible.
- All new or reconstructed sidewalk should meet or exceed all the latest state standards.
- The Project will result in new transportation infrastructure and these changes should always aim to create a comprehensive, integrated, connected network that is safe to use for all modes.

Please also be aware that the Project would be responsible for payment of applicable fees and Caltrans is not responsible for any fair-share contribution to the changes or improvements proposed or required by the Lead Agency.

Caltrans also requests that a traffic control plan or Construction Traffic Management Plan (CTMP) be provided to Caltrans. The following elements shall be implemented, as appropriate:

- Construction traffic routes shall avoid residential areas. This would ensure travel in the surrounding residential neighborhoods is minimized and that construction vehicles travel along arterial roadways to access the Project site rather than through the neighborhoods or along pedestrian routes.

- Schedule construction activities to reduce the effects on traffic flows on surrounding arterial streets during peak hours.
- Obtain the required permits for truck haul routes from the City prior to issuance of any permit for the project.
- The project contractor shall identify and enforce truck haul routes deemed acceptable by the City for construction trucks.
- Signs shall be posted along roads identifying construction traffic access or flow limitations due to single lane conditions during periods of truck traffic, if needed.
- Accommodate all equipment and worker parking on-site to the extent feasible.
- Advance notification to adjacent property owners and occupants, as well as nearby schools, of upcoming construction activities, including durations and daily hours of construction.
- Provide safety precautions for pedestrians and bicyclists through such measures as alternate routing and protection barriers.
- Provide for temporary traffic control during all construction activities adjacent to the public right-of-way to improve traffic flow on public roadways (e.g., flag men).
- Any work that would affect the freeways and its facilities, Caltrans has the jurisdiction for review and approval.

Finally, an encroachment permit will be required for any project work proposed on or in the vicinity of Caltrans right-of-way and all concerns must be adequately addressed.

If you have any questions, please contact project coordinator Anthony Higgins, at anthony.higgins@dot.ca.gov and refer to GTS# 07-LA-2021-04263.

Sincerely,

Miya Edmonson

MIYA EDMONSON
LDR Branch Chief

cc: State Clearinghouse

Los Angeles County
Metropolitan Transportation Authority

Metro

One Gateway Plaza
Los Angeles, CA 90012-2952

213.922.2000 Tel
metro.net

August 11, 2023

Rey Fukuda
Department of City Planning
City of Los Angeles
221 North Figueroa Street, Suite 1350
Los Angeles, CA 90012

Sent by Email: rey.fukuda@lacity.org

RE: Violet Street Creative Office Campus Project – Case No.: ENV-2021-2232-EIR
Notice of Availability of Environmental Impact Report (EIR)

Dear Mr. Fukuda:

Thank you for coordinating with the Los Angeles County Metropolitan Transportation Authority (Metro) regarding the proposed Violet Street Creative Office Campus (Project) located at 2051 Violet Street in the City of Los Angeles (City). Metro is committed to working with local municipalities, developers, and other stakeholders across Los Angeles County on transit-supportive developments to grow ridership, reduce driving, and promote walkable neighborhoods. Transit Oriented Communities (TOCs) are places (such as corridors or neighborhoods) that, by their design, allow people to drive less and access transit more. TOCs maximize equitable access to a multi-modal transit network as a key organizing principle of land use planning and holistic community development.

Per Metro's area of statutory responsibility pursuant to sections 15082(b) and 15086(a) of the Guidelines for Implementation of the California Environmental Quality Act (CEQA: Cal. Code of Regulations, Title 14, Ch. 3), the purpose of this letter is to provide the City with specific detail on the scope and content of environmental information that should be included in the Environmental Impact Report (EIR) for the Project. In particular, this letter outlines topics regarding the Project's potential impacts on the Metro bus facilities and services which should be analyzed in the EIR, and provides recommendations for mitigation measures as appropriate. Effects of a project on transit systems and infrastructure are within the scope of transportation impacts to be evaluated under CEQA.[1]

In addition to the specific comments outlined below, Metro is providing the City and Paul Hogge (Applicant) with the Metro Adjacent Development Handbook (attached), which

[1] See CEQA Guidelines section 15064.3(a); Governor's Office of Planning and Research Technical Advisory on Evaluating Transportation Impacts In CEQA, December 2018, p. 19.

provides an overview of common concerns for development adjacent to Metro right-of-way (ROW) and transit facilities, available at https://www.metro.net/devreview.

Project Description

The Project includes a new 13-story creative office campus on a 6.3-acre site. The Project proposes approximately 435,100 square feet of office uses, 15,499 square feet of ground floor retail and/or restaurant uses, and 1,264 automobile parking spaces located in a seven-story parking garage. The parking garage includes one at-grade, two above-grade, and four below-grade levels. The remainder of the site, which includes an existing 244,795 square foot Warner Music Group building and a five-story parking garage will be retained as part of the Project.

Recommendations for EIR Scope and Content

Bus Service Adjacency

1. Service: Metro Bus Lines 60 and 62, operate eastbound on 7th St./Santa Fe and southbound on Santa Fe Ave., adjacent to the Project. Two Metro Bus stops are directly adjacent to the Project at 7th St./Santa Fe and Santa Fe/Violet Street.

2. Impact Analysis: The EIR should analyze potential effects on Metro Bus service and identify mitigation measures as appropriate. Potential impacts may include impacts to transportation services, stops, and temporary or permanent bus service rerouting. Specific types of impacts and recommended mitigation measures to address them include, without limitation, the following:

    a. Bus Stop Condition: The EIR should identify all bus stops on all streets adjacent to the Project site. During construction, the Applicant may either maintain the stop in its current condition and location, or temporarily relocate the stops consistent with the needs of Metro Bus operations. Temporary or permanent modifications to any bus stop as part of the Project, including any surrounding sidewalk area, must be Americans with Disabilities Act (ADA)-compliant and allow passengers with disabilities a clear path of travel between the bus stop and the Project. Once the Project is completed, the Applicant must ensure any existing Metro bus stop affected by the Project is returned to its pre-Project location and condition, unless otherwise directed by Metro.

    b. Driveways: Driveways accessing parking and loading at the Project site should be located away from transit stops, and be designed and configured to avoid potential conflicts with on-street transit services and pedestrian traffic to the greatest degree possible. Vehicular driveways should not be located in or directly adjacent to areas that are likely to be used as waiting areas for transit.

    c. Bus Stop Enhancements: Metro encourages the installation of enhancements and other amenities that improve safety and comfort for transit riders. These include benches, bus shelters, wayfinding signage, enhanced crosswalks and ADA-compliant ramps, pedestrian lighting, and shade trees in paths of travel to bus stops. The City should consider requesting the installation of such amenities as part of the Project.

d. Bus Operations Coordination: The Applicant shall coordinate with Metro Bus Operations Control Special Events Coordinator at 213-922-4632 and Metro's Stops and Zones Department at 213-922-5190 not later than 30 days before the start of Project construction. Other municipal bus services may also be impacted and shall be included in construction outreach efforts.

If you have any questions regarding this letter, please contact me by phone at 213.547.4326, by email at DevReview@metro.net, or by mail at the following address:

Metro Development Review
One Gateway Plaza
MS 99-22-1
Los Angeles, CA 90012-2952

Sincerely,

Cassie Truong
Senior Transportation Planner, Development Review Team
Transit Oriented Communities

cc: Paul Hogge, Hines

Attachments and links:

- Adjacent Development Handbook: https://www.metro.net/devreview

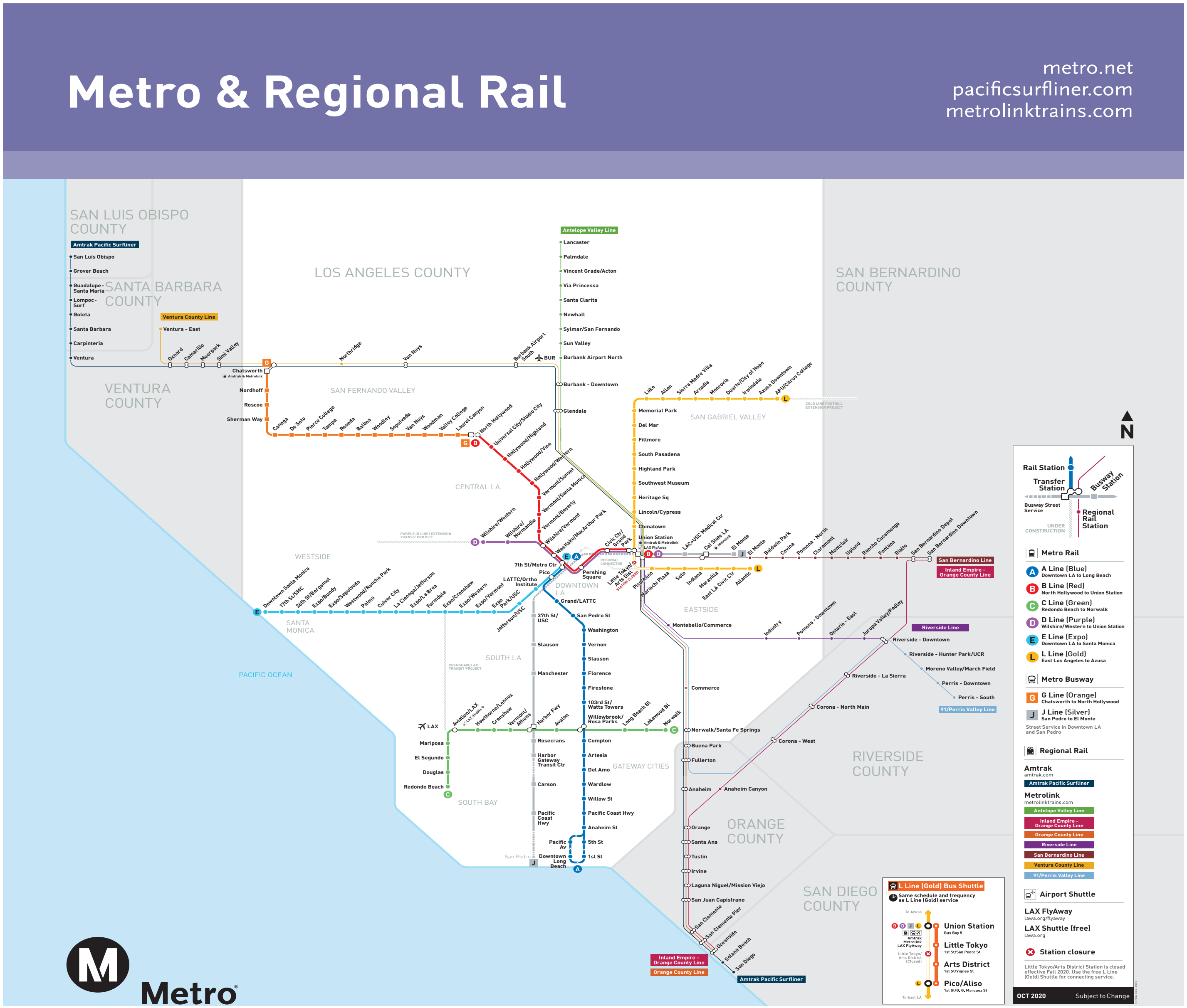
Los Angeles County
Metropolitan Transportation Authority

METRO ADJACENT DEVELOPMENT HANDBOOK

A GUIDE FOR CITIES AND DEVELOPERS

February 2021

Metro and Regional Rail Map



Metro is currently undertaking the largest rail infrastructure expansion effort in the United States. A growing transit network presents new opportunities to catalyze land use investment and shape livable communities.

Table of Contents

Quick Overview

Purpose of Handbook

The Metro Adjacent Development Handbook (Handbook) is intended to provide information and guide coordination for projects adjacent to, below, or above Metro transit facilities (e.g. right-of-way, stations, bus stops) and services.

Overarching Goal
By providing information and encouraging early coordination, Metro seeks to reduce potential conflicts with transit services and facilities, and identify potential synergies to expand mobility and improve access to transit.

Intended Audience
The Handbook is a resource for multiple stakeholder groups engaged in the development process, including:

- Local jurisdictions who review, entitle, and permit development projects,
- Developers,
- Property owners,
- Architects, engineers, and other technical consultants,
- Builders/contractors,
- Utility companies, and
- other Third Parties.

Handbook Content
The Handbook includes:

- **Introduction** of Metro's Development Review coordination process, common concerns, and typical stages of review.
- **Information** on best practices during three key coordination phases to avoid potential conflicts or create compatibility with the Metro transit system:
  - Planning & Conceptual Design,
  - Engineering & Technical Review, and
  - Construction Safety & Monitoring.
- **Glossary** with definitions for key terms used throughout the Handbook.

RULE OF THUMB: 100 FEET

Metro's Development Review process applies to projects that are within 100 feet of Metro transit facilities.

While the Handbook summarizes key concerns and best practices for adjacency conditions, it does not replace Metro's technical requirements and standards.

Prior to receiving approval for any construction activities adjacent to, above, or below Metro facilities, Third Parties must comply with the Metro Adjacent Construction Design Manual, available on Metro's website.

Contact Us
For questions, contact the Development Review Team:

- Email: devreview@metro.net
- Phone: 213.418.3484
- Online In-take Form: https://jpropublic.metro.net/in-take-form

Additional Information & Resources

- Metro Development & Construction Coordination website: https://www.metro.net/devreview
- Metro GIS/KML ROW Files: https://developer.metro.net/portfolio-item/metro-right-of-way-gis-data
- Metrolink Standards and Procedures: https://www.metrolinktrains.com/about/agency/engineering--construction

Metro will continue to revise the Handbook, as needed, to reflect updates to best practices in safety, operations, and transit-supportive development.

Background

Who is Metro?

The Los Angeles County Metropolitan Transportation Authority (Metro) plans, funds, builds, and operates rail, bus, and other mobility services (e.g. bikeshare, microtransit) throughout Los Angeles County (LA County). On average, Metro moves 1.3 million people each day on buses and trains. With funding from the passage of Measure R (2008) and Measure M (2016), the Metro system is expanding. Over the next 40 years, Metro will build over 60 new stations and over 100 miles of transit right-of-way (ROW). New and expanded transit lines will improve mobility across LA County, connecting riders to more destinations and expanding opportunities for development that supports transit ridership. Metro facilities include:

Metro Rail: Metro operates heavy rail (HRT) and light rail (LRT) transit lines in underground tunnels, along streets, off-street in dedicated ROW, and above street level on elevated structures. Heavy rail trains are powered by a "third rail" along the tracks. Light rail vehicles are powered by overhead catenary systems (OCS). To support rail operations, Metro owns and maintains traction power substations (TPSS), maintenance yards, and other infrastructure.

Metrolink/Regional Rail: Metro owns a majority of the ROW within LA County on which the Southern California Regional Rail Authority (SCRRA) operates Metrolink service. Metrolink is a commuter rail system with seven lines that span 388 miles across five counties, including: Los Angeles, Orange, Riverside, San Bernardino, Ventura, and North San Diego. As a SCRRA member agency and property owner, Metro reviews development activity adjacent to Metro-owned ROW on which Metrolink operates, and coordinates with Metrolink on any comments or concerns. Metrolink has its own set of standards and processes, see link on page 1.

Metro Bus Rapid Transit (BRT): Metro operates accelerated bus transit, which acts as a hybrid between rail and traditional bus service. Metro BRT may operate in a dedicated travel lane within a street or freeway, or off-street along dedicated ROW. Metro BRT stations may be located on sidewalks within the public right-of-way, along a median in the center of streets, or off-street on Metro-owned property.

Metro Bus: Metro operates 170 bus lines across more than 1,400 square miles in LA County. The fleet serves over 15,000 bus stops with approximately 2,000 buses. Metro operates "Local" and "Rapid" bus service within the street, typically alongside vehicular traffic, though occasionally in "bus-only" lanes. Metro bus stops are typically located on sidewalks within the public right-of-way, which is owned and maintained by local jurisdictions. Metro's NextGen Bus Plan re-envisions bus service across LA County to make service improvements that better serve riders.

Why is Metro interested in adjacent development?

Metro Supports Transit Oriented Communities: Metro is redefining the role of the transit agency by expanding mobility options, promoting sustainable urban design, and helping transform communities throughout LA County. Metro seeks to partner with local, state, and federal jurisdictions, developers, property owners and other stakeholders across LA County on transit-supportive planning and developments to grow ridership, reduce driving, and promote walkable neighborhoods. Transit Oriented Communities (TOCs) are places (such as corridors or neighborhoods) that, by their design, allow people to drive less and access transit more. TOCs maximize equitable access to a multi-modal transit network as a key organizing principle of land use planning and holistic community development.

Adjacent Development Leads to Transit Oriented Communities: Metro supports private development adjacent to transit as this presents a mutually beneficial opportunity to enrich the built environment and expand mobility options. By connecting communities, destinations, and amenities through improved access to public transit, adjacent developments have the potential to:

- reduce auto dependency,
- reduce greenhouse gas emissions,
- promote walkable and bikeable communities that accommodate more healthy and active lifestyles,
- improve access to jobs and economic opportunities, and
- create more opportunities for mobility – highly desirable features in an increasingly urbanized environment.

Opportunity: Acknowledging an unprecedented opportunity to influence how the built environment develops along and around transit and its facilities, Metro has created this document. The Handbook helps ensure compatibility between private development and Metro's transit infrastructure to minimize operational, safety, and maintenance issues. It serves as a crucial first step to encourage early and active collaboration with local stakeholders and identify potential partnerships that leverage Metro initiatives and support TOCs across LA County.

Metro Purview & Concerns

Metro Purview for Review & Coordination

Metro is interested in reviewing development, construction, and utility projects within 100 feet of Metro transit facilities, real estate assets, and ROW – as measured from the edge of the ROW outward – both to ensure the structural safety of existing or planned transit infrastructure and to maximize integration opportunities with adjacent development. The Handbook seeks to:

- Improve communication and coordination between developers, jurisdictions, and Metro.
- Identify common concerns associated with developments adjacent to Metro ROW.
- Highlight Metro operational needs and requirements to ensure safe, continuous service.
- Prevent potential impacts to Metro transit service or infrastructure.
- Maintain access to Metro facilities for riders and operational staff.
- Avoid preventable conflicts resulting in increased development costs, construction delays, and safety impacts.
- Streamline the review process to be transparent, clear, and efficient.
- Assist in the creation of overall marketable and desirable developments.

Key Audiences for Handbook

The Handbook is intended to be used by:

- Local jurisdictions who review, entitle, and permit development projects and/or develop policies related to land use, development standards, and mobility,
- Developers, property owners,
- Architects, engineers, design consultants,
- Builders/contractors,
- Entitlement consultants,
- Environmental consultants,
- Utility companies, and
- other Third Parties.

Metro Assets & Common Concerns for Adjacent Development

The table on the facing page outlines common concerns for development projects and/or construction activities adjacent to Metro transit facilities and assets. These concerns are discussed in greater detail in the following chapters of the Handbook.

	METRO ASSETS	COMMON ADJACENCY CONCERNS
	**UNDERGROUND ROW** Transit operates below ground in tunnels.	• Excavation near tunnels and infrastructure • Clearance from support structures (e.g. tiebacks, shoring, etc) • Coordination with utilities • Clearance from ventilation shafts, surface penetrations (e.g. emergency exits) • Surcharge loading of adjacent construction • Explosions • Noise and vibration/ground movement • Storm water drainage
	**AERIAL ROW** Transit operates on elevated guideway, typically supported by columns.	• Excavation near columns and support structures • Column foundations • Clearance from OCS • Overhead protection and crane swings • Setbacks from property line for maintenance activities to occur without entering ROW • Coordination with utilities • Noise reduction (e.g. double-paned windows)
	**AT-GRADE ROW** Transit operates in dedicated ROW at street level; in some cases tracks are separated from adjacent property by fence or wall.	• Pedestrian and bicycle movements and safety • Operator site distance/cone of visibility • Clearance from OCS • Crane swings and overhead protection • Trackbed stability • Storm water drainage • Noise/vibration • Driveways near rail crossings • Setbacks from property line for maintenance activities to occur without entering ROW • Utility coordination
	**BUS STOPS** Metro operates bus service on city streets. Bus stops are located on public sidewalks.	• Lane closures and re-routing service during construction • Temporary relocation of bus stops • Impacts to access to bus stops
	**NON-REVENUE/OPERATIONAL** Metro owns and maintains property to support operations (e.g. bus and rail maintenance facilities, transit plazas, traction power substations, park-and-ride parking lots).	• Excavation and clearance from support structures (e.g. tiebacks, shoring, etc) • Ground movement • Drainage • Utility coordination • Access to property

Metro Coordination Process

Typical Stages of Metro Review and Coordination

Early coordination helps avoid conflicts between construction activities and transit operations and maximizes opportunities to identify synergies between the development project and Metro transit services that are mutually beneficial.

*Phases above may include fees for permits and reimbursement of Metro staff time for review and coordination.

Coordination Goal: Metro encourages developers to consult with the Development Review Team early in the design process to ensure compatibility with transit infrastructure and minimize operational, safety, and maintenance issues with adjacent development. The Development Review team will serve as a case manager to developers and other Third Parties to facilitate the review of plans and construction documents across key Metro departments.

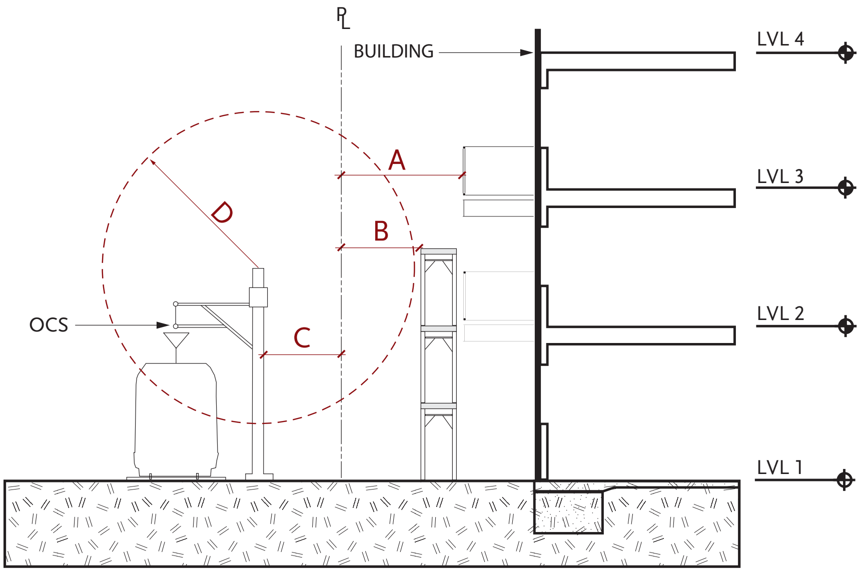
Level of Review: Not all adjacent projects will require significant review and coordination with Metro. The level of review depends on the Project's proximity to Metro, adjacency conditions, and the potential to impact Metro facilities and/or services. For example, development projects that are excavating near Metro ROW or using cranes near transit facilities require a greater level of review and coordination. Where technical review and construction monitoring is needed, Metro charges fees for staff time, as indicated by asterisk in the above diagram.

Permit Clearance: Within the City of Los Angeles, Metro reviews and clears Building & Safety permits for projects within 100 feet of Metro ROW, pursuant to Zoning Information 1117. To ensure timely clearance of these permits, Metro encourages early coordination as noted above.

To begin consultation, submit project information via an online In-Take Form, found on Metro's website. Metro staff will review project information and drawings to screen the project for any potential impacts to transit facilities or services, and determine if require further review and coordination is required. The sample sections on the facing page illustrate adjacency condition information that helps Metro complete project screening.

Contact:
Metro Development Review Team
Website: https://www.metro.net/devreview
Online In-take Form: https://jpropublic.metro.net/in-take-form
Email: devreview@metro.net
Phone: 213.418.3484

Sample Section: Adjacency Conditions



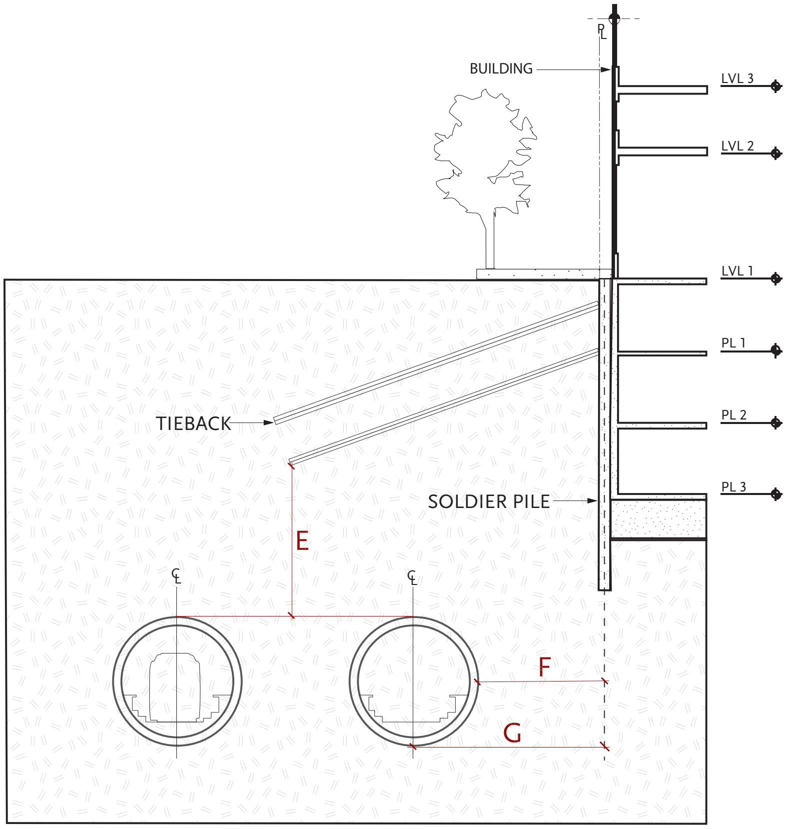
AT-GRADE CONDITION

A. Distance from property line to nearest permanent structure (e.g. building facade, balconies, terraces). Refer to Section 1.3 Building Setback of Handbook.

B. Distance from property line to nearest temporary construction structures (e.g. scaffolding).

C. Distance from property line to nearest Metro facility.

D. Clearance from nearest temporary and/or permanent structure to overhead catenary system (OCS). Refer to Section 1.4, OCS Clearance of Handbook.



BELOW-GRADE CONDITION

E. Vertical distance from top of Metro tunnel to closest temporary and/or permanent structure (e.g. tiebacks, foundation). Refer to Section 2.2, Proximity to Tunnels & Underground Infrastructure of Handbook.

F. Horizontal distance from exterior tunnel wall to nearest structure.

G. Horizontal distance from Metro track centerline to nearest structure.

Best Practices

Best Practices for Developer Coordination

Metro encourages developers of projects adjacent to Metro ROW and/or Real Estate Assets to take the following steps to facilitate Metro project review and approval:

1. **Review Metro resources and policies:** The Metro Development & Construction Coordination website and Handbook provide important information for those interested in constructing on, adjacent, over, or under Metro ROW, non-revenue property, or transit facilities. Developers and other Third Parties should familiarize themselves with these resources and keep in mind common adjacency concerns when planning a project.

2. **Contact Metro early during design process:** Metro welcomes the opportunity to provide feedback early in project design, allowing for detection and resolution of important adjacency issues, identification of urban design and system integration opportunities, and facilitation of permit approval. Metro encourages project submittal through the online In-Take Form to begin consultation.

3. **Maintain communication:** Frequent communication with Metro during project design and construction will reinforce relationships and allow for timely project completion. Contact us at devreview@metro.net or at 213.418.3484.

Best Practices for Local Jurisdiction Notification

To improve communication between Metro and the development community, Metro suggests that local jurisdictions take the following steps to notify property owners of coordination needs for properties adjacent to Metro ROW by:

- **Updating GIS and parcel data:** Integrate Metro ROW files into the City/County GIS and/or Google Earth Files for key departments (e.g. Planning, Public Works, Building & Safety) to notify staff of Metro adjacency and need for coordination during development approval process.Download Metro's ROW files here.

- **Flag Parcels:** Create an overlay zone as part of local Specific Plan(s) and/or Zoning Ordinance(s) to tag parcels that are within 100 feet Metro ROW and require coordination with Metro early during the development process [e.g. City of Los Angeles Zone Information and Map Access System (ZI-1117)].

- **Provide Resources:** Direct all property owners and developers interested in parcels within 100 feet of Metro ROW to Metro's resources (e.g. website, Handbook).


Metro
Downtown
Santa
Monica
E

Site Plan & Conceptual Design

Site Plan & Conceptual Design

1.1 Supporting Transit Oriented Communities

Transit-oriented communities (TOCs) are places that, by their design, make it more convenient to take transit, walk, bike or roll than to drive. By working closely with the development community and local jurisdictions, Metro seeks to ensure safe construction near Metro facilities and improve compatibility with adjacent development to increase transit ridership.

RECOMMENDATION: Consider site planning and building design strategies to that support transit ridership, such as:

- Leveraging planning policies and development incentives to design a more compelling project that capitalizes on transit adjacency and economy of scales.
- Programming a mix of uses to create lively, vibrant places that are active day and night.
- Utilizing Metro policies and programs that support a healthy, sustainable, and welcoming environment around transit service and facilities.
- Prioritizing pedestrian-scaled elements to create spaces that are comfortable, safe, and enjoyable.
- Activating ground floor with retail and outdoor seating/activities to bring life to the public environment.
- Reducing and screening parking to focus on pedestrian activity.
- Incorporating environmental design elements that help reduce crime (e.g. windows and doors that face public spaces, lighting).

The Wilshire/Vermont Metro Joint Development project leveraged existing transit infrastructure to catalyze a dynamic and accessible urban environment. This project accommodates portal access into the Metro Rail system and on-street bus facilities.

1.2 Enhancing Access to Transit

Metro seeks to create a comprehensive, integrated transportation network and supports infrastructure and design that allows safe and convenient access to its multi-modal services. Projects in close proximity to Metro's services and facilities present an opportunity to enhance the public realm and connections to/from these services for transit riders as well as users of the developments.

RECOMMENDATION: Design projects with transit access in mind. Project teams should capitalize on the opportunity to improve the built environment and enhance the public realm for pedestrians, bicyclists, persons with disabilities, seniors, children, and users of green modes. Metro recommends that projects:

- Orient major entrances to transit service, making access and travel safe, intuitive, and convenient.
- Plan for a continuous canopy of shade trees along all public right-of-way frontages to improve pedestrian comfort to transit facilities.
- Add pedestrian lighting along paths to transit facilities and nearby destinations.
- Integrate wayfinding and signage into project design.
- Enhance nearby crosswalks and ramps.
- Ensure new walkways and sidewalks are clear of any obstructions, including utilities, traffic control devices, trees, and furniture.
- Design for seamless, multi-modal pedestrian connections, making access easy, direct, and comfortable.

The City of Santa Monica leveraged investments in rail transit and reconfigured Colorado Avenue to form a multi-modal first/last mile gateway to the waterfront from the Downtown Santa Monica Station. Photo by PWP Landscape Architecture

1.3 Building Setback

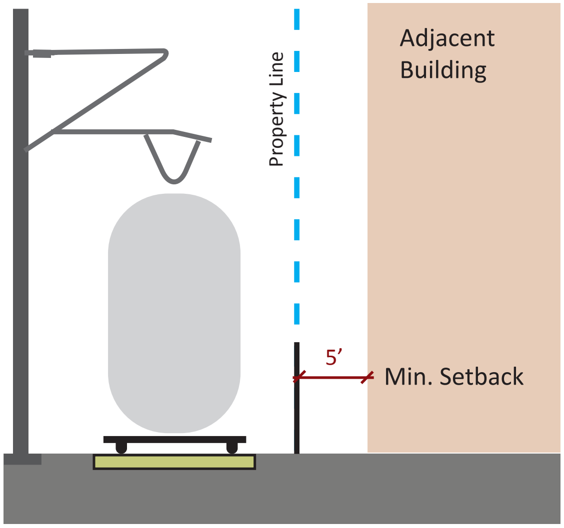
Buildings and structures with a zero lot setback that closely abut Metro ROW can pose concerns to Metro during construction. Encroachment onto Metro property to construct or maintain buildings is strongly discouraged as this presents safety hazards and may disrupt transit service and/or damage Metro infrastructure.

RECOMMENDATION: Include a minimum setback of five (5) feet from the property line to building facade to accommodate the construction and maintenance of structures without the need to encroach upon Metro property. As local jurisdictions also have building setback requirements, new developments should comply with the greater of the two requirements.

Entry into the ROW by parties other than Metro and its affiliated partners requires written approval. Should construction or maintenance of a development necessitate temporary or ongoing access to Metro ROW, a Metro Right of Entry Permit must be requested and obtained from Metro Real Estate for every instance access is required. Permission to enter the ROW is granted solely at Metro's discretion.

Coordination between property owners of fences, walls, and other barriers along property line is recommended. See Section 1.5.

Refer to Section 3.2 – Track Access and Safety for additional information pertaining to ROW access in preparation for construction activities.



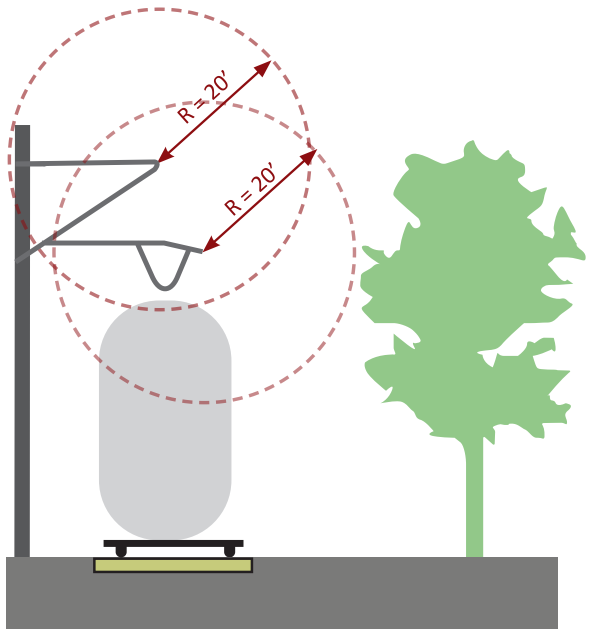
A minimum setback of five (5) feet between an adjacent structure and Metro ROW is strongly encouraged to allow project construction and ongoing maintenance without encroaching on Metro property.

1.4 Overhead Catenary System (OCS) Clearance

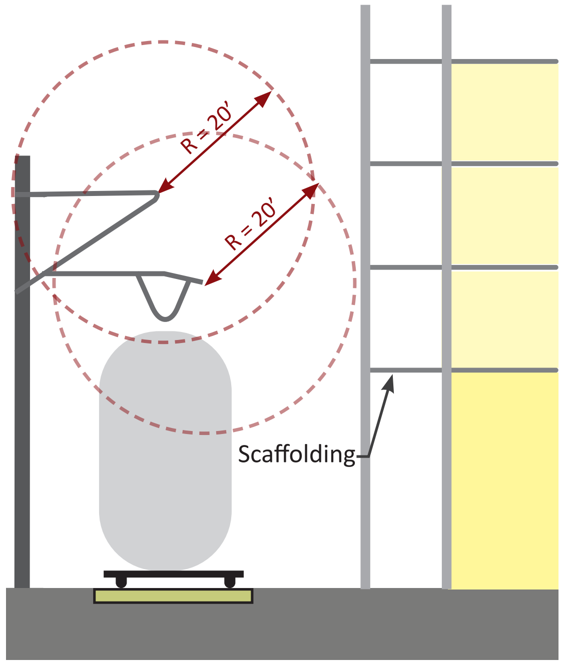
Landscaping and tree canopies can grow into the OCS above light rail lines, creating electrical safety hazards as well as visual and physical impediments for trains. Building appurtenances facing rail ROW, such as balconies, may also pose safety concerns to Metro operations as objects could fall onto the OCS.

RECOMMENDATION: Design project elements facing the ROW to avoid potential conflicts with Metro transit vehicles and infrastructure. Metro recommends that projects:

- Plan for landscape maintenance from private property and prevent growth into Metro ROW. Property owners will not be permitted to access Metro property to maintain private development.
- Design buildings such that balconies do not provide building users direct access to Metro ROW.
- Maintain building appurtenances and landscaping at a minimum distance of ten (10) feet from the OCS and support structures. If Transmission Power (TP) feeder cable is present, twenty (20) feet from the OCS and support structures is required. Different standards will apply for Metro Trolley Wires, Feeder Cables (wires) and Span Wires.



Adjacent structures and landscaping should be sited and maintained to avoid conflicts with the rail OCS.



Scaffolding and construction equipment should be staged to avoid conflicts with the rail OCS.

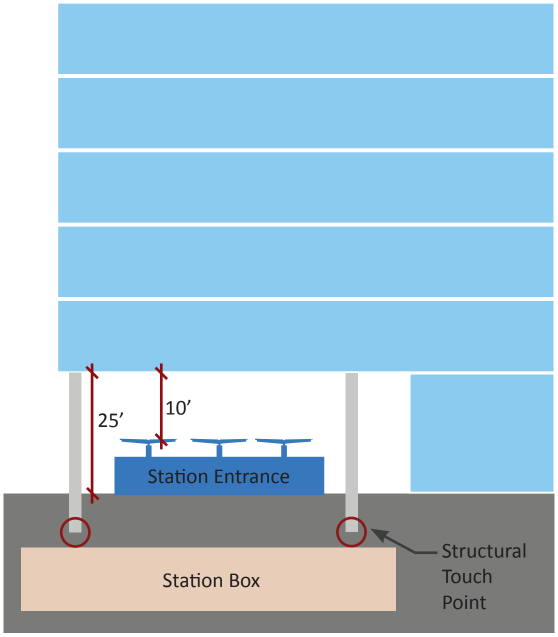
Site Plan & Conceptual Design

1.5 Underground Station Portal Clearance

Metro encourages transit-oriented development. Where development is planned above station entrances, close coordination is needed for structural safety as well as access for patrons, operations, and maintenance. Below are key design rules of thumb for development planned to cantilever over an entrance to an underground Metro Rail station.

RECOMMENDATION:

1. Preserve 25 feet clearance at minimum from plaza grade and the building structure above.
2. Preserve 10 feet clearance at minimum between portal roof and building structure above.
3. Coordinate structural support system and touchdown points to ensure a safe transfer of the building loads above the station portal.
4. Coordinate placement of structural columns and amenities (e.g. signage, lighting, furnishings) at plaza level to facilitate direct and safe connections for people of all mobile abilities to and from station entrance(s).
5. Develop a maintenance plan for the plaza in coordination with Metro.



Projects that propose to cantilever over Metro subway portals require close coordination with Metro Engineering.

1.6 Shared Barrier Construction & Maintenance

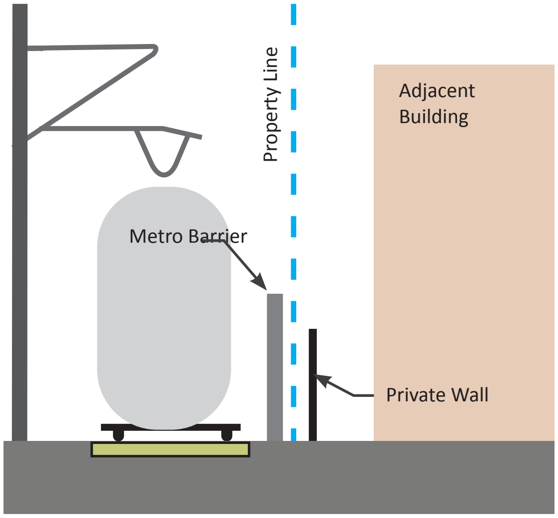
In areas where Metro ROW abuts private property, barrier construction and maintenance responsibilities can be a point of contention with property owners. When double barriers are constructed, the gap created between the Metro-constructed fence and a private property owner's fence can accumulate trash and make regular maintenance challenging without accessing the other party's property.

RECOMMENDATION: Coordinate with Metro Real Estate to create a single barrier condition along the ROW property line. With an understanding that existing conditions along ROW boundaries vary throughout LA County, Metro recommends the following, in order of preference:

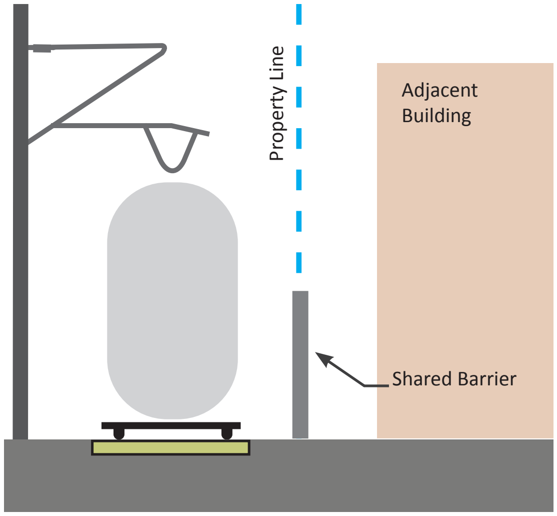
- **Enhance existing Metro barrier:** if structural capacity allows, private property owners and developers should consider physically affixing improvements onto and building upon Metro's existing barrier. Metro is amenable to barrier enhancements such as increasing barrier height and allowing private property owners to apply architectural finishes to their side of Metro's barrier.

- **Replace existing barrier(s):** if conditions are not desirable, remove and replace any existing barrier(s), including Metro's, with a new single "shared" barrier built on the property line.

Metro is amenable to sharing costs for certain improvements that allow for clarity in responsibilities and adequate ongoing maintenance from adjacent property owners without entering Metro's property. Metro Real Estate should be contacted with case-specific questions and will need to approve shared barrier design, shared financing, and construction.



Double barrier conditions allow trash accumulation and create maintenance challenges for Metro and adjacent property owners.



Metro prefers a single barrier condition along its ROW property line.

Site Plan & Conceptual Design

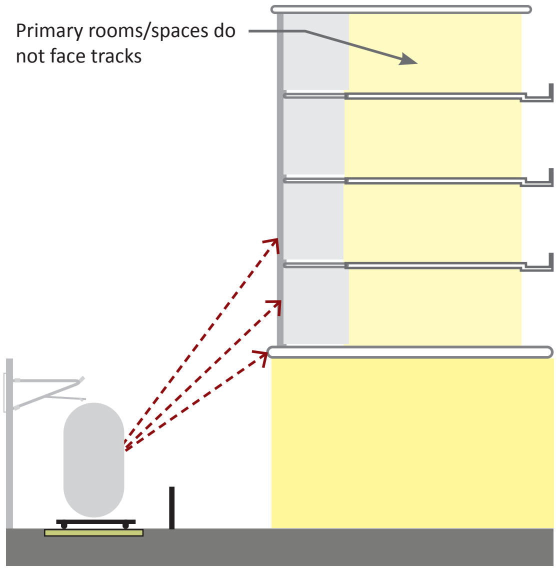
1.7 Project Orientation & Noise Mitigation

Metro may operate in and out of revenue service 24 hours per day, every day of the year, which can create noise and vibration (i.e. horns, power washing). Transit service and maintenance schedules cannot be altered to avoid noise for adjacent developments. However, noise and vibration impacts can be reduced through building design and orientation.

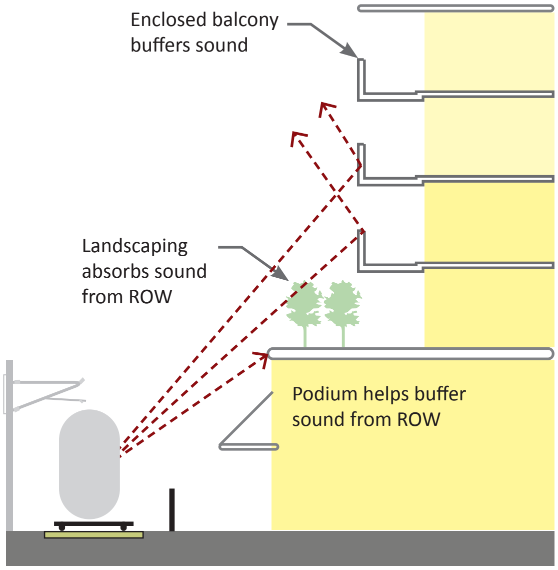
RECOMMENDATION: Use building orientation, programming, and design techniques to reduce noise and vibration for buildings along Metro ROW:

- Locate secondary or "back of house" rooms (e.g. bathrooms, stairways, laundry rooms) along ROW, rather than primary living spaces that are noise sensitive (e.g. bedrooms and family rooms).
- Use upper level setbacks and locate living spaces away from ROW.
- Enclose balconies.
- Install double-pane windows.
- Include language disclosing potential for noise, vibration, and other impacts due to transit proximity in terms and conditions for building lease or sale agreements to protect building owners/ sellers from tenant/buyer complaints.

Developers are responsible for any noise mitigation required, which may include engineering designs for mitigation recommended by Metro or otherwise required by local municipalities. A recorded Noise Easement Deed in favor of Metro may be required for projects within 100 feet of Metro ROW to ensure notification to tenants and owners of any proximity issues.



Building orientation can be designed to face away from tracks, reducing the noise and vibration impacts.



Strategic placement of podiums and upper-level setbacks on developments near Metro ROW can reduce noise and vibration impacts.

1.8 At-Grade Rail Crossings

New development is likely to increase pedestrian activity at rail crossings. Safety enhancements may be needed to upgrade existing rail crossings to better protect pedestrians.

RECOMMENDATION: Coordinate with Metro, the California Public Utilities Commission (CPUC), and any other transit operators using the crossing (e.g. Metrolink) to determine if safety enhancements are needed for nearby rail crossings.

While Metro owns and operates the rail ROW, the CPUC regulates all rail crossings. Contact the CPUC early in the design process to determine if they will require any upgrades to existing rail crossings. The CPUC may request to review development plans and hold a site visit to understand future pedestrian activity. Metro's Corporate Safety Department can support the developer in coordination with the CPUC.

Gates and pedestrian arms are common types of safety elements for pedestrians at rail crossings.

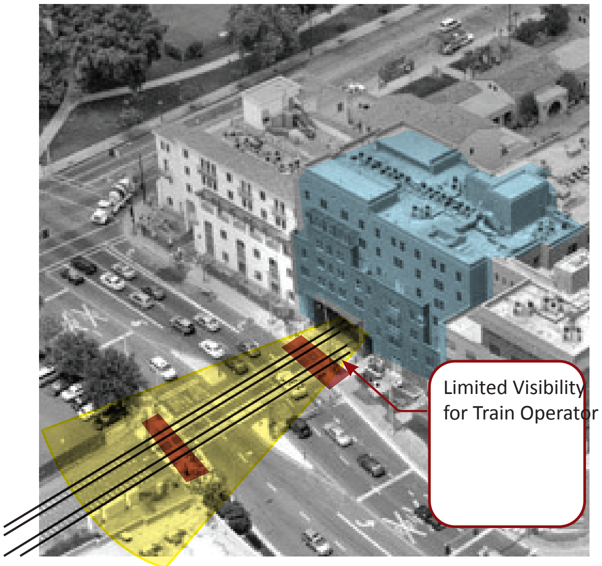
Safety elements of a gate and pedestrian arms have been constructed at the Monrovia Station.

1.9 Sight-Lines at Crossings

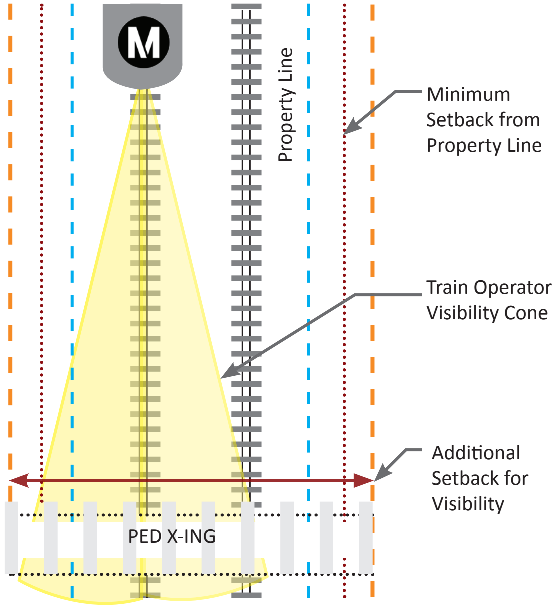
Developments adjacent to Metro ROW can present visual barriers to transit operators approaching vehicular and pedestrian crossings. Buildings and structures in close proximity to transit corridors can reduce sight-lines and create blind corners where operators cannot see pedestrians. This requires operations to reduce train speeds, which decreases efficiency of transit service.

RECOMMENDATION: Design buildings to maximize transit service sight-lines at crossings, leaving a clear cone of visibility to oncoming vehicles and pedestrians.

Metro Rail Operations will review, provide guidance, and determine the extent of operator visibility for safe operations. If the building envelope overlaps with the visibility cone near pedestrian and vehicular crossings, a building setback may be necessary to ensure safe transit service. The cone of visibility at crossings and required setback will be determined based on vehicle approach speed.



Limited sight-lines for trains approaching street crossings create unsafe conditions.



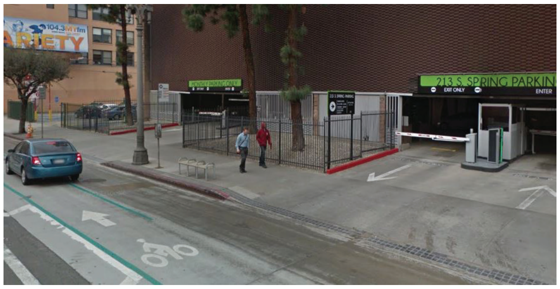
Visibility cones allow train operators to respond to safety hazards.

1.10 Driveway/Access Management

Driveways adjacent to on-street bus stops can create conflict for pedestrians walking to/from or waiting for transit. Additionally, driveways accessing parking lots and loading zones at project sites near Metro Rail and BRT crossings can create queuing issues along city streets and put vehicles in close proximity to fast moving trains and buses, which pose safety concerns.

RECOMMENDATION: Site driveways and other vehicular entrances to avoid conflicts with pedestrians, bicycles, and transit vehicles by:

- Placing driveways along side streets and alleys, away from on-street bus stops and transit crossings to minimize safety conflicts between active ROW, transit vehicles, and people, as well as queuing on streets.
- Locating vehicular driveways away from transit crossings or areas that are likely to be used as waiting areas for transit services.
- Placing loading docks away from sidewalks where transit bus stop activity is/will be present.
- Consolidating vehicular entrances and reduce width of driveways.
- Using speed tables to slow entering/exiting automobiles near pedestrians.
- Separating pedestrian walkways to minimize conflict with vehicles.
- Encouraging safe non-motorized travel.



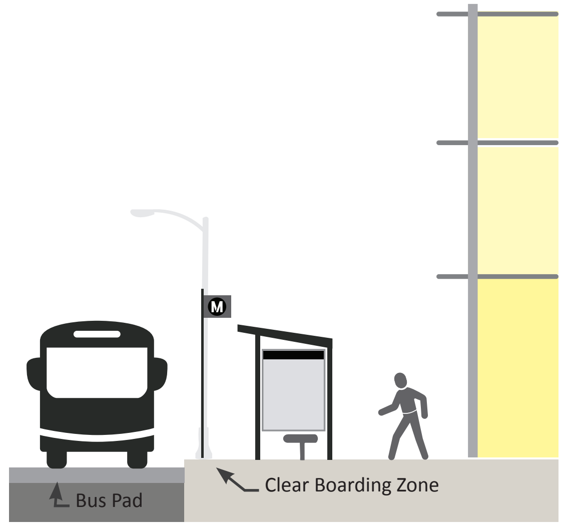
Driveways in close proximity to each other compromise safety for those walking to/from transit and increase the potential for vehicle-pedestrian conflicts.

1.11 Bus Stop & Zones Design

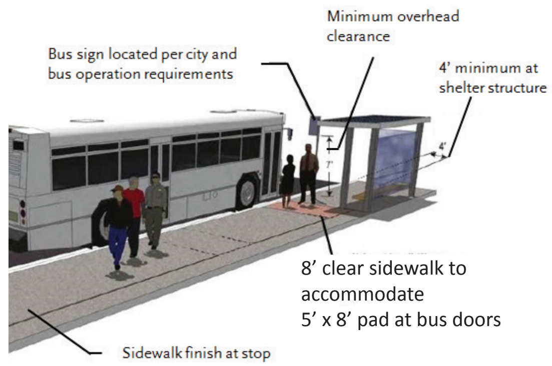
Metro Bus serves over 15,000 bus stops throughout the diverse landscape that is LA County. Typically located on sidewalks within public right-of-way owned and maintained by local jurisdictions, existing bus stop conditions vary from well-lit and sheltered spaces to uncomfortable and unwelcoming zones. Metro is interested in working with developers and local jurisdictions to create a vibrant public realm around new developments by strengthening multi-modal access to/from Metro transit stops and enhancing the pedestrian experience.

RECOMMENDATION: When designing around existing or proposed bus stops:

- Review Metro's Transit Service Policy, which provides standards for design and operation of bus stops and zones for near-side, far-side, and mid-block stops.
- Review Metro's Transfers Design Guide for more information at https://www.metro.net/projects/station-design-projects/
- Accommodate 5' x 8' landing pads at bus doors (front and back door, which are typically 23 to 25 feet apart).
- Locate streetscape elements (e.g. tree planters, street lamps, benches, shelters, trash receptacles and newspaper stands) outside of bus door zones to protect transit access and ensure a clear path of travel.
- Install a concrete bus pad within each bus stop zone to avoid street asphalt damage.
- Replace stand-alone bus stop signs with bus shelters that include benches and adequate lighting.
- Design wide sidewalks (15' preferred) that accommodate bus landing pads as well as street furniture, landscape, and user travel space.
- Consider tree species, height, and canopy shape (higher than 14' preferred) to avoid vehicle conflicts at bus stops. Trees should be set back from the curb and adequately maintained to prevent visual and physical impediments for buses when trees reach maturity. Avoid planting of trees that have an invasive and shallow root system.



A concrete bus pad should be located at bus stops and bus shelters should be located along sidewalks to ensure an accessible path of travel to a clear boarding area.



Well-designed and accessible bus stops are beneficial amenities for both transit riders and users of adjacent developments.

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Engineering & Technical Review

Engineering & Technical Review

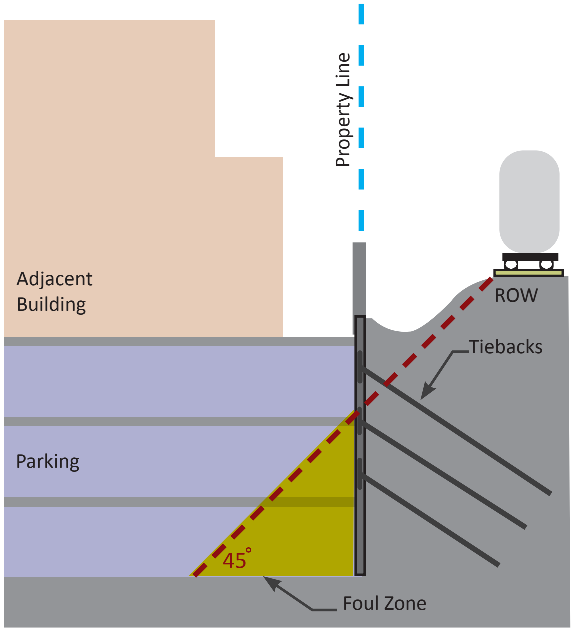
2.1 Excavation Support System Design

Excavation near Metro ROW has the potential to disturb adjoining soils and jeopardize support of existing Metro infrastructure. Any excavation which occurs within the geotechnical foul zone relative to Metro infrastructure is subject to Metro review and approval and meet Cal/OSHA requirements. This foul zone or geotechnical zone of influence shall be defined as the area below a track-way as measured from a 45-degree angle from the edge of the rail track ballast. Construction within this vulnerable area poses a potential risk to Metro service and requires additional Metro Engineering review.

RECOMMENDATION: Coordinate with Metro Engineering staff for review and approval of the excavation support system drawings and calculations prior to the start of excavation or construction. Tiebacks encroaching into Metro ROW may require a tieback easement or license, at Metro's discretion.

Any excavation/shoring within Metrolink operated and maintained ROW will require compliance with SCRRA Engineering standards and guidelines.

See page 7 for a sample section showing Metro adjacent conditions.



An underground structure located within the ROW foul zone would require additional review by Metro.

2.2 Proximity to Tunnels & Underground Infrastructure

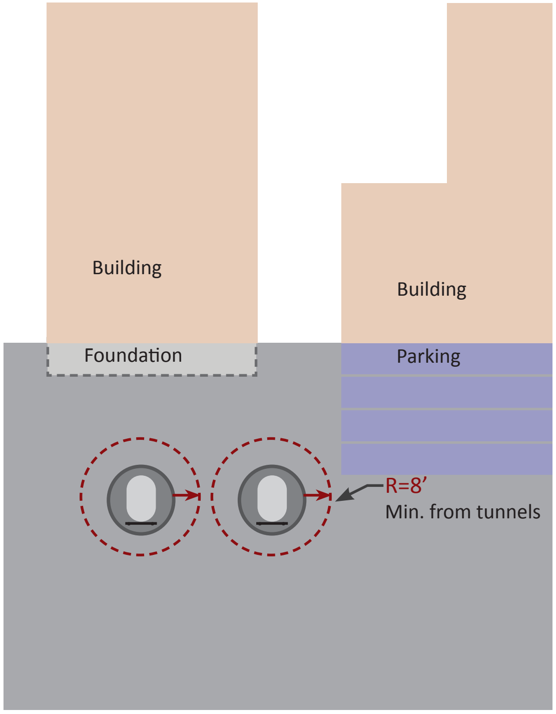
Construction adjacent to, over, or below underground Metro facilities (tunnels, stations and appendages) is of great concern and should be coordinated closely with Metro Engineering.

RECOMMENDATION: Coordinate with Metro early in the design process when proposing to build near underground Metro infrastructure. Metro typically seeks to maintain a minimum eight (8) foot clearance from existing Metro facilities to new construction (shoring or tiebacks). It will be incumbent upon the developer to demonstrate, to Metro's satisfaction, that both the temporary support of construction and the permanent works do not adversely affect the structural integrity, safety, or continued efficient operation of Metro facilities.

Dependent on the nature of the adjacent construction, Metro will need to review the geotechnical report, structural foundation plans, sections, shoring plan sections and calculations.

Metro may require monitoring where such work will either increase or decrease the existing overburden (i.e. weight) to which the tunnels or facilities are subjected. When required, the monitoring will serve as an early indication of excessive structural strain or movement. See Section 3.4, Excavation Drilling/Monitoring for additional information regarding monitoring requirements.

See page 7 for a sample section showing Metro adjacent conditions.

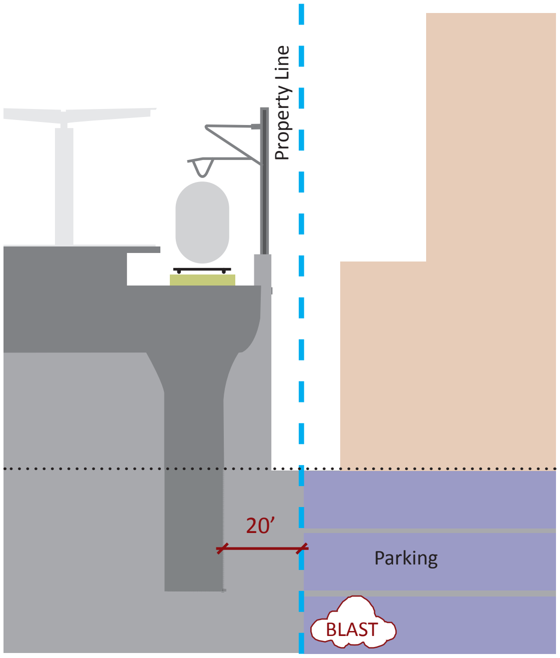


Adjacent project structures in close proximity to underground Metro infrastructure will require additional review by Metro.

2.3 Protection from Explosion/Blast

Metro is obligated to ensure the safety of public transit infrastructure from potential explosive sources which could originate from adjacent underground structures or from at-grade locations, situated below elevated guideways or near stations. Blast protection setbacks or mitigation may be required for large projects constructed near critical Metro facilities.

RECOMMENDATION: Avoid locating underground parking or basement structures within twenty (20) feet from an existing Metro tunnel or facility (exterior face of wall to exterior face of wall). Adjacent developments within this 20-foot envelope may be required to submit a Threat Assessment and Blast/Explosion Study for Metro review and approval.



An underground structure proposed within twenty (20) feet of a Metro structure may require a Threat Assessment and Blast/Explosion Study.

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Construction Safety & Management

Construction Safety & Management

3.1 Pre-Construction Coordination

Metro is concerned with impacts to service requiring rail single line tracking, line closures, speed restrictions, and bus bridging occurring as a result of adjacent project construction. Projects that will require work over, under, adjacent, or on Metro property or ROW and include operation of machinery, scaffolding, or any other potentially hazardous work are subject to evaluation in preparation for and during construction to maintain safe transit operations and passenger well-being.

Metro may need to monitor development construction near Metro facilities.

RECOMMENDATION: Following an initial screening of the project, Metro may determine that additional on-site coordination may be necessary. Dependent on the nature of the adjacent construction, developers may be requested to perform the following as determined on a case-by-case basis:

- Submit a construction work plan and related project drawings and specifications for Metro review.
- Submit a contingency plan, show proof of insurance coverage, and issue current certificates.
- Provide documentation of contractor qualifications.
- Complete pre-construction surveys, perform baseline readings, and install movement instrumentation.
- Complete readiness review and perform practice run of transit service shutdown per contingency plan.
- Designate a ROW observer or other safety personnel and an inspector from the project's construction team.
- Establish a coordination process for access and work in or adjacent to ROW for the duration of construction.

Project teams will be responsible for the costs of adverse impacts to Metro transit operations caused by work on adjacent developments, including remedial work to repair damage to Metro property, facilities, or systems. Additionally, a Construction Monitoring fee may be assessed based on an estimate of required level of effort provided by Metro.

All projects adjacent to Metrolink infrastructure will require compliance with SCRRA Engineering Standards and Guidelines.

3.2 Track Access and Safety

Permission from Metro is required to enter Metro property for rail construction and maintenance along, above, or under Metro ROW as these activities can interfere with Metro utilities and service and pose a safety hazard to construction teams and transit riders. Track access is solely at Metro's discretion and is discouraged to prevent electrocution and collisions with construction workers or machines.

Trained flaggers ensure the safe crossing of pedestrians and workers of an adjacent development.

RECOMMENDATION: Obtain and/or complete the following to work in or adjacent to Metro Rail ROW:

1. **Construction Work Plan:** Dependent on the nature of adjacent construction, Metro may request a construction work plan, which describes means and methods and other construction plan details, to ensure the safety of transit operators and riders.

2. **Safety Training:** All members of the project construction team will be required to attend Metro Rail Safety Training before commencing work activity. Training provides resources and procedures when working near active rail ROW.

3. **Right of Entry Permit/Temporary Construction Easement:** All access to and activity on Metro property, including easements necessary for construction of adjacent projects, must be approved through a Right-of-Entry Permit and/or a Temporary Construction Easement obtained from Metro Real Estate and may require a fee.

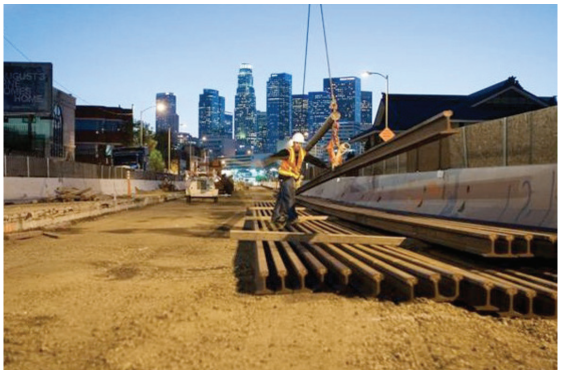
4. **Track Allocation:** All work on Metro Rail ROW must receive prior approval from Metro Rail Operations Control. Track Allocation identifies, reserves, and requests changes to normal operations for a specific track section, line, station, location, or piece of equipment to allow for safe use by a non-Metro entity. If adjacent construction is planned in close proximity to active ROW, flaggers must be used to ensure safety of construction workers and transit riders.

3.3 Construction Hours

Building near active Metro ROW poses safety concerns and may require limiting hours of construction which impact Metro ROW to night or off-peak hours so as not to interfere with Metro revenue service. To maintain public safety and access for Metro riders, construction should be planned, scheduled, and carried out in a way to avoid impacts to Metro service and maintenance.

RECOMMENDATION: In addition to receiving necessary construction approvals from the local jurisdiction, all construction work on or in close proximity to Metro ROW must be scheduled through the Track Allocation Process, detailed in Section 3.2.

Metro prefers that adjacent construction with potential to impact normal, continuous Metro operations take place during non-revenue hours (approximately 1am-4am) or during non-peak hours to minimize impacts to service. The developer may be responsible for additional operating costs resulting from disruption to normal Metro service.



Construction during approved hours ensures the steady progress of adjacent development construction and minimizes impacts to Metro's transit service.

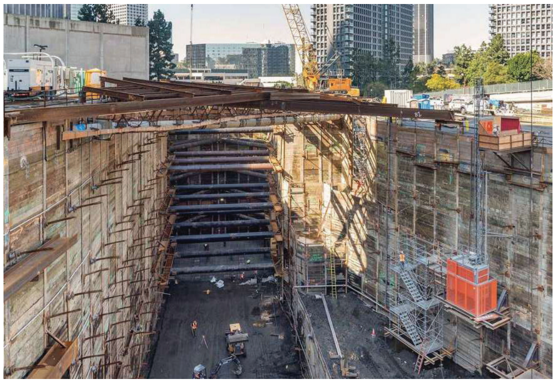
3.4 Excavation/Drilling Monitoring

Excavation is among the most hazardous construction activities and can pose threats to the structural integrity of Metro's transit infrastructure.

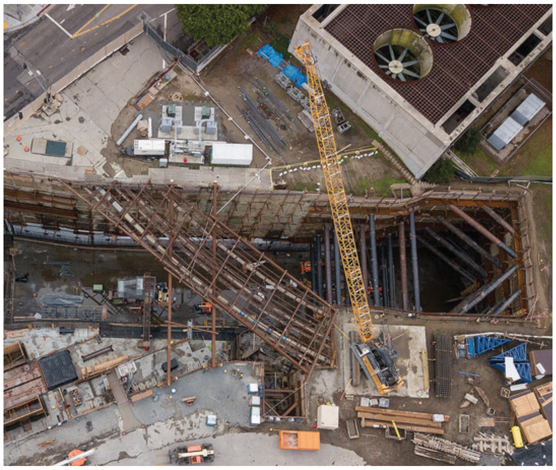
RECOMMENDATION: Coordinate with Metro Engineering to review and approve excavation and shoring plans during design and development, and well in advance of construction (see Sections 2.1 and 2.2).

Geotechnical instrumentation and monitoring will be required for all excavations occurring within Metro's geotechnical zone of influence, where there is potential for adversely affecting the safe and efficient operation of transit vehicles. Monitoring of Metro facilities due to adjacent construction may include the following as determined on a case-by-case basis:

- Pre- and post-construction condition surveys
- Extensometers
- Inclinometers
- Settlement reference points
- Tilt-meters
- Groundwater observation wells
- Movement arrays
- Vibration monitoring



Excavation and shoring plans must be reviewed by Metro to ensure structural compatibility with Metro infrastructure and safety during adjacent development construction.



A soldier pile wall used for Regional Connector station at 2nd/Hope.

Construction Safety & Management

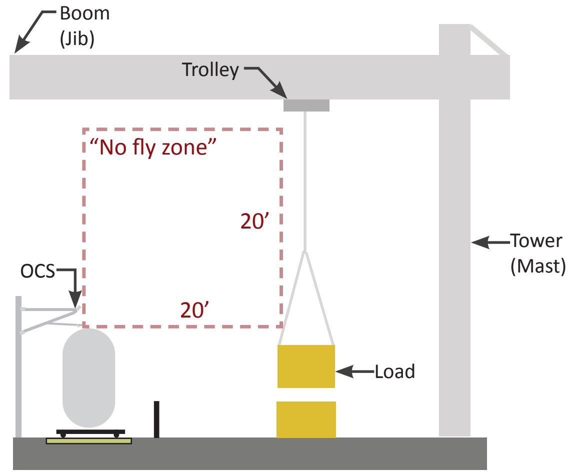
3.5 Crane Operations

Construction activities adjacent to Metro ROW may require moving large, heavy loads of building materials and machinery using cranes. Cranes referenced here include all power-operated equipment that can hoist, lower, and horizontally move a suspended load. To ensure safety for Metro riders, operators, and transit facilities, crane operations adjacent to Metro ROW must follow the safety regulations and precautions below and are subject to California Occupational Safety and Health Administration (Cal/OSHA) standards.

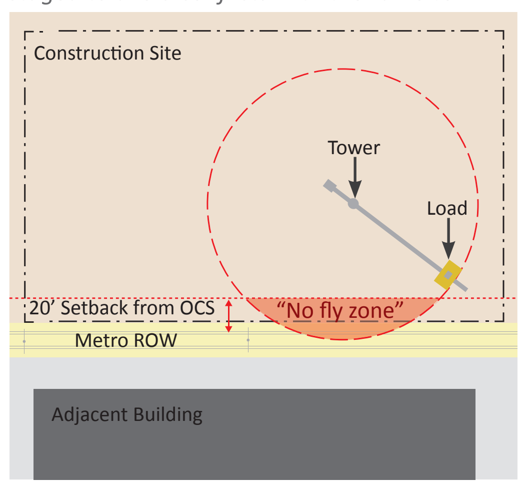
RECOMMENDATION:
Coordinate with Metro to discuss construction methods and confirm if a crane work plan is required. Generally, crane safety near Metro's ROW and facilities largely depends on the following factors: 1) Metro's operational hours and 2) swinging a load over or near Metro power lines and facilities. Note:

1. Clearance: A crane <u>boom</u> may travel over energized Metro OCS only if it maintains a vertical 20-foot clearance and the <u>load</u> maintain a horizontal 20-foot clearance.
2. Power: Swinging a <u>crane boom with a load</u> over Metro facilities or passenger areas is strictly prohibited during revenue hours. To swing a load in the "no fly zone" (see diagrams to right), the construction team must coordinate with Metro to de-energize the OCS.
3. Weathervaning: When not in use, the crane boom may swing 360 degrees with the movement of the wind, including over energized Metro OCS, only if the trolley is fully retracted towards the crane tower and not carrying any loads.
4. Process: Developers and contractors must attend Metro Track Allocation (detailed in Section 3.2) to determine if Metro staff support is necessary during crane erection and load movement.
5. Permit: Developers must apply for a Metro Right-of-Entry permit to swing over Metro facilities.

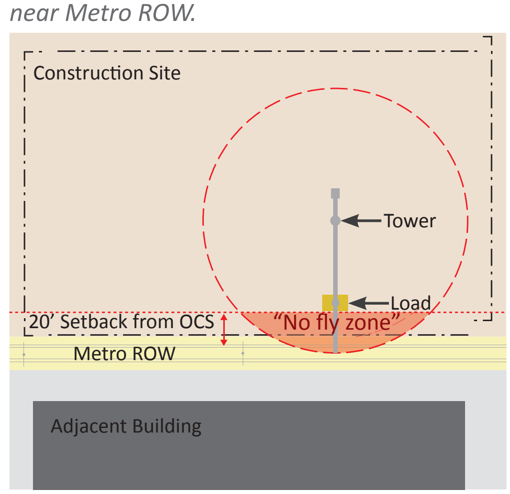
Project teams will bear all costs associated with impacts to Metro Rail operations and maintenance.



Cranes and construction equipment should be staged to avoid conflicts with the rail OCS.



Plan View: Crane swing and load are restricted near Metro ROW.



Plan View: While crane boom swings over "no fly zone," the trolley and load are retracted to maintain clearance from OCS.

3.6 Construction Barriers & Overhead Protection

During construction, falling objects can damage Metro facilities and pose a safety concern to the riders accessing them.

RECOMMENDATION: Erect vertical construction barriers and overhead protection compliant with Metro and Cal/OSHA requirements to prevent objects from falling into Metro ROW or areas designed for public access to Metro facilities. A protection barrier shall be constructed to cover the full height of an adjacent project and overhead protection from falling objects shall be provided over Metro ROW as necessary. Erection of the construction barriers and overhead protection for these areas shall be done during Metro non-revenue hours.

Overhead protection is required when moving heavy objects over Metro ROW or in areas designated for public use.

Constructed above is a wooden box over the entrance portal for overhead protection at the 4th/Hill Station.

3.7 Pedestrian & Emergency Access

Metro's riders rely on the consistency and reliability of access and wayfinding to and from stations, stops, and facilities. Construction on adjacent property must not obstruct pedestrian access, fire department access, emergency egress, or otherwise present a safety hazard to Metro operations, its employees, riders, and the general public. Fire access and safe escape routes within all Metro stations, stops, and facilities must be maintained at all times.

RECOMMENDATION: Ensure pedestrian and emergency access from Metro stations, stops, and transit facilities is compliant with the Americans with Disabilities Act (ADA) and maintained during construction:

- Temporary fences, barricades, and lighting should be installed and watchmen provided for the protection of public travel, the construction site, adjacent public spaces, and existing Metro facilities.
- Temporary signage should be installed where necessary and in compliance with the latest California Manual on Uniform Traffic Control Devices (MUTCD) and in coordination with Metro Art and Design Standards.
- Emergency exits shall be provided and be clear of obstructions at all times.
- Access shall be maintained for utilities such as fire hydrants, stand pipes/connections, and fire alarm boxes as well as Metro-specific infrastructure such as fan and vent shafts.

Sidewalk access is blocked for a construction project, forcing pedestrians into the street or to use less direct paths to the Metro facility.

3.8 Impacts to Bus Routes & Stops

During construction, bus stop zones and routes may need to be temporarily relocated. Metro needs to be informed of activities that require stop relocation or route adjustments in order to ensure uninterrupted service.

RECOMMENDATION: During construction, maintain or relocate existing bus stops consistent with the needs of Metro Bus Operations. Design of temporary and permanent bus stops and surrounding sidewalk areas must be compliant with the ADA and allow passengers with disabilities a clear path of travel to the transit service. Existing bus stops must be maintained as part of the final project. Metro Bus Operations Control Special Events Department and Metro Stops & Zones Department should be contacted at least 30 days before initiating construction activities.

Temporary and permanent relocation of bus stops and layover zones will require coordination between developers, Metro, and other municipal bus operators and local jurisdictions.

3.9 Utility Coordination

Construction has the potential to interrupt utilities that Metro relies on for safe operations and maintenance. Utilities of concern to Metro include, but are not limited to, condenser water piping, potable/fire water, storm and sanitary sewer lines, and electrical/telecommunication services.

RECOMMENDATION: Coordinate with Metro Real Estate during project design to gauge temporary and permanent utility impacts and avoid conflicts during construction.

The contractor shall protect existing above-ground and underground Metro utilities during construction and coordinate with Metro to receive written approval for any utilities pertinent to Metro facilities that may be used, interrupted, or disturbed.

When electrical power outages or support functions are required, approval must be obtained through Metro Track Allocation in coordination with Metro Real Estate for a Right of Entry Permit.

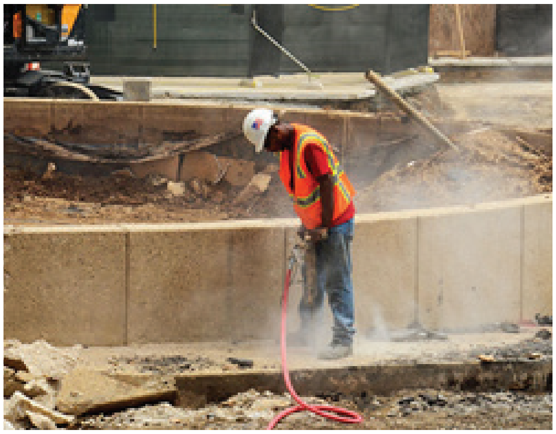
To begin coordination with Metro Real Estate, visit www.metro.net/devreview and select the drop-down "Utility Project Coordination."

Coordination of underground utilities is critical to safely and efficiently operate Metro service.

3.10 Air Quality & Ventilation Protection

Hot or foul air, fumes, smoke, steam, and dust from adjacent construction activities can negatively impact Metro facilities, service, and users.

RECOMMENDATION: Ensure that hot or foul air, fumes, smoke, and steam from adjacent facilities are discharged beyond 40 feet from existing Metro facilities, including but not limited to ventilation system intake shafts and station entrances. Should fumes be discharged within 40 feet of Metro intake shafts, a protection panel around each shaft shall be required.



A worker breaks up concrete creating a cloud of silica dust.

Glossary

Cone of Visibility
A conical space at the front of moving transit vehicles allowing for clear visibility of travel way and/or conflicts.

Construction Work Plan (CWP)
Project management document outlining the definition of work tasks, choice of technology, estimation of required resources and duration of individual tasks, and identification of interactions among the different work tasks.

Flagger/Flagman
Person who controls traffic on and through a construction project. Flaggers must be trained and certified by Metro Rail Operations prior to any work commencing in or adjacent to Metro ROW.

Geotechnical Foul Zone
Area below a track-way as measured from a 45-degree angle from the edge of the rail track ballast.

Guideway
A channel, track, or structure along which a transit vehicle moves.

Heavy Rail Transit (HRT)
Metro HRT systems include exclusive ROW (mostly subway) trains up to six (6) cars long (450’) and utilize a contact rail for traction power distribution (e.g. Metro Red Line).

Joint Development (JD)
JD is the asset management and real estate development program through which Metro collaborates with developers to build housing, retail, and other amenities on Metro properties near transit, typically through ground lease. JD projects directly link transit riders with destinations and services throughout LA County.

Light Rail Transit (LRT)
Metro LRT systems include exclusive, semi-exclusive, or street ROW trains up to three (3) cars long (270’) and utilize OCS for traction power distribution (e.g. Metro Blue Line).

Measure R
Half-cent sales tax for LA County approved in November 2008 to finance new transportation projects and programs. The tax expires in 2039.

Measure M
Half-cent sales tax for LA County approved in November 2016 to fund transportation improvements, operations and programs, and accelerate projects already in the pipeline. The tax will increase to one percent in 2039 when Measure R expires.

Metrolink
A commuter rail system with seven lines throughout Los Angeles, Orange, Riverside, San Bernardino, Ventura, and North San Diego counties governed by the Southern California Regional Rail Authority (SCRRA).

Metro Adjacent Construction Design Manual
Volume III of the Metro Design Criteria & Standards, which outlines the Metro adjacent review procedure as well as operational requirements when constructing over, under, or adjacent to Metro facilities, structures, and property.

Metro Bus
Metro “Local” and “Rapid” bus service runs within the street, typically alongside vehicular traffic, though occasionally in “bus-only” lanes.

Metro Bus Rapid Transit (BRT)
High quality bus service that provides faster and convenient service through the use of dedicated ROW, branded vehicles and stations, high frequency and intelligent transportation systems, all-door boarding, and intersection crossing priority. Metro BRT may run within dedicated ROW or in mixed flow traffic on streets.

Metro Design Criteria and Standards
A compilation of documents that govern how Metro transit service and facilities are designed, constructed, operated, and maintained.

Metro Rail
Urban rail system serving LA County consisting of six lines, including two subway lines and four light rail lines.

Metro Rail Design Criteria (MRDC)
Volume IV of the Metro Design Criteria & Standards which establishes design criteria for preliminary engineering and final design of a Metro Rail Project.

Metro Transit Oriented Communities
Land use planning and community development program that seeks to maximize access to transportation as a key organizing principle and promote equity and sustainable living by offering a mix of uses close to transit to support households at all income levels, as well as building densities, parking policies, urban design elements, and first/last mile facilities that support ridership and reduce auto dependency.

Noise Easement Deed
Easement granted by property owners abutting Metro ROW acknowledging noise due to transit operations and maintenance.

Overhead Catenary System (OCS)
One or more electrified wires situated over a transit ROW that transmit power to light rail trains via pantograph, a current collector mounted on the roof of an electric vehicle. Metro OCS is supported by hollow poles placed between tracks or on the outer edge of parallel tracks.

Right of Entry Permit
Written approval granted by Metro Real Estate to enter Metro ROW and property.

Right of Way (ROW)
Legal right over property reserved for transportation purposes to construct, protect, maintain and operate transit services.

Southern California Regional Rail Authority (SCRRA)
A joint powers authority made up of an 11-member board representing the transportation commissions of Los Angeles, Orange, Riverside, San Bernardino and Ventura counties. SCRRA governs and operates Metrolink service.

Threat Assessment and Blast/Explosion Study
Analysis performed when adjacent developments are proposed within twenty (20) feet from an existing Metro tunnel or facility.

Track Allocation/Work Permit
Permit granted by Metro Rail Operations Control to allocate a section of track and perform work on or adjacent to Metro Rail ROW. This permit should be submitted for any work that could potentially foul the envelope of a train.

Wayfinding
Signs, maps, and other graphic or audible methods used to convey location and directions to travelers.

metro.net/projects/devreview/

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August 14, 2023

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Re: Comments on Draft Environmental Impact Report for the Violet Street Creative Office Campus Project (SCH Number 2022110015; Environmental Case No. ENV -2021-2232-EIR)

Dear Mr. Fukuda, Mr. Bertoni:

We are writing on behalf of the Coalition for Responsible Equitable Economic Development Los Angeles ("CREED LA") to comment on the Draft Environmental Impact Report ("DEIR") prepared by the City of Los Angeles ("City") for the Violet Street Creative Office Campus Project (SCH Number 2022110015; Environmental Case No. ENV -2021-2232-EIR) ("Project") proposed by Al Violet, LLC and Al Violet B2, LLC ("Applicants"). We reserve the right to supplement these comments at later hearings and proceedings on the Project.[1]

The Project proposes to develop a new creative office campus with uses spanning existing and proposed buildings on an approximately 273,930 square-foot (6.3-acre) site.[2] Construction of the Project would require the demolition of the existing 25,798 square feet of warehouse uses, 9,940 square feet of office uses, and associated surface parking, all located on the southwest portion of the Project Site.[3]

[1] Gov. Code § 65009(b); PRC § 21177(a); *Bakersfield Citizens for Local Control v. Bakersfield ("Bakersfield")* (2004) 124 Cal. App. 4th 1184, 1199-1203; *see Galante Vineyards v. Monterey Water Dist*. (1997) 60 Cal. App. 4th 1109, 1121.
[2] DEIR, pg. II-1.
[3] *Id.*

The remainder of the Project Site is developed with the existing 244,795-square-foot Warner Music Group building (originally the Ford Factory building) and a five-story parking garage (including a roof-top level), which would be retained as part of the Project.[4] The Project proposes a 13-story, approximately 450,599-square-foot building featuring 435,100 square feet of office uses, 15,499 square feet of ground floor retail and/or restaurant uses, and 1,264 automobile parking spaces located in a seven-story parking garage, comprised of one at-grade, two above-grade, and four below-grade levels.[5] The Project also includes approximately 74,018 square feet of outdoor areas.[6] The Project also includes a Future Campus Expansion Phase, which encompasses a potential expansion opportunity for additional office use to be developed on Lot 4.[7] Construction of the Future Campus Expansion Phase would require the demolition of an existing 21,880-square-foot building containing office uses.[8] The precise uses and development plan for the Future Campus Expansion Phase are not known at this time.[9]

Based on our review of the DEIR and available supporting documentation, we conclude that the DEIR fails to comply with the requirements of the California Environmental Quality Act ("CEQA")[10]. The DEIR fails to adequately describe and analyze the Project and its impacts, and fails to propose feasible and enforceable mitigation measures, as required by CEQA. The City may not approve the Project until it revises the DEIR to adequately analyze and mitigate the Project's significant direct, indirect and cumulative impacts and incorporates all feasible mitigation measures to avoid or minimize these impacts to the greatest extent feasible.

We reviewed the DEIR, its technical appendices, and available reference documents with the assistance of noise and vibration expert Jack Meighan. Mr. Meighan's comments and qualifications are attached hereto as Exhibit A and are incorporated by reference as if set forth herein. The City must respond to the expert comments separately and fully.

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[4] *Id.*
[5] DEIR, pg. I-26.
[6] DEIR, pg. I-8.
[7] DEIR, pg. II-2.
[8] *Id.*
[9] *Id.*
[10] Pub. Resources Code §§ 21000 et seq.; 14 Cal. Code Regs ("CEQA Guidelines") §§ 15000 et seq. ("CEQA Guidelines").

I. STATEMENT OF INTEREST

CREED LA is an unincorporated association of individuals and labor organizations that may be adversely affected by the potential public and worker health and safety hazards, and the environmental and public service impacts of the Project. The coalition includes the Sheet Metal Workers Local 105, International Brotherhood of Electrical Workers Local 11, Southern California Pipe Trades District Council 16, and District Council of Iron Workers of the State of California, along with their members, their families, and other individuals who live and work in the City of Los Angeles and surrounding areas.

Individual members of CREED LA and its member organizations include Jorge L. Aceves, John P. Bustos, Gerry Kennon, and Chris S. Macias. These individuals live, work, recreate, and raise their families in the City of Los Angeles and surrounding communities. Accordingly, they would be directly affected by the Project's environmental and health and safety impacts. Individual members may also work on the Project itself. They will be first in line to be exposed to any health and safety hazards that exist onsite.

In addition, CREED LA has an interest in enforcing environmental laws that encourage sustainable development and ensure a safe working environment for its members. Environmentally detrimental projects can jeopardize future jobs by making it more difficult and more expensive for business and industry to expand in the region, and by making the area less desirable for new businesses and new residents. Continued environmental degradation can, and has, caused construction moratoriums and other restrictions on growth that, in turn, reduce future employment opportunities.

II. LEGAL BACKGROUND

CEQA requires public agencies to analyze the potential environmental impacts of their proposed actions in an EIR.[11] "The foremost principle under CEQA is that the Legislature intended the act to be interpreted in such manner as to afford the fullest possible protection to the environment within the reasonable scope of the statutory language."[12]

CEQA has two primary purposes. First, CEQA is designed to inform decisionmakers and the public about the potential significant environmental effects

[11] PRC § 21100.
[12] *Laurel Heights Improvement Assn. v. Regents of Univ. of Cal ("Laurel Heights I")* (1988) 47 Cal.3d 376, 390 (internal quotations omitted).

of a project.[13] "Its purpose is to inform the public and its responsible officials of the environmental consequences of their decisions before they are made. Thus, the EIR 'protects not only the environment but also informed self-government.'"[14] The EIR has been described as "an environmental 'alarm bell' whose purpose it is to alert the public and its responsible officials to environmental changes before they have reached ecological points of no return."[15] As the CEQA Guidelines explain, "[t]he EIR serves not only to protect the environment but also to demonstrate to the public that it is being protected."[16]

Second, CEQA requires public agencies to avoid or reduce environmental damage when "feasible" by requiring consideration of environmentally superior alternatives and adoption of all feasible mitigation measures.[17] The EIR serves to provide agencies and the public with information about the environmental impacts of a proposed project and to "identify ways that environmental damage can be avoided or significantly reduced."[18] If the project will have a significant effect on the environment, the agency may approve the project only if it finds that it has "eliminated or substantially lessened all significant effects on the environment" to the greatest extent feasible and that any unavoidable significant effects on the environment are "acceptable due to overriding concerns."[19]

While courts review an EIR using an "abuse of discretion" standard, "the reviewing court is not to 'uncritically rely on every study or analysis presented by a project proponent in support of its position. A clearly inadequate or unsupported study is entitled to no judicial deference."[20] As the courts have explained, a prejudicial abuse of discretion occurs "if the failure to include relevant information precludes informed decision-making and informed public participation, thereby

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[13] Pub. Resources Code § 21061; CEQA Guidelines §§ 15002(a)(1); 15003(b)-(e); *Sierra Club v. County of Fresno* (2018) 6 Cal.5th 502, 517 ("[T]he basic purpose of an EIR is to provide public agencies and the public in general with detailed information about the effect [that] a proposed project is likely to have on the environment; to list ways in which the significant effects of such a project might be minimized; and to indicate alternatives to such a project.").
[14] *Citizens of Goleta Valley,* 52 Cal.3d at p. 564 (quoting *Laurel Heights I*, 47 Cal.3d at 392).
[15] *County of Inyo v. Yorty* (1973) 32 Cal.App.3d 795, 810; *see also Berkeley Keep Jets Over the Bay v. Bd. of Port Comm'rs*. (2001) 91 Cal.App.4th 1344, 1354 ("*Berkeley Jets*") (purpose of EIR is to inform the public and officials of environmental consequences of their decisions *before* they are made).
[16] CEQA Guidelines § 15003(b).
[17] CEQA Guidelines § 15002(a)(2), (3); *see also Berkeley Jets*, 91 Cal.App.4th at 1354; *Citizens of Goleta Valley*, 52 Cal.3d at p. 564.
[18] CEQA Guidelines § 15002(a)(2).
[19] PRC § 21081(a)(3), (b); CEQA Guidelines §§ 15090(a), 15091(a), 15092(b)(2)(A), (B); *Covington v. Great Basin Unified Air Pollution Control Dist*. (2019) 43 Cal.App.5th 867, 883.
[20] *Berkeley Jets*, 91 Cal.App.4th at p. 1355 (emphasis added) (quoting *Laurel Heights I*, 47 Cal.3d at 391, 409, fn. 12).

thwarting the statutory goals of the EIR process."[21] "The ultimate inquiry, as case law and the CEQA guidelines make clear, is whether the EIR includes enough detail 'to enable who did not participate in its preparation to understand and to consider meaningfully the issues raised by the proposed project.'"[22]

III. THE DEIR LACKS AN ACCURATE, COMPLETE AND STABLE PROJECT DESCRIPTION

The DEIR does not meet CEQA's requirements because it fails to include an accurate, complete and stable description of key Project components, rendering the DEIR's impact analysis inadequate. California courts have repeatedly held that "an accurate, stable and finite project description is the *sine qua non* of an informative and legally sufficient EIR."[23] CEQA requires that a project be described with enough particularity that its impacts can be assessed.[24] Without a complete, stable and accurate project description, the environmental analysis under CEQA is impermissibly limited, thus minimizing the project's impacts and undermining meaningful public review.[25]

The DEIR does not provide a stable description of the project, as it (1) does not clearly or consistently describe the Project's square footage, and (2) inconsistently describes and analyzes the Future Campus Expansion Phase ("Future Phase").

First, the DEIR's project description does not clearly state the size of the proposed Project and the DEIR's impact analyses use differing descriptions of the size of the project being analyzed. The DEIR states that the Project proposes a new

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[21] *Berkeley Jets*, 91 Cal.App.4th at p. 1355; *see also San Joaquin Raptor/Wildlife Rescue Center v. County of Stanislaus* (1994) 27 Cal.App.4th 713, 722 (error is prejudicial if the failure to include relevant information precludes informed decision making and informed public participation, thereby thwarting the statutory goals of the EIR process); *Galante Vineyards*, 60 Cal.App.4th at p. 1117 (decision to approve a project is a nullity if based upon an EIR that does not provide decision-makers and the public with information about the project as required by CEQA); *County of Amador v. El Dorado County Water Agency* (1999) 76 Cal.App.4th 931, 946 (prejudicial abuse of discretion results where agency fails to comply with information disclosure provisions of CEQA).
[22] *Sierra Club,* 6 Cal.5th at p. 516 (quoting *Laurel Heights I*, 47 Cal.3d at 405).
[23] *Stopthemillenniumhollywood.com v. City of Los Angeles* (2019) 39 Cal.App.5th 1, 17; *Communities for a Better Environment v. City of Richmond* ("*CBE v. City of Richmond*") (2010) 184 Cal.App.4th 70, 85–89; *County of Inyo v. City of Los Angeles* (3d Dist. 1977) 71 Cal.App.3d 185, 193.
[24] CEQA Guidelines § 15124; *see Laurel Heights Improvement Assn. v. Regents of the Univ. of Cal.* (1988) 47 Cal.3d 376, 192–193; *see also El Dorado County Taxpayers for Quality Growth v. County of El Dorado* (2004) 122 Cal.App.4th 1591, 1597 ("An accurate and complete project description is necessary to fully evaluate the project's potential environmental effects.")
[25] *Id.*

450,599 square foot ("sf") commercial building, consisting of 435,100 sf of office space and 15,499 sf of retail uses.[26] The project description also purports to include the existing 244,795 sf Warner Music Group building, which "would remain with no change in use or alteration of the historic building."[27] Further, the DEIR claims to include in the project description the Future Phase, which would involve demolition of an existing 21,880 sf warehouse building, followed by new construction, for which the "precise uses and development…are not known at this Time."[28] Pursuant to the project description, the DEIR states "the Future Campus Expansion Phase is analyzed as 191,210 square feet of office uses and 20,000 square feet of restaurant uses throughout this DEIR unless otherwise noted."[29]

The above-described components of the Project are summarized in Table II-1 of the DEIR's project description. Table II-1 sets forth a total of 604,182 sf of new floor area for the Project, including the Future Phase and subtracting the square footage that will be demolished.[30] The Project's total square footage, including both the Future Phase and the existing Warner Music building, is stated to be 906,595 sf. Therefore, the DEIR should consistently evaluate a Project consisting of a total of 906,595 sf total floor area (or 604,182 sf to the extent it is analyzing only new net construction.) However, several of the DEIR's impact analyses appear to evaluate a different sized project. For example,

- The Project Transportation Assessment, upon which the DEIR's transportation impacts analysis is based, states that the Project as analyzed in this study involves two different buildout options depending on two different driveway scenarios: one scenario with 435,100 sf of office space and 15,499 sf of retail/restaurant and a second scenario with 432,910 sf of office and 15,499 sf of retail/restaurant.[31] It goes on to say that, including the Future Phase, the Project is analyzed with either 646,301 sf or 626,301 sf of office uses under one driveway scenario and 644,111 sf or 624,111 sf of office uses under the other driveway scenario.[32] None of these scenarios match up with the project description as summarized in Table II-1.

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[26] DEIR, pg. II-7.
[27] DEIR, pg. II-8.
[28] DEIR, pg. II-10.
[29] *Id.*
[30] DEIR, Table II-1 at pg. II-8.
[31] DEIR Appendix M (Transportation), pgs. 6-7.
[32] DEIR Appendix M (Transportation), pg. 7.

- The Project's energy impact analysis describes the Project as consisting of 646,301 sf office and 15,499 sf retail/restaurant.[33] Though the DEIR does not present the added total, the total square footage with these figures is 661,800 sf. Once again, this figure does not match up with any of the figures in Table II-1.

- The Project's air quality impact analysis describes the Project's square footage as a total of 626,301 sf square feet office use and 35,499 sf square foot retail/restaurant use.[34] Though the DEIR does not present the added total, the total square footage with these figures is 661,800 sf, which, again, does not line up with Table II-1.

- The Project's GHG emissions impact analysis uses two different Project totals: (i) 626,301 sf office use / 35,499 square foot retail/restaurant use[35]; and (ii) 646,201 sf office use / 15,399 square foot retail/restaurant use.[36] As explained above, none of these figures nor their totals match up with Table II-1's figures.

Second, as set forth above, the DEIR states that the Future Phase is analyzed as 191,201 square feet of office uses and 20,000 square feet of restaurant uses throughout the DEIR "unless otherwise noted."[37] By explicitly stating that the Future Phase will not always be analyzed the same way, the DEIR introduces ambiguity and undermines accurate impact assessment. In fact, throughout the DEIR, the Future Phase is sometimes analyzed as a split office-retail/restaurant use and other times as office only use. This flip-flopping is anything but "stable." Indeed, Table II-1 purports to summarize the various Project components and phases, but is internally inconsistent. It shows the Project's proposed floor area for the Future Phase as 211,201 sf of office use only, but in a footnote says that the DEIR analyzes the Future Phase as 191,201 sf of office uses and 20,000 sf of restaurant uses, thereby contradicting itself.[38]

As detailed below, the DEIR recognizes that impacts may differ depending on whether the Future Phase is analyzed as office-use only or is split between office use and restaurant/retail. For example, the DEIR's transportation analysis considers office-use only in assessing freeway safety impacts, because as compared

[33] DEIR, pg. IV.C-42.
[34] DEIR, pg. IV.A-48.
[35] DEIR, pg. IV.D-62.
[36] DEIR, pgs. IV.D-65, 70.
[37] DEIR, pg. II-2.
[38] *See* Table II-1. DEIR, pg. II-8.

to the split use version it would "generate the greatest number of trips to the freeway off-ramps."[39] Similarly, the water supply analysis uses the split-use version, because "restaurant uses result in greater water demand than office uses."[40] The DEIR clearly recognizes that the particular land uses assumed for different Project components will affect the impact analyses. This underscores the need for the DEIR to use a consistent and stable project description so that it accurately discloses the Project's expected environmental impacts.

This confusion caused by the shifting project description persists throughout the DEIR. As noted, the Project's water supply and infrastructure impact analysis uses the two different versions of the Future Phase. In the analysis, the DEIR states, "*the Future Campus Expansion Phase is analyzed as 211,201 square feet of office uses throughout this Draft EIR.* However, because restaurant uses result in greater water demand than office uses, the analysis below, as well as the wastewater analysis in Section VI, Other CEQA Considerations, of this Draft EIR, *also analyze an option with 191,201 square feet of office uses and 20,000 square feet of restaurant uses.*"[41] Here, the DEIR's water supply analysis contradicts the project description—which states that, for the Future Phase, the DEIR analyzes 191,201 sf of office uses and 20,000 sf of restaurant uses, *i.e.*, the split use version. In other words, the project description describes the split use version of the Future Phase as the rule, with the office-use only version as the exception. The section quoted above, however, by saying the DEIR generally uses the office only version of the Future Phase, treats the office-only version as the rule and the split use version as the exception.

The Project's Transportation Assessment also assumes that the Future Phase is generally analyzed as office only use, rather than assuming the split use as set out in the Project Description. In the Transportation appendix (Appendix M), it says that "[t]his transportation analysis *generally assumes* the 211,201 additional square feet, referred to as the future campus expansion, to be developed as office but analyzes the 211,201 additional square feet as 191,201 square feet of office and 20,000 square feet of quality restaurant under the VMT analysis for consistency with other sections of the DEIR."[42] Thus, the analysis assumes that the Future Phase will be office only use but analyzes it as split use elsewhere. The DEIR's analysis of two different driveway scenarios as noted above is a further example of how this assumption confuses the DEIR's analysis. Specifically, the analysis includes two versions of the two different driveway scenarios—analyzing each

[39] *Id.*
[40] DEIR, pg. IV.J.1-27.
[41] DEIR, pg. IV.J.1-27 (emphasis added).
[42] DEIR Appendix M (Transportation), pg. 7.

scenario with both the office only version and split use version of the Future Phase––thus creating four different analyses making it impossible to tell what version of the Project is actually being proposed by the DEIR.[43]

The Transportation Assessment brings up the Future Phase in its freeway safety analysis and there, too, the analysis is inconsistent. The freeway safety analysis analyzed the office only version of the Future Phase and did not analyze the split use version.[44] The DEIR states that it uses the office-only total figure because it would "generate the greatest number of trips to the freeway off-ramps."[45] Here, the DEIR only analyzes one version of the Future Phase, and which is a different version than used in the vehicular access analysis, while other DEIR sections like the water supply and infrastructure analysis analyze both the split use and office only use.

These inconsistencies can be found throughout the DEIR. For example, the DEIR's energy impact analysis describes the Project (including the Future Phase) as totaling 646,301 sf office and 15,499 sf retail/restaurant—*i.e.*, uses a total figure for the office use that treats the Future Phase as office use only, departing from the project description's assumption of a split-use version.[46] On the other hand, the air quality impact analysis sticks to a project description that assumes the split use version, describing the Project (including the Future Phase) as a total of 626,301 sf office use and 35,499 sf retail/restaurant use.[47] In the Project's GHG emissions impact analysis, the DEIR uses *both* the split use and the office only version. At one point it describes the Project (including the Future Phase) as proposing 626,301 square feet office use and 35,499 square foot retail/restaurant use [48] but a few pages later, describes it as proposing up to 646,201 square feet of office use and 15,399 square foot retail/restaurant use.[49] This lack of uniformity muddies the waters as to what Project is being analyzed, introducing confusion that prevents clear analysis.

Ultimately the DEIR seems to arbitrarily pick and choose which version of the Future Phase to analyze, sometimes analyzing both versions and other times only one version. This is inconsistent with CEQA's most basic requirement to provide a stable and accurate project description. The City must circulate a revised DEIR that includes a clear and stable project description and clearly defines the Future Phase uses that it purports to analyze.

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[43] DEIR Appendix M (Transportation), pg. 29.
[44] DEIR Appendix M (Transportation), pg. 38.
[45] *Id.*
[46] DEIR, pg. IV.C-42.
[47] DEIR, pg. IV.A-48.
[48] DEIR, pg. IV.D-62.
[49] DEIR, pgs. IV.D-65, 70.

IV. THE DEIR FAILS TO ADEQUATELY ANALYZE THE PROJECT'S PLANNED FUTURE CAMPUS EXPANSION PHASE

The Project's Future Phase is not adequately analyzed under CEQA.[50] Under *Laurel Heights*, an EIR must include an analysis of the environmental effects of future expansion or other actions if two conditions are met: (1) the future expansion or action is a reasonably foreseeable consequence of the initial project; and (2) the future expansion or action will be significant in that it will likely change the scope or nature of the initial project or its environmental effects.[51] Under this standard, "the facts of each case will determine whether and to what extent an EIR must analyze future expansion or other action."[52]

1. The DEIR Must Include Analysis of The Future Campus Expansion Phase Because It Meets the Two-Part Test Under *Laurel Heights.*

First, the Future Phase is more than just a "reasonably foreseeable consequence of the initial project"; it is a fully anticipated future component of the proposed Project. As stated in the Project Description, "the Project includes a Future Campus Expansion Phase. . . to be developed within Lot 4 of the Project Site."[53] The City even plans to set the Future Phase in motion by demolishing land in anticipation for the Expansion Phase.[54] Thus, the Future Phase is a reasonably foreseeable part of the project.

Second, the Future Phase will indeed "change the scope or nature of the project or its environmental effect." The Future Phase is a significant project; even though the precise uses of the Future Phase are not solidified, the City posits it will include an additional building of 211,201 sf. Demolition of an existing 21,880 sf warehouse building and construction of an additional office building with various uses invariably means increased traffic, noise, air quality impacts, and energy usage, among other things. The Future Phase therefore alters the scope of the project in expanding it significantly and will likely increase the environmental impacts of the Project.

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[50] *See, Laurel Heights Improvement Assn. v. Regents of Univ. of California* (1988) 47 Cal. 3d 376, *as modified on denial of reh'g* (Jan. 26, 1989).
[51] *Id.* at 396; *see also Nat'l Parks & Conservation Assn. v. Cnty. of Riverside (1996) 42 Cal.App.4th 1505, 1515; Del Mar Terrace Conservancy v. City Council* (1992) 10 Cal.App.4th 712, 730; *San Jose Raptor Rescue Ctr. V. County of Merced* (2007) 149 Cal.App.4th 645, 660.
[52] *Id.*
[53] DEIR, pg. II-10.
[54] DEIR, pg. II-10 ("Construction of the Future Campus Expansion Phase would require the demolition of an existing 21,880-square-foot warehouse building.")

Accordingly, the Future Phase meets the two-part *Laurel Heights* test and must therefore be adequately analyzed in the DEIR.

2. The DEIR Does Not Adequately Analyze the Future Campus Expansion Phase.

CEQA does not require "prophecy."[55] Lead Agencies are "not required. . . to commit themselves to a particular use or to predict precisely what the environmental effects, if any, of future activity will be."[56] However, "[t]he fact that precision may not be possible. . . does not mean that no analysis is required. Drafting an EIR ... involves some degree of forecasting. While foreseeing the unforeseeable is not possible, an agency must use its best efforts to find out and disclose all that it reasonably can."[57] At the very least, Lead Agencies must discuss "at least the general effects of the reasonably foreseeable future uses of the [Project], the environmental effects of those uses, and the currently anticipated measures for mitigating those effects."[58]

As detailed above, the DEIR contains numerous inconsistencies in describing the Future Phase it purports to analyze. This alone precludes an adequate analysis of the Future Phase as required by *Laurel Heights*. In addition, it is clear that, while claiming to include the Future Phase in its impact analyses, the DEIR does not consistently do so. For example, while the DEIR's air quality analysis purports to calculate emissions specifically anticipating emissions associated with the Future Phase, it is far from clear that the analysis did so. For example, the DEIR's Technical Appendix for Air Quality and Greenhouse Gas Emissions includes the assumptions used in CalEEMod emissions modeling.[59] Those assumption state that the Project will include demolition of 35,738 sf of existing buildings.[60] However, based on Table II-1 of the DEIR's project description, that figure includes demolition of 9,940 sf of existing office space and 25,798 sf of existing warehouse use, *but excludes the demolition of 21,880 sf of building associated with the Future Phase.*[61] Therefore, the DEIR clearly does not analyze all aspects of the Future Phase, and a review of the CalEEMod modeling output files suggests that the new buildings associated with the Future Phase may not have been analyzed either.

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[55] *Laurel Heights*, 47 Cal. 3d at 398.
[56] *Id.*
[57] *Id.* at 399 (internal quotation marks omitted).
[58] *Id.* at 398.
[59] DEIR Appendix C (Air Quality Analysis Assumptions), pdf pg. 24 of 346.
[60] *Id.*
[61] *See* Table II-1. DEIR, pg. II-8.

To meet the standards set forth in the *Laurel Heights* decision, the DEIR must be revised to provide a clear and stable description of the Future Phase and to properly analyze the Project including the Future Phase. As it stands, the DEIR fails to adequately analyze and disclose the potentially significant impacts of the proposed Project, including the Future Phase.

V. THE DEIR FAILS TO ADEQUATELY DISCLOSE, ANALYZE AND MITIGATE THE PROJECT'S NOISE IMPACTS

CREED LA's noise and vibration expert Jack Meighan identifies critical flaws in the DEIR's noise and vibration analysis, including omission of a potentially significant impact that would require mitigation.

First, Mr. Meighan identifies a potential undisclosed significant impact.[62] The DEIR concludes that Project construction result in the generation of excessive ground borne vibration.[63] As Mr. Meighan points out, though, the Project's construction vibration impacts analysis lacks consideration of the use of a vibratory roller.[64] Given the Project's plan to demolish existing spaces and create a new pedestrian plaza through grading, a vibratory roller would likely be employed for the Project.[65] And if a vibratory roller is indeed used for the Project, then the use would be considered a significant impact. As Mr. Meighan explains, as per the Federal Transit Administration's guidelines, a vibratory roller generates a Peak Particle Velocity of 0.21 in/sec at 25 feet – the same distance the closest construction site will be from the historic Ford Factory, which adheres to a 0.12 PPV criteria in the DEIR.[66] This implies that using a vibratory roller at this proximity would result in a significant impact.[67] Therefore, the DEIR must disclose the roller's potential use and, if utilized, disclose and mitigate its impact by, for example, establishing a minimum distance requirement for its operation.

Second, Mr. Meighan's analysis reveals a significant concern regarding the lack of proper citation for source noise levels utilized in the DEIR. While the analysis tables in Section 4 attribute the source of sound levels to "AES, 2022" and refer to Appendix I for details, numerous source levels in Appendix I—such as those associated with mechanical equipment, people, speakers, truck loading, trash compactors, and parking lots—are presented devoid of any context or supporting

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[62] Meighan Comments, pg. 2.
[63] DEIR, pg. IV.F-54.
[64] Meighan Comments, pg. 2.
[65] *Id.*
[66] *Id.*
[67] *Id.*

references.[68] Indeed, as Mr. Meighan points out, without the supporting references "it is impossible to verify the accuracy of the noise source levels or to evaluate the DEIR's noise impacts analysis."[69] Although certain sources, such as off-site traffic noise calculations, construction equipment noise levels, and construction equipment vibration levels, are explicitly cited, Mr. Meighan underscores the necessity of revising the DEIR to explicitly specify the origins of all noise sources.[70] This step is crucial to ensure the use of transparent, reasonable and verifiable noise levels in the assessment.

Mr. Meighan's comments and analysis provide substantial evidence that the Project may have significant unmitigated noise and vibration impacts that are completely unexamined in the DEIR, and explains why the DEIR's operational noise impact analysis is not supported by substantial evidence. The City must revise the DEIR to evaluate the risk of using a vibratory roller and include appropriate mitigation measures and citations.

VI. THE DEIR IMPROPERLY RELIES ON UNENFORCEABLE PROJECT DESIGN FEATURES TO CONCLUDE THAT THE PROJECT'S IMPACTS ARE LESS THAN SIGNIFICANT

In the DEIR's analyses of the Project's GHG emissions, noise, transportation, and water supply and infrastructure impacts, the DEIR includes measures that are classified as Project Design Features ("PDFs"), even though they serve to mitigate the Project's impacts. The DEIR underestimates the significance of the Project's impacts by using these mitigating PDFs for its initial significance determination. By applying PDFs as mitigation to the Project's unmitigated impacts, the DEIR "compress[es] the analysis of impacts and mitigation measures into a single issue,"[71] in violation of CEQA. This approach is prohibited by CEQA because it fails to inform the public and decision makers of the true severity of an impact.

CEQA requires that an EIR disclose the significance of an impact prior to mitigation.[72] The purpose of this analysis is both to require public disclosure of a project's impacts, and to require the lead agency to "identify and focus on the significant environmental effects of the proposed project."[73] In evaluating the significance of an impact, an EIR must discuss the physical changes in the environment that the project will cause, including:

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[68] *Id.* at pg. 3.
[69] *Id.*
[70] *Id.*
[71] *Lotus v. Dep't of Transp*. (2014) 223 Cal. App. 4th 645, 656.
[72] 14 CCR § 15126.2.
[73] 14 CCR § 15126.2(a).

> relevant specifics of the area, the resources involved, physical changes, alterations to ecological systems, and changes induced in population distribution, population concentration, the human use of the land (including commercial and residential development), health and safety problems caused by the physical changes, and other aspects of the resource base such as water, historical resources, scenic quality, and public services.[74]

Only after this discussion occurs may the agency identify and apply mitigation measures to reduce potentially significant impacts to less than significant levels.[75] The discussion is rendered meaningless (or, as here, omitted entirely) if the EIR falsely concludes that a project's impact is less than significant based on premature application of mitigation measures.

Moreover, none of these PDFs are incorporated into the DEIR as binding mitigation measures, in further violation of CEQA. CEQA defines mitigation as including any measures designed to avoid, minimize, rectify, reduce, or compensate for a significant impact.[76] The PDFs described in the DEIR are actually mitigation measures because they perform these functions. These PDFs are not designed to simply modify a physical element of the Project, as is inherent in a true project "design feature." The PDFs are designed to reduce impacts. This makes them mitigation measures within the meaning of CEQA. For example, as discussed below, WAT-PDF-1's requirement to use various water conservation techniques is clearly designed as mitigation to reduce the Project's water supply impacts that would result from using equipment with less efficient water conservation controls.

CEQA requires that mitigation measures be fully enforceable through permit conditions, agreements or other legally binding instruments.[77] Because the City has not characterized these PDFs as mitigation measures, they are not binding on the Applicants, and will not be included in the Project's Mitigation Monitoring and Reporting Program ("MMRP"). Reliance on "proposed" nonmandatory and unenforceable PDFs to reduce impacts therefore provides no assurance that the Applicant would later comply with the "design features." The PDFs therefore fail to provide the binding mechanism required by CEQA to compel the Applicant's compliance with mitigation following Project approval.

California courts have made clear that mitigation must be incorporated directly into a project's MMRP to be considered enforceable. In *Lotus v. Department*

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[74] 14 CCR § 15126.2(a).
[75] 14 CCR § 15126.4.
[76] 14 CCR § 15370.
[77] 14 CCR §15126.4(a)(2).

of Transportation,[78] an EIR approved by Caltrans contained several measures "[t]o help minimize potential stress on the redwood trees" during construction of a highway. Although those measures were clearly separate mitigation, the project proponents considered them "part of the project." The EIR concluded that due to the planned implementation of those measures, the project would not result in significant impacts. The Court disagreed, finding that the EIR had "disregard[ed] the requirements of CEQA" by "compressing the analysis of impacts and mitigation measures into a single issue." The Court continued, stating "[a]bsent a determination regarding the significance of the impacts … it is impossible to determine whether mitigation measures are required or to evaluate whether other more effective measures than those proposed should be considered."[79]

Similar to the inadequate analysis contained in the *Lotus* EIR, the DEIR asserts that incorporation of their PDFs would reduce the Project's GHG emissions, noise, transportation, and water supply and infrastructure impacts to less than significant levels prior to mitigation. This approach improperly "compress[es] the analysis of impacts and mitigation measures into a single issue."[80] Even if the DEIR's conclusions were accurate, which is unclear, the PDFs must be incorporated into the Project's MMRP as formal mitigation measures in order to be factored into the City's ultimate significance findings. "Simply stating that there will be no significant impacts because the project incorporates 'special construction techniques' is not adequate or permissible."[81]

The City has a duty to disclose unmitigated impacts and compare them to the applicable significance thresholds before applying mitigation measures. As a result of its improper reliance on PDFs, the DEIR underestimates the true unmitigated that will be generated by the Project. The City has already demonstrated it is aware and capable of excluding PDFs in its impact analysis through its decision to complete its air quality impact analysis without accounting for PDFs.[82] It is unclear why the City is inconsistent in its analyses and did not do the same for these other impact analyses. The DEIR must be revised and recirculated to include an accurate analysis of the Project's air quality impacts, and to require that any and all mitigation measures that are intended to reduce emissions are incorporated as binding mitigation in the Project's MMRP.

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[78] *Lotus v. Dep't of Transp*. (2014) 223 Cal. App. 4th 645, 651-52.
[79] *Id.*
[80] *Id.* at 656.
[81] *Id.* at 657.
[82] DEIR, pg. IV.A-45 ("To provide a conservative analysis these PDFs were not accounted for in the emissions presented below").

1. The DEIR's GHG Emissions Impact Analysis Improperly Relies on Project Design Features to Conclude that the Project's Impacts Are Less Than Significant.

In analyzing the Project's GHG Emissions, the DEIR utilizes WAT-PDF-1 to conclude the Project's impacts are less than significant. Specifically, in calculating the annual GHG emissions from water/wastewater, the project "takes into account Project Design Feature WAT-PDF-1."[83] The DEIR concludes that the "Project GHG emissions from water/wastewater usage would result in a . . . reduction in water/wastewater emissions *with implementation of Project Design Feature WAT-PDF-1*."[84] This approach incorrectly dismisses the significance of the Project's actual, unmitigated emissions. Without disclosing the Project's unmitigated GHG emissions, the DEIR only discloses estimated emissions with the application of WAT-PDF-1. This "downward adjustment" of the Project's emissions artificially reduces their significance. The DEIR failed to undertake the requisite analysis required by CEQA Guidelines Section 15126.2 for the Project's GHG emissions because the DEIR did not disclose the Project's GHG emission impacts prior to incorporating WAT-PDF-1.

2. The DEIR's Noise Impact Analysis Improperly Relies on Project Design Features to Conclude that the Project's Impacts Are Less Than Significant.

The DEIR proposes NOI-PDF-1 through NOI-PDF-5 relating to noise and vibration.[85] Because these are not formal mitigation measures, these PDFs are neither mandatory nor enforceable. Nevertheless, the DEIR assumes that the PDFs will be implemented and will reduce the Project's noise and vibration impacts, and are used as support for the conclusion that building damage impacts from on-site construction and impacts from on-site stationary noise sources will be less than significant.

For example, the DEIR uses PDFs to conclude that several on-site stationary noise sources would have less than significant impacts. In regard to noise impacts from mechanical equipment, it concludes that "as provided above in Project Design Feature NOI-PDF-3, all outdoor mounted mechanical equipment will be screened from off-site noise-sensitive receptors by the building roof parapet."[86] With respect to outdoor spaces, it finds that "[a]n additional potential noise source would be the

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[83] DEIR, pg. IV.D-76
[84] DEIR, pg. IV.D-81 (emphasis added).
[85] DEIR, pg. IV.F-30
[86] DEIR, pg. IV.F-39.

use of an outdoor sound system" but concludes that "[a]s set forth in Project Design Feature NOI-PDF-5, amplified sound system will be designed so as to not exceed the maximum noise levels as shown in Table IV.F-15."[87] With respect to loading dock and trash collection areas, it finds that noise impacts from loading dock and trash compactor operations would be mitigated because "as provided above in Project Design Feature NOI-PDF-4, the loading area will be acoustically screened from off-site noise-sensitive receptors."[88] Thus, the DEIR relies several times on PDFs to conclude that these various on-site stationary sources will have a less than significant impact. Additionally, in the DEIR's analysis of building damage impacts from on-site construction, it intentionally avoids analyzing impact pile driving vibration because NOI-PDF-2 directs the Project not to include the use of driven (impact) pile systems.[89] These analyses should have been completed without consideration of these PDFs.

As with the DEIR's improper use of PDFs with respect to GHG emission impacts, the DEIR's noise and vibration impact analysis violates CEQA as it improperly "compress[es] the analysis of impacts and mitigation measures into a single issue." The DEIR must be revised to assess and disclose the Project's noise and vibration impacts without consideration of the optional and unenforceable PDFs, and to require that any and all mitigation measures that are intended to reduce noise impacts are incorporated as binding mitigation in the Project's MMRP.

3. The DEIR Improperly Relies on a Transportation Project Design Feature to Conclude that the Project's Impacts Are Less Than Significant.

The DEIR proposes TR-PDF-1, which would require a Construction Traffic Management Plan that must be prepared and submitted to LADOT for review and approval before construction begins. In its transportation impact analysis, the DEIR concludes that the Project would not result in inadequate emergency access to the Project Site in part because even if the Project may require temporary lane closures, "the remaining travel lanes would be maintained in accordance with the Project's Construction Management Plan prepared and approved by the LADOT pursuant to Project Design Feature TR-PDF-1."[90] It then concludes that the Project would have less than significant impacts on inadequate emergency access and that no

[87] *Id.*
[88] DEIR, pg.IV.F-42
[89] DEIR, pg. IV.F-49.
[90] DEIR, pg. IV.H-35.

mitigation measures are required.[91] In so doing, it improperly relies on the PDF as an assured solution to the Project's potential impact.

The DEIR also relies on TR-PDF-1 in its water supply and infrastructure analysis. In concluding that the Project would not require or result in the relocation or construction of certain facilities that could cause significant environmental effects, it finds that "while trenching and installation activities could temporarily affect traffic flow and access on the adjacent streets and sidewalks, a Construction Traffic Management Plan prepared pursuant to TR-PDF-1 … would ensure the safe and efficient flow of vehicular and pedestrian traffic."[92] Thus, the DEIR fails to analyze or disclose a potentially significant impact through using a temporary, unenforceable PDF as a solution. It then uses that altered analysis to ultimately conclude that Project construction and operational impacts would be less than significant, in violation of CEQA.

For the reasons explained above, the DEIR must be revised and recirculated to assess and disclose the Project's transportation impacts—particularly the impact on emergency access—without consideration of optional and unenforceable PDFs, and to require that any and all mitigation measures that are intended to reduce transportation impacts are incorporated as binding mitigation in the Project's MMRP.

4. The DEIR's Water Supply and Infrastructure Impact Analysis Improperly Relies on a Project Design Feature to Conclude that the Project's Impacts Are Less Than Significant.

The DEIR proposes WAT-PDF-1 to address water conservation.[93] The PDF is referenced in the DEIR's calculation of the Project's water demand. Specifically, the DEIR notes the estimated daily water demand "*after* implementation of…water conservation measures included as a project design feature."[94] The DEIR ultimately concludes that "the LADWP would have sufficient water supplies to serve the Project's operational activities and therefore the Project's operation-related water supply impacts would be less than significant."[95] The calculation should have been made without the mitigated effects of the PDF. Since PDFs are not required and unenforceable, it is entirely possible that the Project may not utilize the

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[91] *Id.*
[92] DEIR, pg. IV.J.1-31 (with respect to Project construction); *see also* DEIR, pg. IV.J.1-32. (same conclusion with respect to Project operations).
[93] DEIR, pg. IV.J.1-29
[94] DEIR pg. IV.J.1-34 (emphasis added).
[95] DEIR pg. IV.J.1-38.

conservation efforts mentioned in the PDF leading to a higher daily water demand than disclosed in the DEIR. In fact, the DEIR explicitly states that these water conservation methods are "voluntary."[96]

For the reasons explained above, the DEIR must be revised to assess and disclose the Project's water supply and infrastructure impacts without consideration of optional and unenforceable PDFs, and to require that any and all mitigation measures that are intended to reduce water supply and infrastructure impacts are incorporated as binding mitigation in the Project's MMRP.

VII. THE DEIR FAILS TO ANALYZE AND MITIGATE THE PROJECT'S POTENTIALLY SIGNIFICANT HEALTH IMPACTS FROM EMISSIONS

The DEIR's air quality analysis includes the conclusions that Project construction and operation will not expose nearby sensitive receptors to substantial pollutant concentrations, finding that such impacts will be less than significant without mitigation.[97] However, these conclusions are not supported by any analysis of the potential health risks of the Project's emissions to nearby residential receptors. The City's significance determination is not supported by accurate scientific and factual data, as required by CEQA.[98] An agency cannot conclude that an impact is less than significant unless it produces rigorous analysis and concrete substantial evidence justifying the finding.[99]

These standards apply to an agency's analysis of public health impacts of a project under CEQA. In *Sierra Club v. County of Fresno*, the California Supreme Court affirmed CEQA's mandate to protect public health and safety by holding that an EIR fails as an informational document when it fails to disclose the public health impacts from air pollutants that would be generated by a development project.[100] In *Sierra Club*, the Supreme Court held that the EIR for the Friant Ranch Project—a 942-acre master-planned, mixed-use development with 2,500 senior residential units, 250,000 square feet of commercial space, and open space on former agricultural land in north central Fresno County—was deficient as a matter of law in its informational discussion of air quality impacts as they relate to adverse human health effects.[101]

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[96] DEIR, pg. IV.J.1-29 ("This project design feature identifies the additional (*voluntary*) water conservation measures to be implemented as part of the Project…").
[97] DEIR, pgs. IV.A-59—65.
[98] 14 C.C.R. § 15064(b).
[99] *Kings County Farm Bureau*, 221 Cal.App.3d at 732.
[100] *Sierra Club v. County of Fresno* (2018) 6 Cal.5th 502, 518–522.
[101] *Id.* at 507–508, 518–522.

As the *Sierra Club* Court explained, "a sufficient discussion of significant impacts requires not merely a determination of whether an impact is significant, but some effort to explain the nature and magnitude of the impact."[102] The Court concluded that the County's EIR was inadequate for failing to disclose the nature and extent of public health impacts caused by the project's air pollution. As the Court explained, the EIR failed to comply with CEQA because after reading the EIR, "the public would have no idea of the health consequences that result when more pollutants are added to a nonattainment basin."[103] CEQA mandates discussion, supported by substantial evidence, of the nature and magnitude of impacts of air pollution on public health.[104]

Furthermore, in *Berkeley Jets*, the Court of Appeal held that a CEQA document must analyze the impacts from human exposure to toxic substances.[105] In that case, the Port of Oakland approved a development plan for the Oakland International Airport.[106] The EIR admitted that the Project would result in an increase in the release of toxic air contaminants ("TACs") and adopted mitigation measures to reduce TAC emissions, but failed to quantify the severity of the Project's impacts on human health.[107] The Court held that mitigation alone was insufficient, and that the Port had a duty to analyze the health risks associated with exposure to TACs.[108] As the CEQA Guidelines explain, "[t]he EIR serves not only to protect the environment but also to demonstrate to the public that it is being protected."[109]

Here, the DEIR states that the City did not perform a construction health risk analysis due to the "short-term" nature of construction emissions.[110] It states, "[g]iven the short-term construction schedule of approximately 33 months, the Project would not result in a long-term (i.e., 70-year) source of TAC emissions.

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[102] *Id.* at 519, citing *Cleveland National Forest Foundation v. San Diego Assn. of Governments* (2017) 3 Cal.5th 497, 514–515.
[103] *Id.* at 518. CEQA's statutory scheme and legislative intent also include an express mandate that agencies analyze human health impacts and determine whether the "***environmental effects of a project will cause substantial <u>adverse effects on human beings</u>, either directly or indirectly***." (Public Resources Code § 21083(b)(3) (emphasis added).) Moreover, CEQA directs agencies to "take immediate steps to identify any critical thresholds for the ***<u>health and safety of the people</u>*** of the state and take all coordinated actions necessary to prevent such thresholds being reached." (Public Resources Code § 21000(d) (emphasis added).)
[104] *Sierra Club*, 6 Cal.5th at 518–522.
[105] *Berkeley Jets*, 91 Cal.App.4th at 1369–1371.
[106] *Id.* at 1349–1350.
[107] *Id.* at 1364–1371.
[108] *Id.*
[109] 14 C.C.R. § 15003(b).
[110] DEIR, pg. IV.A-61

Additionally, the SCAQMD CEQA Guidance does not require a health risk assessment (HRA) for short-term construction emissions."[111] The City's assertion that it need not evaluate health risks from sources lasting less than 70 years is not supported by substantial evidence, and violates CEQA's requirement to disclose a project's potential health risks to a degree of specificity that would allow the public to make the correlation between the project's impacts and adverse effects to human health.[112] Indeed, California's Office of Environmental Health Hazard Assessment's ("OEHHA") risk assessment guidelines recommend a formal health risk analysis ("HRA") for short-term construction exposures lasting longer than 2 months and that exposures from projects lasting more than 6 months should be evaluated for the duration of the project.[113] As Project construction will last nearly 3 years, CEQA requires that the health risk from each of the construction phases be quantified and disclosed. And under the OEHHA risk assessment guidelines, which are used throughout California for assessing health risks under CEQA, the DEIR should include a quantified HRA to assess risks to nearby sensitive receptors from construction emissions.

In evaluating the impact of potential toxic air contaminant (TAC) emissions, the DEIR concludes that "the Project would not result in the exposure of off-site sensitive receptors to carcinogenic or toxic air contaminants that exceed the maximum incremental cancer risk. . . and potential TAC impacts would be less than significant."[114] In fact, the DEIR asserts that the Project's incremental cancer risk due to TAC emissions would be "well below" 10 in one million, and the cancer burden would be less than 0.5 cancer case.[115] However, these conclusions are not supported by substantial evidence because the City did not actually quantify the cancer risk. With respect to the Project's construction activities, the DEIR states that "the greatest potential for TAC emissions during construction would be from diesel particulate emissions associated with heavy equipment operations."[116] Off-site receptors would therefore be exposed to these diesel particulate emissions ("DPM"). But the DEIR's analysis of LSTs does not quantify DPM or any other TAC emissions, because DPM and other TACs are not criteria pollutants. Therefore, the City's analysis of criteria pollutants does not satisfy its obligation to analyze TACs.

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[111] *Id.*
[112] *Bakersfield Citizens for Local Control v. City of Bakersfield* (2004) 124 Cal.App.4th 1184.
[113] Office of Environmental Health Hazard Assessment (OEHHA), Risk Assessment Guidelines: Guidance Manual for Preparation of Health Risk Assessments, February 2015 (OEHHA 2015), Section 8.2.10: Cancer Risk Evaluation of Short Term Projects, pp. 8-17/18; https://oehha.ca.gov/air/crnr/notice-adoption-air-toxics-hot-spots-program-guidance-manual-preparation-health-risk-0.
[114] DEIR, pg. IV.A-65.
[115] DEIR, pg. IV.A-64.
[116] DEIR, pg. IV.A-60.

The DEIR does not further analyze TAC impacts of the construction activities because of the "short-term construction schedule."[117] But as discussed above, since project construction will last nearly 3 years, the City should have analyzed the health risk that will be posed by construction activities during that time.

With respect to the Project's operational activities, the DEIR claims that the activities and land uses associated with the project, including diesel particulate matter from delivery trucks, are "not considered uses that generate substantial TAC emissions,"[118] and therefore did not perform a health risk assessment. The DEIR also acknowledges that SCAQMD recommends a health risk assessment be done for substantial individual sources of DPM, but claims that the Project "would not be expected to generate a large number of heavy duty truck trips" because the Project primarily consists of office and retail use.[119] But the Project may still very well produce some TAC emissions that could potentially increase cancer risk. TACs are emitted from a variety of sources, and the expected source of emissions from truck traffic should be properly analyzed to ensure that it would not result in elevated TAC exposure. The DEIR lacks substantial evidence supporting its conclusion that the Project's TAC emissions will not exceed the maximum incremental cancer risk. Because the DEIR lacks any meaningful analysis of the health risks from exposure to TACs, it fails to meet CEQA's informational standards and the City's significance finding is not supported by substantial evidence. The City must prepare a revised DEIR which fully discloses, analyzes and mitigates its impacts.

Because the DEIR lacks any analysis disclosing health risks from exposure to TACs, it fails to meet CEQA's informational standards and the City's significance finding is not supported by substantial evidence. The City must revise the DEIR to include an analysis of the Project's construction and operation health risks.

VIII. CONCLUSION

For the reasons discussed above, the DEIR for the Project is wholly inadequate under CEQA. It must be revised to provide legally adequate analysis of, and mitigation for, all of the Project's potentially significant impacts. These revisions will necessarily require that the DEIR be recirculated for additional public review. Until the DEIR has been revised and recirculated, as described herein, the City may not lawfully approve the Project.

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[117] DEIR, pg. IV.A-61.
[118] DEIR, pg. IV.A-64.
[119] *Id.*

Thank you for your consideration of these comments. Please include them in the record of proceedings for the Project.

Sincerely,

Ariana Abedifard
Richard Franco

Attachment
AA:acp

L7064-004acp

EXHIBIT A

WI #23-005.21

August 7, 2023

Richard M. Franco
Adams Broadwell Joseph & Cardozo
601 Gateway Blvd., Suite 1000
South San Francisco, CA 94080

SUBJECT: Comments on Violet Street Creative Office Noise Analysis

Dear Mr. Franco,

Per your request, we have reviewed the subject matter document for the Violet Street Creative Office Draft Environmental Impact Report (DEIR) in Los Angeles, California[1]. The proposed project involves the demolition of 25,798 square feet of warehouse uses and 9,940 square feet of office space as well as the construction, use and maintenance of a 13-story 450,599 square foot mixed-use building with retail and office uses. The project is surrounded by sensitive uses, most notably apartments directly to the north across 7th street and to the east across Mateo Street.

Wilson Ihrig is an acoustical consulting firm that has practiced exclusively in the field of acoustics since 1966. During our almost 57 years of operation, we have prepared hundreds of noise studies for Environmental Impact Reports and Statements. We have one of the largest technical laboratories in the acoustical consulting industry. We also utilize industry-standard acoustical programs such as Roadway Construction Noise Model (RCNM), SoundPLAN, and CadnaA. In short, we are well qualified to prepare environmental noise studies and review studies prepared by others.

Adverse Effects of Noise[2]

Although the health effects of noise are not taken as seriously in the United States as they are in other countries, they are real and, in many parts of the country, pervasive.

Noise-Induced Hearing Loss. If a person is repeatedly exposed to loud noises, he or she may experience noise-induced hearing impairment or loss. In the United States, both the Occupational Health and Safety Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) promote standards and regulations to protect the hearing of people exposed to high levels of industrial noise.

[1] Violet Street Creative Office Campus Project, Draft Environmental Report, City of Los Angeles, June 2023
[2] More information on these and other adverse effects of noise may be found in *Guidelines for Community Noise*, eds B Berglund, T Lindvall, and D Schwela, World Health Organization, Geneva, Switzerland, 1999. (https://www.who.int/docstore/peh/noise/Comnoise-1.pdf)

Speech Interference. Another common problem associated with noise is speech interference. In addition to the obvious issues that may arise from misunderstandings, speech interference also leads to problems with concentration fatigue, irritation, decreased working capacity, and automatic stress reactions. For complete speech intelligibility, the sound level of the speech should be 15 to 18 dBA higher than the background noise. Typical indoor speech levels are 45 to 50 dBA at 1 meter, so any noise above 30 dBA begins to interfere with speech intelligibility. The common reaction to higher background noise levels is to raise one's voice. If this is required persistently for long periods of time, stress reactions and irritation will likely result.

Sleep Disturbance. Noise can disturb sleep by making it more difficult to fall asleep, by waking someone after they are asleep, or by altering their sleep stage, e.g., reducing the amount of rapid eye movement (REM) sleep. Noise exposure for people who are sleeping has also been linked to increased blood pressure, increased heart rate, increase in body movements, and other physiological effects. Not surprisingly, people whose sleep is disturbed by noise often experience secondary effects such as increased fatigue, depressed mood, and decreased work performance.

Cardiovascular and Physiological Effects. Human's bodily reactions to noise are rooted in the "fight or flight" response that evolved when many noises signaled imminent danger. These include increased blood pressure, elevated heart rate, and vasoconstriction. Prolonged exposure to acute noises can result in permanent effects such as hypertension and heart disease.

Impaired Cognitive Performance. Studies have established that noise exposure impairs people's abilities to perform complex tasks (tasks that require attention to detail or analytical processes) and it makes reading, paying attention, solving problems, and memorizing more difficult. This is why there are standards for classroom background noise levels and why offices and libraries are designed to provide quiet work environments.

Construction Noise and Vibration Analysis Underestimates Potential Impacts

Construction Vibration Levels do not Include Worst-Case Sources

Table IV.F-22 presents Construction Vibration Impacts for building damage that could be potentially caused by the project. However, there is no vibratory roller in the construction analysis. Vibratory rollers are generally used to compact soil, gravel, concrete, asphalt or other materials in road construction. The project calls for the demolition and removal of the existing 25,798 square feet of warehouse uses, 9,940 square feet of office uses, and associated surface parking which would then have to be graded to build a new pedestrian plaza with new materials. As such, it is likely that a vibratory roller would be used in the project. According to the Federal Transit Administration Noise and Vibration Impact Assessment Manual[3] the Vibratory Roller has a Peak Particle Velocity (PPV) 0.21 in/sec at 25 feet. This is the same distance between the closest the construction site will be to the historic Ford Factory at 2060 7th street, which has a stated criteria in the DEIR of 0.12 PPV. This means that the closest potential use of a vibratory roller would be considered a significant impact. As such, the DEIR should be re-written to address whether a vibratory roller will be used during construction, or alternately to disclose the significant impact and propose appropriate mitigation measures, such as a requirement of a minimum distance that a vibratory roller could be used, that would reduce the impact.

[3] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/118131/transit-noise-and-vibration-impact-assessment-manual-fta-report-no-0123_0.pdf Table 7-4

Source Noise Levels used in the Analysis are Uncited.

All Tables in section 4 of the DEIR state the source of the sound level is "AES, 2022. See Appendix I of this Draft EIR." Appendix I details the noise calculation worksheets used to determine noise impacts. Several source levels, such as noise from: mechanical equipment (Appendix I, PDF page 66), people (page 70), speakers (page 76), truck loading (page 95), trash compactors (page 97), and parking lots (page 100) are given without context or supporting references. If these are taken from measurements by AES of each of these sources, this should be stated in either section 4 or in Appendix I. If these levels are from the SoundPLAN program defaults, that should be stated as well. Without supporting references, it is impossible to verify the accuracy of the noise source levels or to evaluate the DEIR's noise impacts analysis. The source for the analysis of off-site traffic noise calculations (FHWA TNM Version 2.5 - Appendix I, PDF page 103), construction equipment noise levels (DEIR, page IV.F-32), and construction equipment vibrations levels (DEIR, page IV.F-49) are explicitly given. The current document recognizes that noise sources are important to properly cite. As such, the DEIR should be revised to explicitly include where all noise sources come from, in order to determine reasonable levels are currently being used.

Project Design Features are Not Proper Mitigation Measures.

On page IV.F-30 the DEIR includes Project Design Features ("PDFs") that are meant to reduce the impact of noise and vibration. However, these features are not designated as mitigation measures and are therefore not mandatory nor enforceable under CEQA. The DEIR must not merely assume that these features will be implemented without demonstrating how the impacts would be reduced to a level below the "significant impact" threshold. The DEIR should be revised to disclose the Project's noise impacts before applying the PDFs. It should also be revised to include these features as mitigation measures and demonstrate how they would bring the project's impacts to an acceptable or less-than-significant level.

These revisions are necessary to fulfill CEQA's purposes of ensuring that decision-makers have a clear understanding of the available options for minimizing environmental impacts and can make informed choices when approving or denying the project.

Conclusions

There are several errors and omissions in the DEIR noise analysis. Correcting these would potentially identify several significant impacts which require mitigation.

Please feel free to contact me with any questions on this information.

Very truly yours,
WILSON IHRIG

Jack Meighan
Associate

Comments on Violet Street Creative Office Noise Analysis.docx

WILSON IHRIG
ACOUSTICS, NOISE & VIBRATION

JACK MEIGHAN

Associate

Jack joined Wilson Ihrig in 2021 and is an experienced acoustics engineer with expertise in projects involving rail transit systems, highways, CEQA analysis, environmental noise reduction, mechanical drawing reviews, and construction noise and vibration mitigation. He has hands-on experience with project management, including client coordination and presentations, as well as in designing, developing, and testing MATLAB code used in acoustics applications. Additionally, his expertise includes taking field measurements, developing test plans and specifying, purchasing, setting up and repairing acoustic measurement equipment. He has experience in using Traffic Noise Model (TNM), CadnaA, EASE, Visual Basic, LabView, and CAD software.

Education

- B.S. in Mechanical Engineering, University of Southern California, Los Angeles, CA

Project Experience

Metro Regional Connector, Los Angeles CA

Planned, took, and processed measurements as part of a team to determine the effectiveness of floating slab trackwork for a new subway in downtown Los Angeles that travels below the Walt Disney Concert Hall and the Colburn School of Music.

Rodeo Credit Enterprise CEQA Analysis for New Construction, Palmdale, CA

Wrote an accepted proposal and executed it for a noise study project to determine noise mitigation requirements on a new housing development. Led all aspects of the project and managed the budget during all phases of project completion. Completed 5 separate projects of this type for this developer.

Blackhall Studios, Santa Clarita, CA

Led the vibration measurement effort for a new soundstage directly adjacent to an existing freight and commuter rail line. Tested equipment, processed data, and analyzed results to determine the vibration propagation through the soil to the proposed soundstage locations, and was part of the team that developed mitigation techniques for the office spaces directly next to the rail line.

Octavia Residential Condos CEQA Study, San Francisco, CA

Calculated the STC ratings for the proposed windows to meet Title 24 requirements, modeled the acoustic performance of floor and ceiling structures, researched noise codes, helped with a mechanical design review, and wrote a report summarizing the results for a new Condominium project being developed in San Francisco.

San Diego International Airport Terminal I Replacement, CA

Conducted interior noise and vibration measurements, analyzed measurement data to help determine project criteria, modeled the existing and future terminals in CadnaA, and was part of a team that did a complete HVAC analysis of the entire terminal, as part of a CEQA analysis where a new terminal for the airport is being designed.

Five Points Apartments Noise Study, Whittier, CA
Took measurements, researched sound data and solutions, and recommended mitigation for a new apartment complex that was located next to an existing car wash, as part of a CEQA review.

USC Ellison Vibration Survey, Los Angeles, CA
Conducted vibration measurements as part of a survey to determine the effectiveness of vibration isolation platforms that are used to insulate cell growth in a cancer research facility. Determined the effectiveness and presented this information to the client. Researched and recommended a permanent monitoring system so the client could view data in real time.

TEN50 Condos 'Popping' Noise Investigation, Los Angeles, CA
Was part of a team that investigated the noise source of an unwanted popping noise in luxury condos in Downtown Los Angeles. Helped isolate the noise source location with accelerometers to determine where vibrations were occurring first and used an acoustic camera to determine where in the condo the noise was coming from.

2000 University Project, Berkely, CA
Wrote a construction noise monitoring plan based on environmental noise calculations, wrote a report summarizing the results, and attending a meeting with the client to discuss options.

Bay Area Rapid Transit (BART) On-Track, CA, San Francisco Bay Area, CA*
Day to day project manager, responsible for meetings, presentations, and coordination with the client for an ongoing noise study on the BART system. Developed MATLAB code to process measurements and determine areas where high corrugation was present, contributing to excessively high in-car noise levels. Performed noise measurements inside both the right of way and the vehicle cabin, in addition to rail corrugation measurements.

California I-605/SR-60 Interchange Improvement, Los Angeles, CA*
Developed a noise model of the area that predicted sound levels for abatement design, in addition to conducting noise measurements and analysis. Led the Team in use of the FHWA Traffic Noise Model Software for the project, involving three major highways and two busy interchanges extending over 17 miles in southern California.

Sound Transit On-Track, Seattle, WA*
Took measurements, fixed equipment, and developed software in MATLAB to process Corrugation Analysis Trolley measurements as part of an ongoing noise study on the Sound Transit Link system. Tested vibration data to determine the best measurement and processing techniques to store the data in an online database for in-car measurements.

LA Metro CRRC Railcar Testing, Los Angeles, CA*
Led the effort to plan the measurements, determine measurement locations and finalize the test plan. Formulated a method to capture speed data directly from legacy train vehicles. Executed noise and vibration specification measurements for new rail cars delivered by CRRC.

City of Los Angeles, Pershing Square Station Rehabilitation Noise Monitoring, CA*
Built noise models, wrote a construction noise plan, and assisted in on-site construction noise issues as they arose for a renovation of the Pershing Square metro station in downtown Los

** Work done prior to working for Wilson Ihrig*

Angeles. Trained construction personnel in techniques for noise reduction and how to conduct noise monitoring measurements to meet project specifications.

City of Orange Metrolink Parking Garage Construction Monitoring, CA*
Wrote an adaptive management vibration monitoring plan, set up equipment to monitor live vibration levels, and generated weekly reports as part of an effort to build a new parking garage. Designed, planned, and completed measurements to predict and mitigate pile driving construction impacts at three historic building locations adjacent to the construction site. Coordinated with the client whenever an on-site problem arose.

LA Metro Westside Subway Construction, Los Angeles, CA*
Planned, organized, and processed noise measurements for the Purple Line extension construction. Implemented both long term microphones to measure noise levels and accelerometers to measure vibration levels in existing subway tunnels. Oversaw noise monitoring at sensitive construction sites for the project and worked with the contractor to find ways to reduce construction noise levels by approximately 10dB.

Montreal Réseau Express Métropolitain, Canada*
Conducted vibration propagation measurements used to create models to predict operational vibration levels for an under-construction transit line. Managed equipment, solved problems in the field, and wrote parts of the report summarizing the findings of the acoustic study.

NHCRP Barrier*
Took on-highway measurements and wrote, designed, developed, and tested MATLAB code to identify specific spectrograms to use for analyses for a project evaluating barrier reflected highway traffic noise differences in the presence of a single absorptive or reflective noise barrier.

Siemens Railcar Testing for Sound Transit, Seattle, WA*
Measured in-car noise and vibration for new rail cars delivered by Siemens. Developed new internal techniques for measurements based on the written specifications. Contributed to the team that helped identify issues that new cars had in meeting the Sound Transit specifications for noise and vibration. Participated in developing the test plan and specified then acquired new equipment for the measurement.

Toronto/Ontario Eglinton Crosstown Light Rail, Final Design, Canada*
Assisted in vibration propagation measurements, analysis, and recommendations for mitigation for a 12-mile light-rail line both on and under Eglinton Avenue. Set up and ran equipment for at-grade measurements with an impact hammer for underground measurements with an impact load cell that was used during pre-construction borehole drilling.

** Work done prior to working for Wilson Ihrig*

GUIDELINES FOR COMMUNITY NOISE

Edited by

Birgitta Berglund
Thomas Lindvall
Dietrich H Schwela

This WHO document on the *Guidelines for Community Noise* is the outcome of the WHO-expert task force meeting held in London, United Kingdom, in April 1999. It bases on the document entitled "Community Noise" that was prepared for the World Health Organization and published in 1995 by the Stockholm University and Karolinska Institute.

World Health Organization, Geneva
Cluster of Sustainable Development and Healthy Environment (SDE)
Department for Protection of the Human Environment (PHE)
Occupational and Environmental Health (OEH)

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Foreword

Noise has always been an important environmental problem for man. In ancient Rome, rules existed as to the noise emitted from the ironed wheels of wagons which battered the stones on the pavement, causing disruption of sleep and annoyance to the Romans. In Medieval Europe, horse carriages and horse back riding were not allowed during night time in certain cities to ensure a peaceful sleep for the inhabitants. However, the noise problems of the past are incomparable with those of modern society. An immense number of cars regularly cross our cities and the countryside. There are heavily laden lorries with diesel engines, badly silenced both for engine and exhaust noise, in cities and on highways day and night. Aircraft and trains add to the environmental noise scenario. In industry, machinery emits high noise levels and amusement centres and pleasure vehicles distract leisure time relaxation.

In comparison to other pollutants, the control of environmental noise has been hampered by insufficient knowledge of its effects on humans and of dose-response relationships as well as a lack of defined criteria. While it has been suggested that noise pollution is primarily a "luxury" problem for developed countries, one cannot ignore that the exposure is often higher in developing countries, due to bad planning and poor construction of buildings. The effects of the noise are just as widespread and the long term consequences for health are the same. In this perspective, practical action to limit and control the exposure to environmental noise are essential. Such action must be based upon proper scientific evaluation of available data on effects, and particularly dose-response relationships. The basis for this is the process of risk assessment and risk management.

The extent of the noise problem is large. In the European Union countries about 40 % of the population are exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dB(A) daytime and 20 % are exposed to levels exceeding 65 dB(A). Taking all exposure to transportation noise together about half of the European Union citizens are estimated to live in zones which do not ensure acoustical comfort to residents. More than 30 % are exposed at night to equivalent sound pressure levels exceeding 55 dB(A) which are disturbing to sleep. The noise pollution problem is also severe in cities of developing countries and caused mainly by traffic. Data collected alongside densely travelled roads were found to have equivalent sound pressure levels for 24 hours of 75 to 80 dB(A).

The scope of WHO's effort to derive guidelines for community noise is to consolidate actual scientific knowledge on the health impacts of community noise and to provide guidance to environmental health authorities and professional trying to protect people from the harmful effects of noise in non-industrial environments. Guidance on the health effects of noise exposure of the population has already been given in an early publication of the series of Environmental Health Criteria. The health risk to humans from exposure to environmental noise was evaluated and guidelines values derived. The issue of noise control and health protection was briefly addressed.

At a WHO/EURO Task Force Meeting in Düsseldorf, Germany, in 1992, the health criteria and guideline values were revised and it was agreed upon updated guidelines in consensus. The essentials of the deliberations of the Task Force were published by Stockholm University and

Karolinska Institute in 1995. In an recent Expert Task Force Meeting convened in April 1999 in London, United Kingdom, the Guidelines for Community Noise were extended to provide global coverage and applicability, and the issues of noise assessment and control were addressed in more detail. This document is the outcome of the consensus deliberations of the WHO Expert Task Force.

Dr Richard Helmer
Director, Department of Protection of the Human Environment
Cluster Sustainable Development and Healthy Environments

Preface

Community noise (also called environmental noise, residential noise or domestic noise) is defined as noise emitted from all sources except noise at the industrial workplace. Main sources of community noise include road, rail and air traffic, industries, construction and public work, and the neighbourhood. The main indoor sources of noise are ventilation systems, office machines, home appliances and neighbours. Typical neighbourhood noise comes from premises and installations related to the catering trade (restaurant, cafeterias, discotheques, etc.); from live or recorded music; sport events including motor sports; playgrounds; car parks; and domestic animals such as barking dogs. Many countries have regulated community noise from road and rail traffic, construction machines and industrial plants by applying emission standards, and by regulating the acoustical properties of buildings. In contrast, few countries have regulations on community noise from the neighbourhood, probably due to the lack of methods to define and measure it, and to the difficulty of controlling it. In large cities throughout the world, the general population is increasingly exposed to community due to the sources mentioned above and the health effects of these exposures are considered to be a more and more important public health problem. Specific effects to be considered when setting community noise guidelines include: interference with communication; noise-induced hearing loss; sleep disturbance effects; cardiovascular and psycho-physiological effects; performance reduction effects; annoyance responses; and effects on social behaviour.

Since 1980, the World Health Organization (WHO) has addressed the problem of community noise. Health-based guidelines on community noise can serve as the basis for deriving noise standards within a framework of noise management. Key issues of noise management include abatement options; models for forecasting and for assessing source control action; setting noise emission standards for existing and planned sources; noise exposure assessment; and testing the compliance of noise exposure with noise immission standards. In 1992, the WHO Regional Office for Europe convened a task force meeting which set up guidelines for community noise. A preliminary publication of the Karolinska Institute, Stockholm, on behalf of WHO, appeared in 1995. This publication served as the basis for the globally applicable *Guidelines for Community Noise* presented in this document. An expert task force meeting was convened by WHO in March 1999 in London, United Kingdom, to finalize the guidelines.

The *Guidelines for Community Noise* have been prepared as a practical response to the need for action on community noise at the local level, as well as the need for improved legislation, management and guidance at the national and regional levels. WHO will be pleased to see that these guidelines are used widely. Continuing efforts will be made to improve its content and structure. It would be appreciated if the users of the *Guidelines* provide feedback from its use and their own experiences. Please send your comments and suggestions on the WHO *Guidelines for Community Noise – Guideline document* to the Department of the Protection of the Human Environment, Occupational and Environmental Health, World Health Organization, Geneva, Switzerland (Fax: +41 22-791 4123, e-mail: schwelad@who.int).

Acknowledgements

The World Health Organization thanks all who have contributed to the preparation of this document, *Guidelines for Community Noise.* The international, multidisciplinary group of contributors to, and reviewers of, the *Guidelines* are listed in the "Participant list" in Annex 6. Special thanks are due to the chairpersons and workgroups of the WHO expert task force meeting held in London, United Kingdom, in March 1999: Professor Thomas Lindvall, who acted as the chairperson of the meeting, Professor Birgitta Berglund, Dr John Bradley and Professor Gerd Jansen, who chaired the three workgroups. Special contributions from those who provided the background papers and who contributed to the success of the WHO expert meeting are gratefully acknowledged:

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Particular thanks are due to the Ministry of Environment of Germany, which provided the funding to convene the WHO expert task force meeting in London, United Kingdom, in March 1999 to produce the Guidelines for Community Noise.

Executive Summary

1. Introduction

Community noise (also called environmental noise, residential noise or domestic noise) is defined as noise emitted from all sources except noise at the industrial workplace. Main sources of community noise include road, rail and air traffic; industries; construction and public work; and the neighbourhood. The main indoor noise sources are ventilation systems, office machines, home appliances and neighbours.

In the European Union about 40% of the population is exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dB(A) daytime, and 20% are exposed to levels exceeding 65 dB(A). When all transportation noise is considered, more than half of all European Union citizens is estimated to live in zones that do not ensure acoustical comfort to residents. At night, more than 30% are exposed to equivalent sound pressure levels exceeding 55 dB(A), which are disturbing to sleep. Noise pollution is also severe in cities of developing countries. It is caused mainly by traffic and alongside densely-travelled roads equivalent sound pressure levels for 24 hours can reach 75–80 dB(A).

In contrast to many other environmental problems, noise pollution continues to grow and it is accompanied by an increasing number of complaints from people exposed to the noise. The growth in noise pollution is unsustainable because it involves direct, as well as cumulative, adverse health effects. It also adversely affects future generations, and has socio-cultural, esthetic and economic effects.

2. Noise sources and measurement

Physically, there is no distinction between sound and noise. Sound is a sensory perception and the complex pattern of sound waves is labeled noise, music, speech etc. Noise is thus defined as unwanted sound.

Most environmental noises can be approximately described by several simple measures. All measures consider the frequency content of the sounds, the overall sound pressure levels and the variation of these levels with time. Sound pressure is a basic measure of the vibrations of air that make up sound. Because the range of sound pressures that human listeners can detect is very wide, these levels are measured on a logarithmic scale with units of decibels. Consequently, sound pressure levels cannot be added or averaged arithmetically. Also, the sound levels of most noises vary with time, and when sound pressure levels are calculated, the instantaneous pressure fluctuations must be integrated over some time interval.

Most environmental sounds are made up of a complex mix of many different frequencies. Frequency refers to the number of vibrations per second of the air in which the sound is propagating and it is measured in Hertz (Hz). The audible frequency range is normally considered to be 20–20 000 Hz for younger listeners with unimpaired hearing. However, our hearing systems are not equally sensitive to all sound frequencies, and to compensate for this various types of filters or frequency weighting have been used to determine the relative strengths of frequency components making up a particular environmental noise. The A-weighting is most commonly used and weights lower frequencies as less important than mid- and higher-frequencies. It is intended to approximate the frequency response of our hearing system.

The effect of a combination of noise events is related to the combined sound energy of those events (the equal energy principle). The sum of the total energy over some time period gives a level equivalent to the average sound energy over that period. Thus, LAeq,T is the energy average equivalent level of the A-weighted sound over a period T. LAeq,T should be used to measure continuing sounds, such as road traffic noise or types of more-or-less continuous industrial noises. However, when there are distinct events to the noise, as with aircraft or railway noise, measures of individual events such as the maximum noise level (LAmax), or the weighted sound exposure level (SEL), should also be obtained in addition to LAeq,T. Time-varying environmental sound levels have also been described in terms of percentile levels.

Currently, the recommended practice is to assume that the equal energy principle is approximately valid for most types of noise and that a simple LAeq,T measure will indicate the expected effects of the noise reasonably well. When the noise consists of a small number of discrete events, the A-weighted maximum level (LAmax) is a better indicator of the disturbance to sleep and other activities. In most cases, however, the A-weighted sound exposure level (SEL) provides a more consistent measure of single-noise events because it is based on integration over the complete noise event. In combining day and night LAeq,T values, night-time weightings are often added. Night-time weightings are intended to reflect the expected increased sensitivity to annoyance at night, but they do not protect people from sleep disturbance.

Where there are no clear reasons for using other measures, it is recommended that LAeq,T be used to evaluate more-or-less continuous environmental noises. Where the noise is principally composed of a small number of discrete events, the additional use of LAmax or SEL is recommended. There are definite limitations to these simple measures, but there are also many practical advantages, including economy and the benefits of a standardized approach.

3. Adverse health effects of noise

The health significance of noise pollution is given in chapter 3 of the *Guidelines* under separate headings according to the specific effects: noise-induced hearing impairment; interference with speech communication; disturbance of rest and sleep; psychophysiological, mental-health and performance effects; effects on residential behaviour and annoyance; and interference with intended activities. This chapter also considers vulnerable groups and the combined effects of mixed noise sources.

Hearing impairment is typically defined as an increase in the threshold of hearing. Hearing deficits may be accompanied by tinnitus (ringing in the ears). Noise-induced hearing impairment occurs predominantly in the higher frequency range of 3 000–6 000 Hz, with the largest effect at 4 000 Hz. But with increasing LAeq,8h and increasing exposure time, noise-induced hearing impairment occurs even at frequencies as low as 2 000 Hz. However, hearing impairment is not expected to occur at LAeq,8h levels of 75 dB(A) or below, even for prolonged occupational noise exposure.

Worldwide, noise-induced hearing impairment is the most prevalent irreversible occupational hazard and it is estimated that 120 million people worldwide have disabling hearing difficulties.

In developing countries, not only occupational noise but also environmental noise is an increasing risk factor for hearing impairment. Hearing damage can also be caused by certain diseases, some industrial chemicals, ototoxic drugs, blows to the head, accidents and hereditary origins. Hearing deterioration is also associated with the ageing process itself (presbyacusis).

The extent of hearing impairment in populations exposed to occupational noise depends on the value of LAeq,8h, the number of noise-exposed years, and on individual susceptibility. Men and women are equally at risk for noise-induced hearing impairment. It is expected that environmental and leisure-time noise with a LAeq,24h of 70 dB(A) or below will not cause hearing impairment in the large majority of people, even after a lifetime exposure. For adults exposed to impulse noise at the workplace, the noise limit is set at peak sound pressure levels of 140 dB, and the same limit is assumed to be appropriate for environmental and leisure-time noise. In the case of children, however, taking into account their habits while playing with noisy toys, the peak sound pressure should never exceed 120 dB. For shooting noise with LAeq,24h levels greater than 80 dB(A), there may be an increased risk for noise-induced hearing impairment.

The main social consequence of hearing impairment is the inability to understand speech in daily living conditions, and this is considered to be a severe social handicap. Even small values of hearing impairment (10 dB averaged over 2 000 and 4 000 Hz and over both ears) may adversely affect speech comprehension.

Speech intelligibility is adversely affected by noise. Most of the acoustical energy of speech is in the frequency range of 100–6 000 Hz, with the most important cue-bearing energy being between 300–3 000 Hz. Speech interference is basically a masking process, in which simultaneous interfering noise renders speech incapable of being understood. Environmental noise may also mask other acoustical signals that are important for daily life, such as door bells, telephone signals, alarm clocks, fire alarms and other warning signals, and music.

Speech intelligibility in everyday living conditions is influenced by speech level; speech pronunciation; talker-to-listener distance; sound level and other characteristics of the interfering noise; hearing acuity; and by the level of attention. Indoors, speech communication is also affected by the reverberation characteristics of the room. Reverberation times over 1 s produce loss in speech discrimination and make speech perception more difficult and straining. For full sentence intelligibility in listeners with normal hearing, the signal-to-noise ratio (i.e. the difference between the speech level and the sound level of the interfering noise) should be at least 15 dB(A). Since the sound pressure level of normal speech is about 50 dB(A), noise with sound levels of 35 dB(A) or more interferes with the intelligibility of speech in smaller rooms. For vulnerable groups even lower background levels are needed, and a reverberation time below 0.6 s is desirable for adequate speech intelligibility, even in a quiet environment.

The inability to understand speech results in a large number of personal handicaps and behavioural changes. Particularly vulnerable are the hearing impaired, the elderly, children in the process of language and reading acquisition, and individuals who are not familiar with the spoken language.

Sleep disturbance is a major effect of environmental noise. It may cause primary effects during sleep, and secondary effects that can be assessed the day after night-time noise exposure. Uninterrupted sleep is a prerequisite for good physiological and mental functioning, and the primary effects of sleep disturbance are: difficulty in falling asleep; awakenings and alterations of sleep stages or depth; increased blood pressure, heart rate and finger pulse amplitude; vasoconstriction; changes in respiration; cardiac arrhythmia; and increased body movements. The difference between the sound levels of a noise event and background sound levels, rather than the absolute noise level, may determine the reaction probability. The probability of being awakened increases with the number of noise events per night. The secondary, or after-effects, the following morning or day(s) are: reduced perceived sleep quality; increased fatigue; depressed mood or well-being; and decreased performance.

For a good night's sleep, the equivalent sound level should not exceed 30 dB(A) for continuous background noise, and individual noise events exceeding 45 dB(A) should be avoided. In setting limits for single night-time noise exposures, the intermittent character of the noise has to be taken into account. This can be achieved, for example, by measuring the number of noise events, as well as the difference between the maximum sound level and the background sound level. Special attention should also be given to: noise sources in an environment with low background sound levels; combinations of noise and vibrations; and to noise sources with low-frequency components.

Physiological Functions. In workers exposed to noise, and in people living near airports, industries and noisy streets, noise exposure may have a large temporary, as well as permanent, impact on physiological functions. After prolonged exposure, susceptible individuals in the general population may develop permanent effects, such as hypertension and ischaemic heart disease associated with exposure to high sound levels. The magnitude and duration of the effects are determined in part by individual characteristics, lifestyle behaviours and environmental conditions. Sounds also evoke reflex responses, particularly when they are unfamiliar and have a sudden onset.

Workers exposed to high levels of industrial noise for 5–30 years may show increased blood pressure and an increased risk for hypertension. Cardiovascular effects have also been demonstrated after long-term exposure to air- and road-traffic with LAeq,24h values of 65–70 dB(A). Although the associations are weak, the effect is somewhat stronger for ischaemic heart disease than for hypertension. Still, these small risk increments are important because a large number of people are exposed.

Mental Illness. Environmental noise is not believed to cause mental illness directly, but it is assumed that it can accelerate and intensify the development of latent mental disorders. Exposure to high levels of occupational noise has been associated with development of neurosis, but the findings on environmental noise and mental-health effects are inconclusive. Nevertheless, studies on the use of drugs such as tranquillizers and sleeping pills, on psychiatric symptoms and on mental hospital admission rates, suggest that community noise may have adverse effects on mental health.

Performance. It has been shown, mainly in workers and children, that noise can adversely affect performance of cognitive tasks. Although noise-induced arousal may produce better performance in simple tasks in the short term, cognitive performance substantially deteriorates for more complex tasks. Reading, attention, problem solving and memorization are among the cognitive effects most strongly affected by noise. Noise can also act as a distracting stimulus and impulsive noise events may produce disruptive effects as a result of startle responses.

Noise exposure may also produce after-effects that negatively affect performance. In schools around airports, children chronically exposed to aircraft noise under-perform in proof reading, in persistence on challenging puzzles, in tests of reading acquisition and in motivational capabilities. It is crucial to recognize that some of the adaptation strategies to aircraft noise, and the effort necessary to maintain task performance, come at a price. Children from noisier areas have heightened sympathetic arousal, as indicated by increased stress hormone levels, and elevated resting blood pressure. Noise may also produce impairments and increase in errors at work, and some accidents may be an indicator of performance deficits.

Social and Behavioural Effects of Noise; Annoyance. Noise can produce a number of social and behavioural effects as well as annoyance. These effects are often complex, subtle and indirect and many effects are assumed to result from the interaction of a number of non-auditory variables. The effect of community noise on annoyance can be evaluated by questionnaires or by assessing the disturbance of specific activities. However, it should be recognized that equal levels of different traffic and industrial noises cause different magnitudes of annoyance. This is because annoyance in populations varies not only with the characteristics of the noise, including the noise source, but also depends to a large degree on many non-acoustical factors of a social, psychological, or economic nature. The correlation between noise exposure and general annoyance is much higher at group level than at individual level. Noise above 80 dB(A) may also reduce helping behaviour and increase aggressive behaviour. There is particular concern that high-level continuous noise exposures may increase the susceptibility of schoolchildren to feelings of helplessness.

Stronger reactions have been observed when noise is accompanied by vibrations and contains low-frequency components, or when the noise contains impulses, such as with shooting noise. Temporary, stronger reactions occur when the noise exposure increases over time, compared to a constant noise exposure. In most cases, LAeq,24h and L_{dn} are acceptable approximations of noise exposure related to annoyance. However, there is growing concern that all the component parameters should be individually assessed in noise exposure investigations, at least in the complex cases. There is no consensus on a model for total annoyance due to a combination of environmental noise sources.

Combined Effects on Health of Noise from Mixed Sources. Many acoustical environments consist of sounds from more than one source, i.e. there are mixed sources, and some combinations of effects are common. For example, noise may interfere with speech in the day and create sleep disturbance at night. These conditions certainly apply to residential areas heavily polluted with noise. Therefore, it is important that the total adverse health load of noise be considered over 24 hours, and that the precautionary principle for sustainable development be applied.

Vulnerable Subgroups. Vulnerable subgroups of the general population should be considered when recommending noise protection or noise regulations. The types of noise effects, specific environments and specific lifestyles are all factors that should be addressed for these subgroups. Examples of vulnerable subgroups are: people with particular diseases or medical problems (e.g. high blood pressure); people in hospitals or rehabilitating at home; people dealing with complex cognitive tasks; the blind; people with hearing impairment; fetuses, babies and young children; and the elderly in general. People with impaired hearing are the most adversely affected with respect to speech intelligibility. Even slight hearing impairments in the high-frequency sound range may cause problems with speech perception in a noisy environment. A majority of the population belongs to the subgroup that is vulnerable to speech interference.

4. Guideline values

In chapter 4, guideline values are given for specific health effects of noise and for specific environments.

Specific health effects.

Interference with Speech Perception. A majority of the population is susceptible to speech interference by noise and belongs to a vulnerable subgroup. Most sensitive are the elderly and persons with impaired hearing. Even slight hearing impairments in the high-frequency range may cause problems with speech perception in a noisy environment. From about 40 years of age, the ability of people to interpret difficult, spoken messages with low linguistic redundancy is impaired compared to people 20–30 years old. It has also been shown that high noise levels and long reverberation times have more adverse effects in children, who have not completed language acquisition, than in young adults.

When listening to complicated messages (at school, foreign languages, telephone conversation) the signal-to-noise ratio should be at least 15 dB with a voice level of 50 dB(A). This sound level corresponds on average to a casual voice level in both women and men at 1 m distance. Consequently, for clear speech perception the background noise level should not exceed 35 dB(A). In classrooms or conference rooms, where speech perception is of paramount importance, or for sensitive groups, background noise levels should be as low as possible. Reverberation times below 1 s are also necessary for good speech intelligibility in smaller rooms. For sensitive groups, such as the elderly, a reverberation time below 0.6 s is desirable for adequate speech intelligibility even in a quiet environment.

Hearing Impairment. Noise that gives rise to hearing impairment is by no means restricted to occupational situations. High noise levels can also occur in open air concerts, discotheques, motor sports, shooting ranges, in dwellings from loudspeakers, or from leisure activities. Other important sources of loud noise are headphones, as well as toys and fireworks which can emit impulse noise. The ISO standard 1999 gives a method for estimating noise-induced hearing impairment in populations exposed to all types of noise (continuous, intermittent, impulse) during working hours. However, the evidence strongly suggests that this method should also be used to calculate hearing impairment due to noise exposure from environmental and leisure time activities. The ISO standard 1999 implies that long-term exposure to $L_{Aeq,24h}$ noise levels of up to 70 dB(A) will not result in hearing impairment. To avoid hearing loss from impulse noise exposure, peak sound pressures should never exceed 140 dB for adults, and 120 dB for children.

Sleep Disturbance. Measurable effects of noise on sleep begin at L_{Aeq} levels of about 30 dB. However, the more intense the background noise, the more disturbing is its effect on sleep. Sensitive groups mainly include the elderly, shift workers, people with physical or mental disorders and other individuals who have difficulty sleeping.

Sleep disturbance from intermittent noise events increases with the maximum noise level. Even if the total equivalent noise level is fairly low, a small number of noise events with a high maximum sound pressure level will affect sleep. Therefore, to avoid sleep disturbance, guidelines for community noise should be expressed in terms of the equivalent sound level of the noise, as well as in terms of maximum noise levels and the number of noise events. It should be noted that low-frequency noise, for example, from ventilation systems, can disturb rest and sleep even at low sound pressure levels.

When noise is continuous, the equivalent sound pressure level should not exceed 30 dB(A) indoors, if negative effects on sleep are to be avoided. For noise with a large proportion of low-frequency sound a still lower guideline value is recommended. When the background noise is low, noise exceeding 45 dB LAmax should be limited, if possible, and for sensitive persons an even lower limit is preferred. Noise mitigation targeted to the first part of the night is believed to be an effective means for helping people fall asleep. It should be noted that the adverse effect of noise partly depends on the nature of the source. A special situation is for newborns in incubators, for which the noise can cause sleep disturbance and other health effects.

Reading Acquisition. Chronic exposure to noise during early childhood appears to impair reading acquisition and reduces motivational capabilities. Evidence indicates that the longer the exposure, the greater the damage. Of recent concern are the concomitant psychophysiological changes (blood pressure and stress hormone levels). There is insufficient information on these effects to set specific guideline values. It is clear, however, that daycare centres and schools should not be located near major noise sources, such as highways, airports, and industrial sites.

Annoyance. The capacity of a noise to induce annoyance depends upon its physical characteristics, including the sound pressure level, spectral characteristics and variations of these properties with time. During daytime, few people are highly annoyed at LAeq levels below 55 dB(A), and few are moderately annoyed at LAeq levels below 50 dB(A). Sound levels during the evening and night should be 5–10 dB lower than during the day. Noise with low-frequency components require lower guideline values. For intermittent noise, it is emphasized that it is necessary to take into account both the maximum sound pressure level and the number of noise events. Guidelines or noise abatement measures should also take into account residential outdoor activities.

Social Behaviour. The effects of environmental noise may be evaluated by assessing its interference with social behavior and other activities. For many community noises, interference with rest/recreation/watching television seem to be the most important effects. There is fairly consistent evidence that noise above 80 dB(A) causes reduced helping behavior, and that loud noise also increases aggressive behavior in individuals predisposed to aggressiveness. In schoolchildren, there is also concern that high levels of chronic noise contribute to feelings of helplessness. Guidelines on this issue, together with cardiovascular and mental effects, must await further research.

Specific environments.

A noise measure based only on energy summation and expressed as the conventional equivalent measure, LAeq, is not enough to characterize most noise environments. It is equally important to measure the maximum values of noise fluctuations, preferably combined with a measure of the number of noise events. If the noise includes a large proportion of low-frequency components, still lower values than the guideline values below will be needed. When prominent low-frequency components are present, noise measures based on A-weighting are inappropriate. The difference between dB(C) and dB(A) will give crude information about the presence of low-frequency components in noise, but if the difference is more than 10 dB, it is recommended that a frequency analysis of the noise be performed. It should be noted that a large proportion of low-frequency components in noise may increase considerably the adverse effects on health.

In Dwellings. The effects of noise in dwellings, typically, are sleep disturbance, annoyance and speech interference. For bedrooms the critical effect is sleep disturbance. Indoor guideline values for bedrooms are 30 dB LAeq for continuous noise and 45 dB LAmax for single sound events. Lower noise levels may be disturbing depending on the nature of the noise source. At night-time, outside sound levels about 1 metre from facades of living spaces should not exceed 45 dB LAeq, so that people may sleep with bedroom windows open. This value was obtained by assuming that the noise reduction from outside to inside with the window open is 15 dB. To enable casual conversation indoors during daytime, the sound level of interfering noise should not exceed 35 dB LAeq. The maximum sound pressure level should be measured with the sound pressure meter set at "Fast".

To protect the majority of people from being seriously annoyed during the daytime, the outdoor sound level from steady, continuous noise should not exceed 55 dB LAeq on balconies, terraces and in outdoor living areas. To protect the majority of people from being moderately annoyed during the daytime, the outdoor sound level should not exceed 50 dB LAeq. Where it is practical and feasible, the lower outdoor sound level should be considered the maximum desirable sound level for new development.

In Schools and Preschools. For schools, the critical effects of noise are speech interference, disturbance of information extraction (e.g. comprehension and reading acquisition), message communication and annoyance. To be able to hear and understand spoken messages in class rooms, the background sound level should not exceed 35 dB LAeq during teaching sessions. For hearing impaired children, a still lower sound level may be needed. The reverberation time in the classroom should be about 0.6 s, and preferably lower for hearing impaired children. For assembly halls and cafeterias in school buildings, the reverberation time should be less than 1 s. For outdoor playgrounds the sound level of the noise from external sources should not exceed 55 dB LAeq, the same value given for outdoor residential areas in daytime.

For preschools, the same critical effects and guideline values apply as for schools. In bedrooms in preschools during sleeping hours, the guideline values for bedrooms in dwellings should be used.

In Hospitals. For most spaces in hospitals, the critical effects are sleep disturbance, annoyance, and communication interference, including warning signals. The LAmax of sound events during the night should not exceed 40 dB(A) indoors. For ward rooms in hospitals, the guideline values indoors are 30dB LAeq, together with 40 dB LAmax during night. During the day and evening the guideline value indoors is 30 dB LAeq. The maximum level should be measured with the sound pressure instrument set at "Fast".

Since patients have less ability to cope with stress, the LAeq level should not exceed 35 dB in most rooms in which patients are being treated or observed. Attention should be given to the sound levels in intensive care units and operating theaters. Sound inside incubators may result in health problems for neonates, including sleep disturbance, and may also lead to hearing impairment. Guideline values for sound levels in incubators must await future research.

Ceremonies, Festivals and Entertainment Events. In many countries, there are regular ceremonies, festivals and entertainment events to celebrate life periods. Such events typically produce loud sounds, including music and impulsive sounds. There is widespread concern about the effect of loud music and impulsive sounds on young people who frequently attend concerts, discotheques, video arcades, cinemas, amusement parks and spectator events. At these events, the sound level typically exceeds 100 dB LAeq. Such noise exposure could lead to significant hearing impairment after frequent attendances.

Noise exposure for employees of these venues should be controlled by established occupational standards; and at the very least, the same standards should apply to the patrons of these premises. Patrons should not be exposed to sound levels greater than 100 dB LAeq during a four-hour period more than four times per year. To avoid acute hearing impairment the LAmax should always be below 110 dB.

Headphones. To avoid hearing impairment from music played back in headphones, in both adults and children, the equivalent sound level over 24 hours should not exceed 70 dB(A). This implies that for a daily one hour exposure the LAeq level should not exceed 85 dB(A). To avoid acute hearing impairment LAmax should always be below 110 dB(A). The exposures are expressed in free-field equivalent sound level.

Toys, Fireworks and Firearms. To avoid acute mechanical damage to the inner ear from impulsive sounds from toys, fireworks and firearms, adults should never be exposed to more than 140 dB(lin) peak sound pressure level. To account for the vulnerability in children when playing, the peak sound pressure produced by toys should not exceed 120 dB(lin), measured close to the ears (100 mm). To avoid acute hearing impairment LAmax should always be below 110 dB(A).

Parkland and Conservation Areas. Existing large quiet outdoor areas should be preserved and the signal-to-noise ratio kept low.

Table 1 presents the WHO guideline values arranged according to specific environments and critical health effects. The guideline values consider all identified adverse health effects for the specific environment. An adverse effect of noise refers to any temporary or long-term impairment of physical, psychological or social functioning that is associated with noise exposure. Specific noise limits have been set for each health effect, using the lowest noise level that produces an adverse health effect (i.e. the critical health effect). Although the guideline values refer to sound levels impacting the most exposed receiver at the listed environments, they are applicable to the general population. The time base for LAeq for "daytime" and "night-time" is 12–16 hours and 8 hours, respectively. No time base is given for evenings, but typically the guideline value should be 5–10 dB lower than in the daytime. Other time bases are recommended for schools, preschools and playgrounds, depending on activity.

It is not enough to characterize the noise environment in terms of noise measures or indices based only on energy summation (e.g., LAeq), because different critical health effects require different descriptions. It is equally important to display the maximum values of the noise fluctuations, preferably combined with a measure of the number of noise events. A separate characterization of night-time noise exposures is also necessary. For indoor environments, reverberation time is also an important factor for things such as speech intelligibility. If the noise includes a large proportion of low-frequency components, still lower guideline values should be applied. Supplementary to the guideline values given in Table 1, precautions should be taken for vulnerable groups and for noise of certain character (e.g. low-frequency components, low background noise).

Table 1: Guideline values for community noise in specific environments.

Specific environment	Critical health effect(s)	L_{Aeq} [dB(A)]	Time base [hours]	L_{Amax} fast [dB]
Outdoor living area	Serious annoyance, daytime and evening Moderate annoyance, daytime and evening	55 50	16 16	- -
Dwelling, indoors Inside bedrooms	Speech intelligibility & moderate annoyance, daytime & evening Sleep disturbance, night-time	35 30	16 8	 45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
School class rooms & pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	during class	-
Pre-school bedrooms, indoor	Sleep disturbance	30	sleeping-time	45
School, playground outdoor	Annoyance (external source)	55	during play	-
Hospital, ward rooms, indoors	Sleep disturbance, night-time Sleep disturbance, daytime and evenings	30 30	8 16	40 -
Hospitals, treatment rooms, indoors	Interference with rest and recovery	#1		
Industrial, commercial shopping and traffic areas, indoors and outdoors	Hearing impairment	70	24	110
Ceremonies, festivals and entertainment events	Hearing impairment (patrons:<5 times/year)	100	4	110
Public addresses, indoors and outdoors	Hearing impairment	85	1	110
Music and other sounds through headphones/ earphones	Hearing impairment (free-field value)	85 #4	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults) Hearing impairment (children)	- -	- -	140 #2 120 #2
Outdoors in parkland and conservations areas	Disruption of tranquillity	#3		

#1: As low as possible.
#2: Peak sound pressure (not LAF, max) measured 100 mm from the ear.

#3: Existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low.
#4: Under headphones, adapted to free-field values.

5. Noise Management

Chapter 5 is devoted to noise management with discussions on: strategies and priorities in managing indoor noise levels; noise policies and legislation; the impact of environmental noise; and on the enforcement of regulatory standards.

The fundamental goals of noise management are to develop criteria for deriving safe noise exposure levels and to promote noise assessment and control as part of environmental health programmes. These basic goals should guide both international and national policies for noise management. The United Nation's Agenda 21 supports a number of environmental management principles on which government policies, including noise management policies, can be based: the principle of precaution; the "polluter pays" principle; and noise prevention. In all cases, noise should be reduced to the lowest level achievable in the particular situation. When there is a reasonable possibility that the public health will be endangered, even though scientific proof may be lacking, action should be taken to protect the public health, without awaiting the full scientific proof. The full costs associated with noise pollution (including monitoring, management, lowering levels and supervision) should be met by those responsible for the source of noise. Action should be taken where possible to reduce noise at the source.

A legal framework is needed to provide a context for noise management. National noise standards can usually be based on a consideration of international guidelines, such as these *Guidelines for Community Noise*, as well as national criteria documents, which consider dose-response relationships for the effects of noise on human health. National standards take into account the technological, social, economic and political factors within the country. A staged program of noise abatement should also be implemented to achieve the optimum health protection levels over the long term.

Other components of a noise management plan include: noise level monitoring; noise exposure mapping; exposure modeling; noise control approaches (such as mitigation and precautionary measures); and evaluation of control options. Many of the problems associated with high noise levels can be prevented at low cost, if governments develop and implement an integrated strategy for the indoor environment, in concert with all social and economic partners. Governments should establish a "National Plan for a Sustainable Noise Indoor Environment" that applies both to new construction as well as to existing buildings.

The actual priorities in rational noise management will differ for each country. Priority setting in noise management refers to prioritizing the health risks to be avoided and concentrating on the most important sources of noise. Different countries have adopted a range of approaches to noise control, using different policies and regulations. A number of these are outlined in chapter 5 and Appendix 2, as examples. It is evident that noise emission standards have proven insufficient and that the trends in noise pollution are unsustainable.

The concept of environmental an environmental noise impact analysis is central to the philosophy of managing environmental noise. Such an analysis should be required before implementing any project that would significantly increase the level of environmental noise in a community (typically, greater than a 5 dB increase). The analysis should include: a baseline description of the existing noise environment; the expected level of noise from the new source; an assessment of the adverse health effects; an estimation of the population at risk; the calculation of exposure-response relationships; an assessment of risks and their acceptability; and a cost-benefit analysis.

Noise management should:

1. Start monitoring human exposures to noise.
2. Have health control require mitigation of noise immissions, and not just of noise source emissions. The following should be taken into consideration:
    - specific environments such as schools, playgrounds, homes, hospitals.
    - environments with multiple noise sources, or which may amplify the effects of noise.
    - sensitive time periods such as evenings, nights and holidays.
    - groups at high risk, such as children and the hearing impaired.
3. Consider the noise consequences when planning transport systems and land use.
4. Introduce surveillance systems for noise-related adverse health effects.
5. Assess the effectiveness of noise policies in reducing adverse health effects and exposure, and in improving supportive "soundscapes".
6. Adopt these *Guidelines for Community Noise* as intermediary targets for improving human health.
7. Adopt precautionary actions for a sustainable development of the acoustical environments.

Conclusions and recommendations

In chapter 6 are discussed: the implementation of the guidelines; further WHO work on noise; and research needs are recommended.

Implementation. For implementation of the guidelines it is recommended that:

- Governments should protection the population from community noise and consider it an integral part of their policy of environmental protection.
- Governments should consider implementing action plans with short-term, medium-term and long-term objectives for reducing noise levels.
- Governments should adopt the *Health Guidelines for Community Noise* values as targets to be achieved in the long-term.
- Governments should include noise as an important public health issue in environmental impact assessments.
- Legislation should be put in place to allow for the reduction of sound levels.
- Existing legislation should be enforced.
- Municipalities should develop low noise implementation plans.

- Cost-effectiveness and cost-benefit analyses should be considered potential instruments for meaningful management decisions.
- Governments should support more policy-relevant research.

Future Work. The Expert Task Force worked out several suggestions for future work for the WHO in the field of community noise. WHO should:

- Provide leadership and technical direction in defining future noise research priorities.
- Organize workshops on how to apply the guidelines.
- Provide leadership and coordinate international efforts to develop techniques for designing supportive sound environments (e.g. "soundscapes").
- Provide leadership for programs to assess the effectiveness of health-related noise policies and regulations.
- Provide leadership and technical direction for the development of sound methodologies for environmental and health impact plans.
- Encourage further investigation into using noise exposure as an indicator of environmental deterioration (e.g. black spots in cities).
- Provide leadership and technical support, and advise developing countries to facilitate development of noise policies and noise management.

Research and Development. A major step forward in raising the awareness of both the public and of decision makers is the recommendation to concentrate more research and development on variables which have monetary consequences. This means that research should consider not only dose-response relationships between sound levels, but also politically relevant variables, such as noise-induced social handicap; reduced productivity; decreased performance in learning; workplace and school absenteeism; increased drug use; and accidents.

In Appendices 1–6 are given: bibliographic references; examples of regional noise situations (African Region, American Region, Eastern Mediterranean Region, South East Asian Region, Western Pacific Region); a glossary; a list of acronyms; and a list of participants.

1. Introduction

Community noise (also called environmental noise, residential noise or domestic noise) is defined as noise emitted from all sources, except noise at the industrial workplace. Main sources of community noise include road, rail and air traffic, industries, construction and public work, and the neighbourhood. Typical neighbourhood noise comes from premises and installations related to the catering trade (restaurant, cafeterias, discotheques, etc.); from live or recorded music; from sporting events including motor sports; from playgrounds and car parks; and from domestic animals such as barking dogs. The main indoor sources are ventilation systems, office machines, home appliances and neighbours. Although many countries have regulations on community noise from road, rail and air traffic, and from construction and industrial plants, few have regulations on neighbourhood noise. This is probably due to the lack of methods to define and measure it, and to the difficulty of controlling it. In developed countries, too, monitoring of compliance with, and enforcement of, noise regulations are weak for lower levels of urban noise that correspond to occupationally controlled levels (>85 dB LAeq,8h; Frank 1998). Recommended guideline values based on the health effects of noise, other than occupationally-induced effects, are often not taken into account.

The extent of the community noise problem is large. In the European Union about 40% of the population is exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dBA daytime; and 20% is exposed to levels exceeding 65 dBA (Lambert & Vallet 19 1994). When all transportation noise is considered, about half of all European Union citizens live in zones that do not ensure acoustical comfort to residents. At night, it is estimated that more than 30% is exposed to equivalent sound pressure levels exceeding 55 dBA, which are disturbing to sleep. The noise pollution problem is also severe in the cities of developing countries and is caused mainly by traffic. Data collected alongside densely traveled roads were found to have equivalent sound pressure levels for 24 hours of 75–80 dBA (e.g. National Environment Board Thailand 19 1990; Mage & Walsh 19 1998).

(a) In contrast to many other environmental problems, noise pollution continues to grow, accompanied by an increasing number of complaints from affected individuals. Most people are typically exposed to several noise sources, with road traffic noise being a dominant source (OECD-ECMT 19 1995). Population growth, urbanization and to a large extent technological development are the main driving forces, and future enlargements of highway systems, international airports and railway systems will only increase the noise problem. Viewed globally, the growth in urban environmental noise pollution is unsustainable, because it involves not simply the direct and cumulative adverse effects on health. It also adversely affects future generations by degrading residential, social and learning environments, with corresponding economical losses (Berglund 1998). Thus, noise is not simply a local problem, but a global issue that affects everyone (Lang 1999; Sandberg 1999) and calls for precautionary action in any environmental planning situation.

The objective of the World Health Organization (WHO) is the attainment by all peoples of the highest possible level of health. As the first principle of the WHO Constitution the definition of 'health' is given as: "A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". This broad definition of health embraces the concept of well-being and, thereby, renders noise impacts such as population annoyance, interference with communication, and impaired task performance as 'health' issues. In 1992, a WHO Task Force also identified the following specific health effects for the general population that may result from community noise: interference with communication; annoyance responses; effects on sleep, and on the cardiovascular and psychophysiological systems; effects on performance, productivity, and social behavior; and noise-induced hearing impairment (WHO 1993; Berglund & Lindvall 1995; *cf.* WHO 1980). Hearing damage is expected to result from both occupational and environmental noise, especially in developing countries, where compliance with noise regulation is known to be weak (Smith 1998).

Noise is likely to continue as a major issue well into the next century, both in developed and in developing countries. Therefore, strategic action is urgently required, including continued noise control at the source and in local areas. Most importantly, joint efforts among countries are necessary at a system level, in regard to the access and use of land, airspace and seawaters, and in regard to the various modes of transportation. Certainly, mankind would benefit from societal reorganization towards healthy transport. To understand noise we must understand the different types of noise and how we measure it, where noise comes from and the effects of noise on human beings. Furthermore, noise mitigation, including noise management, has to be actively introduced and in each case the policy implications have to be evaluated for efficiency.

This document is organized as follows. In Chapter 2 noise sources and measurement are discussed, including the basic aspects of source characteristics, sound propagation and transmission. In Chapter 3 the adverse health effects of noise are characterized. These include noise-induced hearing impairment, interference with speech communication, sleep disturbance, cardiovascular and physiological effects, mental health effects, performance effects, and annoyance reactions. This chapter is rounded out by a consideration of combined noise sources and their effects, and a discussion of vulnerable groups. In Chapter 4 the Guideline values are presented. Chapter 5 is devoted to noise management. Included are discussions of: strategies and priorities in the management of indoor noise levels; noise policies and legislation; environmental noise impact; and enforcement of regulatory standards. In Chapter 6 implementation of the WHO Guidelines is discussed, as well as future WHO work on noise and its research needs. In Appendices 1–6 are given: bibliographic references; examples of regional noise situations (African Region, American Region, Eastern Mediterranean Region, South East Asian Region, Western Pacific Region); a glossary; a list of acronyms; and a list of participants.

2. Noise sources and their measurement

2.1.Basic Aspects of Acoustical Measurements

Most environmental noises can be approximately described by one of several simple measures. They are all derived from overall sound pressure levels, the variation of these levels with time and the frequency of the sounds. Ford (1987) gives a more extensive review of various environmental noise measures. Technical definitions are found in the glossary in Appendix 3.

2.1.1. Sound pressure level

The sound pressure level is a measure of the air vibrations that make up sound. All measured sound pressures are referenced to a standard pressure that corresponds roughly to the threshold of hearing at 1 000 Hz. Thus, the sound pressure level indicates how much greater the measured sound is than this threshold of hearing. Because the human ear can detect a wide range of sound pressure levels (10–102 Pascal (Pa)), they are measured on a logarithmic scale with units of decibels (dB). A more technical definition of sound pressure level is found in the glossary.

The sound pressure levels of most noises vary with time. Consequently, in calculating some measures of noise, the instantaneous pressure fluctuations must be integrated over some time interval. To approximate the integration time of our hearing system, sound pressure meters have a standard *Fast* response time, which corresponds to a time constant of 0.125 s. Thus, all measurements of sound pressure levels and their variation over time should be made using the *Fast* response time, to provide sound pressure measurements more representative of human hearing. Sound pressure meters may also include a *Slow* response time with a time constant of 1 s, but its sole purpose is that one can more easily estimate the average value of rapidly fluctuating levels. Many modern meters can integrate sound pressures over specified periods and provide average values. It is not recommended that the *Slow* response time be used when integrating sound pressure meters are available.

Because sound pressure levels are measured on a logarithmic scale they cannot be added or averaged arithmetically. For example, adding two sounds of equal pressure levels results in a total pressure level that is only 3 dB greater than each individual sound pressure level. Consequently, when two sounds are combined the resulting sound pressure level will be significantly greater than the individual sound levels only if the two sounds have similar pressure levels. Details for combining sound pressure levels are given in Appendix 2.

2.1.2. Frequency and frequency weighting

The unit of frequency is the Hertz (Hz), and it refers to the number of vibrations per second of the air in which the sound is propagating. For tonal sounds, frequency is associated with the perception of pitch. For example, orchestras often tune to the frequency of 440 Hz. Most environmental sounds, however, are made up of a complex mix of many different frequencies. They may or may not have discrete frequency components superimposed on noise with a broad frequency spectrum (i.e. sound with a broad range of frequencies). The audible frequency range is normally considered to range from 20–20 000 Hz. Below 20 Hz we hear individual sound pulses rather than recognizable tones. Hearing sensitivity to higher frequencies decreases with age and exposure to noise. Thus, 20 000 Hz represents an upper limit of audibility for younger listeners with unimpaired hearing.

Our hearing systems are not equally sensitive to all sound frequencies (ISO 1987a). Thus, not all frequencies are perceived as being equally loud at the same sound pressure level, and when calculating overall environmental noise ratings it is necessary to consider sounds at some frequencies as more important than those at other frequencies. Detailed frequency analyses are commonly performed with standard sets of octave or 1/3 octave bandwidth filters. Alternatively, Fast Fourier Transform techniques or other types of filters can be used to determine the relative strengths of the various frequency components making up a particular environmental noise.

Frequency weighting networks provide a simpler approach for weighting the importance of different frequency components in one single number rating. The A-weighting is most commonly used and is intended to approximate the frequency response of our hearing system. It weights lower frequencies as less important than mid- and higher-frequency sounds. C-weighting is also quite common and is a nearly flat frequency response with the extreme high and low frequencies attenuated. When no frequency analysis is possible, the difference between A-weighted and C-weighted levels gives an indication of the amount of low frequency content in the measured noise. When the sound has an obvious tonal content, a correction to account for the additional annoyance may be used (ISO 1987b).

2.1.3. Equivalent continuous sound pressure level

According to the equal energy principle, the effect of a combination of noise events is related to the combined sound energy of those events. Thus, measures such as the equivalent continuous sound pressure level (LAeq,T) sum up the total energy over some time period (T) and give a level equivalent to the average sound energy over that period. Such average levels are usually based on integration of A-weighted levels. Thus LAeq,T is the average energy equivalent level of the A-weighted sound over a period T.

2.1.4. Individual noise events

It is often desired to measure the maximum level (LAmax) of individual noise events. For cases such as the noise from a single passing vehicle, LAmax values should be measured using the *Fast* response time because it will give a good correlation with the integration of loudness by our hearing system. However, for very short-duration impulsive sounds it is often desirable to measure the instantaneous peak amplitude to assess potential hearing-damage risk. If actual instantaneous pressure cannot be determined, then a time-integrated 'peak' level with a time constant of no more than 0.05 ms should be used (ISO 1987b). Such peak readings are often made using the C- (or linear) frequency weightings.

Alternatively, discrete sound events can be evaluated in terms of their A-weighted sound exposure level (SEL, for defintion see appendix 5). The total amount of sound energy in a particular event is assessed by the SEL. One can add up the SEL values of individual events to calculate a LAeq,T over some time period, T, of interest. In some cases the SEL may provide more consistent evaluations of individual noise events because they are derived from the complete history of the event and not just one maximum value. However, A-weighted SEL measurements have been shown to be inadequate for assessing the (perceived) loudness of complex impulsive sounds, such as those from large and small weapons (Berglund et al. 1986). In contrast, C-weighted SEL values have been found useful for rating impulsive sounds such as gun shots (Vos 1996; Buchta 1996; ISO 1987b).

2.1.5. Choice of noise measure

LAeq,T should be used to measure continuing sounds such as road traffic noise, many types of industrial noises and noise from ventilation systems in buildings. When there are distinct events to the noise such as with aircraft or railway noise, measures of the individual events should be obtained (using, for example, LAmax or SEL), in addition to LAeq,T measurements.

In the past, time-varying environmental sound levels have also been described in terms of percentile levels. These are derived from a statistical distribution of measured sound levels over some period. For example, L10 is the A-weighted level exceeded 10% of the time. L10 values have been widely used to measure road-traffic noise, but they are usually found to be highly correlated measures of the individual events, as are LAmax and SEL. L90 or L95 can be used as a measure of the general background sound pressure level that excludes the potentially confounding influence of particular local noise events.

2.1.6. Sound and noise

Physically, there is no distinction between sound and noise: sound is a sensory perception evoked by physiological processes in the auditory brain. The complex pattern of sound waves is perceptually classified as "Gestalts" and are labeled as noise, music, speech, etc. Consequently, it is not possible to define noise exclusively on the basis of the physical parameters of sound. Instead, it is common practice to define noise simply as unwanted sound. However, in some situations noise may adversely affect health in the form of acoustical energy.

2.2. Sources of Noise

This section describes various sources of noise that can affect a community. Namely, noise from industry, transportation, and from residential and leisure areas. It should be noted that equal values of LAeq,T for different sources do not always imply the same expected effect.

2.2.1. Industrial noise

Mechanized industry creates serious noise problems. It is responsible for intense noise indoors as well as outdoors. This noise is due to machinery of all kinds and often increases with the power of the machines. Sound generation mechanisms of machinery are reasonably well understood. The noise may contain predominantly low or high frequencies, tonal components, be impulsive or have unpleasant and disruptive temporal sound patterns. Rotating and reciprocating machines generate sound that includes tonal components; and air-moving equipment tends also to generate noise with a wide frequency range. The high sound pressure levels are caused by components or gas flows that move at high speed (for example, fans, steam pressure relief valves), or by operations involving mechanical impacts (for example, stamping, riveting, road breaking). Machinery should preferably be silenced at the source.

Noise from fixed installations, such as factories or construction sites, heat pumps and ventilation systems on roofs, typically affect nearby communities. Reductions may be achieved by encouraging quieter equipment or by zoning of land into industrial and residential areas. Requirements for passive (sound insulating enclosures) and active noise control, or restriction of operation time, may also be effective.

2.2.2. Transportation noise

Transportation noise is the main source of environmental noise pollution, including road traffic, rail traffic and air traffic. As a general rule, larger and heavier vehicles emit more noise than smaller and lighter vehicles. Exceptions would include: helicopters and 2- and 3-wheeled road vehicles.

The noise of road vehicles is mainly generated from the engine and from frictional contact between the vehicle and the ground and air. In general, road-contact noise exceeds engine noise at speeds higher than 60 km/h. The physical principle responsible for generating noise from tire-road contact is less well understood. The sound pressure level from traffic can be predicted from the traffic flow rate, the speed of the vehicles, the proportion of heavy vehicles, and the nature of the road surface. Special problems can arise in areas where the traffic movements involve a change in engine speed and power, such as at traffic lights, hills, and intersecting roads; or where topography, meteorological conditions and low background levels are unfavourable (for example, mountain areas).

Railway noise depends primarily on the speed of the train, but variations are present depending upon the type of engine, wagons, and rails and their foundations, as well as the roughness of wheels and rails. Small radius curves in the track, such as may occur for urban trains, can lead to very high levels of high-frequency sound referred to as wheel squeal. Noise can be generated in stations because of running engines, whistles and loudspeakers, and in marshaling yards because of shunting operations. The introduction of high-speed trains has created special noise problems with sudden, but not impulsive, rises in noise. At speeds greater than 250 km/h, the proportion of high-frequency sound energy increases and the sound can be perceived as similar to that of overflying jet aircraft. Special problems can arise in areas close to tunnels, in valleys or in areas where the ground conditions help generate vibrations. The long-distance propagation of noise from high-speed trains will constitute a problem in the future if otherwise environment-friendly railway systems are expanded.

Aircraft operations generate substantial noise in the vicinity of both commercial and military airports. Aircraft takeoffs are known to produce intense noise, including vibration and rattle. The landings produce substantial noise in long low-altitude flight corridors. The noise is produced by the landing gear and automatic power regulation, and also when reverse thrust is applied, all for safety reasons. In general, larger and heavier aircraft produce more noise than lighter aircraft. The main mechanism of noise generation in the early turbojet-powered aircraft was the turbulence created by the jet exhaust mixing with the surrounding air. This noise source has been significantly reduced in modern high by-pass ratio turbo-fan engines that surround the high-velocity jet exhaust with lower velocity airflow generated by the fan. The fan itself can be a significant noise source, particularly during landing and taxiing operations. Multi-bladed turbo-prop engines can produce relatively high levels of tonal noise. The sound pressure level from aircraft is, typically, predicted from the number of aircraft, the types of airplanes, their flight paths, the proportions of takeoffs and landings and the atmospheric conditions. Severe noise problems may arise at airports hosting many helicopters or smaller aircraft used for private business, flying training and leisure purposes. Special noise problems may also arise inside airplanes because of vibration. The noise emission from future superjets is unknown.

A sonic boom consists of a shock wave in the air, generated by an aircraft when it flies at a speed slightly greater than the local speed of sound. An aircraft in supersonic flight trails a sonic boom that can be heard up to 50 km on either side of its ground track, depending upon the flight altitude and the size of the aircraft (Warren 1972). A sonic boom can be heard as a loud double-boom sound. At high intensity it can damage property.

Noise from military airfields may present particular problems compared to civil airports (von Gierke & Harris 1987). For example, when used for night-time flying, for training interrupted landings and takeoffs (so-called touch-and-go), or for low-altitude flying. In certain instances, including wars, specific military activities introduce other intense noise pollution from heavy vehicles (tanks), helicopters, and small and large fire-arms.

2.2.3. Construction noise and building services noise

Building construction and excavation work can cause considerable noise emissions. A variety of sounds come from cranes, cement mixers, welding, hammering, boring and other work processes. Construction equipment is often poorly silenced and maintained, and building operations are sometimes carried out without considering the environmental noise consequences. Street services such as garbage disposal and street cleaning can also cause considerable disturbance if carried out at sensitive times of day. Ventilation and air conditioning plants and ducts, heat pumps, plumbing systems, and lifts (elevators), for example, can compromise the internal acoustical environment and upset nearby residents.

2.2.4. Domestic noise and noise from leisure activities

In residential areas, noise may stem from mechanical devices (e.g. heat pumps, ventilation systems and traffic), as well as voices, music and other kinds of sounds generated by neighbours (e.g. lawn movers, vacuum cleaners and other household equipment, music reproduction and noisy parties). Aberrant social behavior is a well-recognized noise problem in multifamily dwellings, as well as at sites for entertainment (e.g. sports and music events). Due to predominantly low-frequency components, noise from ventilation systems in residential buildings may also cause considerable concern even at low and moderate sound pressure levels.

The use of powered machines in leisure activities is increasing. For example, motor racing, off-road vehicles, motorboats, water skiing, snowmobiles etc., and these contribute significantly to loud noises in previously quiet areas. Shooting activities not only have considerable potential for disturbing nearby residents, but can also damage the hearing of those taking part. Even tennis playing, church bell ringing and other religious activities can lead to noise complaints.

Some types of indoor concerts and discotheques can produce extremely high sound pressure levels. Associated noise problems outdoors result from customers arriving and leaving. Outdoor concerts, fireworks and various types of festivals can also produce intense noise. The general problem of access to festivals and leisure activity sites often adds to road traffic noise problems. Severe hearing impairment may also arise from intense sound produced as music in headphones or from children's toys.

2.3. The Complexity of Noise and Its Practical Implications

2.3.1. The problem

One must consider many different characteristics to describe environmental noises completely. We can consider the sound pressure level of the noise and how this level varies over a variety of periods, ranging from minutes or seconds to seasonal variations over several months. Where sound pressure levels vary quite substantially and rapidly, such as in the case of low-level jet aircraft, one might also want to consider the rate of change of sound pressure levels (Berry 1995; Kerry et al. 1997). At the same time, the frequency content of each noise will also determine its effect on people, as will the number of events when there are relatively small numbers of discrete noisy events. Combinations of these characteristics determine how each type of environmental noise affects people. These effects may be annoyance, sleep disturbance, speech interference, increased stress, hearing impairment or other health-related effects.

Thus, in total there is a very complex multidimensional relationship between the various characteristics of the environmental noise and the effects it has on people. Unfortunately, we do not completely understand all of the complex links between noise characteristics and the resulting effects on people. Thus, current practice is to reduce the assessment of environmental noise to a small number of quite simple quantities that are known to be reasonably well related to the effects of noise on people (LAeq,T for continuing sounds and LAmax or SEL where there are a small number of distinct noise events). These simple measures have the distinct advantage that they are relatively easy and inexpensive to obtain and hence are more likely to be widely adopted. On the other hand, they may ignore some details of the noise characteristics that relate to particular types of effects on people.

2.3.2. Time variation

There is evidence that the pattern of noise variation with time relates to annoyance (Berglund et al. 1976). It has been suggested that the equal-energy principle is a simple concept for obtaining a measure representative of the annoyance of a number of noise events. For example, the LAeq,T of the noise from a busy road may be a good indicator of the annoyance this noise may cause for nearby residents. However, such a measure may not be very useful for predicting the disturbance to sleep of a small number of very noisy aircraft fly-overs. The disturbance caused by small numbers of such discrete events is usually better related to maximum sound pressure levels and the number of events.

While using LAeq,T measures is the generally accepted approach, it is still important to appreciate the limitations and errors that may occur. For example, some years ago measures that assessed the variation of sound pressure levels with time were popular. Subsequently, these have been shown not to improve predictions of annoyance with road traffic noise (Bradley 1978). However, it is possible that time variations may contribute to explaining the very different amounts of annoyance caused by equal LAeq,T levels of road-traffic noise, train noise and aircraft noise (*cf.* Miedema & Vos 1998).

More regular variations of sound pressure levels with time have been found to increase the annoying aspects of the noise. For example, noises that vary periodically to create a throbbing or pulsing sensation can be more disturbing than continuous noise (Bradley 1994b). Research suggests that variations at about 4 per second are most disturbing (Zwicker 1989). Noises with very rapid onsets could also be more disturbing than indicated by their LAeq,T (Berry 1995; Kerry et al. 1997).

LAeq,T values can be calculated for various time periods and it is very important to specify this period. It is quite common to calculate LAeq,T values separately for day- and night-time periods. In combining day and night LAeq,T values it is usually assumed that people will be more sensitive to noise during the night-time period. A weighting is thus normally added to night-time LAeq,T values when calculating a combined measure for a 24 hour period. For example, day-night sound pressure measures commonly include a 10 dB night-time weighting. Other night-time weightings have been proposed, but it has been suggested that it is not possible to determine precisely an optimum value for night-time weightings from annoyance survey responses, because of the large variability in responses within groups of people (Fields 1986; see also Berglund & Lindvall 1995). Night-time weightings are intended to indicate the expected increased sensitivity to annoyance at night and do not protect people from sleep disturbance.

2.3.3. Frequency content and loudness

Noise can also be characterized by its frequency content. This can be assessed by various types of frequency analysis to determine the relative contributions of the frequency components to the total noise. The combined effects of the different frequencies on people, perceived as noise, can be approximated by simple frequency weightings. The A-weighting is now widely used to obtain an approximate, single-number rating of the combined effects of the various frequencies. The A-weighting response is a simplification of an equal-loudness contour. There is a family of these equal-loudness contours (ISO 1987a) that describe the frequency response of the hearing system for a wide range of frequencies and sound pressure levels. These equal-loudness contours can be used to determine the perceived loudness of a single frequency sound. More complicated procedures have been derived to estimate the perceived loudness of complex sounds (ISO 1975). These methods involve determining the level of the sound in critical bands and the mutual masking of these bands.

Many studies have compared the accuracy of predictions based on A-weighted levels with those based on other frequency weightings, as well as more complex measures such as loudness levels and perceived noise levels (see also Berglund & Lindvall 1995). The comparisons depend on the particular effect that is being predicted, but generally the correlation between the more complex measures and subjective scales are a little stronger. A-weighted measures have been particularly criticized as not being accurate indicators of the disturbing effects of noises with strong low-frequency components (Kjellberg et al. 1984; Persson & Björkman 1988; Broner & Leventhall 1993; Goldstein 1994). However, these differences in prediction accuracy are usually smaller than the variability of responses among groups of people (Fields 1986; see also Berglund & Lindvall 1995). Thus, in practical situations the limitations of A-weighted measures may not be so important.

In addition to equal-loudness contours, equal-noisiness contours have also been developed for calculating perceived noise levels (PNL) (Kryter 1959; Kryter 1994; see also section 2.7.2). Critics have pointed out that in addition to equal-loudness and equal-noisiness contours, we could have many other families of equal-sensation contours corresponding to other attributes of the noises (Molino 1974). There seems to be no limit to the possible complexity and number of such measures.

2.3.4. Influence of ambient noise level

A number of studies have suggested that the annoyance effect of a particular noise would depend on how much that noise exceeded the level of ambient noise. This has been shown to be true for noises that are relatively constant in level (Bradley 1993), but has not been consistently found for time-varying noises such as aircraft noise (Gjestland et al. 1990; Fields 1998). Because at some time during an aircraft fly-over the noise almost always exceeds the ambient level, responses to this type of noise are less likely to be influenced by the level of the ambient noise.

2.3.5. Types of noise

A number of studies have concluded that equal levels of different noise types lead to different annoyance (Hall et al. 1981; Griffiths 1983; Miedema 1993; Bradley 1994a; Miedema & Vos 1998). For example, equal LAeq,T levels of aircraft noise and road traffic noise will not lead to the same mean annoyance in groups of people exposed to these noises. This may indicate that the LAeq,T measure is not a completely satisfactory description of these noises and perhaps does not completely reflect the characteristics of these noises that lead to annoyance. Alternatively, the differences may be attributed to various other factors that are not part of the noise characteristics (e.g. Flindell & Stallen 1999). For example, it has been said that aircraft noise is more disturbing, because of the associated fear of aircraft crashing on people's homes (cf. Berglund & Lindvall 1995).

2.3.6. Individual differences

Finally, there is the problem of individual response differences. Different people will respond quite differently to the same noise stimulus (Job 1988). These individual differences can be quite large and it is often most useful to consider the average response of groups of people exposed to the same sound pressure levels. In annoyance studies the percentage of highly annoyed individuals is usually considered, because it correlates better with measured sound pressure levels. Individual differences also exist for susceptibility to hearing impairment (e.g. Katz 1994).

2.3.7. Recommendations

In many cases we do not have specific, accurate measures of how annoying sound will be and must rely on the simpler quantities. As a result, current practice is to assume that the equal energy principle is approximately valid for most types of noise, and that a simple LAeq,T type measure will indicate reasonably well the expected effects of the noise. Where the noise consists of a small number of discrete events, the A-weighted maximum level (LAmax) will be a better indicator of the disturbance to sleep and other activities. However, in most cases the A-weighted sound exposure level (SEL) will provide a more consistent measure of such single-noise events, because it is based on an integration over the complete noise event.

2.4. Measurement Issues

2.4.1. Measurement objectives

The details of noise measurements must be planned to meet some relevant objective or purpose. Some typical objectives would include:

a. Investigating complaints.
b. Assessing the number of persons exposed.
c. Compliance with regulations.
d. Land use planning and environmental impact assessments.
e. Evaluation of remedial measures.
f. Calibration and validation of predictions.
g. Research surveys.
h. Trend monitoring.

The sampling procedure, measurement location, type of measurements and the choice of equipment should be in accord with the objective of the measurements.

2.4.2. Instrumentation

The most critical component of a sound pressure meter is the microphone, because it is difficult to produce microphones with the same precision as the other, electronic components of a pressure meter. In contrast, it is usually not difficult to produce the electronic components of a microphone with the desired sensitivity and frequency-response characteristics. Lower quality microphones will usually be less sensitive and so cannot measure very low sound pressure levels. They may also not be able to accurately measure very high sound pressure levels found closer to loud noise sources. Lower quality microphones will also have less well-defined frequency-response characteristics. Such lower quality microphones may be acceptable for survey type measurements of overall A-weighted levels, but would not be preferred for more precise measurements, including detailed frequency analysis of the sounds.

Sound pressure meters will usually include both A- and C-weighting frequency-response curves. The uses of these frequency weightings were discussed above. They may also include a linear weighting. Linear weightings are not defined in standards and may in practice be limited by the response of the particular microphone being used. Instead of, or in addition to, frequency-response weightings, more complex sound pressure meters can also include sets of standard bandpass filters, to permit frequency analysis of sounds. For acoustical measurements, octave and one-third octave bandwidth filters are widely used with centre frequencies defined in standards (ISO 1975b).

The instantaneous sound pressures are integrated with some time constant to provide sound pressure levels. As mentioned above most meters will include both *Fast*- and *Slow*-response times. *Fast*-response corresponds to a time constant of 0.125 s and is intended to approximate the time constant of the human hearing system. *Slow*-response corresponds to a time constant of 1 s and is an old concept intended to make it easier to obtain an approximate average value of fluctuating levels from simple meter readings.

Standards (IEC 1979) classify sound pressure meters as type 1 or type 2. Type 2 meters are adequate for broad band A-weighted level measurements, where extreme precision is not required and where very low sound pressure levels are not to be measured. Type 1 meters are usually much more expensive and should be used where more precise results are needed, or in cases where frequency analysis is required.

Many modern sound pressure meters can integrate sound pressure levels over some specified time period, or may include very sophisticated digital processing capabilities. Integrating meters make it possible to directly obtain accurate measures of LAeq,T values over a user-specified time interval, T. By including small computers in some sound pressure meters, quite complex calculations can be performed on the measured levels and many such results can be stored for later read out. For example, some meters can determine the statistical distribution of sound pressure levels over some period, in addition to the simple LAeq,T value. Recently, hand-held meters that perform loudness calculations in real time have become available. Continuing rapid developments in instrumentation capabilities are to be expected.

2.4.3. Measurement locations

Where local regulations do not specify otherwise, measurements of environmental noise are usually best made close to the point of reception of the noise. For example, if there is concern about residents exposed to road traffic noise it is better to measure close to the location of the residents, rather than close to the road. If environmental noises are measured close to the source, one must then estimate the effect of sound propagation to the point of reception. Sound propagation can be quite complicated and estimates of sound pressure levels at some distance from the source will inevitably introduce further errors into the measured sound pressure levels. These errors can be avoided by measuring at locations close to the point of reception.

Measurement locations should normally be selected so that there is a clear view of the sound source and so that the propagation of the sound to the microphone is not shielded or blocked by structures that would reduce the incident sound pressure levels. For example, measurements of aircraft noise should be made on the side of the building directly exposed to the noise. The position of the measuring microphone relative to building façades or other sound-reflective surfaces is also important and will significantly influence measured sound pressure levels (ISO 1978). If the measuring microphone is located more than several meters from reflecting surfaces, it will provide an unbiased indication of the incident sound pressure level. At the other extreme, when a measuring microphone is mounted on a sound-reflecting surface, such as a building façade, sound pressure levels will be increased by 6 dB, because the direct and reflected sound will coincide. Some standards recommend a position 2 m from the façade and an associated 3 dB correction (ISO 1978; ASTM 1992). The effect of façade reflections must be accounted for to represent the true level of the incident sound. Thus, while locating the measuring microphone close to the point of reception is desirable, it leads to some other issues that must be considered to accurately interpret measurement results. Where exposures are measured indoors, it is necessary to measure at several positions to characterize the average sound pressure level in a room. In other situations, it may be necessary to measure at the position of the exposed person.

2.4.4. Sampling

Many environmental noises vary over time, such as for different times of day or from season to season. For example, road traffic noise may be considerably louder during some hours of the day but much quieter at night. Aircraft noise may vary with the season due to different numbers of aircraft operations. Although permanent noise monitoring systems are becoming common around large airports, it is usually not possible to measure sound pressure levels continuously over a long enough period of time to completely define the environmental noise exposure. In practice, measurements usually only sample some part of the total exposure. Such sampling will introduce uncertainties in the estimates of the total noise exposure.

Traffic noise studies have identified various sampling schemes that can introduce errors of 2-3 dB in estimates of daytime LAeq,T values and even larger errors in night-time sound pressure levels (Vaskor et al. 1979). These errors relate to the statistical distributions of sound pressure levels over time (Bradley et al. 1979). Thus, the sampling errors associated with road traffic noise may be quite different from those associated with other noise, because of the quite different variations of sound pressure levels over time. It is also difficult to give general estimates of sampling errors due to seasonal variations. When making environmental noise measurements it is important that the measurement sample is representative of all of the variations in the noise in question, including variations of the source and variations in sound propagation, such as due to varying atmospheric conditions.

2.4.5. Calibration and quality assurance

Sound pressure meters can be calibrated using small calibrated sound sources. These devices are placed on the measurement microphone and produce a known sound pressure level with a specified accuracy. Such calibrations should be made at least daily, and more often if there is some possibility that handling of the sound pressure meter may have modified its sensitivity. It is also important to have a complete quality assurance plan. This should require annual calibration of all noise measuring equipment to traceable standards and should clearly specify correct measurement and operating procedures (ISO 1994).

2.5. Source Characteristics and Sound Propagation

To make a correct assessment of noise it is important to have some appreciation of the characteristics of environmental noise sources and of how sound propagates from them. One should consider the directionality of noise sources, the variability with time and the frequency content. If these are in some way unusual, the noise may be more disturbing than expected. The most common types of environmental noise sources are directional and include: road-traffic noise, aircraft noise, train noise, industrial noise and outdoor entertainment facilities (*cf.* section 2.2). All of these types of environmental noise are produced by multiple sources, which in many cases are moving. Thus, the characteristics of individual sources, as well as the characteristics of the combined sources, must be considered.

For example, we can consider the radiation of sound from individual vehicles, as well as from a line of vehicles on a particular road. Sound from an ideal point source (i.e. non-directional source) will spread out spherically and sound pressure levels would decrease 6 dB for each doubling of distance from the source. However, for a line of such sources, or for an integration over the complete pass-by of an individual moving source, the combined effect leads to sound that spreads cylindrically and to sound pressure levels that decrease at 3 dB per doubling of distance. Thus, there are distinct differences between the propagation of sound from an ideal point source and from moving sources. In practice one cannot adequately assess the noise from a fixed source with measurements at a single location; it is essential to measure in a number of directions from the source. If the single source is moving, it is necessary to measure over a complete pass-by, to account for sound variation with direction and time.

In most real situations this simple behaviour is considerably modified by reflections from the ground and from other nearby surfaces. One expects that when sound propagates over loose ground, such as grass, that some sound energy will be absorbed and sound pressure levels will actually decrease more rapidly with distance from the source. Although this is approximately true, the propagation of sound between sources and receivers close to the ground is much more complicated than this. The combination of direct and ground-reflected sound can combine in a complex manner which can lead to strong cancellations at some frequencies and not at others (Embleton & Piercy 1976). Even at quite short source-to-receiver distances, these complex interference effects can significantly modify the propagating sound. At larger distances (approximately 100 m or more), the propagation of sound will also be significantly affected by various atmospheric conditions. Temperature and wind gradients as well as atmospheric turbulence can have large effects on more distant sound pressure levels (Daigle et al. 1986). Temperature and wind gradients can cause propagating sound to curve either upwards or downwards, creating either areas of increased or decreased sound pressure levels at points quite distant from the source. Atmospheric turbulence can randomize sound so that the interference effects resulting from combinations of sound paths are reduced. Higher frequency sound is absorbed by air depending on the exact temperature and relative humidity of the air (Crocker &

Price 1975; Ford 1987). Because there are many complex effects, it is not usually possible to accurately predict sound pressure levels at large distances from a source.

Using barriers or screens to block the direct path from the source to the receiver can reduce the propagation of sound. The attenuating effects of the screen are limited by sound energy that diffracts or bends around the screen. Screens are more effective at higher frequencies and when placed either close to the sound source or the receiver; they are less effective when placed far from the receiver. Although higher screens are better, in practice it is difficult to achieve more than about a 10 dB reduction. There should be no gaps in the screen and it must have an adequate mass per unit area. A long building can be an effective screen, but gaps between buildings will reduce the sound attenuation.

In some cases, it may be desirable to estimate environmental sound pressure levels using mathematical models implemented as computer programmes (House 1987). Such computer programmes must first model the characteristics of the source and then estimate the propagation of the sound from the source to some receiver point. Although such prediction schemes have several advantages, there will be some uncertainty as to the accuracy of the predicted sound pressure levels. Such models are particularly useful for road traffic noise and aircraft noise, because it is possible to create data bases of information describing particular sources. For more varied types of noise, such as industrial noise, it would be necessary to first characterize the noise sources. The models then sum up the effects of multiple sources and calculate how the sound will propagate to receiver points. Techniques for estimating sound propagation are improving and the accuracy of these models is also expected to improve. These models can be particularly useful for estimating the combined effect of a large number of sources over an extended period of time. For example, aircraft noise prediction models are typically used to predict average yearly noise exposures, based on the combination of aircraft events over a complete year. Such models can be applied to predict sound pressure level contours around airports for these average yearly conditions. This is of course much less expensive than measuring at many locations over a complete one year-period. However, such models can be quite complex, and require skilled users and accurate data bases. Because environmental noise prediction models are still developing, it is advisable to confirm predictions with measurements.

2.6. Sound transmission Into and Within Buildings

Sources of environmental noise are usually located outdoors; for example, road traffic, aircraft or trains. However, people exposed to these noises are often indoors, inside their home or some other building. It is, therefore, important to understand how environmental noises are transmitted into buildings. Most of the same fundamentals discussed earlier apply to airborne sound propagation between homes in multifamily dwellings, via common walls and floors. However, within buildings we can also consider impact sound sources, such as footsteps, as well as airborne sounds.

The amount of incident sound that is transmitted through a building façade is measured in terms of the sound reduction index. The sound reduction index, or transmission loss, is defined as 10 times the logarithm of the ratio of incident-to-transmitted sound power, and it describes in decibels how much the incident sound is reduced on passing through a particular panel. This index of constructions usually increases with the frequency of the incident sound and with the mass of the construction (Kremer 1950). Thus, heavier or more massive constructions tend to have higher sound reductions. When it is not possible to achieve the desired transmission loss by increasing the mass of a panel, increased sound reduction can be achieved by a double panel construction. The two layers should be isolated with respect to vibrations and there should be sound absorbing material in the cavity. Such double panel constructions can provide much greater sound reduction than a single panel. Because sound reduction is also greater at higher frequencies most problems occur at lower frequencies, where most environmental noise sources produce relatively high sound pressure levels.

The sound reduction of buildings can be measured in standard laboratory tests, where the test panel is constructed in an opening between two reverberant test chambers (ISO 1995; ASTM 1997). In these tests sound fields are quite diffuse in both test chambers and the sound reduction index is calculated as the difference between the average sound pressure levels in the two rooms, plus a correction involving the area of the test panel and the total sound absorption in the receiving room. The sound reduction of a complete building façade can also be measured in the field using either natural environmental noises or test signals from loudspeakers (ISO 1978; ASTM 1992). In either case the noise, as transmitted through the façade, must be greater in level than other sounds in the receiving room. For this outdoor-to-indoor sound propagation case, the measured sound reduction index will also depend on the angle of incidence of the outdoor sound, as well as the position of the outdoor measuring microphone relative to the building façade. Corrections of up to 6 dB must be made to the sound pressure level measured outdoors, to account for the effect of reflections from the façade (see also section 2.4.3).

The sound reduction of most real building façades is determined by a combination of several different elements. For example, a wall might include windows, doors or some other type of element. If the sound reduction index values of each element are known, the values for the combined construction can be calculated from the area-weighted sums of the sound energy transmitted through each separate element. Although parts of the building façade, such as massive wall constructions, can be very effective barriers to sound, the sound reduction index of the complete façade is often greatly reduced by less effective elements such as windows, doors or ventilation openings. Completely open windows as such would have a sound reduction index of 0 dB. If window openings makes up 10% of the area of a wall, the sound reduction index of the combined wall and open window could not exceed 10 dB. Thus it is not enough to specify effective sound reducing façade constructions, without also solving the problem of adequate ventilation that does not compromise the sound transmission reduction by the building façade.

Sound reduction index values are measured at different frequencies and from these, single number ratings are determined. Most common are the ISO weighted sound reduction index (ISO 1996) and the equivalent ASTM sound transmission class (ASTM 1994a). However, in their original form these single number ratings are only appropriate for typical indoor noises that usually do not have strong low frequency components. Thus, they are usually not appropriate single number ratings of the ability of a building façade to block typical environmental noises. More recent additions to the ISO procedure have included source spectrum corrections intended to correct approximately for other types of sources (ISO 1996). Alternatively, the ASTM-Outdoor-Indoor Transmission Class rating calculates the A-weighted level reduction to a standard environmental noise source spectrum (ASTM 1994b). Within buildings the impact sound insulation index can be measured with a standard impact source and determined according to ISO and ASTM standards (ISO 1998; ASTM 1994c 1996)

2.7. More Specialized Noise Measures

2.7.1. Loudness and perceived noise levels

There are procedures to accurately rate the loudness of complex sounds (Zwicker 1960; Stevens 1972; ISO 1975a). These usually start from a 1/3 octave spectrum of the noise. The combination of the loudness contributions of each 1/3 octave band with estimates of mutual masking effects, leads to a single overall loudness rating in sones. A similar system for rating the noisiness of sounds has also been developed (Kryter 1994). Again a 1/3 octave spectrum of the noise is required and the 1/3 octave noise levels are compared with a set of equal-noisiness contours. The individual 1/3 octave band noisiness estimates are combined to give an overall perceived noise level (PNL) that is intended to accurately estimate subjective evaluations of the same sound. The PNL metric was initially developed to rate jet aircraft noise.

PNL values will vary with time, for example when an aircraft flies by a measuring point. The effective perceived noise level measure (EPNL) is derived from PNL values and is intended to provide a complete rating of an aircraft fly-over. EPNL values add both a duration correction and a tone correction to PNL values. The duration correction ensures that longer duration events are rated as more disturbing. Similarly, noise spectra that seem to have prominent tonal components are rated as more disturbing by the tone-correction procedure. There is some evidence that these tone corrections are not always successful in improving predictions of adverse responses to noise events (Scharf & Hellman 1980). EPNL values are used in the certification testing of new aircraft. These more precise measures ensure that the noise from new aircraft is rated as accurately as possible.

2.7.2. Aviation noise measures

There are many measures for evaluating the long-term average sound pressure levels from aircraft near airports (Ford 1987; House 1987). They include different frequency weightings, different summations of levels and numbers of events, as well as different time-of-day weightings. Most measures are based on either A-weighted or PNL-weighted sound pressure levels. Because of the many other large uncertainties in predicting community response to aircraft noise, there seems little justification for using the more complex PNL-weighted sound pressure levels and there is a trend to change to A-weighted measures.

Most aviation noise measures are based on an equal energy approach and hence they sum up the total energy of a number of aircraft fly-overs. However, some older measures were based on different combinations of the level of each event and the number of events. These types of measures are gradually being replaced by measures based on the equal energy hypothesis such as LAeq,T values. There is also a range of time-of-day weightings incorporated into current aircraft noise measures. Night-time weightings of 6–12 dB are currently in use. Some countries also include an intermediate evening weighting.

The day-night sound pressure level L_{dn} (von Gierke 1975; Ford 1987) is an LAeq,T based measure with a 10 dB night-time weighting. It is based on A-weighted sound pressure levels and the equal energy principle. The noise exposure forecast (NEF) (Bishop & Horonjeff 1967) is based on the EPNL values of individual aircraft events and includes a 12 dB night-time weighting. It sums multiple events on an equal energy basis. However, the Australian variation of the NEF measure has a 6 dB evening weighting and a 6 dB night-time weighting (Bullen & Hede 1983). The German airport noise equivalent level (LEQ(FLG)) is based on A-weighted levels, but does not follow the equal energy principle.

The weighted equivalent continuous perceived noise level (WECPNL) measure (Ford 1987) proposed by ICAO is based on the equal energy principle and maximum PNL values of aircraft fly-overs. However, in Japan an approximation to this measure is used and is based on maximum A-weighted levels. The noise and number index (NNI), formerly used in the United Kingdom, was derived from maximum PNL values but was not based on the equal energy principle. An approximation to the original version of the NNI has been used in Switzerland and is based on maximum A-weighted levels of aircraft fly-overs, but its use will soon be discontinued. Changes in these measures are slow because their use is often specified in national legislation. However, several countries have changed to measures that are based on the equal energy principle and A-weighted sound pressure levels.

2.7.3. Impulsive noise measures

Impulsive sounds, such as gun shots, hammer blows, explosions of fireworks or other blasts, are sounds that significantly exceed the background sound pressure level for a very short duration. Typically each impulse lasts less than one second. Measurements with the meter set to 'Fast' response (section 2.1.1) do not accurately represent impulsive sounds. Therefore the meter response time must be shorter to measure such impulse type sounds. C-weighted levels have been found useful for ratings of gun shots (ISO 1987). Currently no mathematical description exists which unequivocally defines impulsive sounds, nor is there a universally accepted procedure for rating the additional annoyance of impulsive sounds (HCN 1997). Future versions of ISO Standard 1996 (present standard in ISO 1987b) are planned to improve this situation.

2.7.4. Measures of speech intelligibility

The intelligibility of speech depends primarily on the speech-to-noise ratio. If the level of the speech sounds are 15 dB or more above the level of the ambient noise, the speech intelligibility at 1 m distance will be close to 100% (Houtgast 1981; Bradley 1986b). This can be most simply rated in terms of the speech-to-noise ratio of the A-weighted speech and noise levels. Alternatively, the speech intelligibility index (formerly the articulation index) can be used if octave or 1/3 octave band spectra of the speech and noise are available (ANSI 1997).

When indoors, speech intelligibility also depends on the acoustical properties of the space. The acoustical properties of spaces have for many years been rated in terms of reverberation times. The reverberation time is approximately the time it takes for a sound in a room to decrease to inaudibility after the source has been stopped. Optimum reverberation times for speech have been specified as a function of the size of the room. In large rooms, such as lecture halls and theaters, a reverberation time for speech of about 1 s is recommended. In smaller rooms such as classrooms, the recommended value for speech is about 0.6 s (Bradley 1986b,c). More modern measures of room acoustics have been found to be better correlates of speech intelligibility, and some combine an assessment of both the speech/noise ratio and room acoustics (Bradley 1986a,c). The most widely known is the speech transmission index (STI) (Houtgast & Steeneken 1983), or the abbreviated version of this measure referred to as RASTI (Houtgast & Steeneken 1985; IEC 1988). In smaller rooms, such as school classrooms, the conventional approach of requiring adequately low ambient noise levels, as well as some optimum reverberation time, is probably adequate to ensure good speech intelligibility (Bradley 1986b). In larger rooms and other more specialized situations, use of the more modern measures may be helpful.

2.7.5. Indoor noise ratings

The simplest procedure for rating levels of indoor noise is to measure them in terms of integrated A-weighted sound pressure levels, as measured by LAeq,T. As discussed earlier, this approach has been criticized as not being the most accurate rating of the negative effects of various types of noises, and is thought to be particularly inadequate when there are strong low-frequency components. Several more complex rating schemes are available based on octave band measurements of indoor noises. In Europe the noise rating system (Burns 1968), and in North America the noise criterion (Beranek 1971), both include sets of equal-disturbance type contours. Measured octave band sound pressure levels are compared with these contours and an overall noise rating is determined. More recently, two new schemes have been proposed: the balanced noise criterion procedure (Beranek 1989) and the room criterion system (Blazier 1998). These schemes are based on a wider range of octave bands extending from 16–8 000 Hz. They provide both a numerical and a letter rating of the noise. The numerical part indicates the level of the central frequencies important for speech communication and the letter indicates whether the quality of the sound is predominantly low-, medium- or high-frequency in nature. Extensive comparisons of these room noise rating procedures have yet to be performed. Because the newer measures include a wider range of frequencies, they can better assess a wider range of noise problems.

2.8. Summary

Where there are no clear reasons for using other measures, it is recommended that LAeq,T be used to evaluate more-or-less continuous environmental noises. LAeq,T should also be used to assess ongoing noises that may be composed of individual events with randomly varying sound pressure levels. Where the noise is principally composed of a small number of discrete events the additional use of LAmax or SEL is recommended. As pointed out in this chapter, there are definite limitations to these simple measures, but there are also many practical advantages, including economy and the benefits of a standardized approach.

The sound pressure level measurements should include all variations over time to provide results that best represent the noise in question. This would include variations in both the source and in propagation of the noise from the source to the receiver. Measurements should normally be made close to typical points of reception. The accuracy of the measurements and the details of the measurement procedure must be adapted to the type of noise and to other details of the noise exposure. Assessment of speech intelligibility, aviation noise or impulse noise may require the use of more specialized methods. Where the exposed people are indoors and noise measurements are made outdoors, the sound attenuating properties of the building façade must also be measured or estimated.

3. Adverse Health Effects Of Noise

3.1. Introduction

The perception of sounds in day-to-day life is of major importance for human well-being. Communication through speech, sounds from playing children, music, natural sounds in parklands, parks and gardens are all examples of sounds essential for satisfaction in every day life. Conversely, this document is related to the adverse effects of sound (noise). According to the International Programme on Chemical Safety (WHO 1994), an adverse effect of noise is defined as a change in the morphology and physiology of an organism that results in impairment of functional capacity, or an impairment of capacity to compensate for additional stress, or increases the susceptibility of an organism to the harmful effects of other environmental influences. This definition includes any temporary or long-term lowering of the physical, psychological or social functioning of humans or human organs. The health significance of noise pollution is given in this chapter under separate headings, according to the specific effects: noise-induced hearing impairment; interference with speech communication; disturbance of rest and sleep; psychophysiological, mental-health and performance effects; effects on residential behaviour and annoyance; as well as interference with intended activities. This chapter also considers vulnerable groups and the combined effects of sounds from different sources. Conclusions based on the details given in this chapter are given in Chapter 4 as they relate to guideline values.

3.2. Noise-Induced Hearing Impairment

Hearing impairment is typically defined as an increase in the threshold of hearing. It is assessed by threshold audiometry. Hearing handicap is the disadvantage imposed by hearing impairment sufficient to affect one's personal efficiency in the activities of daily living. It is usually expressed in terms of understanding conventional speech in common levels of background noise (ISO 1990). Worldwide, noise-induced hearing impairment is the most prevalent irreversible occupational hazard. In the developing countries, not only occupational noise, but also environmental noise is an increasing risk factor for hearing impairment. In 1995, at the World Health Assembly, it was estimated that there are 120 million persons with disabling hearing difficulties worldwide (Smith 1998). It has been shown that men and women are equally at risk of noise-induced hearing impairment (ISO 1990; Berglund & Lindvall 1995).

Apart from noise-induced hearing impairment, hearing damage in populations is also caused by certain diseases; some industrial chemicals; ototoxic drugs; blows to the head; accidents; and hereditary origins. Deterioration of hearing capability is also associated with the aging process *per se* (presbyacusis). Present knowledge of the physiological effects of noise on the auditory system is based primarily on laboratory studies on animals. After noise exposure, the first morphological changes are usually found in the inner and outer hair cells of the cochlea, where the stereocilia become fused and bent. After more prolonged exposure, the outer and inner hair cells related to transmission of high-frequency sounds are missing. See Berglund & Lindvall (1995) for further discussion.

The ISO Standard 1999 (ISO 1990) gives a method for calculating noise-induced hearing impairment in populations exposed to all types of noise (continuous, intermittent, impulse) during working hours. Noise exposure is characterized by LAeq over 8 hours (LAeq,8h). In the Standard, the relationships between LAeq,8h and noise-induced hearing impairment are given for frequencies of 500–6 000 Hz, and for exposure times of up to 40 years. These relations show that noise-induced hearing impairment occurs predominantly in the high-frequency range of 3 000–6 000 Hz, the effect being largest at 4 000 Hz. With increasing LAeq,8h and increasing exposure time, noise-induced hearing impairment also occurs at 2 000 Hz. But at LAeq,8h levels of 75 dBA and lower, even prolonged occupational noise exposure will not result in noise-induced hearing impairment (ISO 1990). This value is equal to that specified in 1980 by the World Health Organization (WHO 1980a).

The ISO Standard 1999 (ISO 1990) specifies hearing impairment in statistical terms (median values, and percentile fractions between 0.05 and 0.95). The extent of noise-induced hearing impairment in populations exposed to occupational noise depends on the value of LAeq,8h and the number of years of noise exposure. However, for high LAeq,8h values, individual susceptibility seems to have a considerable effect on the rate of progression of hearing impairment. For daily exposures of 8–16 h, noise-induced hearing impairment can be reasonably well estimated from LAeq,8h extrapolated to the longer exposure times (Axelsson et al. 1986). In this adaptation of LAeq,8h for daily exposures other than 8 hours, the equal energy principle is assumed to be applicable. For example, the hearing impairment due to a 16 h daily exposure is equivalent to that at LAeq,8h plus 3 dB ($LAeq,16h = LAeq,8h + 10*\log_{10}(16/8) = LAeq,8h + 3$ dB. For a 24 h exposure, $LAeq,24h = LAeq,8h + 10*\log_{10}(24/8) = LAeq,8h + 5$ dB).

Since the calculation method specified in the ISO Standard 1999 (ISO 1990) is the only universally adopted method for estimating occupational noise-induced hearing impairment, attempts have been made to assess whether the method is also applicable to hearing impairment due to environmental noise, including leisure-time noise. There is ample evidence that shooting noise, with LAeq,24h values of up to 80 dB, induces the same hearing impairment as an equivalent occupational noise exposure (Smoorenburg 1998). Moreover, noise-induced hearing impairment studies from motorbikes are also in agreement with results from ISO Standard 1999 (ISO 1990). Hearing impairment in young adults and children 12 years and older has been assessed by LAeq on a 24 h time basis, for a variety of environmental and leisure-time exposure patterns (e.g. Passchier-Vermeer 1993; HCN 1994). These include pop music in discotheques and concerts (Babisch & Ising 1989; ISO 1990); pop music through headphones (Ising et al. 1994; Struwe et al. 1996; Passchier-Vermeer et al. 1998); music played by brass bands and symphony orchestras (van Hees 1992). The results are in agreement with values predicted by the ISO Standard 1999 method on the basis of adjusted time.

In the publications cited above, exposure to noise with known characteristics, such as duration and level, was related to hearing impairment. In addition to these publications, there is also an extensive literature showing hearing impairment in populations exposed to specific types of non-occupational noise, although these exposures are not well characterized. These noises originate from shooting, motorcycling, snowmobile driving, playing in arcades, listening to music at concerts and through headphones, using noisy toys, and fireworks (e.g. Brookhouser et al. 1992; see also Berglund & Lindvall 1995). Although the characteristics of these exposures are to a certain extent unknown, the details in the publications suggest that LAeq,24h values of these exposures exceed 70 dB.

In contrast, epidemiological studies failed to show hearing damage in populations exposed to an LAeq,24h of less than 70 dB (Lindemann et al. 1987). The data imply that even a lifetime exposure to environmental and leisure-time noise with an LAeq,24h <70 dBA would not cause hearing impairment in the large majority of people (over 95%). Overall, the results of many studies strongly suggest that the method from ISO Standard 1999 can also be used to estimate hearing impairment due to environmental and leisure-time noise, in addition to estimating the effects of occupational noise exposure.

Although the evidence suggests that the calculation method from ISO Standard 1999 (ISO 1990) should also be accepted for environmental and leisure time noise exposures, large-scale epidemiological studies of the general population do not exist to support this proposition. Taking into account the limitations of the studies, care should be taken with respect to the following aspects:

a. Data from animal experiments indicate that children may be more vulnerable in acquiring noise-induced hearing impairment than adults.

b. At very high instantaneous sound pressure levels, mechanical damage to the ear may occur (Hanner & Axelsson 1988). Occupational limits are set at peak sound pressure levels of 140 dB (EU 1986a). For adults exposed to environmental and leisure-time noise, this same limit is assumed to be valid. In the case of children, however, taking into account their habits while playing with noisy toys, peak sound pressure levels should never exceed 120 dB.

c. For shooting noise with LAeq,24h over 80 dB, studies on temporary threshold shift suggest the possibility of an increased risk for noise-induced hearing impairment (Smoorenburg 1998).

d. Risk for noise-induced hearing impairment may increase when the noise exposure is combined with exposure to vibrations, the use of ototoxic drugs, or some chemicals (Fechter 1999). In these circumstances, long-term exposure to LAeq,24h of 70 dBA may induce small hearing impairments.

e. It is uncertain whether the relationships between hearing impairment and noise exposure given in ISO Standard 1999 (ISO 1990) are applicable for environmental sounds of short rise time. For example, in the case of military low-altitude flying areas (75–300 m above ground) LAmax values of 110–130 dB occur within seconds after the onset of the sound.

Usually noise-induced hearing impairment is accompanied by an abnormal loudness perception which is known as loudness recruitment (*cf.* Berglund & Lindvall 1995). With a considerable loss of auditory sensitivity, some sounds may be perceived as distorted (paracusis). Another sensory effect that results from noise exposure is tinnitus (ringing in the ears). Commonly, tinnitus is referred to as sounds that are emitted by the inner ear itself (physiological tinnitus). Tinnitus is a common and often disturbing accompaniment of occupational hearing impairment (Vernon and Moller 1995) and has become a risk for teenagers attending pop concerts and discotheques (Hetu & Fortin 1995; Passchier-Vermeer et al. 1998; Axelsson & Prasher 1999). Noise-induced tinnitus may be temporary, lasting up to 24 hours after exposure, or may have a more permanent character, such as after prolonged occupational noise exposure. Sometimes tinnitus is due to the sound produced by the blood flow through structures in the ear.

The main social consequence of hearing impairment is an inability to understand speech in daily living conditions, which is considered a severe social handicap. Even small values of hearing impairment (10 dB averaged over 2 000 and 4 000 Hz, and over both ears) may have an effect on the understanding of speech. When the hearing impairment exceeds 30 dB (again averaged over 2 000 and 4 000 Hz and both ears) a social hearing handicap is noticeable (*cf.* Katz 1994; Berglund & Lindvall 1995).

In the past, hearing protection has mainly emphasized occupational noise exposures at high values of LAeq,8h, or situations with high impulsive sounds. The near-universal adoption of an LAeq,8h value of 85 dB (or lower) as the limit for unprotected occupational noise exposure, together with requirements for personal hearing protection, has made cases of severe unprotected exposures more rare. This is particularly true for developed countries. However, monitoring of compliance and enforcement action for sound pressure levels just over the limits may be weak, especially in non-industrial environments in developed countries (Franks 1998), as well as in occupational and urban environments in developing countries (Smith 1998). Nevertheless, regulations for occupational noise exposure exist almost worldwide and exposures to occupational noise are to a certain extent under control.

On the other hand, environmental noise exposures due to a number of noisy activities, especially those during leisure-time activities of children and young adults, have scarcely been regulated. Given both the increasing number of noisy activities and the increasing exposure duration, such as loud music in cars and the use of Walkmen and Discmen, regulatory activities in this field are to be encouraged. Dose-response data are lacking for the general population. However, judging from the limited data for study groups (teenagers, young adults and women), and the assumption that time of exposure can be equated with sound energy, the risk for hearing impairment would be negligible for LAeq,24h values of 70 dBA over a lifetime. To avoid hearing impairment, impulse noise exposures should never exceed 140 dB peak sound pressure in adults, and 120 dB peak sound pressure in children.

3.3. Interference with Speech Communication

Noise interference with speech comprehension results in a large number of personal disabilities, handicaps and behavioural changes. Problems with concentration, fatigue, uncertainty and lack of self-confidence, irritation, misunderstandings, decreased working capacity, problems in human relations, and a number of stress reactions have all been identified (Lazarus 1998). Particularly vulnerable to these types of effects are the hearing impaired, the elderly, children in the process of language and reading acquisition, and individuals who are not familiar with the spoken language (e.g., Lazarus 1998). Thus, vulnerable persons constitute a substantial proportion of a country's population.

Most of the acoustical energy of speech is in the frequency range 100–6 000 Hz, with the most important cue-bearing energy being between 300–3 000 Hz. Speech interference is basically a masking process in which simultaneous, interfering noise renders speech incapable of being understood. The higher the level of the masking noise, and the more energy it contains at the most important speech frequencies, the greater will be the percentage of speech sounds that become indiscernible to the listener. Environmental noise may also mask many other acoustical signals important for daily life, such as door bells, telephone signals, alarm clocks, fire alarms and other warning signals, and music (e.g., Edworthy & Adams 1996). The masking effect of interfering noise in speech discrimination is more pronounced for hearing-impaired persons than for persons with normal hearing, particularly if the interfering noise is composed of speech or babble.

As the sound pressure level of an interfering noise increases, people automatically raise their voice to overcome the masking effect upon speech (increase of vocal effort). This imposes an additional strain on the speaker. For example, in quiet surroundings, the speech level at 1 m distance averages 45–50 dBA, but is 30 dBA higher when shouting. However, even if the interfering noise is moderately loud, most of the sentences during ordinary conversation can still be understood fairly well. Nevertheless, the interpretation required for compensating the masking effect of the interfering sounds, and for comprehending what was said, imposes an additional strain on the listener. One contributing factor could be that speech spoken loudly is more difficult to understand than speech spoken softly, when compared at a constant speech-to-noise ratio (*cf.* Berglund & Lindvall 1995).

Speech levels vary between individuals because of factors such as gender and vocal effort. Moreover, outdoor speech levels decrease by about 6 dB for a doubling in the distance between talker and listener. Speech intelligibility in everyday living conditions is influenced by speech level, speech pronunciation, talker-to-listener distance, sound pressure levels, and to some extent other characteristics of interfering noise, as well as room characteristics (e.g. reverberation). Individual capabilities of the listener, such as hearing acuity and the level of attention of the listener, are also important for the intelligibility of speech. Speech communication is affected also by the reverberation characteristics of the room. For example, reverberation times greater than 1 s produce loss in speech discrimination. Longer reverberation times, especially when combined with high background interfering noise, make speech perception more difficult. Even in a quiet environment, a reverberation time below 0.6 s is desirable for adequate speech intelligibility by vulnerable groups. For example, for older hearing-handicapped persons, the optimal reverberation time for speech intelligibility is 0.3–0.5 s (Plomp 1986).

For complete sentence intelligibility in listeners with normal hearing, the signal-to-noise ratio (i.e. the difference between the speech level and the sound pressure level of the interfering noise) should be 15–18 dBA (Lazarus 1990). This implies that in smaller rooms, noise levels above 35 dBA interferes with the intelligibility of speech (Bradley 1985). Earlier recommendations suggested that sound pressure levels as high as 45 dBA would be acceptable (US EPA 1974). With raised voice (increased vocal effort) sentences may be 100% intelligible for noise levels of up to 55 dBA; and sentences spoken with straining vocal effort can be 100% intelligible with noise levels of about 65 dBA. For speech to be intelligible when listening to complicated messages (at school, listening to foreign languages, telephone conversation), it is recommended that the signal-to-noise ratio should be at least 15 dBA. Thus, with a speech level of 50 dBA, (at 1 m distance this level corresponds to a casual speech level of both women and men), the sound pressure level of interfering noise should not exceed 35 dBA. For vulnerable groups even lower background levels are needed. If it is not possible to meet the strictest criteria for vulnerable persons in sensitive situations (e.g. in classrooms), one should strive for as low background levels as possible.

3.4. Sleep Disturbance

Uninterrupted sleep is known to be a prerequisite for good physiological and mental functioning of healthy persons (Hobson 1989); sleep disturbance, on the other hand, is considered to be a major environmental noise effect. It is estimated that 80-90% of the reported cases of sleep disturbance in noisy environments are for reasons other than noise originating outdoors. For example, sanitary needs; indoor noises from other occupants; worries; illness; and climate (e.g. Reyner & Horne 1995). Our understanding of the impact of noise exposure on sleep stems mainly from experimental research in controlled environments. Field studies conducted with people in their normal living situations are scarce. Most of the more recent field research on sleep disturbance has been conducted for aircraft noise (Fidell et al. 1994 1995a,b 1998; Horne et al. 1994 1995; Maschke et al. 1995 1996; Ollerhead et al. 1992; Passchier-Vermeer 1999). Other field studies have examined the effects of road traffic and railway noise (Griefahn et al. 1996 1998).

The primary sleep disturbance effects are: difficulty in falling asleep (increased sleep latency time); awakenings; and alterations of sleep stages or depth, especially a reduction in the proportion of REM-sleep (REM = rapid eye movement) (Hobson 1989). Other primary physiological effects can also be induced by noise during sleep, including increased blood pressure; increased heart rate; increased finger pulse amplitude; vasoconstriction; changes in respiration; cardiac arrhythmia; and an increase in body movements (cf. Berglund & Lindvall 1995). For each of these physiological effects, both the noise threshold and the noise-response relationships may be different. Different noises may also have different information content and this also could affect physiological threshold and noise-response relationships (Edworthy 1998).

Exposure to night-time noise also induces secondary effects, or so-called after effects. These are effects that can be measured the day following the night-time exposure, while the individual is awake. The secondary effects include reduced perceived sleep quality; increased fatigue; depressed mood or well-being; and decreased performance (Öhrström 1993a; Passchier-Vermeer 1993; Carter 1996; Pearsons et al. 1995; Pearsons 1998).

Long-term effects on psychosocial well-being have also been related to noise exposure during the night (Öhrström 1991). Noise annoyance during the night-time increased the total noise annoyance expressed by people in the following 24 h. Various studies have also shown that people living in areas exposed to night-time noise have an increased use of sedatives or sleeping pills. Other frequently reported behavioural effects of night-time noise include closed bedroom windows and use of personal hearing protection. Sensitive groups include the elderly, shift workers, persons especially vulnerable to physical or mental disorders and other individuals with sleeping difficulties.

Questionnaire data indicate the importance of night-time noise on the perception of sleep quality. A recent Japanese investigation was conducted for 3 600 women (20–80 years old) living in eight roadside zones with different road traffic noise. The results showed that four measures of perceived sleep quality (difficulty in falling asleep; waking up during sleep; waking up too early; feelings of sleeplessness one or more days a week) correlated significantly with the average traffic volumes during night-time. An in-depth investigation of 19 insomnia cases and their matched controls (age,work) measured outdoor and indoor sound pressure levels during sleep (Kageyama et al. 1997). The study showed that road traffic noise in excess of 30 dB LAeq for nighttime induced sleep disturbance, consistent with the results of Öhrström (1993b).

Meta-analyses of field and laboratory studies have suggested that there is a relationship between the SEL for a single night-time noise event and the percentage of people awakened, or who showed sleep stage changes (e.g. Ollerhead et al. 1992; Passchier-Vermeer 1993; Finegold et al. 1994; Pearsons et al. 1995). All of these studies assumed that the number of awakenings per night for each SEL value is proportional to the number of night-time noise events. However, the results have been criticized for methodological reasons. For example, there were small groups of sleepers; too few original studies; and indoor exposure was estimated from outdoor sound pressure levels (NRC-CNRC 1994; Beersma & Altena 1995; Vallet 1998). The most important result of the meta-analyses is that there is a clear difference in the dose-response curves for laboratory and field studies, and that noise has a lower effect under real-life conditions (Pearsons et al. 1995; Pearsons 1998).

However, this result has been questioned, because the studies were not controlled for such things as the sound insulation of the buildings, and the number of bedrooms with closed windows. Also, only two indicators of sleep disturbance were considered (awakening and sleep stage changes). The meta-analyses thus neglected other important sleep disturbance effects (Öhrström 1993b; Carter et al. 1994a; Carter et al. 1994b; Carter 1996; Kuwano et al. 1998). For example, for road traffic noise, perceived sleep quality is related both to the time needed to fall asleep and the total sleep time (Öhrström & Björkman 1988). Individuals who are more sensitive to noise (as assessed by different questionnaires) report worse sleep quality both in field studies and in laboratory studies.

A further criticism of the meta-analyses is that laboratory experiments have shown that habituation to night-time noise events occurs, and that noise-induced awakening decreases with increasing number of sound exposures per night. This is in contrast to the assumption used in the meta-analyses, that the percentage of awakenings is linearly proportional to the number of night-time noise events. Studies have also shown that the frequency of noise-induced awakenings decreases for at least the first eight consecutive nights. So far, habituation has been shown for awakenings, but not for heart rate and after effects such as perceived sleep quality, mood and performance (Öhrström and Björkman 1988).

Other studies suggest that it is the difference in sound pressure levels between a noise event and background, rather than the absolute sound pressure level of the noise event, that determines the reaction probability. The time interval between two noise events also has an important influence of the probability of obtaining a response (Griefahn 1977; *cf.* Berglund & Lindvall 1995). Another possible factor is the person's age, with older persons having an increased probability of awakening. However, one field study showed that noise-induced awakenings are independent of age (Reyner & Horne 1995).

For a good sleep, it is believed that indoor sound pressure levels should not exceed approximately 45 dB LAmax more than 10–15 times per night (Vallet & Vernet 1991), and most studies show an increase in the percentage of awakenings at SEL values of 55–60 dBA (Passchier-Vermeer 1993; Finegold et al. 1994; Pearsons et al. 1995). For intermittent events that approximate aircraft noise, with an effective duration of 10–30 s, SEL values of 55–60 dBA correspond to a LAmax value of 45 dB. Ten to 15 of these events during an eight-hour night-time implies an LAeq,8h of 20–25 dB. This is 5–10 dB below the LAeq,8h of 30 dB for continuous night-time noise exposure, and shows that the intermittent character of noise has to be taken into account when setting night-time limits for noise exposure. For example, this can be achieved by considering the number of noise events and the difference between the maximum sound pressure level and the background level of these events.

Special attention should also be given to the following considerations:

a. Noise sources in an environment with a low background noise level. For example, night-traffic in suburban residential areas.

b. Environments where a combination of noise and vibrations are produced. For example, railway noise, heavy duty vehicles.

c. Sources with low-frequency components. Disturbances may occur even though the sound pressure level during exposure is below 30 dBA.

If negative effects on sleep are to be avoided the equivalent sound pressure level should not exceed 30 dBA indoors for continuous noise. If the noise is not continuous, sleep disturbance correlates best with LAmax and effects have been observed at 45 dB or less. This is particularly true if the background level is low. Noise events exceeding 45 dBA should therefore be limited if possible. For sensitive people an even lower limit would be preferred. It should be noted that it should be possible to sleep with a bedroom window slightly open (a reduction from outside to inside of 15 dB). To prevent sleep disturbances, one should thus consider the equivalent sound pressure level and the number and level of sound events. Mitigation targeted to the first part of the night is believed to be effective for the ability to fall asleep.

3.5. Cardiovascular and Physiological Effects

Epidemiological and laboratory studies involving workers exposed to occupational noise, and general populations (including children) living in noisy areas around airports, industries and noisy streets, indicate that noise may have both temporary and permanent impacts on physiological functions in humans. It has been postulated that noise acts as an environmental stressor (for a review see Passchier-Vermeer 1993; Berglund & Lindvall 1995). Acute noise exposures activate the autonomic and hormonal systems, leading to temporary changes such as increased blood pressure, increased heart rate and vasoconstriction. After prolonged exposure, susceptible individuals in the general population may develop permanent effects, such as hypertension and ischaemic heart disease associated with exposures to high sound pressure levels (for a review see Passchier-Vermeer 1993; Berglund & Lindvall 1995). The magnitude and duration of the effects are determined in part by individual characteristics, lifestyle behaviours and environmental conditions. Sounds also evoke reflex responses, particularly when they are unfamiliar and have a sudden onset.

Laboratory experiments and field quasi-experiments show that if noise exposure is temporary, the physiological system usually returns - after the exposure terminates - to a normal (pre-exposure) state within a time in the range of the exposure duration. If the exposure is of sufficient intensity and unpredictability, cardiovascular and hormonal responses may appear, including increases in heart rate and peripheral vascular resistance; changes in blood pressure, blood viscosity and blood lipids; and shifts in electrolyte balance (Mg/Ca) and hormonal levels (epinephrine, norepinephrine, cortisol). The first four effects are of interest because of noise-related coronary heart disease (Ising & Günther 1997). Laboratory and clinical data suggest that noise may significantly elevate gastrointestinal motility in humans.

By far the greatest number of occupational and community noise studies have focused on the possibility that noise may be a risk factor for cardiovascular disease. Many studies in occupational settings have indicated that workers exposed to high levels of industrial noise for 5–30 years have increased blood pressure and statistically significant increases in risk for hypertension, compared to workers in control areas (Passchier-Vermeer 1993). In contrast, only a few studies on environmental noise have shown that populations living in noisy areas around airports and on noisy streets have an increased risk for hypertension. The overall evidence suggests a weak association between long-term environmental noise exposure and hypertension (HCN 1994; Berglund & Lindvall 1995; IEH 1997), and no dose-response relationships could be established.

Recently, an updated summary of available studies for ischaemic heart disease has been presented (Babisch 1998a; Babisch 1998b; Babisch et al. 1999; see also Thompson 1996). The studies reviewed include case-control and cross-sectional designs, as well as three longitudinal studies. However, it has not yet been possible to conduct the most advanced quantitative integrated analysis of the available studies. Relative risks and their confidence intervals could be estimated only for the classes of high noise levels (mostly >65 dBA during daytime) and low levels (mostly <55 dBA during daytime), rather than a range of exposure levels. For methodological reasons identified in the meta-analysis, a cautious interpretation of the results is warranted (Lercher et al. 1998).

Prospective studies that controlled for confounding factors suggest an increase in ischaemic heart disease when the noise levels exceed 65–70 dB for LAeq (6–22). (For road traffic noise, the difference between LAeq (6-22h) and LAeq,24h usually is of the order of 1.5 dB). When orientation of the bedroom, window opening habits and years of exposure are taken into account, the risk of heart disease is slightly higher (Babisch et al. 1998; Babisch et al. 1999). However, disposition, behavioural and environmental factors were not sufficiently accounted for in the analyses carried out to date. In epidemiological studies the lowest level at which traffic noise had an effect on ischaemic heart disease was 70 dB for LAeq,24h (HCN 1994).

The overall conclusion is that cardiovascular effects are associated with long-term exposure to LAeq,24h values in the range of 65–70 dB or more, for both air- and road-traffic noise. However, the associations are weak and the effect is somewhat stronger for ischaemic heart disease than for hypertension. Nevertheless, such small risks are potentially important because a large number of persons are currently exposed to these noise levels, or are likely to be exposed in the future. Furthermore, only the average risk is considered and sensitive subgroups of the populations have not been sufficiently characterized. For example, a 10% increase in risk factors (a relative risk of 1.1) may imply an increase of up to 200 cases per 100 000 people at risk per year. Other observed psychophysiological effects, such as changes in stress hormones, magnesium levels, immunological indicators, and gastrointestinal disturbances are too inconsistent for conclusions to be drawn about the influence of noise pollution.

3.6. Mental Health Effects

Mental health is defined as the absence of identifiable psychiatric disorders according to current norms (Freeman 1984). Environmental noise is not believed to be a direct cause of mental illness, but it is assumed that it accelerates and intensifies the development of latent mental disorder. Studies on the adverse effects of environmental noise on mental health cover a variety of symptoms, including anxiety; emotional stress; nervous complaints; nausea; headaches; instability; argumentativeness; sexual impotency; changes in mood; increase in social conflicts, as well as general psychiatric disorders such as neurosis, psychosis and hysteria. Large-scale population studies have suggested associations between noise exposure and a variety of mental health indicators, such as single rating of well-being; standard psychological symptom profiles; the intake of psychotropic drugs; and consumption of tranquilizers and sleeping pills. Early studies showed a weak association between exposure to aircraft noise and psychiatric hospital admissions in the general population surrounding an airport (see also Berglund & Lindvall 1995). However, the studies have been criticized because of problems in selecting variables and in response bias (Halpern 1995).

Exposure to high levels of occupational noise has been associated with development of neurosis and irritability; and exposure to high levels of environmental noise with deteriorated mental health (Stansfeld 1992). However, the findings on environmental noise and mental health effects are inconclusive (HCN 1994; Berglund & Lindvall 1995; IEH 1997). The only longitudinal study in this field (Stansfeld et al. 1996) showed an association between the initial level of road traffic noise and minor psychiatric disorders, although the association for increased anxiety was weak and non-linear. It turned out that psychiatric disorders are associated with noise sensitivity, rather than with noise exposure, and the association was found to disappear after adjustment for baseline trait anxiety. These and other results show the importance of taking vulnerable groups into account, because they may not be able to cope sufficiently with unwanted environmental noise (e.g. Stansfeld 1992). This is particularly true of children, the elderly and people with preexisting illnesses, especially depression (IEH 1997). Despite the weaknesses of the various studies, the possibility that community noise has adverse effects on mental health is suggested by studies on the use of medical drugs, such as tranquilizers and sleeping pills, on psychiatric symptoms and on mental hospital admission rates.

3.7. The Effects of Noise on Performance

It has been documented in both laboratory subjects and in workers exposed to occupational noise, that noise adversely affects cognitive task performance. In children, too, environmental noise impairs a number of cognitive and motivational parameters (Cohen et al. 1980; Evans & Lepore 1993; Evans 1998; Hygge et al. 1998; Haines et al. 1998). However, there are no published studies on whether environmental noise at home also impairs cognitive performance in adults. Accidents may also be an indicator of performance deficits. The few field studies on the effects of noise on performance and safety showed that noise may produce some task impairment and increase the number of errors in work, but the effects depend on the type of noise and the task being performed (Smith 1990).

Laboratory and workplace studies showed that noise can act as a distracting stimulus. Also, impulsive noise events (e.g. sonic booms) may produce disruptive effects as a result of startle responses. In the short term, noise-induced arousal may produce better performance of simple tasks, but cognitive performance deteriorates substantially for more complex tasks (i.e. tasks that require sustained attention to details or to multiple cues; or tasks that demand a large capacity of working memory, such as complex analytical processes). Some of the effects are related to loss in auditory comprehension and language acquisition, but others are not (Evans & Maxwell 1997). Among the cognitive effects, reading, attention, problem solving and memory are most strongly affected by noise. The observed effects on motivation, as measured by persistence with a difficult cognitive task, may either be independent or secondary to the aforementioned cognitive impairments.

Two types of memory deficits have been identified under experimental noise exposure: incidental memory and memory for materials that the observer was not explicitly instructed to focus on during a learning phase. For example, when presenting semantic information to subjects in the presence of noise, recall of the information content was unaffected, but the subjects were significantly less able to recall, for example, in which corner of the slide a word had been located. There is also some evidence that the lack of "helping behavior" that was noted under experimental noise exposure may be related to inattention to incidental cues (Berglund & Lindvall 1995). Subjects appear to process information faster in working memory during noisy performance conditions, but at a cost of available memory capacity. For example, in a running memory task, in which subjects were required to recall in sequence letters that they had just heard, subjects recalled recent items better under noisy conditions, but made more errors farther back into the list.

Experimental noise exposure consistently produces negative after-effects on performance (Glass & Singer 1972). Following exposure to aircraft noise, schoolchildren in the vicinity of Los Angeles airport were found to be deficient in proofreading, and in persistence with challenging puzzles (Cohen et al. 1980). The uncontrollability of noise, rather than the intensity of the noise, appears to be the most critical variable. The only prospective study on noise-exposed schoolchildren, designed around the move of the Munich airport (Hygge et al. 1996; Evans et al. 1998), confirmed the results of laboratory and workplace studies in adults, as well the results of the Los Angeles airport study with children (Cohen et al. 1980). An important finding was that some of the adaptation strategies for dealing with aircraft noise, such as tuning out or ignoring the noise, and the effort necessary to maintain task performance, come at a price. There is heightened sympathetic arousal, as indicated by increased levels of stress hormone, and elevation of resting blood pressure (Evans et al. 1995; Evans et al. 1998). Notably, in the airport studies reported above, the adverse effects were larger in children with lower school achievement.

For aircraft noise, it has been shown that chronic exposure during early childhood appears to impair reading acquisition and reduces motivational capabilities. Of recent concern are concomitant psychophysiological changes (blood pressure and stress hormone levels). Evidence indicates that the longer the exposure, the greater the damage. It seems clear that daycare centers and schools should not be located near major sources of noise, such as highways, airports and industrial sites.

3.8. Effects of Noise on Residential Behaviour and Annoyance

Noise annoyance is a global phenomenon. A definition of annoyance is "a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them" (Lindvall & Radford 1973; Koelega 1987). However, apart from "annoyance", people may feel a variety of negative emotions when exposed to community noise, and may report anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation, or exhaustion (Job 1993; Fields et al. 1997 1998). Thus, although the term annoyance does not cover all the negative reactions, it is used for convenience in this document.

Noise can produce a number of social and behavioural effects in residents, besides annoyance (for review see Berglund & Lindvall 1995). The social and behavioural effects are often complex, subtle and indirect. Many of the effects are assumed to be the result of interactions with a number of non-auditory variables. Social and behavioural effects include changes in overt everyday behaviour patterns (e.g. closing windows, not using balconies, turning TV and radio to louder levels, writing petitions, complaining to authorities); adverse changes in social behaviour (e.g. aggression, unfriendliness, disengagement, non-participation); adverse changes in social indicators (e.g. residential mobility, hospital admissions, drug consumption, accident rates); and changes in mood (e.g. less happy, more depressed).

Although changes in social behaviour, such as a reduction in helpfulness and increased aggressiveness, are associated with noise exposure, noise exposure alone is not believed to be sufficient to produce aggression. However, in combination with provocation or pre-existing anger or hostility, it may trigger aggression. It has also been suspected that people are less willing to help, both during exposure and for a period after exposure. Fairly consistent evidence shows that noise above 80 dBA is associated with reduced helping behaviour and increased aggressive behaviour. Particularly, there is concern that high-level continuous noise exposures may contribute to the susceptibility of schoolchildren to feelings of helplessness (Evans & Lepore 1993)

The effects of community noise can be evaluated by assessing the extent of annoyance (low, moderate, high) among exposed individuals; or by assessing the disturbance of specific activities, such as reading, watching television and communication. The relationship between annoyance and activity disturbances is not necessarily direct and there are examples of situations where the extent of annoyance is low, despite a high level of activity disturbance. For aircraft noise, the most important effects are interference with rest, recreation and watching television. This is in contrast to road traffic noise, where sleep disturbance is the predominant effect (Berglund & Lindvall 1995).

A number of studies have shown that equal levels of traffic and industrial noises result in different magnitudes of annoyance (Hall et al. 1981; Griffiths 1983; Miedema 1993; Bradley 1994a; Miedema & Vos 1998). This has led to criticism (e.g. Kryter 1994; Bradley 1994a) of averaged dose-response curves determined by meta-analysis, which assumed that all traffic noises are the same (Fidell et al. 1991; Fields 1994a; Finegold et al. 1994). Schultz (1978) and Miedema & Vos (1998) have synthesized curves of annoyance associated with three types of traffic noise (road, air, railway). In these curves, the percentage of people highly or moderately annoyed was related to the day and night continuous equivalent sound level, L_{dn}. For each of the three types of traffic noise, the percentage of highly annoyed persons in a population started to increase at an L_{dn} value of 42 dBA, and the percentage of moderately annoyed persons at an L_{dn} value of 37 dBA (Miedema & Vos 1998). Aircraft noise produced a stronger annoyance response than road traffic, for the same L_{dn} exposure, consistent with earlier analyses (Kryter 1994; Bradley 1994a). However, caution should be exercised when interpreting synthesized data from different studies, since five major parameters should be randomly distributed for the analyses to be valid: personal, demographic, and lifestyle factors, as well as the duration of noise exposure and the population experience with noise (Kryter 1994).

Annoyance in populations exposed to environmental noise varies not only with the acoustical characteristics of the noise (source, exposure), but also with many non-acoustical factors of social, psychological, or economic nature (Fields 1993). These factors include fear associated with the noise source, conviction that the noise could be reduced by third parties, individual noise sensitivity, the degree to which an individual feels able to control the noise (coping strategies), and whether the noise originates from an important economic activity. Demographic variables such as age, sex and socioeconomic status, are less strongly associated with annoyance. The correlation between noise exposure and general annoyance is much higher at the group level than at the individual level, as might be expected. Data from 42 surveys showed that at the group level about 70% of the variance in annoyance is explained by noise exposure characteristics, whereas at the individual level it is typically about 20% (Job 1988).

When the type and amount of noise exposure is kept constant in the meta-analyses, differences between communities, regions and countries still exist (Fields 1990; Bradley 1996). This is well demonstrated by a comparison of the dose-response curve determined for road-traffic noise

(Miedema & Vos 1998) and that obtained in a survey along the North-South transportation route through the Austrian Alps (Lercher 1998b). The differences may be explained in terms of the influence of topography and meteorological factors on acoustical measures, as well as the low background noise level on the mountain slopes.

Stronger reactions have been observed when noise is accompanied by vibrations and contains low frequency components (Paulsen & Kastka 1995; Öhrström 1997; for review see Berglund et al. 1996), or when the noise contains impulses, such as shooting noise (Buchta 1996; Vos 1996; Smoorenburg 1998). Stronger, but temporary, reactions also occur when noise exposure is increased over time, in comparison to situations with constant noise exposure (e.g. HCN 1997; Klæboe et al. 1998). Conversely, for road traffic noise, the introduction of noise protection barriers in residential areas resulted in smaller reductions in annoyance than expected for a stationary situation (Kastka et al. 1995).

To obtain an indicator for annoyance, other methods of combining parameters of noise exposure have been extensively tested, in addition to metrics such as LAeq,24h and L_{dn}. When used for a set of community noises, these indicators correlate well both among themselves and with LAeq,24h or L_{dn} values (e.g. HCN 1997). Although LAeq,24h and L_{dn} are in most cases acceptable approximations, there is a growing concern that all the component parameters of the noise should be individually assessed in noise exposure investigations, at least in the complex cases (Berglund & Lindvall 1995).

3.9. The Effects of Combined Noise Sources

Many acoustical environments consist of sounds from more than one source. For these environments, health effects are associated with the total noise exposure, rather than with the noise from a single source (WHO 1980b). When considering hearing impairment, for example, the total noise exposure can be expressed in terms of LAeq,24h for the combined sources. For other adverse health effects, however, such a simple model most likely will not apply. It is possible that some disturbances (e.g. speech interference, sleep disturbance) may more easily be attributed to specific noises. In cases where one noise source clearly dominates, the magnitude of an effect may be assessed by taking into account the dominant source only (HCN 1997). Furthermore, at a policy level, there may be little need to identify the adverse effect of each specific noise, unless the responsibility for these effects is to be shared among several polluters (*cf.* The Polluter Pays Principle in Chapter 5, UNCED 1992).

There is no consensus on a model for assessing the total annoyance due to a combination of environmental noise sources. This is partly due to a lack of research into the temporal patterns of combined noises. The current approach for assessing the effects of "mixed noise sources" is limited to data on "total annoyance" transformed to mathematical principles or rules of thumb (Ronnebaum et al. 1996; Vos 1992; Miedema 1996; Berglund & Nilsson 1997). Models to assess the total annoyance of combinations of environmental noises may not be applicable to those health effects for which the mechanisms of noise interaction are unknown, and for which different cumulative or synergistic effects cannot be ruled out. When noise is combined with different types of environmental agents, such as vibrations, ototoxic chemicals, or chemical odours, again there is insufficient knowledge to accurately assess the combined effects on health

(Berglund & Lindvall 1995; HCN 1994; Miedema 1996; Zeichart 1998; Passchier-Vermeer & Zeichart 1998). Therefore, caution should be exercised when trying to predict the adverse health effects of combined factors in residential populations.

The evidence on low-frequency noise is sufficiently strong to warrant immediate concern. Various industrial sources emit continuous low-frequency noise (compressors, pumps, diesel engines, fans, public works); and large aircraft, heavy-duty vehicles and railway traffic produce intermittent low-frequency noise. Low-frequency noise may also produce vibrations and rattles as secondary effects. Health effects due to low-frequency components in noise are estimated to be more severe than for community noises in general (Berglund et al. 1996). Since A-weighting underestimates the sound pressure level of noise with low-frequency components, a better assessment of health effects would be to use C-weighting.

In residential populations heavy noise pollution will most certainly be associated with a combination of health effects. For example, cardiovascular disease, annoyance, speech interference at work and at home, and sleep disturbance. Therefore, it is important that the total adverse health load over 24 hours be considered and that the precautionary principle for sustainable development is applied in the management of health effects (see Chapter 5).

3.10. Vulnerable Groups

Protective standards are essentially derived from observations on the health effects of noise on "normal" or "average" populations. The participants of these investigations are selected from the general population and are usually adults. Sometimes, samples of participants are selected because of their easy availability. However, vulnerable groups of people are typically underrepresented. This group includes people with decreased personal abilities (old, ill, or depressed people); people with particular diseases or medical problems; people dealing with complex cognitive tasks, such as reading acquisition; people who are blind or who have hearing impairment; fetuses, babies and young children; and the elderly in general (Jansen 1987; AAP 1997). These people may be less able to cope with the impacts of noise exposure and be at greater risk for harmful effects.

Persons with impaired hearing are the most adversely affected with respect to speech intelligibility. Even slight hearing impairments in the high-frequency range may cause problems with speech perception in a noisy environment. From about 40 years of age, people typically demonstrate an impaired ability to understand difficult, spoken messages with low linguistic redundancy. Therefore, based on interference with speech perception, a majority of the population belongs to the vulnerable group.

Children have also been identified as vulnerable to noise exposure (see Agenda 21: UNCED 1992). The evidence on noise pollution and children's health is strong enough to warrant monitoring programmes at schools and preschools to protect children from the effects of noise. Follow up programmes to study the main health effects of noise on children, including effects on speech perception and reading acquisition, are also warranted in heavily noise polluted areas (Cohen et al. 1986; Evans et al. 1998).

The issue of vulnerable subgroups in the general population should thus be considered when developing regulations or recommendations for the management of community noise. This consideration should take into account the types of effects (communication, recreation, annoyance, etc.), specific environments (*in utero*, incubator, home, school, workplace, public institutions, etc.) and specific lifestyles (listening to loud music through headphones, or at discotheques and festivals; motor cycling, etc.).

4. Guideline Values

4.1. Introduction

The human ear and lower auditory system continuously receive stimuli from the world around us. However, this does not mean that all the acoustical inputs are necessarily disturbing or have harmful effects. This is because the auditory nerve provides activating impulses to the brain that enable us to regulate the vigilance and wakefulness necessary for optimal performance. On the other hand, there are scientific reports that a completely silent world can have harmful effects, because of sensory deprivation. Thus, both too little sound and too much sound can be harmful. For this reason, people should have the right to decide for themselves the quality of the acoustical environment they live in.

Exposure to noise from various sources is most commonly expressed as the average sound pressure level over a specific time period, such as 24 hours. This means that identical average sound levels for a given time period could be derived from either a large number of sound events with relatively low, almost inaudible levels, or from a few events with high sound levels. This technical concept does not fully agree with common experience on how environmental noise is experienced, or with the neurophysiological characteristics of the human receptor system.

Human perception of the environment through vision, hearing, touch, smell and taste is characterized by a good discrimination of stimulus intensity differences, and by a decaying response to a continuous stimulus (adaptation or habituation). Single sound events cannot be discriminated if the interval between events drops below a threshold value; if this occurs, the sound is interpreted as continuous. These characteristics are linked to survival, since new and different stimuli with low probability and high information value indicate warnings. Thus, when assessing the effects of environmental noise on people it is relevant to consider the importance of the background noise level, the number of events, and the noise exposure level independently.

Community noise studies have traditionally considered noise annoyance from single specific sources such as aircraft, road traffic or railways. In recent years, efforts have been made to compare the results from road traffic, aircraft and railway surveys. Data from a number of sources show that aircraft noise is more annoying than road traffic noise, which, in turn, is more annoying than railway noise. However, there is not a clear understanding of the mechanisms that create these differences. Some populations may also be at greater risk for the harmful effects of noise. Young children (especially during language acquisition), the blind, and perhaps fetuses are examples of such populations. There are no definite conclusions on this topic, but the reader should be alerted that guidelines in this report are developed for the population at large; guidelines for potentially more vulnerable groups are addressed only to a limited extent.

In the following, guideline values are summarized with regard to specific environments and effects. For each environment and situation, the guideline values take into consideration the identified health effects and are set, based on the lowest levels of noise that affect health (critical health effect). Guideline values typically correspond to the lowest effect level for general populations, such as those for indoor speech intelligibility. By contrast, guideline values for annoyance have been set at 50 or 55 dBA, representing daytime levels below which a majority of the adult population will be protected from becoming moderately or seriously annoyed, respectively.

In these *Guidelines for Community Noise* only guideline values are presented. These are essentially values for the onset of health effects from noise exposure. It would have been preferred to establish guidelines for exposure-response relationships. Such relationships would indicate the effects to be expected if standards were set above the WHO guideline values and would facilitate the setting of standards for sound pressure levels (noise immission standards). However, exposure-response relationships could not be established as the scientific literature is very limited. The best-studied exposure-response relationship is that between L_{dn} and annoyance (WHO 1995a; Berglund & Lindvall 1995; Miedema & Vos 1998). Even the most recent relationships between integrated noise levels and the percentage of highly or moderately annoyed people are still being scrutinized. The results of a forthcoming meta-analysis are expected to be published in the near future (Miedema, personal communication).

4.2. Specific Effects

4.2.1. Interference with communication

Noise tends to interfere with auditory communication, in which speech is a most important signal. However, it is also vital to be able to hear alarming and informative signals such as door bells, telephone signals, alarm clocks, fire alarms etc., as well as sounds and signals involved in occupational tasks. The effects of noise on speech discrimination have been studied extensively and deal with this problem in lexical terms (mostly words but also sentences). For communication distances beyond a few metres, speech interference starts at sound pressure levels below 50 dB for octave bands centered on the main speech frequencies at 500, 1 000 and 2 000 Hz. It is usually possible to express the relationship between noise levels and speech intelligibility in a single diagram, based on the following assumptions and empirical observations, and for speaker-to-listener distance of about 1 m:

a. Speech in relaxed conversation is 100% intelligible in background noise levels of about 35 dBA, and can be understood fairly well in background levels of 45 dBA.

b. Speech with more vocal effort can be understood when the background sound pressure level is about 65 dBA.

A majority of the population belongs to groups sensitive to interference with speech perception. Most sensitive are the elderly and persons with impaired hearing. Even slight hearing impairments in the high-frequency range may cause problems with speech perception in a noisy environment. From about 40 years of age, people demonstrate impaired ability to interpret difficult, spoken messages with low linguistic redundancy, when compared to people aged 20–30 years. It has also been shown that children, before language acquisition has been completed, have more adverse effects than young adults to high noise levels and long reverberation times.

For speech outdoors and for moderate distances, the sound level drops by approximately 6 dB for a doubling of the distance between speaker and listener. This relationship is also applicable to indoor conditions, but only up to a distance of about 2 m. Speech communication is affected also by the reverberation characteristics of the room, and reverberation times beyond 1 s can produce a loss in speech discrimination. A longer reverberation time combined with background noise makes speech perception still more difficult.

Speech signal perception is of paramount importance, for example, in classrooms or conference rooms. To ensure any speech communication, the signal-to-noise relationship should exceed zero dB. But when listening to complicated messages (at school, listening to foreign languages, telephone conversation) the signal-to-noise ratio should be at least 15 dB. With a voice level of 50 dBA (at 1 m distance this corresponds on average to a casual voice level in both women and men), the background level should not exceed 35 dBA. This means that in classrooms, for example, one should strive for as low background levels as possible. This is particularly true when listeners with impaired hearing are involved, for example, in homes for the elderly. Reverberation times below 1 s are necessary for good speech intelligibility in smaller rooms; and even in a quiet environment a reverberation time below 0.6 s is desirable for adequate speech intelligibility for sensitive groups.

4.2.2. Noise-induced hearing impairment

The ISO Standard 1999 (ISO 1990) gives a method of calculating noise-induced hearing impairment in populations exposed to all types of occupational noise (continuous, intermittent, impulse). However, noise-induced hearing impairment is by no means restricted to occupational situations alone. High noise levels can also occur in open-air concerts, discotheques, motor sports, shooting ranges, and from loudspeakers or other leisure activities in dwellings. Other loud noise sources, such as music played back in headphones and impulse noise from toys and fireworks, are also important. Evidence strongly suggests that the calculation method from ISO Standard 1999 for occupational noise (ISO 1990) should also be used for environmental and leisure time noise exposures. This implies that long term exposure to LAeq,24h of up to 70 dBA will not result in hearing impairment. However, given the limitations of the various underlying studies, care should be taken with respect to the following:

a. Data from animal experiments indicate that children may be more vulnerable in acquiring noise-induced hearing impairment than adults.

b. At very high instantaneous sound pressure levels mechanical damage to the ear may occur (Hanner & Axelsson 1988). Occupational limits are set at peak sound pressure levels of 140 dBA (EU 1986a). For adults, this same limit is assumed to be in order for exposure to environmental and leisure time noise. In the case of children, however, considering their habits while playing with noisy toys, peak sound pressure levels should never exceed 120 dBA.

c. For shooting noise with LAeq,24h over 80 dB, studies on temporary threshold shift suggest there is the possibility of an increased risk for noise-induced hearing impairment (Smoorenburg 1998).

d. The risk for noise-induced hearing impairment increases when noise exposure is combined with vibrations, ototoxic drugs or chemicals (Fechter 1999). In these circumstances, long-term exposure to LAeq,24h of 70 dB may induce small hearing impairments.

e. It is uncertain whether the relationships in ISO Standard 1999 (ISO 1990) are applicable to environmental sounds having a short rise time. For example, in the case of military low-altitude flying areas (75–300 m above ground) LAmax values of 110–130 dB occur within seconds after onset of the sound.

In conclusion, dose-response data are lacking for the general population. However, judging from the limited data for study groups (teenagers, young adults and women), and on the assumption that time of exposure can be equated with sound energy, the risk for hearing impairment would be negligible for LAeq,24h values of 70 dB over a lifetime. To avoid hearing impairment, impulse noise exposures should never exceed a peak sound pressure of 140 dB peak in adults, and 120 dB in children.

4.2.3. Sleep disturbance effects

Electrophysiological and behavioral methods have demonstrated that both continuous and intermittent noise indoors lead to sleep disturbance. The more intense the background noise, the more disturbing is its effect on sleep. Measurable effects on sleep start at background noise levels of about 30 dB LAeq. Physiological effects include changes in the pattern of sleep stages, especially a reduction in the proportion of REM sleep. Subjective effects have also been identified, such as difficulty in falling asleep, perceived sleep quality, and adverse after-effects such as headache and tiredness. Sensitive groups mainly include elderly persons, shift workers and persons with physical or mental disorders.
Where noise is continuous, the equivalent sound pressure level should not exceed 30 dBA indoors, if negative effects on sleep are to be avoided. When the noise is composed of a large proportion of low-frequency sounds a still lower guideline value is recommended, because low-frequency noise (e.g. from ventilation systems) can disturb rest and sleep even at low sound pressure levels. It should be noted that the adverse effect of noise partly depends on the nature of the source. A special situation is for newborns in incubators, for which the noise can cause sleep disturbance and other health effects.

If the noise is not continuous, LAmax or SEL are used to indicate the probability of noise-induced awakenings. Effects have been observed at individual LAmax exposures of 45 dB or less. Consequently, it is important to limit the number of noise events with a LAmax exceeding 45 dB. Therefore, the guidelines should be based on a combination of values of 30 dB LAeq,8h and 45 dB LAmax. To protect sensitive persons, a still lower guideline value would be preferred when the background level is low. Sleep disturbance from intermittent noise events increases with the maximum noise level. Even if the total equivalent noise level is fairly low, a small number of noise events with a high maximum sound pressure level will affect sleep.

Therefore, to avoid sleep disturbance, guidelines for community noise should be expressed in terms of equivalent sound pressure levels, as well as LAmax/SEL and the number of noise events. Measures reducing disturbance during the first part of the night are believed to be the most effective for reducing problems in falling asleep.

4.2.4. Cardiovascular and psychophysiological effects

Epidemiologial studies show that cardiovascular effects occur after long-term exposure to noise (aircraft and road traffic) with LAeq,24h values of 65–70 dB. However, the associations are weak. The association is somewhat stronger for ischaemic heart disease than for hypertension. Such small risks are important, however, because a large number of persons are currently exposed to these noise levels, or are likely to be exposed in the future. Other possible effects, such as changes in stress hormone levels and blood magnesium levels, and changes in the immune system and gastro-intestinal tract, are too inconsistent to draw conclusions. Thus, more research is required to estimate the long-term cardiovascular and psychophysiological risks due to noise. In view of the equivocal findings, no guideline values can be given.

4.2.5. Mental health effects

Studies that have examined the effects of noise on mental health are inconclusive and no guideline values can be given. However, in noisy areas, it has been observed that there is an increased use of prescription drugs such as tranquilizers and sleeping pills, and an increased frequency of psychiatric symptoms and mental hospital admissions. This strongly suggests that adverse mental health effects are associated with community noise.

4.2.6. Effects on performance

The effects of noise on task performance have mainly been studied in the laboratory and to some extent in work situations. But there have been few, if any, detailed studies on the effects of noise on human productivity in community situations. It is evident that when a task involves auditory signals of any kind, noise at an intensity sufficient to mask or interfere with the perception of these signals will also interfere with the performance of the task. A novel event, such as the start of an unfamiliar noise, will also cause distraction and interfere with many kinds of tasks. For example, impulsive noises such as sonic booms can produce disruptive effects as the result of startle responses; and these types of responses are more resistant to habituation.

Mental activities involving high load in working memory, such as sustained attention to multiple cues or complex analysis, are all directly sensitive to noise and performance suffers as a result. Some accidents may also be indicators of noise-related effects on performance. In addition to the direct effects on performance, noise also has consistent after-effects on cognitive performance with tasks such as proof-reading, and on persistence with challenging puzzles. In contrast, the performance of tasks involving either motor or monotonous activities is not always degraded by noise.

Chronic exposure to aircraft noise during early childhood appears to damage reading acquisition. Evidence indicates that the longer the exposure, the greater the damage. Although there is insufficient information on these effects to set specific guideline values, it is clear that day-care centres and schools should not be located near major noise sources, such as highways, airports and industrial sites.

4.2.7. Annoyance responses

The capacity of a noise to induce annoyance depends upon many of its physical characteristics, including its sound pressure level and spectral characteristics, as well as the variations of these properties over time. However, annoyance reactions are sensitive to many non-acoustical factors of social, psychological or economic nature, and there are also considerable differences in individual reactions to the same noise. Dose-response relations for different types of traffic noise (air, road and railway) clearly demonstrate that these noises can cause different annoyance effects at equal LAeq,24h values. And the same type of noise, such as that found in residential areas around airports, can also produce different annoyance responses in different countries.

The annoyance response to noise is affected by several factors, including the equivalent sound pressure level and the highest sound pressure level of the noise, the number of such events, and the time of day. Methods for combining these effects have been extensively studied. The results are not inconsistent with the simple, physically based equivalent energy theory, which is represented by the LAeq noise index.

Annoyance to community noise varies with the type of activity producing the noise. Speech communication, relaxation, listening to radio and TV are all examples of noise-producing activities. During the daytime, few people are seriously annoyed by activities with LAeq levels below 55 dB; or moderately annoyed with LAeq levels below 50 dB. Sound pressure levels during the evening and night should be 5–10 dB lower than during the day. Noise with low-frequency components require even lower levels. It is emphasized that for intermittent noise it is necessary to take into account the maximum sound pressure level as well as the number of noise events. Guidelines or noise abatement measures should also take into account residential outdoor activities.

4.2.8. Effects on social behaviour

The effects of environmental noise may be evaluated by assessing the extent to which it interferes with different activities. For many community noises, interference with rest, recreation and watching television seem to be the most important issues. However, there is evidence that noise has other effects on social behaviour: helping behaviour is reduced by noise in excess of 80 dBA; and loud noise increases aggressive behavior in individuals predisposed to aggressiveness. There is concern that schoolchildren exposed to high levels of chronic noise could be more susceptible to helplessness. Guidelines on these issues must await further research.

4.3. Specific Environments

Noise measures based solely on LAeq values do not adequately characterize most noise environments and do not adequately assess the health impacts of noise on human well-being. It is also important to measure the maximum noise level and the number of noise events when deriving guideline values. If the noise includes a large proportion of low-frequency components, values even lower than the guideline values will be needed, because low-frequency components in noise may increase the adverse effects considerably. When prominent low-frequency components are present, measures based on A-weighting are inappropriate. However, the difference between dBC (or dBlin) and dBA will give crude information about the presence of low-frequency components in noise. If the difference is more than 10 dB, it is recommended that a frequency analysis of the noise be performed.

4.3.1. Dwellings

In dwellings, the critical effects of noise are on sleep, annoyance and speech interference. To avoid sleep disturbance, indoor guideline values for bedrooms are 30 dB LAeq for continuous noise and 45 dB LAmax for single sound events. Lower levels may be annoying, depending on the nature of the noise source. The maximum sound pressure level should be measured with the instrument set at "*Fast*".

To protect the majority of people from being seriously annoyed during the daytime, the sound pressure level on balconies, terraces and outdoor living areas should not exceed 55 dB LAeq for a steady, continuous noise. To protect the majority of people from being moderately annoyed during the daytime, the outdoor sound pressure level should not exceed 50 dB LAeq. These values are based on annoyance studies, but most countries in Europe have adopted 40 dB LAeq as the maximum allowable level for new developments (Gottlob 1995). Indeed, the lower value should be considered the maximum allowable sound pressure level for all new developments whenever feasible.

At night, sound pressure levels at the outside façades of the living spaces should not exceed 45 dB LAeq and 60 dB LAmax, so that people may sleep with bedroom windows open. These values have been obtained by assuming that the noise reduction from outside to inside with the window partly open is 15 dB.

4.3.2. Schools and preschools

For schools, the critical effects of noise are on speech interference, disturbance of information extraction (e.g. comprehension and reading acquisition), message communication and annoyance. To be able to hear and understand spoken messages in classrooms, the background sound pressure level should not exceed 35 dB LAeq during teaching sessions. For hearing impaired children, an even lower sound pressure level may be needed. The reverberation time in the classroom should be about 0.6 s, and preferably lower for hearing-impaired children. For assembly halls and cafeterias in school buildings, the reverberation time should be less than 1 s. For outdoor playgrounds, the sound pressure level of the noise from external sources should not exceed 55 dB LAeq, the same value given for outdoor residential areas in daytime.

For preschools, the same critical effects and guideline values apply as for schools. In bedrooms in preschools during sleeping hours, the guideline values for bedrooms in dwellings should be used.

4.3.3. Hospitals

For most spaces in hospitals, the critical effects of noise are on sleep disturbance, annoyance and communication interference, including interference with warning signals. The LAmax of sound events during the night should not exceed 40 dB indoors. For wardrooms in hospitals, the guideline values indoors are 30 dB LAeq, together with 40 dB LAmax during the night. During the day and evening the guideline value indoors is 30 dB LAeq. The maximum level should be measured with the instrument set at "*Fast*".

Since patients have less ability to cope with stress, the equivalent sound pressure level should not exceed 35 dB LAeq in most rooms in which patients are being treated or observed. Particular attention should be given to the sound pressure levels in intensive care units and operating theatres. Sound inside incubators may result in health problems, including sleep disturbance, and may lead to hearing impairment in neonates. Guideline values for sound pressure levels in incubators must await future research.

4.3.4. Ceremonies, festivals and entertainment events

In many countries, there are regular ceremonies, festivals and other entertainment to celebrate life events. Such events typically produce loud sounds including music and impulsive sounds. There is widespread concern about the effect of loud music and impulse sounds on young people who frequently attend concerts, discotheques, video arcades, cinemas, amusement parks and spectator events, etc. The sound pressure level is typically in excess of 100 dB LAeq. Such a noise exposure could lead to significant hearing impairment after frequent attendance.

Noise exposure for employees of these venues should be controlled by established occupational standards. As a minimum, the same standards should apply to the patrons of these premises. Patrons should not be exposed to sound pressure levels greater than 100 dB LAeq during a 4-h period, for at most four times per year. To avoid acute hearing impairment the LAmax should always be below 110 dB.

4.3.5. Sounds through headphones

To avoid hearing impairment in both adults and children from music and other sounds played back in headphones, the LAeq,24h should not exceed 70 dB. This implies that for a daily one-hour exposure the LAeq should not exceed 85 dB. The exposures are expressed in free-field equivalent sound pressure levels. To avoid acute hearing impairment, the LAmax should always be below 110 dB.

4.3.6. Impulsive sounds from toys, fireworks and firearms

To avoid acute mechanical damage to the inner ear, adults should never be exposed to more than 140 dB peak sound pressure. To account for the vulnerability in children, the peak sound pressure level produced by toys should not surpass 120 dB, measured close to the ears (100 mm). To avoid acute hearing impairment, LAmax should always be below 110 dB.

4.3.7. Parkland and conservation areas

Existing large quiet outdoor areas should be preserved and the signal-to-noise ratio kept low.

4.4. WHO Guideline Values

The WHO guideline values in Table 4.1 are organized according to specific environments. When multiple adverse health effects are identified for a given environment, the guideline values are set at the level of the lowest adverse health effect (the critical health effect). An adverse health effect of noise refers to any temporary or long-term deterioration in physical, psychological or social functioning that is associated with noise exposure. The guideline values represent the sound pressure levels that affect the most exposed receiver in the listed environment.

The time base for LAeq for "daytime" and "night-time" is 16 h and 8 h, respectively. No separate time base is given for evenings alone, but typically, guideline value should be 5 –10 dB lower than for a 12 h daytime period. Other time bases are recommended for schools, preschools and playgrounds, depending on activity.

The available knowledge of the adverse effects of noise on health is sufficient to propose guideline values for community noise for the following:

a. Annoyance.
b. Speech intelligibility and communication interference.
c. Disturbance of information extraction.
d. Sleep disturbance.
e. Hearing impairment.

The different critical health effects are relevant to specific environments, and guideline values for community noise are proposed for each environment. These are:

a. Dwellings, including bedrooms and outdoor living areas.
b. Schools and preschools, including rooms for sleeping and outdoor playgrounds.
c. Hospitals, including ward and treatment rooms.
d. Industrial, commercial shopping and traffic areas, including public addresses, indoors and outdoors.
e. Ceremonies, festivals and entertainment events, indoors and outdoors.
f. Music and other sounds through headphones.
g. Impulse sounds from toys, fireworks and firearms.

h. Outdoors in parkland and conservation areas.

It is not enough to characterize the noise environment in terms of noise measures or indices based only on energy summation (e.g. LAeq), because different critical health effects require different descriptions. Therefore, it is important to display the maximum values of the noise fluctuations, preferably combined with a measure of the number of noise events. A separate characterization of noise exposures during night-time would be required. For indoor environments, reverberation time is also an important factor. If the noise includes a large proportion of low frequency components, still lower guideline values should be applied.

Supplementary to the guideline values given in Table 4.1, precautionary recommendations are given in Section 4.2 and 4.3 for vulnerable groups, and for noise of a certain character (e.g. low-frequency components, low background noise), respectively. In Section 3.10, information is given regarding which critical effects and specific environments are considered relevant for vulnerable groups, and what precautionary noise protection would be needed in comparison to the general population.

Table 4.1: Guideline values for community noise in specific environments.

Specific environment	Critical health effect(s)	LAeq [dB]	Time base [hours]	LAmax, fast [dB]
Outdoor living area	Serious annoyance, daytime and evening Moderate annoyance, daytime and evening	55 50	16 16	- -
Dwelling, indoors Inside bedrooms	Speech intelligibility and moderate annoyance, daytime and evening Sleep disturbance, night-time	35 30	16 8	 45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
School class rooms and pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	during class	-
Pre-school bedrooms, indoors	Sleep disturbance	30	sleeping -time	45
School, playground outdoor	Annoyance (external source)	55	during play	-
Hospital, ward rooms, indoors	Sleep disturbance, night-time Sleep disturbance, daytime and evenings	30 30	8 16	40 -
Hospitals, treatment rooms, indoors	Interference with rest and recovery	#1		
Industrial, commercial shopping and traffic areas, indoors and outdoors	Hearing impairment	70	24	110
Ceremonies, festivals and entertainment events	Hearing impairment (patrons:<5 times/year)	100	4	110
Public addresses, indoors and outdoors	Hearing impairment	85	1	110
Music through headphones/ earphones	Hearing impairment (free-field value)	85 #4	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults) Hearing impairment (children)	- -	- -	140 #2 120 #2
Outdoors in parkland and conservation areas	Disruption of tranquillity	#3		

#1: as low as possible;
#2: peak sound pressure (not LAmax, fast), measured 100 mm from the ear;
#3: existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low;
#4: under headphones, adapted to free-field values

5. Noise Management

The goal of noise management is to maintain low noise exposures, such that human health and well-being are protected. The specific objectives of noise management are to develop criteria for the maximum safe noise exposure levels, and to promote noise assessment and control as part of environmental health programmes. This is not always achieved (Jansen 1998). The United Nations′ Agenda 21 (UNCED 1992), as well as the European Charter on Transport, Environment and Health (London Charter 1999), both support a number of environmental management principles on which government policies, including noise management policies, can be based. These include:

a. **The precautionary principle**. In all cases, noise should be reduced to the lowest level achievable in a particular situation. Where there is a reasonable possibility that public health will be damaged, action should be taken to protect public health without awaiting full scientific proof.

b. **The polluter pays principle**. The full costs associated with noise pollution (including monitoring, management, lowering levels and supervision) should be met by those responsible for the source of noise.

c. **The prevention principle**. Action should be taken where possible to reduce noise at the source. Land-use planning should be guided by an environmental health impact assessment that considers noise as well as other pollutants.

The government policy framework is the basis of noise management. Without an adequate policy framework and adequate legislation it is difficult to maintain an active or successful noise management programme. A policy framework refers to transport, energy, planning, development and environmental policies. The goals are more readily achieved if the interconnected government policies are compatible, and if issues which cross different areas of government policy are co-ordinated.

5.1. Stages in Noise Management

A legal framework is needed to provide a context for noise management (Finegold 1998; Hede 1998a). While there are many possible models, an example of one is given in Figure 5.1. This model depicts the six stages in the process for developing and implementing policies for community noise management. For each policy stage, there are groups of 'policy players' who ideally would participate in the process.

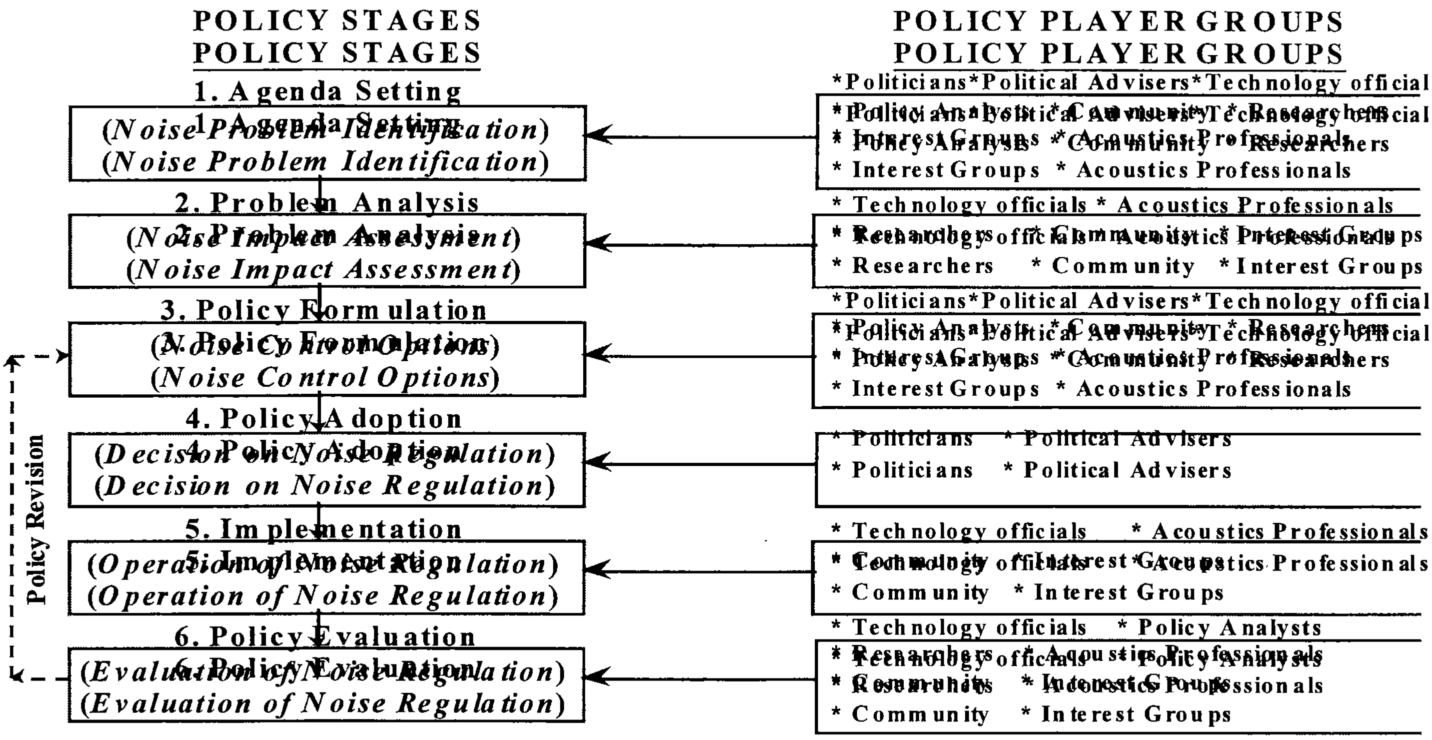

Figure 5.1. A model of the policy process for community noise management (Hede 1998a)

When goals and policies have been developed, the next stage is the development of the strategy or plan. Figure 5.2 summarizes the stages involved in the development of a noise management strategy. Specific abatement measures 19 are listed in Table 5.1.

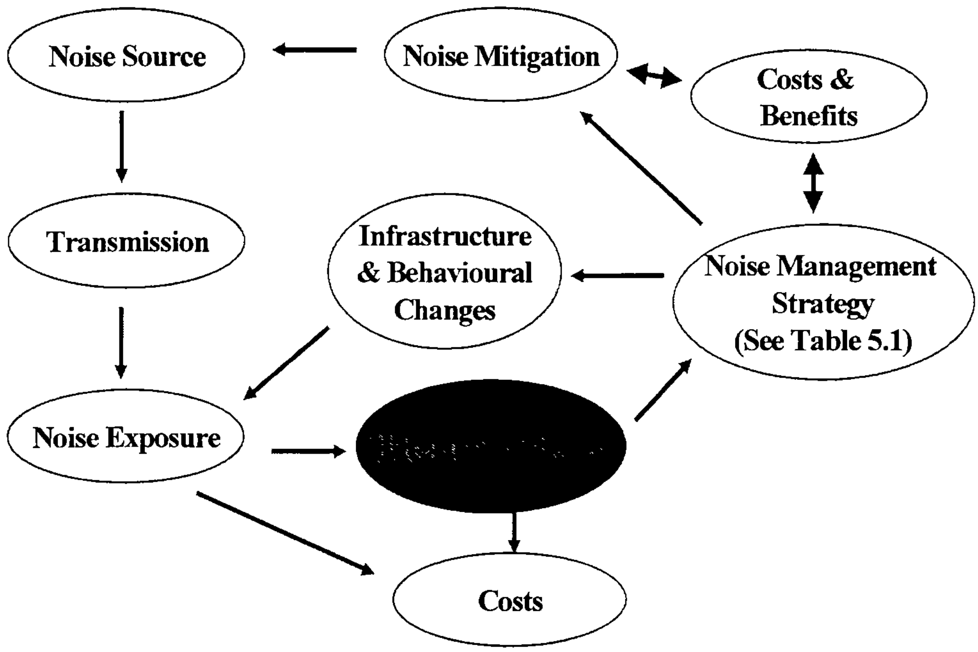

Figure 5.2. Stages involved in the development of a noise abatement strategy.

Table 5.1. Recommended Noise Management Measures (following EEA 1995)

Legal measures	**Examples**
Control of noise emissions	Emission standards for road and off-road vehicles; emission standards for construction equipment; emission standards for plants; national regulations, EU Directives
Control of noise transmission	Regulations on sound-obstructive measures
Noise mapping and zoning around roads, airports, industries	Initiation of monitoring and modeling programmes
Control of noise immissions	Limits for exposure levels such as national immission standards; noise monitoring and modeling; regulations for complex noise situations; regulations for recreational noise
Speed limits	Residential areas; hospitals
Enforcement of regulations	Low Noise Implementation Plan
Minimum requirements for acoustical properties of buildings	Construction codes for sound insulation of building parts
Engineering Measures	
Emission reduction by source modification	Tyre profiles; low-noise road surfaces; changes in engine properties
New engine technology	Road vehicles; aircraft; construction machines
Transmission reduction	Enclosures around machinery; noise screens
Orientation of buildings	Design and structuring of tranquille uses; using buildings for screening purposes
Traffic management	Speed limits; guidance of traffic flow by electronic means
Passive protection	Ear plugs; ear muffs; insulation of dwellings; façade design
Implementation of land-use planning	Minimum distance between industrial, busy roads and residential areas; location of tranquillity areas; by-pass roads for heavy traffic; separating out incompatible functons
Education and information	
Raising public awareness	Informing the public on the health impacts of noise, enforcement action taken, noise levels, complaints
Monitoring and modeling of soundscapes	Publication of results
Sufficient number of noise experts	University or highschool curricula
Initiation of research and development	Funding of information generation according to scientific research needs
Initiation of behaviour changes	Speed reduction when driving; use of horns; use of loudspeakers for advertisements

The process outlined in Figure 5.2 can start with the development of noise standards or guidelines. Ideally, it should also involve the identification and mapping of noise sources and exposed communities. Meteorological conditions and noise levels would also normally be monitored. These data can be used to validate the output of models that estimate noise levels. Noise standards and model outputs may be considered in devising noise control tactics aimed at achieving the noise standards. Before being enforced, current control tactics need to be revised, and if the standards are achieved they need continued enforcement. If the standards are not achieved after a reasonable period of time, the noise control tactics may need to be revised.

National noise standards can usually be based on a consideration of international guidelines, such as these Guidelines for Community Noise, as well as national criteria documents, which consider dose-response relations for the effects of noise on human health. National standards take into account the technological, social, economic, political and other factors specific for the country.

In many cases monitoring may show that noise levels are considerably higher than established guidelines. This may be particularly true in developing countries, and the question has to be raised as to whether national standards should reflect the optimum levels needed to protect human health, when this objective is unlikely to be achieved in the short- or medium-term with available resources. In some countries noise standards are set at levels that are realistically attainable under prevailing technological, social, economic and political conditions, even though they may not be fully consistent with the levels needed to protect human health. In such cases, a staged programme of noise abatement should be implemented to achieve the optimum health protection levels over the long term. Noise standards periodically change after reviews, as conditions in a country change over time, and with improved scientific understanding of the relationship between noise pollution and the health of the population. Noise level monitoring (Chapter 2) is used to assess whether noise levels at particular locations are in compliance with the standards selected.

5.2. Noise Exposure Mapping

A crucial component of a low-noise implementation plan is a reasonably quantitative knowledge of exposure (see Figure 5.2). Exposure should be mapped for all noise sources impacting a community; for example, road traffic, aircraft, railway, industry, construction, festivals and human activity in general. For some components of a noise exposure map or noise exposure inventory, accurate data may be available. In other cases, exposure can be calculated from the characteristics of the mechanical processes. While estimates of noise emissions are needed to develop exposure maps, measurements should be undertaken to confirm the veracity of the assumptions used in the estimates. Sample surveys may be used to provide an overall picture of the noise exposure. Such surveys would take account of all the relevant characteristics of the noise source. For example motor vehicle emissions may be estimated by calculations involving the types of vehicles, their number, their age and the characteristic properties of the road surface.

In developing countries, there is usually a lack of appropriate statistical information to produce noise exposure estimates. However, where action is needed to lower noise levels, the absence of comprehensive information should not prevent the development of provisional noise exposure estimates. Basic information about the exposed population, transport systems, industry and other relevant factors can be used to calculate provisional noise exposures. These can then be used to develop and implement interim noise management plans. The preliminary exposure estimates can be revised as more accurate information becomes available.

5.3. Noise Exposure Modeling

As indicated in Chapter 2 modeling is a powerful tool for the interpolation, prediction and optimization of control strategies. However, models need to be validated by monitoring data. A strength of models is that they enable examination and comparison of the consequences for noise exposure of the implementation of the various options for improving noise. However, the accuracy of the various models available depends on many factors, including the accuracy of the source emissions data and details of the topography (for which a geographical information system may be used). For transportation noise parameters such as the number, type and speed of vehicles, aircraft or trains, and the noise characteristics of each individual event must be known. An example of a model is the annoyance prediction model of the Government of the Netherlands (van den Berg 1996).

5.4. Noise Control Approaches

An integrated noise policy should include several control procedures: measures to limit the noise at the source, noise control within the sound transmission path, protection at the receiver's site, land-use planning, education and raising of public awareness. Ideally, countries should give priority to precautionary measures that prevent noise, but they must also implement measures to mitigate existing noise problems.

5.4.1. Mitigation measures

The most effective mitigation measure is to reduce noise emissions at the source. Therefore, regulations with noise level limits for the main noise sources should be introduced.

Road traffic noise. Limits on the noise emission of vehicles have been introduced in many countries (Sandberg 1995). Such limits, together with the relevant measuring methods, should also be introduced in other regions of the world. Besides these limits a special class of "low-noise trucks" has been introduced in Europe. These trucks follow state-of-the-art noise control and are widely used in Austria and Germany (Lang 1995). Their use is encouraged by economic incentives; for example, low-noise trucks are excepted from a night-time ban on certain routes, and their associated taxes are lower than for other trucks. In Europe, the maximum permissible noise levels range from 69 dBA for motor vehicles to 77 dBA for cars, and 83 dBA for heavy two-wheeled vehicles to 84 dBA for trucks. A number of European Directives give permissible sound levels for motor vehicles and motorcycles (EU 1970; EU 1978; EU 1996a; EU 1997). In addition to noise level limits for new vehicles (type test), noise emissions of vehicles already in use should be controlled regularly. Limits on the sound pressure levels for vehicles reduce the noise emission from the engines.

However, the main noise from traffic on highways is rolling noise. This may be reduced by quiet road surfaces (porous asphalt, "drain asphalt") or by selection of quiet tires. Road traffic noise may also be reduced by speed limits, provided the limits are enforced. For example, reducing the speed of trucks from 90 to 60 km/h on concrete roads would reduce the maximum sound pressure level by 5 dB, and the equivalent sound pressure level by 4 dB. Decreasing the speed of cars from 140 to 100 km/h would result in the same noise reduction (WHO 1995a). In the central parts of cities a speed limit of 30 km/h may be introduced. At 30 km/h cars produce maximum sound pressure levels that are 7 dB lower, and equivalent sound pressure levels that are 5 dB lower, than cars driving at 50 km/h.

Noise emission from road traffic may be further reduced by a night-time ban for all vehicles, or especially for heavy vehicles. Traffic management designed to ensure uniform traffic flow in towns also serves to reduce noise. "Low-noise behaviour" of drivers should be encouraged as well, by advocating defensive driving manners. In some countries, car drivers use their horns frequently, which results in noise with high peak levels. The unnecessary use of horns within cities should be forbidden, especially during night-time, and this rule should be enforced.

Railway noise and noise from trams. The main noise sources are the engine and the wheel-rail contact. Noise at the source can be reduced by well-maintained rails and wheels, and by the use of disc brakes. Sound pressure levels may vary by more than 10 dB, depending on the type of railway material. Replacement of steel wheels by rubber wheels could also reduce noise from railways and trams substantially. Other measures include innovations in engine and track technology (Moehler 1988; Öhrström & Skånberg 1996).

Aircraft noise. The noise emission of aircraft is limited by ICAO Annex 16, Chapter 2 and Chapter 3, which estimates maximum potential sound emissions under certification procedures (ICAO 1993). Aircraft following the norms of Chapter 3 represent the state-of-the-art of noise control of the 1970s. In many countries, non-certified aircraft (i.e. aircraft not fulfilling the ICAO requirements) are not permitted and Chapter 2 aircraft may not be registered again. After the year 2002 only Chapter 3 aircraft will be allowed to operate in many countries.

Similar legislation should be adopted in other countries. The use of low-noise aircraft may also be encouraged by setting noise-related charges (that is, landing charges that are related not only to aircraft weight and capacity, but also to noise emission). Examples of systems for noise-related financial charges are given in OECD 1991 (see also OECD-ECMT 1995). Night-time aircraft movements should be discouraged where they impact residential communities. Particular categories of aircraft (such as helicopters, rotorcraft and supersonic aircraft) pose additional problems that require appropriate controls. For subsonic airplanes two EU Directive give the permissible sound levels (EU 1980; EU 1989).

Machines and Equipment. Noise emission has to be considered a main property of all types of machines and equipment. Control measures include design, insulation, enclosure and maintenance.

Consumers should be encouraged to take noise emission into account when buying a product. Declaring the A-weighted sound power level of a product would assist the consumer in making this decision. The introduction of sound labeling is a major tool for reducing the noise emission of products on the market. For example, within the European Community, "permissible sound levels" and "sound power levels" have to be stated for several groups of machines; for example, lawn mowers, construction machines and household equipment (EU 1984a-f; EU 1986b,c). For other groups of machines sound level data have been compiled and are state-of-the-art with respect to noise control.

A second step would be the introduction of limits on the sound power levels for certain groups of machines, heating and ventilation systems (e.g. construction machines, household appliances). These limits may be set by law, in recommendations and by consumers, using state-of-the-art measurements. There have also been promising developments in the use of active noise control (involving noise cancellation techniques). These are to be encouraged.

Noise control within the sound transmission path. The installation of noise barriers can protect dwellings close to the traffic source. In several European countries noise barrier regulations have been established (WHO 1995b), but in practice they are often not adequately implemented. These regulations must define:

a. Measuring and calculation methods for deriving the equivalent sound pressure level of road or railway traffic, and schemes for determining the effectiveness of the barrier.

b. The sound pressure limits that are to be achieved by installing barriers.

c. The budgetary provisions.

d. The responsible authority.

Noise protection at the receiver's site. This approach is mainly used for existing situations. However, this approach must also be considered for new and, eventually, for old buildings in noisy areas. Residential buildings near main roads with heavy traffic, or near railway lines, may be provided with sound-proofed windows.

5.4.2. Precautionary measures

With careful planning, noise exposure can be avoided or reduced. A sufficient distance between residential areas and an airport will make noise exposure minimal, although the realization of such a situation is not always possible. Additional insulation of houses can help to reduce noise exposure from railroad and road traffic. For new buildings, standards or building codes should describe the positions of houses, as well as the ground plans of houses with respect to noise sources. The required sound insulation of the façades should also be described. Various countries have set standards for the maximum sound pressure levels in front of buildings and for the minimum sound insulation values required for façades.

Land use planning. Land use planning is one of the main tools for noise control and includes:

a. Calculation methods for predicting the noise impact caused by road traffic, railways, airports, industries and others.

b. Noise level limits for various zones and building types. The limits should be based on annoyance responses to noise.

c. Noise maps or noise inventories that show the existing noise situation. The construction of noise-sensitive buildings in noisy areas, or the construction of noisy buildings in quiet areas may thus be avoided.

Suggestions on how to use land use planning tools are given in several dedicated books (e.g. Miller & de Roo 1997). Different zones, such as quiet areas, hospitals, residential areas, commercial and industrial districts, can be characterized by the maximum equivalent sound pressure levels permissible in the zones. Examples of this approach can be found in OECD 1991 (also see OECD-ECMT 1995). More emphasis needs to be given to the design or retrofit of urban centres, with noise management as a priority (e.g. "soundscapes").

It is recommended that countries adopt the precautionary principle in their national noise policies. This principle should be applied to all noise situations where adverse noise effects are either expected or possible, even when the noise is below standard values.

Education and public awareness. Noise abatement policies can only be established if basic knowledge and background material is available, and the people and authorities are aware that noise is an environmental hazard that needs to be controlled. It is, therefore, necessary to include noise in school curricula and to establish scientific institutes to study acoustics and noise control. People working in such institutes should have the option of studying in other countries and exchanging information at international conferences. Dissemination of noise control information to the public is an issue for education and public awareness. Ideally, national and local advisory groups should be formed to promote the dissemination of information, to establish uniform methods of noise measurement and impact assessment, and to participate in the development and implementation of educational and public awareness programmes.

5.5. Evaluation of Control Options

Unless legal constraints in a country prescribe a particular option, the evaluation of control options must take into account technical, financial, social, health and environmental factors. The speed with which control options can be implemented, and their enforceability, must also be considered. Although considerable improvements in noise levels have been achieved in some developed countries, the financial costs have been high, and the resource demands of some of these approaches make them unsuitable for the poorer developing countries.

Technical factors. There needs to be confidence that the selected options are technically practical given the resources of the region. It must be possible to bring a selected option into operation, and maintain the expected level of performance in the long term, given the resources available. This may require regular staff training and other programmes, especially in developing countries.

Financial factors. The selected options must be financially viable in the long term. This may require a comparative cost-benefit assessment of different options. These assessments must include not only the capital costs of bringing an option into operation, but also the costs of maintaining the expected level of performance in the long term.

Social factors. The costs and benefits of each option should be assessed for social equity, and the potential impact of an option on people's way of life, community structures and cultural traditions must be considered. Impacts may include disruption or displacement of residents, changes of land-use, and impacts on community, culture and recreation. Some impacts can be managed; in other cases, the impacts of an option can be mitigated by substitution of resources or uses.

Health and environmental factors. The costs and benefits of each option should be assessed for health and environmental factors. This may involve use of dose-response relations, or risk assessment techniques.

Effect-oriented and source-oriented principles. Noise control requirements in European countries are typically determined from the effects of noise on health and the environment (effect oriented) (e.g. Gottlob 1995; ten Wolde 1998). Increased noise emissions may be permitted if there would be no adverse health impacts, or if noise standards would not be exceeded. Action may be taken to reduce noise levels when it is shown that adverse health impacts will occur, or when noise levels exceed limits. Other countries base their noise management policies on the requirement for best available technology, or for best available techniques that do not entail excessive cost (source-oriented) (e.g. for aircraft noise, ICAO 1993; for road traffic noise, Sandberg 1995). Most developed countries apply a combination of both source-oriented and effect-oriented principles (EU 1996b; Jansen 1998; ten Wolde 1998).

5.6. Management of Indoor Noise

In modern societies, human beings spend most of their time in indoor environments. Pollution and degradation of the indoor environment cause illness, increased mortality, loss of productivity, and have major economic and social implications. Indoor noise problems are related to inadequate urban planning, design, operation and maintenance of buildings, and to the materials and equipment in buildings. Problems with indoor noise affect all types of buildings, including homes, schools, offices, health care facilities and other public and commercial buildings. The health effects of indoor noise include an increase in the rates of diseases and disturbances described in chapter 2. World-wide, the medical and social cost associated with these illnesses, and the related reduction in human productivity, can result in substantial economic losses.

Protection against noise generated within a building, or originating from outside the building, is a very complex problem. Soundproofing of ceilings, walls, doors and windows against airborne noise is important. Soundproofing of ceilings has to be sufficient to absorb sounds due to treading. Finally, noise emissions from the technological devices in the house must be sufficiently low. Governments should provide measurement protocols and data for use in reducing noise exposures in buildings. Governments should also be encouraged to support research on the relationship between noise levels inside buildings and health effects.

5.6.1. Government policy on indoor noise

Many of the problems associated with high noise levels can be prevented at low cost if governments develop and implement an integrated strategy for the indoor environment, in concert with all social and economic partners. Governments should establish a "National Plan for a Sustainable Indoor Noise Environment", that would apply to new construction as well as to existing buildings. Governments should set up a specific structure at an appropriate governmental level to achieve acceptable sound exposure levels within buildings. An example of existing documents that provide guidance and regulations, including strategies and management for the design of buildings, is given by Jansen & Gottlob (1996).

Guidance/education. Because our understanding of indoor noise is still developing, government activity should be focused on raising the awareness of various audiences. This education can take the form of providing general information, as well as providing technical guidance and training on how to minimize indoor noise levels. General information presented in the form of documents, videos, and other media can bring indoor noise issues to the attention of the general public and building professionals, including architects

Research support. Research is needed to develop technology for indoor noise diagnosis, mitigation and control. Efforts are also required to provide economical and practical alternatives for mitigation and control. Better means of measuring the effectiveness of absorption devices are needed; and diagnostic tools that are inexpensive and easy to use also need to be developed to help facility personnel. There is a particular need, too, for improving soundproofing methods, their implementation and for predicting the health effects of soundproofing techniques.

To provide accurate information for use in setting priorities for public health problems, governments should support problem assessment and surveys of indoor noise conditions. Building surveys are also necessary to provide baseline information about building characteristics and noise levels. When combined with occupant health surveys, these studies will help to establish the correlations between noise levels and adverse health effects. Surveys should be conducted to identify building types or vintages in which problems occur more frequently. The results of these studies will support effective risk reduction programmes. Epidemiological studies are also needed to aid in differentiating between noise-related symptoms and those due to other causes. Moreover, epidemiological studies are needed to assist in quantifying the extent of risk for indoor noise levels.

Economic research is needed to measure the costs of indoor noise control strategies to individuals, businesses and society. This includes developing methods for quantifying productivity loss and increased health costs due to noise, and for measuring the costs of various control strategies, including increased soundproofing and source control.

Development of standards and protocols. Efforts should be made to protect public health by setting reasonable noise exposure limits (immission standards) from known dose-response relationships. In cases where dose-response relationships have yet to be determined, but where health effects are generally recognized, exposure limits should be set conservatively and take into account risk, economic impact and feasibility. Efforts should also be made to incorporate noise-related specifications into building codes. Areas to target with building codes include ventilation design, building envelope design, site preparation, materials selection and commissioning. Standards and other regulations governing the use of sound proofing materials should also be developed.

Individuals involved in the diagnosis and mitigation of indoor noise problems should be trained in the multidisciplinary nature of the noise field. By instituting a series of credentials that recognize and highlight areas of expertise, consumers would be provided with the information to make informed choices when procuring indoor noise services. Companies which provide such services should be officially accredited. Guidelines or standards for sound emissions of air-conditioners, power generators and other building devices, would also provide useful information for manufacturers, architects, design engineers, building managers and others who play a role in selecting products used indoors.

5.6.2. Design considerations

Site investigation. Potential sites should be evaluated to determine whether they are prone to indoor noise problems. This evaluation should be consistent with national and local land use planning guidelines. Sites should be investigated to determine past uses and whether any sources of sound remain as a result. The potential for outdoor noise being carried to the site from adjacent areas, such as busy streets, should also be evaluated.

Building design. Buildings should be designed to be soundproof, to improve control over indoor noise. Soundproofing requires that outside noise be prevented from entering the building, and this should be estimated as part of the architectural and engineering design process. When soundproofing for outdoor noise, the total indoor noise load and the desired quality of the indoor space should be considered. Adequate soundproofing against outdoor noise is important in residential as well as commercial properties, and should be re-evaluated when interior spaces are rebuilt or renovated.

Indoor Spaces. The architectural layout should aim to reduce noise and provide a good sound quality to the space. This would include designing indoor spaces to have sufficiently short reverberation times. Designers and contractors should be encouraged to use sound-absorbing materials that lead to lower indoor noise levels, and materials with the best sound-absorbing properties should be specified. However, use of these materials should not be the only solution (Harris 1991). Possible conflicts with other environmental demands should also be identified; for example, the special demands by allergic people.

5.6.3. Indoor noise level control

Building maintenance personnel should be trained to understand the indoor noise aspects of their work, and be aware of how their work can directly impact the health and comfort of occupants. Many maintenance activities directly affect indoor noise levels, and some may indicate potential problems. Preventive maintenance is essential for the building systems to operate correctly and to provide suitable comfort conditions and low indoor noise levels. Detailed maintenance logs should be kept for all equipment. A schedule should be developed for routine equipment checks and calibration of control system components. Selection of low-noise domestic products should encouraged as far as is possible.

5.6.4. Resolving indoor noise problems

Addressing occupant complaints and symptoms. When complaints are received from occupants of a building, the cognizant authority should be responsive. The initial investigation into the cause of the complaint may be conducted by the in-house management staff, and they should continue an investigation as far as possible. If necessary, they should be responsible for hiring an outside consultant

Building diagnostic procedures. After receiving complaints related to indoor noise levels, facility personnel or consultants should attempt to identify the cause of the problem through an iterative process of information collection and hypothesis testing. To begin, a walkthrough inspection of the building, including the affected areas and the mechanical systems serving these spaces is required. A walkthrough can provide information on the soundproofing system of the building, the sound pathways and sound sources. Visual indicators of sound sources and soundproofing malfunctions should be evaluated first. Symptom logs and schedules of building activities may provide enough additional information to resolve the problem.

If a walkthrough alone does not provide a solution, measurements of sound pressure levels at various locations should be taken, and indoor and ambient levels of noise pollution should be compared. As part of the investigation, the absorption characteristics of walls and ceilings should be evaluated. Sophisticated sampling methods may be necessary to provide proof of a problem to the building owner or other responsible party. The results may be used to confirm a hypothesis or ascertain the source of the indoor noise problem. Whenever a problem is discovered during the investigation, a remedy to the situation should be attempted and a determination made of whether the complaint has been resolved.

In some cases, it should be recognized that difficulties in interpreting the sampling results may exist. The costs of certain types of testing should also be taken into account. Simple, cost-effective screening methods should be developed to make sampling a more attractive option for both investigators and clients. Finally, it must be remembered that several factors cause symptoms similar to those induced by noise pollution. Examples include air pollutants, ergonomics, lighting, vibration and psychosocial factors. Consequently, any investigation of noise complaints should also evaluate non-noise factors.

5.7. Priority Setting in Noise Management

Priorities in noise management will differ between countries, according to policy objectives, needs and capabilities. Priority setting in noise management refers to prioritizing health risks and concentrating on the most important sources of noise. For effective noise management, the goals, policies and noise control schemes have to be defined. Goals for noise management include eliminating noise, or reducing noise to acceptable levels, and avoiding the adverse health effects of noise on human health. Policies for noise management encompass laws and regulations for setting noise standards and for ensuring compliance. The amount of information to be included in low-noise implementation plans and the use of cost-benefit comparisons also fall within the purview of noise management policies. Techniques for noise control include source control, barriers in noise pathways and receiver protection. Adequate calculation models for noise propagation, as well as programmes for noise monitoring, are part of an overall noise control scheme.

As emphasized above, a framework for a political, regulatory and administrative approach is required to guarantee the consistent and transparent promulgation of noise standards. This ensures a sound and practical framework for risk-reducing measures and for the selection of abatement strategies.

5.7.1. Noise policy and legislation

Noise is both a local and a global problem. Governments in every country have a responsibility to set up policies and legislation for controlling community noise. There is a direct relationship between the level of development in a country and the degree of noise pollution impacting its people. As a society develops, it increases its level of urbanization and industrialization, and the extent of its transportation system. Each of these developments brings an increase in noise load. Without appropriate intervention the noise impact on communities will escalate (see Figure 5.3). If governments implement only weak noise policies and regulations, they will not be able to prevent a continuous increase in noise pollution and associated adverse health effects. Failure to enforce strong regulations is ineffective in combating noise as well.

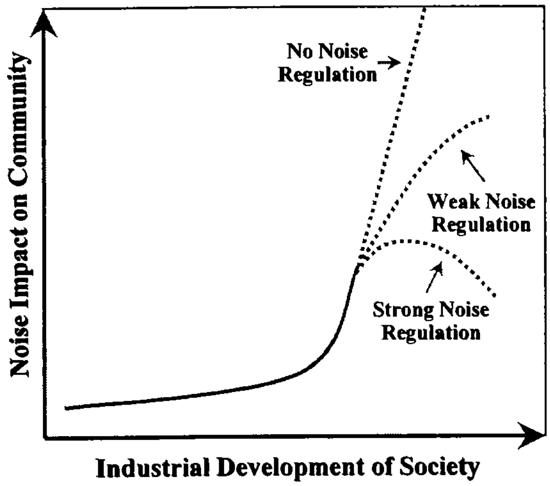

Figure 5.3. Relationship between noise regulation and impact with development (from Hede 1998b)

Policies for noise regulatory standards at the municipal, regional, national and supranational levels are usually determined by the legislatures. The regulatory standards adopted strongly depend on the risk management strategies of the legislatures, and can be influenced by sociopolitical considerations and/or international agreements. Although regulatory standards may be country specific, in general the following issues are taken into consideration:

a. Identification of the adverse public health effects that are to be avoided.

b. Identification of the population to be protected.

c. The type of parameters describing noise and the limit applicable to the parameters.

d. Applicable monitoring methodology and its quality assurance.

e. Enforcement procedures to achieve compliance with noise regulatory standards within a defined time frame.

f. Emission control measures and emission regulatory standards.

g. Immission standards (limits for sound pressure levels).

h. Identification of authorities responsible for enforcement.

i. Resource commitment.

Regulatory standards may be based solely on scientific and technical data showing the adverse effects of noise on public health. But other aspects are usually considered, either when setting standards or when designing appropriate noise abatement measures. These other aspects include the technological feasibility, costs of compliance, prevailing exposure levels, and the social, economic and cultural conditions. Several standards may be set. For example, effect-oriented regulatory standards may be set as a long-term goal, while less-stringent standards are adopted for the short term. As a consequence, noise regulatory standards differ widely from country to country (WHO 1995a; Gottlob 1995).

Noise regulatory standards can set the reference point for emission control and abatement policies at the national, regional or municipal levels, and can thus strongly influence the implementation of noise control policies. In many countries, exceeding regulatory standards is linked to an obligation to develop abatement action plans at the municipal, regional or national levels (low-noise implementation plans). Such plans have to address all relevant sources of noise pollution.

5.7.2. Examples of noise policies

Different countries have adopted a range of policies and regulations for noise control. A number of these are outlined in this section as examples.

Argentina. In Argentina, a national law recently limited the daily 8-h exposure to industrial noise to 80 dB, and it has had beneficial effects on hearing impairment and other hearing disorders among workers. In general, industry has responded by introducing constant controls on noise sources, combined with hearing tests and medical follow-ups for workers. Factory owners have recruited permanent health and safety engineers who control noise, supply advice on how to make further improvements, and routinely assess excessive noise levels. The engineers also provide education in personal protection and in the correct use of ear plugs, mufflers etc.

At the municipal level two types of noise have been considered. Unnecessary noise, which is forbidden; and excessive noise, which is defined for neighbourhood activities (zones), and for which both day and night-time maximum limits have been introduced. The results have been relatively successful in mitigating unwanted noise effects. At the provincial level, similar results have been accomplished for many cities in Argentina and Latin America.

Australia. In Australia, the responsibility for noise control is shared primarily by state and local governments. There are nationally-agreed regulatory standards for airport planning and new vehicle noise emissions. The Australian Noise Exposure Forecast (ANEF) index is used to describe how much aircraft noise is received at locations around an airport (DoTRS 1999). Around all airports, planning controls restrict the construction of dwellings within the 25 ANEF exposure contour and require sound insulation for those within 20 ANEF. Road traffic noise limits are set by state governments, but vary considerably in both the exposure metric and in maximum allowable levels. New vehicles are required to comply with stringent design rules for noise and air emissions. For example, new regulation in New South Wales adopts LAeq as the metric and sets noise limits of 60 dBA for daytime, and 55 dBA for night-time, along new roads. Local governments set regulations restricting noise emissions for household equipment, such as air conditioners, and the hours of use for noisy machines such as lawn mowers.

Europe. In Europe, noise legislation is not generally enforced. As a result, environmental noise levels are often higher than the legislated noise limits. Moreover, there is a gap between long-term political goals and what represents a "good acoustical environment". One reason for this gap is that noise pollution is most commonly regulated only for new land use or for the development of transportation systems, whereas enlargements at existing localities may be approved even though noise limits or guideline values are already surpassed (Gottlob 1995). A comprehensive overview of the noise situation in Europe is given in the Green Paper (EU 1996b), which was established to give noise abatement a higher priority in policy making. The Green Paper outlines a new framework for noise policy in Europe with the following options for future action:

a. Harmonizing the methods for assessing noise exposure, and encouraging the exchange of information among member states.

b. Establishing plans to reduce road traffic noise by applying newer technologies and fiscal instruments.

c. Paying more attention to railway noise in view of the future extension of rail networks.

d. Introducing more stringent regulation on air transport and using economic instruments to encourage compliance.

e. Simplifying the existing seven regulations on outdoor equipment by proposing a Framework Directive that covers a wider range of equipment, including construction machines and others.

Pakistan. In Pakistan, the Environmental Protection Agency is responsible for the control of air pollution nationwide. However, only recently have controls been enforced in Sindh in an attempt to raise public awareness and carry out administrative control on road vehicles producing noise (Zaidi, personal communication).

South Africa. In South Africa, noise control is three decades old. It began with codes of practice issued by the South African Bureau of Standards to address noise pollution in various sectors of the country (e.g. see SABS 1994 1996; and the contribution of Grond in Appendix 2). In 1989, the Environment Conservation Act made provision for the Minister of Environmental Affairs and Tourism to make regulations for noise, vibration and shock (DEAT 1989). These regulations were published in 1990 and local authorities could apply to the Minister to make them applicable in their areas. Later, the act was changed to make it obligatory for all authorities to apply the regulations. However, according to the new Constitution of South Africa of 1996, legislative responsibility for noise control rests exclusively with provincial and local authorities. The noise control regulations will apply to local authorities in South Africa as soon as they are published in the provinces. This will not only give local authorities the power to enforce the regulations, but also place an obligation on them to see that the regulations are enforced.

Thailand. In 1996, noise pollution regulations in Thailand stipulated that not more than 70 dBA $L_{Aeq,24h}$ should be allowed in residential areas, and the maximum level of noise in industry should be no more than 85 dBA Leq 8h (Prasansuk 1997).

United States of America. Environmental noise was not addressed as a national policy issue in the USA until the implementation of the Noise Control Act of 1972. This congressional act directed the US Environmental Protection Agency to publish scientific information about noise exposure and its effects, and to identify acceptable levels of noise exposure under various conditions. The Noise Control Act was supposed to protect the public health and well-being with an adequate margin of safety. This was accomplished in 1974 with the publication of the US EPA "Levels Document" (US EPA 1974). It addressed issues such as the use of sound descriptions to describe sound exposure, the identification of the most important human effects resulting from noise exposure, and the specification of noise exposure criteria for various effects. Subsequent to the publication of the US EPA "Levels Document", guidelines for conducting environmental impact analysis were developed (Finegold et al. 1998). The day-night average sound level was thus established as the predominant sound descriptor for most environmental noise exposure.

It is evident from these examples that noise policies and regulations vary considerably across countries and regions. Moves towards global noise policies need to be encouraged to ensure that the world population gains the maximum health benefits from new developments in noise control.

5.7.3. Noise emission standards have proven to be inadequate

Much of the progress towards solving the noise pollution problem has come from advanced technology, which in turn has come about mainly as a result of governmental regulations (e.g. OECD-ECMT 1995). So far, however, the introduction of noise emission standards for vehicles has had limited impact on exposure to transportation noise, especially from aircraft and road traffic noise (Sandberg 1995). In part, this is because changes in human behaviour (of polluters, planners and citizens) have tended to offset some of the gains made. For example, mitigation efforts such as developing quieter vehicles, moving people to less noise-exposed areas, improving traffic systems and direct noise abatement and control (sound insulation, barriers etc.), have been counteracted by increases in the number of roads and highways built, by the number of traffic movements, and by higher driving speeds and the number of kilometers driven (OECD 1991; OECD-ECMT 1995).

Traffic planning and correction policies may diminish the number of people exposed to the very high community noise levels (>70 dB LAeq), but the number exposed to moderately high levels (55-65 dB LAeq) continues to increase in industrialized countries (Stanners & Bordeau 1995). In developing countries, exposure to excessive sound pressure levels (>85 dB LAeq), not only from occupational noise but also from urban, environmental noise, is the major avoidable cause of permanent hearing impairment (Smith 1998). Such sound pressure levels can also be reached by leisure activities at concerts, discotheques, motor sports and shooting ranges; by music played back in headphones; and by impulse noises from toys and fireworks.

A substantial growth in air transport is also expected in the future. Over the next 10 years large international airports may have to accommodate a doubling in passenger movements. General aviation noise at regional airports is also expected to increase (Large & House 1989). Although jet aircraft are expected to become less noisy due to regulation of noise emissions (ICAO 1993), the number of passengers is expected to increase. Increased air traffic movement between 1980 and 1990 is considered to be the main reason for the average 22% increase in the number of people exposed to noise above 67 dB LAeq at German airports (OECD 1993).

5.7.4. Unsustainable trends in noise pollution future policy planning

A number of trends are expected to increase environmental noise pollution, and are considered to be unsustainable in the long term. The OECD (1991) identified the following factors to be of increasing importance in the future:

a. The expanding use of increasingly powerful sources of noise.

b. The wider geographical dispersion of noise sources, together with greater individual mobility and spread of leisure activities.

c. The increasing invasion of noise, particularly into the early morning, evenings and weekends.

d. The increasing public expectations that are closely linked to increases in incomes and in education levels.

Apart from these, increased noise pollution is also linked to systemic changes in business practices (OECD-ECMT 1995). By accepting a just-in-time concept in transportation, products and components are stored in heavy-duty vehicles on roads, instead of in warehouses; and workers are recruited as temporary consultants just in time for the work, instead of as long-term employees.

In addition, the OECD (1991) report forecasts:

a. A strengthening of present noise abatement policies and their applications.

b. A further sharpening of emission standards.

c. A co-ordination of noise abatement measures and transport planning, to specifically reduce mobility.

d. A co-ordination of noise abatement measures with urban planning.

Planners need to know the likely effects of introducing a new noise source, or of increasing the level of an existing source, on the noise pollution in a community. Policy makers, when considering applications for new developmental projects, must take into account maximum levels, continuous equivalent sound pressure levels of both the background and the new noise source, the frequency of noise occurrence and the operating times of major noise sources.

5.7.5. Analysis of the impact of environmental noise

The concept of an environmental noise impact analysis (ENIA) is central to the philosophy of managing environmental noise. An ENIA should be required before implementing any project that would significantly increase the level of environmental noise in a community (typically, greater than a 5dB increase). The first step in performing an ENIA is to develop a baseline description of the existing noise environment. Next, the expected level of noise from a new source is added to the baseline exposure level to produce the new overall noise level. If the new total noise level is expected to cause an unacceptable impact on human health, trade-off analyses should then be performed to assess the cost, technical feasibility and community acceptance of noise mitigation measures. It is strongly recommended that countries develop standardized procedures for performing ENIAs (Finegold et al. 1998; SABS 1998).

Assessment of adverse health effects. In setting noise standards (for example on the basis of these guidelines), the adverse health effects from which the population is to be protected need to be defined. Health effects range from hearing impairment to sleep disturbance, speech interference to annoyance. The distinction between adverse and non-adverse effects sometimes poses considerable difficulties. Even the elaborate definition of an adverse health effect given in Chapter 3 incorporates significant subjectivity and uncertainty. More serious noise effects, such as hearing impairment or permanent threshold shift, are generally accepted as adverse. Consideration of health effects that are both temporary and reversible, or that involve functional changes with uncertain clinical significance, requires a judgement on whether these less-serious effects should be considered when deriving guideline values. Judgements as to the adversity of health effects may differ between countries, because of factors such as cultural backgrounds and different levels of health status.

Estimation of the population at risk. The population at risk is that part of the population in a given country or community that is exposed to enhanced levels of noise. Each population has sensitive groups or subpopulations that are at higher risk of developing health effects due to noise exposure. Sensitive groups include individuals impaired by concurrent diseases or other physiological limitations and those with specific characteristics that makes them more vulnerable to noise (e.g. premature babies; see the contribution of Zaidi in Appendix 2). The sensitive groups in a population may vary across countries due to differences in medical care, nutritional status, lifestyle and demographic factors, prevailing genetic factors, and whether endemic or debilitating diseases are prevalent.

Calculation of exposure-response relationships. In developing standards, regulators should consider the degree of uncertainty in the exposure-response relationships provided in the noise guidelines. Differences in the population structure (age, health status), climate (temperature, humidity) and geography (altitude, environment) can influence the prevalence and severity of noise-related health effects. In consequence, modified exposure-response relationships may need to be applied when setting noise standards.

Assessment of risks and their acceptability. In the absence of distinct thresholds for the onset of health effects, regulators must determine what constitutes an acceptable health risk for the population and select an appropriate noise standard to protect public health. This is also true in cases where thresholds are present, but where it would not be feasible to adopt noise guidelines as standards because of economical and/or technical constraints. The acceptability of the risks involved, and hence the standards selected, will depend on several factors. These include the expected incidence and severity of the potential effects, the size of the population at risk, the perception of related risks, and the degree of scientific uncertainty that the effects will occur at any given noise level. For example, if it is suspected that a health effect is severe and the size of the population at risk is large, a more cautious approach would be appropriate than if the effect were less troubling, or if the population were smaller.

Again, the acceptability of risk may vary among countries because of differences in social norms, and the degree of adversity and risk perception by the general population and stakeholders. Risk acceptability is also influenced by how the risks associated with noise compare with risks from other pollution sources or human activities.

5.7.6. Cost-benefit analysis

In the derivation of noise standards from noise guidelines two different approaches for decision making can be applied. Decisions can be based purely on health, cultural and environmental consequences, with little weight to economic efficiency. This approach has the objective of reducing the risk of adverse noise effects to a socially acceptable level. The second approach is based on a formal cost-effectiveness, or cost-benefit analysis (CBA). The objective is to identify control actions that achieve the greatest net economic benefit, or are the most economically efficient. The development of noise standards should account for both extremes, and involve stakeholders and assure social equity to all the parties involved. It should also provide sufficient information to guarantee that stakeholders understand the scientific and economic consequences.

To determine the costs of control action, the abatement measures used to reduce emissions must be known. This is usually the case for direct measures at the source and these measures can be monetarized. Costs of action should include all costs of investment, operation and maintenance. It may not be possible to monetarize indirect measures, such as alternative traffic plans or change in behaviour of individuals.

The steps in a cost-benefit analysis include:

a. The identification and cost analysis of control action (such as emission abatement strategies and tactics).

b. An assessment of noise and population exposure, with and without the control action.

c. The identification of benefit categories, such as improved health and reduced property loss.

d. A comparison of the health effects, with and without control action.

e. A comparison of the estimated costs of control action with the benefits that accrue from such action.

f. A sensitivity and uncertainty analysis.

Action taken to reduce one pollutant may increase or decrease the concentration of other pollutants. These additional effects should be considered, as well as pollutant interactions that may lead to double counting of costs or benefits, or to disregarding some costly but necessary action. Due to different levels of knowledge about the costs of control action and health effects, there is a tendency to overestimate the cost of control action and underestimate the benefits.

CBA is a highly interdisciplinary task. Appropriately applied, it is a legitimate and useful way of providing information for managers who must make decisions that impact health. CBA is also an appropriate tool for drawing the attention of politicians to the benefits of noise control. In any case, however, a CBA should be peer-reviewed and never be used as the sole and overriding determinant of decisions.

5.7.7. Review of standard setting

The setting of standards should involve stakeholders at all levels (industry, local authorities, non-governmental organizations and the general public), and should strive for social equity or fairness to all parties involved. It should also provide sufficient information to guarantee that the scientific and economic consequences of the proposed standards are clearly understood by the stakeholders. The earlier that stakeholders are involved, the more likely is their co-operation. Transparency in moving from noise guidelines to noise standards helps to increase public acceptance of necessary measures. Raising public awareness of noise-induced health effects (changing of risk perception) also leads to a better understanding of the issues involved (risk communication) and serves to obtain public support for necessary control action, such as reducing vehicle emissions. Noise standards should be regularly reviewed, and revised as new scientific evidence emerges.

5.7.8. Enforcement of noise standards: Low-noise implementation plans

The main objective of enforcing noise standards is to achieve compliance with the standards. The instrument used to achieve this goal is a Low-Noise Implementation Plan (LNIP). The outline of such a plan should be defined in the regulatory policies and should use the tactical instruments discussed above. A typical low-noise implementation plan includes:

a. A description of the area to be regulated.

b. An emissions inventory.

c. A monitored or simulated inventory of noise levels.

d. A comparison of the plan with emissions and noise standards or guidelines.

e. An inventory of the health effects.

f. A causal analysis of the health effects and their attribution to individual sources.

g. An analysis of control measures and their costs.

h. An analysis of transportation and land-use planning.

i. Enforcement procedures.

j. An analysis of the effectiveness of the noise management procedures.

k. An analysis of resource commitment.

l. Projections for the future.

As the LNIP also addresses the effectiveness of noise control technologies and policies, it is very much in line with the Noise Control Assessment Programme (NCAP) proposed recently (Finegold et al. 1999).

5.8. Conclusions on Noise Management

Successful noise management should be based on the fundamental principles of precaution, the polluter pays and prevention. The noise abatement strategy typically starts with the development of noise standards or guidelines, and the identification, mapping and monitoring of noise sources and exposed communities. A powerful tool in developing and applying the control strategy is to make use of modeling. These models need to be validated by monitoring data. Noise parameters relevant to the important sources of noise must be known. Indoor noise exposures present specific and complex problems, but the general principles for noise management hold. The main means for noise control in buildings include careful site investigations, adequate building designs and building codes, effective means for addressing occupant complaints and symptoms, and building diagnostic procedures.

Noise control should include measures to limit the noise at the source, to control the sound transmission path, to protect the receiver's site, to plan land use, and to raise public awareness. With careful planning, exposure to noise can be avoided or reduced. Control options should take into account the technical, financial, social, health and environmental factors of concern. Cost-benefit relationships, as well as the cost-effectiveness of the control measures, must be considered in the context of the social and financial situation of each country. A framework for a political, regulatory and administrative approach is required for the consistent and transparent promulgation of noise standards. Examples are given for some countries, which may guide others in their development of noise policies.

Noise management should:

a. Start monitoring human exposures to noise.

b. Have health control require mitigation of noise emissions. The mitigation procedures should take into consideration specific environments such as schools, playgrounds, homes and hospitals; environments with multiple noise sources, or which may amplify the effects of noise; sensitive time periods, such as evenings, nights and holidays; and groups at high risk, such as children and the hearing impaired.

c. Consider noise consequences when making decisions on transport-system and land-use planning.

d. Introduce surveillance systems for noise-related adverse health effects.

e. Assess the effectiveness of noise policies in reducing noise exposure and related adverse health effects, and in improving supportive "soundscapes."

a. Adopt these Guidelines for Community Noise as long-term targets for improving human health.

g. Adopt precautionary actions for sustainable development of acoustical environments.

6. Conclusions And Recommendations

6.1. Implementation of the Guidelines

The potential health effects of community noise include hearing impairment; startle and defense reactions; aural pain; ear discomfort speech interference; sleep disturbance; cardiovascular effects; performance reduction; and annoyance responses. These health effects, in turn, can lead to social handicap; reduced productivity; decreased performance in learning; absenteeism in the workplace and school; increased drug use; and accidents. In addition to health effects of community noise, other impacts are important such as loss of property value. In these guidelines the international literature on the health effects of community noise was reviewed and used to derive guideline values for community noise. Besides the health effects of noise, the issues of noise assessment and noise management were also addressed. Other issues considered were priority setting in noise management; quality assurance plans; and the cost-efficiency of control actions. The aim of the guidelines is to protect populations from the adverse health impacts of noise.

The following recommendations were considered appropriate:

a. Governments should consider the protection of populations from community noise as an integral part of their policy for environmental protection.

b. Governments should consider implementing action plans with short-term, medium-term and long-term objectives for reducing noise levels.

c. Governments should adopt the health guidelines for community noise as targets to be achieved in the long-term.

h. Governments should include noise as an important issue when assessing public health matters and support more research related to the health effects of noise exposure.

f. Legislation should be enacted to reduce sound pressure levels, and existing legislation should be enforced.

g. Municipalities should develop low-noise implementation plans.

h. Cost-effectiveness and cost-benefit analyses should be considered as potential instruments when making management decisions.

i. Governments should support more policy-relevant research into noise pollution (see section 6.3).

6.2. Further WHO Work on Noise

The WHO Expert Task Force proposed several issues for future work in the field of community noise. These are:

a. The WHO should consider updating the guidelines on a regular basis.

b. The WHO should provide leadership and technical direction in defining future research priorities into noise.

c. The WHO should organize workshops on the application of the guidelines.

d. The WHO should provide leadership and co-ordinate international efforts to develop techniques for the design of supportive sound environments (e.g. 'soundscapes").

e. The WHO should provide leadership for programmes to assess the effectiveness of health-related noise policies and regulations.

f. The WHO should provide leadership and technical direction for the development of sound methodologies for EIAP and EHIAP.

g. The WHO should encourage further investigation into using noise exposure as an indicator of environmental deterioration, such as found in black spots in cities.

a. The WHO should provide leadership, technical support and advice to developing countries, to facilitate the development of noise policies and noise management.

6.3. Research Needs

In the publication entitled "Community Noise", examples of essential research and development needs were given (Berglund & Lindvall 1995). In part, the scientific community has already addressed these issues.

A major step forward in raising public awareness and that of decision makers is the recommendation of the present Expert Task Force to concentrate more **on variables which have monetary consequences. This means that research should consider the dose-response relationships between sound pressure levels and politically relevant variables, such as noise-induced social handicap, reduced productivity, decreased performance in learning, workplace and school absenteeism, increased drug use and accidents.**

There is also a need for continued efforts to understand community noise and its effects on the health of the world population. Below is a list of essential research needs in non-prioritized order. Research priorities may vary over time and by place and capabilities. The main goal in suggesting these research activities is to improve the scientific basis for policy-making and noise management. This will protect and improve the public health with regard to the effects of community noise pollution.

Research related to measurement and monitoring systems for health effects

- Development of a global noise impact monitoring study. The study should be designed to obtain longitudinal data across countries on the health effects on communities of various types of environmental noise. A baseline survey could be undertaken in both developed and developing countries and monitoring surveys conducted every 3-5 years. Since a national map of noise exposure from all sources would be prohibitively expensive, periodic surveys of a representative sample of about 1000 people (using standard probability techniques) could be reliably generalized to the whole population of a country with an accuracy of plus-or-minus 3%. A small number of standard questions could be used across countries to obtain comparative data on the impact of all the main types of noise pollution.
- Development of continuous monitoring systems for direct health effects in critical locations.
- Development of standardized methods for low-cost assessment of local sound levels by measurement or model calculations.
- Development of instruments appropriate for local/regional surveys of people's perceptions of their noise/sound environments.
- Protocols for reliable measurements of high-frequency hearing (8000 Hz and above) and for evaluation of such measures as early biomarkers for hearing impairment/deficits.

Research related to combined noise sources and combined health effects

- Research into the combined health effects of traffic noise, with emphasis on the distribution of sound levels over time and over population sub-environments (time-activity pattern).
- Comprehensive studies on combined noise sources and their combinations of health effects in the 3 large areas of transport (road, rail and aircraft).
- Procedures for evaluating the various health effects of complex combined noise exposures over 24 hours on vulnerable groups and on the general population.
- Methods for assessing the total health effect from noise immission (and also other pollution) in sensitive areas (for example, airports, city centers and heavily-trafficked highways)

Research related to direct and/or long-term health effects (sensitive risk groups, sensitive areas and combined exposures)

- Identification of potential risk groups, including identification of sensitive individuals (such as people with particular health problems; people dealing with complex cognitive tasks; the blind; the hearing impaired; young children and the elderly), differences between sexes, discrimination of risk among age groups, and influence of transportation noise on pregnancy course and on fetal development.
- Studies of dose-response relationships for various effects, and for continuous transportation noise at relatively low levels of exposure and low number of noise events per unit time (including traffic flow composition).
- Studies on the perception of control of noise exposure, genetic traits, coping strategies and noise annoyance as modifiers of the effects of noise on the cardiovascular system, and as causes of variability in individual responses to noise.
- Prospective longitudinal studies of transportation noise that examine physiological measures of health, including standardized health status inventory, blood pressure, neuro-endocrine and immune function.
- Knowledge on the health effects of low-frequency components in noise and vibration.
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Research related to indirect or after-effects of noise exposure

- Field studies on the effects of exposure to specific sounds such as aircraft noise and loud music, including effects such as noise-induced temporary and permanent threshold shifts, speech perception and misperception, tinnitus and information retrieval.
- Studies on the influence of noise-induced sleep disturbance on health, work performance, accident risk and social life.
- Assessment of dose-response relationships between sound levels and politically relevant variables such as noise-induced social handicap, reduced productivity, decreased performance in learning, workplace and school absenteeism, increased drug use and accidents.
- Determination of the causal connection between noise and mental health effects, annoyance and (spontaneous) complaints in areas such as around large airports, heavy-trafficked highways, high-speed rail tracks and heavy vehicles transit routes. The connections could be examined by longitudinal studies, for example.
- Studies on the impact of traffic noise on recovery from noise-related stress, or from nervous system hyperactivity due to work and other noise exposures.

Research on the efficiency of noise abatement policies which are health based

- Determination of the accuracy and effectiveness of modern sound insulation (active noise absorption), especially in residential buildings, in reducing the long-term effects of noise on annoyance/sleep disturbance/speech intelligibility. This can be accomplished by studying sites that provide data on remedial activities and changes in behavioral patterns among occupants.
- Evaluation of environmental (area layout, architecture) and traffic planning (e.g. rerouting) interventions on annoyance, speech interference and sleep disturbance.
- Comparative studies to determine whether children and the hearing impaired have equitable access to healthier lives when compared with normal adults in noise-exposed areas.
- Development of a methodology for the environmental health impact assessment of noise that is applicable in developing as well as developed countries.

Research into positive acoustical needs of the general population and vulnerable groups

- Development of techniques/protocols for the design of supportive acoustical environments for the general population and for vulnerable groups. The protocols should take into account time periods that are sensitive from physiological, psychological and socio-cultural perspectives.
- Studies to characterize good "restoration areas" which provide the possibility for rest without adverse noise load.
- Studies to assess the effectiveness of noise policies in maintaining and improving soundscapes and reducing human exposures.

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Appendix 2 : Examples Of Regional Noise Situations

REGION OF THE AMERICAS

Latin America (Guillermo Fuchs, Argentina).

As more and more cities in Latin America surpass the 20 million inhabitants mark, the noise pollution situation will continue to deteriorate. Most noise pollution in Latin American cities comes from traffic, industry, domestic situations and from the community. Traffic is the main source of outdoor noise in most big cities. The increase in automobile engine power and lack of adequate silencing results in LAeq street levels >70 dB, above acceptable limits. Vehicle noise has strong low-frequency peaks at ~13 Hz, and at driving speeds of 100 Km/h noise levels can exceed 100 dB. The low-frequency (LF) noise is aerodynamic in origin produced, for example, by driving with the car windows open. Little can be done to mitigate these low-frequency noises, except to drive with all the windows closed. Noise exposure due to leisure activities such as carting, motor racing and Walkman use is also growing at a fast rate. Walkman use in the street not only contributes to temporary threshold shifts (TTS) in hearing, but also endangers the user because they may not hear warning signals Construction sites, pavement repairs and advertisements also contribute to street noise, and noise levels of 85–100 dB are common.

The Centro de Investigaciones Acústicas y Luminotécnicas (CIAL) in Córdoba, Argentina has investigated noise pollution in both the field and in the laboratory. The most noticeable effect of excessive urban noise is hearing impairment, but other psychophysiological effects also result. For example, tinnitus resulting from sudden or continuous noise bursts, can produce a TTS of 20–30 dB, and prolonged exposures can result in permanent threshold shifts (PTS). By analyzing sound spectra down to a few Hertz, and at levels of up to 120 dB, discrete frequencies and bands of infrasound were found which damage hearing. With LF sounds at levels of 120 dB, TTS resulted after brief exposure, and PTS after only 30 min of exposure. The effects of noise on hearing can be especially detrimental to children in schools located downtown. Field studies in Córdoba city schools located near streets with high traffic density showed that speech intelligibility was dramatically degraded in classrooms that did not meet international acoustical standards. This is a particularly worrying problem for the younger students, who are in the process of language acquisition, and interferes with their learning process.

In general, community noise in Latin America remains above accepted limits. Particularly at night, sleep and rest are affected by transient noise signals from electronically amplified sounds, music and propaganda. Field research was carried out in four zones of Buenos Aires, to determine the effects of urban noise on the well-being, health and activities of the inhabitants. The effects of confounding variables were taken into consideration. It was concluded that night-time noise levels in downtown Buenos Aires were barely lower than daytime levels. The results showed that sleep, concentration, communication and well-being were affected in most people when noise levels exceeded those permitted by international laws. The reactions of the inhabitants to protect themselves from the effects of noise varied, and included changing rooms, closing windows and complaining to authorities.

Individual responses to noise also vary, and depend on factors such as social, educational and economic levels, individual sensibility, attitudes towards noise, satisfaction with home or neighborhood, and cognitive and affective parameters. For example, at CIAL, two pilot studies were carried out with a group of adolescents to determine the influence of environmental conditions on the perception of noise. When music was played at very high sound levels (with sound peaks of 119 dBA) in a discotheque, judged to be a pleasant environment, the subjects showed less TTS than when exposed to the same music in the laboratory, which was considered to be an unpleasant environment.

At the municipal level Argentinean Ordinances consider two types of noises: unnecessary and excessive. Unnecessary noises are forbidden. Excessive noises are classified according to neighboring activities and are limited by maximum levels allowed for daytime (7 am to 10 pm) and night-time (10 pm to 7 am). This regulation has been relatively successful, but control has to be continuous. Similar actions have been prescribed at the provincial level in many cities of Argentina and Latin America. Control efforts aimed at reducing noise levels from individual vehicles are showing reasonably good improvements. However, many efforts of municipal authorities to mitigate noise pollution have failed because of economic, political and other pressures. For example, although noise control for automobiles has shown some improvement, efforts have been counteracted by the growth in the number and power of automobiles.

CIAL has designed both static and dynamic tests that can be used to set annual noise control limits. For roads and freeways where permitted speeds are above 80 Km/h, CIAL has also designed barriers which protect buildings lining the freeways. Considerable improvements have been obtained using these barriers with noise reductions of over 20 dB at buildings fronts. The most common types of barrier are concrete slabs or wooden structures, made translucent or covered with vegetation. Planted vegetation does not act as an efficient noise shield for freeway noise, except in cases of thick forest strips. In several cities, CIAL also designed ring roads to avoid heavy traffic along sensitive areas such as hospitals, schools and laboratories.

Efforts have not been successful in reducing the noise pollution from popular sports such as carting, motorboating and motocross, where noise levels can exceed 100 dB. In part, this is because individuals do not believe these activities can result in hearing impairment or have other detrimental effects, in spite of the scientific evidence. Argentinean and other Latin American authorities also have not been successful in reducing the sound levels from music centres, such as discotheques, where sound levels can exceed 100 dB between 11 pm and 6 am. However, public protest is increasing and municipal authorities have been applying some control. For instance, in big cities, discotheque owners and others are beginning to seek advice on how to isolate their businesses from apartment buildings and residential areas. Some improvements have been observed, but accepted limits have not yet been generally attained.

United States of America (Larry Finegold)

Noise Exposure.

In the United States, there have only been a few major attempts to describe broad environmental noise exposures. Early estimates for the average daily exposure of various population groups were reported in the U.S. Environmental Protection Agency's *Levels Document* (US EPA 1974), but these were only partially verified by subsequent large-scale measurements. Another EPA publication the same year provided estimates of the national population distribution as a function of outdoor noise level, and established population density as the primary predictor of a community's noise exposure (Galloway et al. 1974). Methodological issues that need be considered when measuring community noise, including both temporal and geographic sampling techniques, have been addressed by Eldred (1975). This paper also provided early quantitative estimates of noise exposure at a variety of sites, from an isolated spot on the North rim of the Grand Canyon to a spot in downtown Harlem in New York City. Another nationwide survey focused on exposure to everyday urban noises, rather than the more traditional approach of measuring exposure to high-level transportation noise from aircraft, traffic and rail (Fidell 1978). This study included noise exposure and human response data from over 2 000 participants at 24 sites.

A comprehensive report, *Noise In America: The Extent of the Problem,* included estimates of occupational noise exposure in the US in standard industrial classification categories (Bolt, Beranek & Newman, Inc. 1981). A more recent paper reviewed the long-term trends of noise exposure in the US and its impact over a 30-year time span, starting in the early 1970's. The focus was primarily on motor vehicle and aircraft noise, and the prediction was for steadily decreasing population-weighted day-night sound exposure (Eldred 1988). However, it remains to be seen whether the technological improvements in noise emission, such as changing from Chapter 2 to Chapter 3 aircraft, will be offset in the long run by the larger carriers and increased operations levels that are forecast for all transportation modes. Although never implemented in its entirety, a comprehensive plan for measuring community environmental noise and associated human responses was proposed over 25 years ago in the US (Sutherland et al. 1973).

Environmental Noise Policy in the United States

One of the first major breakthroughs in developing an environmental noise policy in the United States occurred in 1969 with the adoption of the National Environmental Policy Act (NEPA). This Congressional Act mandated that the environmental effects of any major development project be assessed if federal funds were involved in the project. Through the Noise Control Act (NCA) of 1972, the U.S. Congress directed the US Environmental Protection Agency (EPA) to publish scientific information about the kind and extent of all identifiable effects of different qualities and quantities of noise. The US EPA was also requested to define acceptable noise levels under various conditions that would protect the public health and welfare with an adequate margin of safety. To accomplish this objective, the 1974 US EPA *Levels Document* formally introduced prescribed noise descriptors and prescribed levels of environmental noise exposure. Along with its companion document, *Guidelines for Preparing Environmental Impact Statements on Noise*, which was published by the U.S. National Research Council in 1977, the

Levels Document has been the mainstay of U.S. environmental noise policy for nearly a quarter of a century. These documents were supplemented by additional Public Laws, Presidential Executive Orders, and many-tiered noise exposure guidelines, regulations, and Standards. Important examples include *Guidelines for Considering Noise in Land Use Planning and Control*, published in 1980 by the US Federal Interagency Committee on Urban Noise; and *Guidelines for Noise Impact Analysis*, published in 1982 by the US EPA.

One of the distinctive features of the US EPA *Levels Document* is that it does not establish regulatory goals. This is because the noise exposure levels identified in this document were determined by a negotiated scientific consensus and were chosen without concern for their economic and technological feasibility; they also included an additional margin of safety. For these reasons, an A-weighted Day-Night Average Sound Level (DNL) of 55 dB was selected in the *Levels Document* as that required to totally protect against outdoor activity interference and annoyance. Land use planning guidelines developed since its publication allow for an outdoor DNL exposure in non-sensitive areas of up to 65 dB before sound insulation or other noise mitigation measures must be implemented. Thus, separation of short-, medium- and long-term goals allow noise-exposure goals to be established that are based on human effects research data, yet still allow for the financial and technological constraints within which all countries must work.

The US EPA's Office of Noise Abatement and Control (ONAC) provided a considerable amount of impetus to the development of environmental noise policies for about a decade in the US. During this time, several major US federal agencies, including the US EPA, the Department of Transportation, the Federal Aviation Administration, the Department of Housing and Urban Development, the National Aeronautics and Space Administration, the Department of Defense, and the Federal Interagency Committee on Noise have all published important documents addressing environmental noise and its effects on people. Lack of funding, however, has made the EPA ONAC largely ineffective in the past decade. A new bill, the *Quiet Communities Act* has recently been introduced in the U.S. Congress to re-enact and fund this office (House of Representatives Bill, H.R. 536). However, the passage of this bill is uncertain, because noise in the US, as in Europe, has not received the attention that other environmental issues have, such as air and water quality.

In the USA there is growing debate over whether to continue to rely on the use of DNL (and the A-Weighted Equivalent Continuous Sound Pressure Level upon which DNL is based) as the primary environmental noise exposure metric, or whether to supplement it with other noise descriptors. Because a growing number of researchers believe that "Sound Exposure" is more understandable to the public, the American National Standards Institute has prepared a new Standard, which allows the equivalent use of either DNL or Sound Exposure (ANSI 1996). The primary purpose of this new standard, however, is to provide a methodology for modeling the Combined or Total Noise Environment, by making numerical adjustments to the exposure levels from various noise sources before assessing their predicted impacts on people. A companion standard (ANSI 1998) links DNL and Sound Exposure with the current USA land use planning table. The latter is currently being updated by a team of people from various federal government agencies and when completed should improve the capabilities of environmental and community land-use planners. These documents will complement the newly revised ANSI standard on acoustical terminology (ANSI 1994).

To summarize progress in noise control made in the USA in the nearly 25 years since the initial national environmental noise policy documents were written, the Acoustical Society of America held a special session in Washington, D.C. in 1995. The papers presented in this special session were then published as a collaborative effort between the Acoustical Society of America and the Institute of Noise Control Engineering (von Gierke & Johnson 1996). This document is available from the Acoustical Society of America, as are a wide range of standards related to various environmental noise and bioacoustics topics from the ANSI.

A document from the European Union is now also available, which includes guidelines for addressing noise in environmental assessments (EU 1996). Policy documents from organizations such as ISO, CEN, and ICAO have shown that international cooperation is quite possible in the environmental noise arena. The ISO document, entitled *Acoustics - Description and Measurement of Environmental Noise* (ISO 1996), and other international standards have already proven themselves to be invaluable in moving towards the development of a harmonized environmental noise policy. The best way to move forward in developing a harmonized environmental noise policy is to take a look at the various national policies that have already been adopted in many countries, including those both from the European member states and from the USA, and to decide what improvements need to be made to the existing policy documents. A solid understanding of the progress that has already been achieved around the world would obviously provide the foundation for the development of future noise policies.

Implementation Concepts and Tools

Development of appropriate policies, regulations, and standards, particularly in the noise measurement and impact assessment areas, is a necessary foundation for implementing effective noise abatement policies and noise control programs. A well-trained cadre of environmental planners will be needed in the future to perform land-use planning and environmental impact analysis. These professionals will require both a new generation of standardized noise propagation models to deal with the Total Noise Environment, as well as sophisticated computer-based impact analysis and land-use planning tools.

A more thorough description of the current noise environment in major cities, suburbs, and rural areas is needed to support the noise policy development process. A new generation of noise measurement and monitoring systems, along with standards related to their use, are already providing considerable improvement in our ability to accurately describe complex noise environments. Finally, both active and passive noise control technologies, and other noise mitigation techniques, are rapidly becoming available for addressing local noise problems. Combined with a strong public awareness and education program, land-use planning and noise abatement efforts certainly have the potential to provide us with an environment with acceptable levels of noise exposure.

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AFRICAN REGION

South Africa (Etienne Grond, South Africa)

Introduction

Cultural and developmental levels diverge greatly in South Africa, and the country can be divided into a first world sector, a developing sector and a third world sector. This contributes to huge variations in both the awareness of noise pollution and in population exposure to noise pollution. Noise-related health problems will in all probability show the same large variations.

Legal requirements

Noise control in South Africa has a history dating back about three decades. Noise control began with codes of practice issued by the South African Bureau of Standards (SABS) to address noise pollution in different sectors. Since then, Section 25 of the Environment Conservation Act (Act 73 of 1989) made provision for the Minister of Environmental Affairs and Tourism to regulate noise, vibration and shock at the national level. These regulations were published in 1990 and local authorities could apply to the Minister to make them applicable in their areas of jurisdiction. However, a number of the bigger local authorities did not apply for the regulations since they already had by-laws in place, which they felt were sufficient. By the middle of 1992 only 29 local authorities had applied the regulations and so the act was changed to make it obligatory for all authorities to apply the regulations. However, by the time the regulations were ready to be published, the new Constitution of South Africa came into effect and this listed noise control as an exclusive legislative competence of provincial and local authorities. This meant that the national government could not publish the regulations. However, provincial governments have agreed to publish the regulations in their respective areas. The regulations will apply to all local authorities as soon as they are published in the provinces, and will give local authorities both the power and the obligation to enforce the regulations.

The Department of Environmental Affairs and Tourism also published regulations during 1997 to make Environmental Impact Assessments mandatory for most new developments, as well as for changes in existing developments. This means that any impact that a development might have on its surrounding environment must be evaluated and, where necessary, the impact must be mitigated to acceptable levels. The noise control regulations also state that a local authority may declare a "controlled area," which is an area where the average noise level exceeds 65 dBA over a period of 24 h period. This means that educational and residential buildings, hospitals and churches may not be situated within such areas.

Occupational noise exposure is regulated by the Department of Manpower, under the Occupational Health and Safety Act (Act 85 of 1993). These regulations states that workers may not be exposed to noise levels of higher than 85 dBA and that those exposed to such levels must make use of equipment to protect their hearing. The problem, however, is that most workers tend not to make use of the provided equipment, either because the equipment is not comfortable, or because they are not aware of the risks high noise levels pose to their hearing. A further problem is that small industries often do not supply the workers with the necessary equipment, or supply inferior equipment that is less costly.

Codes of practice

The codes of practice issued by the SABS were for the most part replaced by IEC (International Electrotechnical Commission) standards and adopted as SABS ISO codes of practice. They are still being used in South Africa and are regularly updated. A relevant list can be found in the references. The SABS has also published a number of recommended practices (ARP). These include the ARP 020: "Sound impact investigations for integrated environmental management" that is currently being upgraded to a code of practice. Such codes of practice can be referred to as requirements in legislation and will be known as SABS 0328: "Methods for environmental noise impact assessments." The codes of practice published in South Africa cover hearing protection; measurement of noise; occupational noise; environmental noise; airplane noise; and building acoustics, etc.

Courses

Local authorities responsible for applying regulations published by the Department of Environmental Affairs and Tourism must employ a noise control officer who has at least three years tertiary education in engineering, physical sciences or health sciences, and who is registered with a professional council. Alternatively, a consultant with similar training may be employed. Most of the universities in South Africa provide the relevant training, with at least part of the training in acoustics. Universities and technical colleges also provide a number of special acoustics courses. Over the last couple of years awareness of environmental conservation has expanded dramatically within the academic community, and most universities and colleges now have degree courses in environmental management. At the very least, these courses include a six-month module in acoustics, and usually also include training in basic mathematics; the physics of sound; sound measuring methodologies; and noise pollution.

Community awareness and exposure to noise pollution

This topic should be discussed with respect to three separate population sectors: the first-world sector (developed), the developing sector and the third-world sector (rural).

Developed sector

This sector of the population is more-or-less as developed as their European and American counterparts. They have been exposed to noise pollution for a considerable time and, for the most part, are aware of the health consequences of high noise levels. People in this group are also aware of the existence of legal measures by which noise pollution can be addressed. Not surprisingly, most of the complaints and legal action regarding noise pollution are received from this group. Information about noise-related health problems is very limited, but because this group is highly aware of the risks posed by high noise levels, future studies will probably show that people in this category have the fewest health problems. The majority of people in this group are less exposed to high noise levels at work, and they live in more affluent neighborhoods with large plots and separating walls. Their houses tend to be built with materials that are noise reducing. They also live further away from major noise-producing activities, such as highways, airports and large industries.

Developing sector

This sector of the population has the greatest exposure to high noise levels, both at home and in the workplace. Overall, they are relatively poor and cannot afford to live in quiet areas, or afford large plots or solid building materials. A large component of this sector resides in squatter communities where building are made of any material available, from plastic to corrugated sheets and wood. The buildings are right next to each other and there is almost no noise attenuation between residencies.

People in this category usually live close to major access routes into the cities, because they make use of public transportation and taxis to get to their places of work. Often, too, they live close to their places of work, which are usually big industries with relatively high levels of noise pollution. These people usually work in high noise areas, and because of their lack of awareness of the effects of high noise levels, often do not make use of available hearing protection equipment. Because of a lack of funds, these people also cannot get out of high noise areas and go to recreational areas for relaxation and lower noise levels. Not much information is available on the adverse health problems in this sector. However, workers in this sector should undergo regular medical examinations and the results can be obtained from the industries involved.

Rural sector

As the name suggests, people in this sector live in rural surroundings and for the most part are not subjected to noise levels that could be detrimental to their health. However, they are almost totally unaware of the risks posed by high noise levels. Some of these people work on farms and work with machinery that emits relatively high noise levels, but because of their lack of awareness they do not make use of hearing protection equipment. One advantage they do have is that they return to homes in quiet surroundings and their hearing has a chance to recover. To date, no studies have been carried out to determine the state of their hearing and it would be impossible to state that they have no health problems related to high noise levels.

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EASTERN MEDITERRANEAN REGION (Shabih H. Zaidi)

Scope

In the Eastern Mediterranean region some countries have highly developed industries, while others have none. In other cases, the agricultural economy is inseparably mixed with high-technology industries, such as the oil industry, which can be seen in nearly the whole of the Arabian Peninsula. Other examples of where agriculture and industry are intertwined can be seen in Pakistan, Jordan and Egypt. The main focus of this paper is community noise, but because industry is so widely distributed, some discussion of industrial noise is inevitable. The scope of this paper is to document the available scientific data on community noise in the WHO Regional Office of the Eastern Mediterranean (EMRO) region, including preventive strategies, legislation, compensation and future trends.

Sources of Noise Pollution

Sources of noise pollution in the Eastern Mediterranean region include noise from transportation, social and religious activities, building and civil works, roadside workshops, mechanical floor shops and others. During civil works and building booms, noise levels in all countries of the Eastern Mediterranean region could easily reach 85dBA during the daytime over an 8 h work period. In Pakistan, unprotected construction work goes on at all times of the day and night and uses outdated machinery; and the noise is compounded by workers shouting. On a typical building site noise levels reach 90–100 dBA.

In Karachi, the main artery for daily commuters is a long road that terminates at the harbor. In the densest area of this road there are a hundred small and large mechanical workshops, garages, metal sheet workers, dent removers, painters, welders and repair shops, all of which create a variety of noises. In the middle of this area at the Tibet Centre the LAeq,8h is 90dBA (Zaidi 1989). A similar picture is seen elsewhere in cities like Lahore, Peshawar, etc. Fortunately, the same is not true for other newly built cities in the EMRO region, such as Dubai, or Tripoli, where strict rules separate industrial zones from residential areas.

A special noise problem is Karachi harbour. This port serves the whole of Pakistan as well as Afghanistan and several Asian states, such as Kyrgyzstan, Kazakhstan and Uzbekistan. The noise level at the main wharf of Karachi Port ranges between 90–110 dBA on any given day. Other special sources of noise are the Eastern Mediterranean airports, and indeed most of the airports in the Middle East. Most northbound air traffic originates in Pakistan, Dubai, Sharjah etc. and flights usually depart after midnight so as to arrive in Europe during the daytime. A study is currently underway in Karachi to identify the damage caused by these nocturnal flights to those living under the flight path (SH Zaidi, GH Shaikh & AN Zaidi, personal communication).

Sadly, violence has become part of Eastern culture and is a significant source of noise pollution. Wars generate a lot of noise, and although noise-induced hearing loss is a secondary issue compared with the killing, after the wars many people are hearing impaired. This has been seen following conflicts in Balochistan, Peshawar and Afghanistan, where perforated ear drums, profound hearing loss and stress-related psychosomatic illnesses are common in the refugee camps. The noise levels during a recent mass demonstration in Karachi, which included the firing of automatic weapons, reached 120 dBA at a distance of 50 m from the scene.

The Effects of Noise on Health

There is good evidence that environmental noise causes a range of health effects, including hearing loss, annoyance, cardiovascular changes, sleep disturbance and psychological effects. Although the health effects of noise pollution have not been documented for the entire EMRO region, data are available for Pakistan and can be used to illustrate the general problem. In this report, noise exposure is mainly expressed as LAeq,24h values.

Noise-induced hearing loss (NIHL).

It is believed that exposure to environmental noise in the EMRO countries is directly related to the living habits, economic prosperity and outdoor habits of people. It has been estimated that no more than 5% of the people are exposed to environmental sound levels in excess of 65dBA over a 24-h period. Similarly, for indoor noise, it is believed that the average family is not exposed to sound levels in excess of 70 dBA over a 24-h period. However, it is difficult to generalize for all countries in the EMRO region, because of ancient living styles and different cultural practices, such as taking siestas between 13:00–16:00 and stopping work at 20:00.

Exposure to noise while travelling to schools, offices or workplaces may vary tremendously between cities in the region. In Karachi, for example, traffic flow is undisciplined, erratic and irrational, with LAeq,8h values of 80–85 dBA. In Riyadh, by contrast, traffic flow is orderly with LAeq levels of 70 dBA during a normal working day. In Karachi, noise levels show significant diurnal variation, reaching levels in excess of 140 dB during the peak rush hour at around 5.00 p.m. (Zaidi 1989). At the Tibet Centre, located at a busy downtown junction, noise levels were 60–70 dB at 9 am, but reached levels in excess of 140 dB between 5-7 p.m. A study conducted on a day that transportation workers went on strike established that road traffic is the most significant source of noise pollution in this city: in the absence of buses, rickshaws, trucks and other public vehicles the LAeq level declined from 90dB to 75dB (Zaidi 1990). Motor engines, horns, loud music on public buses and rickshaws generate at least 65% of the noise in Karachi (Zaidi 1997; Shams 1997). Rickshaws can produce noise levels of 100–110 dBA and do not have silencers. On festive occasions, such as national holidays or political rallies, motorbikes running at high speeds along the Clifton beach in Karachi easily make noise exceeding 120 dBA. (Zaidi 1996).

Another study conducted at 14 different sites in Karachi showed that, in 11 of the sites, the average noise level ranged between 79–80 dB (Bosan & Zaidi 1995). The maximum noise levels at all these sites exceeded 100 dB. Speech interference, measured by the Preferred Speech Interference Level and the Articulation Index, was significant (Shaikh & Rizvi 1990). The study results indicated that two people facing each other at a distance of 1.2 m would have to shout to be intelligible; and the Articulation Indexes demonstrated that communication was unsatisfactory. Of perhaps greater concern are the results of a survey of 587 males between the ages of 17 and 45 years old, who worked as shopkeepers, vehicle drivers, builders and office assistants. Audiograms showed that 14.6% of the subjects had significant hearing impairment at 3 000–4 000 Hertz (Hasan et al., 2000).

Noise pollution from leisure activities can vary from country to country in the EMRO region. The Panthans in northern Pakistan, for example, like to shoot in the air on festive occasions, such as weddings, without using any noise protection devices. A minimum of 1 000 shots are fired on such occasions; and at a traditional tribal dance called the 'Khattak" the noise level recorded during a particularly enthralling performance in a sports arena was 120dBA. The hunting of wild boar is a common sport in the hinterlands of Sindh. With the rifle shots and the noise made by the beaters, noise levels can easily reach 110 –120 dBA. In some EMRO countries, the younger crowd has taken up the Western habit of listening to Pop music for many hours. Discos and floorshows are confined to a few countries, such as Egypt. Open-air concerts are usually held in stadiums. The noise level recorded at a particularly popular concert was 130 dBA at a distance of 20 m from the stage and 35 m from the amplifiers.

In a study of road traffic at 25 different sites in Peshawar, the third most populous city in Pakistan, 90 traffic constables were taken as cohorts to investigate the extent of NIHL. Of these, 50 did not have any previous history of noise exposure and were taken as controls. Detailed evaluation and audiological investigations established that constables exposed to a noise level of 90 dBA for 8 hours every day suffered from NIHL. Compared to the control subjects, the constables had significant hearing impairment at 3 000 Hz, measured by Pure Tone Audiometry (Akhter 1996).

A similar study of traffic constables in Karachi showed that 82.8% of the constables suffered from NIHL (Itrat & Zaidi 1999). The study also showed that 33.3% of rickshaw drivers, and 56.9% of shopkeepers who worked in noisy bazaars, had hearing impairment. If these findings can be extrapolated to the total populations, there are 1 566 traffic constables (out of a total of 1 890 constables), and 4 067 rickshaw drivers (out of a total of 12 202 drivers) who suffer from NIHL. As has been reported by other researchers, the study also found evidence of acclimatization in the subjects: following an initial, rapid decline, hearing loss stabilized after prolonged noise exposure.

Annoyance.

The citizens of Karachi commonly complain that noise causes irritability and stress. The main sources have been identified as traffic noise, industrial noise and noise generated by human activity. Unfortunately no data are available for the level of annoyance caused by noise exposure in the EMRO region. From limited research around the world, it can be estimated that 35–40% of employees in office buildings are seriously annoyed by noise at sound levels in excess of 55–60 dBA. In countries such as Pakistan, Iran, Jordan and Egypt that level is often seen in most offices. Annoyance is a non-tangible entity and cannot be quantified scientifically. It is a human reaction and perhaps its parameters could include irritability, apprehension, fear, anger, frustration, uneasiness, apathy, chaos and confusion. If such are the parameters, then on a scale of 0–10, with 10 being the greatest annoyance, many EMRO countries could easily score 6 or higher.

Effects of noise on sleep and the cardiovascular system.

In the Eastern Mediterranean region no specific data are available on the effects of noise on sleep or the cardiovascular system. However, factory workers, traffic constables, rickshaw drivers and shopkeepers frequently complain about fatigue, irritability and headaches; and one of the most common causes of poor performance in offices is sleep disturbance. The rising incidence of tinnitus in cities like Karachi is also related to noise exposure, and tinnitus itself can lead to sleep deprivation. Although the effects of noise on the cardiovascular system have been well documented for other countries (Berglund & Lindvall 1995), data are lacking for the EMRO region. However, the prevalence of cardiovascular diseases are on the rise in the EMRO countries, particularly hypertension. While most of the increase in these diseases is due to a rich diet and lack of exercise, the relationship between noise and cardiovascular changes is worth investigating.

The risk to unborn babies and newborns.

Although evidence from other countries indicates that noise may damage the hearing of a fetus, there are no data from the EMRO countries to confirm this. With newborn babies, however, noise from incubators is a major cause of hearing loss in the EMRO region, particularly as 20–27% of them are born underweight (Razi et al. 1995). Once exposed to noise in an incubator, the chances of hearing impairment rapidly rises compared with cohorts in developed countries. Several other factors have also been identified as causing deafness and hearing impairment in newborns in the Eastern Mediterranean region (Zaidi 1998; Zakzouk et al. 1994). They are:

a. Discharge from the ears.

b. Communicable infections.

c. Ototoxicity.

d. Noise.

e. Consanguinity.

f. Iodine deficiency.

Noise Control

Although noise control legislation exists in several EMRO countries, it is seldom enforced, particularly in Pakistan and some neighboring countries. Noise control begins with education, public awareness and the appropriate use of media in highlighting the effects of noise. In Calcutta, for instance, public orientation and mass media mobilization have produced tangible results, and this can easily be done in other countries. Three strategies have been devised for noise control, all of which are practicable in EMRO region countries. They are control at the source, control along the path and control at the receiving end.

There are many ways noise can be controlled at the source. For example, most of the equipment and machinery used in EMRO countries is imported from the West. Noise control could begin by importing quieter machinery, built with newer materials like ceramics or frictionless parts. And at the local level, the timely replacement of parts and proper maintenance of the machines should be carried out. Vehicles like the rickshaw should be banned, or at least be compelled to maintain their silencers, and all vehicles must be put to a road worthiness test periodically. This already occurs in some EMRO countries, but not all. Horns, hooters, music players and other noise making factors must also be controlled. The use of amplifiers and public address systems should also be banned, and social, leisure and religious activities should be restricted to specific places and times.

Along the sound path, barriers can be used to control noise. There are three kinds of barriers available, namely, space absorbers made out of porous material, resonant absorbers and panel absorbers. Architects, for example, use hollow blocks of porous material. The air gaps between building walls not only keep the buildings cool in hot weather, but also reduce the effects of noise. Ceilings and roofs are often treated with absorbent material. In large factories, architects use corrugated sheets and prefabricated material, which are helpful in reducing noise levels. In Pakistan, some people use clay pots in closely ranked positions on rooftops to reduce the effect of heat as well as noise. For civic works and buildings, special enclosures, barriers and vibration controlling devices should be used. Public halls, such as cinemas, mosques and meeting places should have their walls and floors carpeted, and covered with hangings, mats etc. An effective material is jute, which is grown in many countries, mainly Bangladesh, and it is quite economical. Some of the old highways and most of the busy expressways need natural noise barriers, such as earth banks, trees and plants.

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SOUTH-EAST ASIAN REGION. (Sudhakar B. Ogale)

Introduction

The ability to hear sound is a sensory function vital for human survival and communication. However, not all sounds are wanted. Unwanted sounds, for which the term "noise" is normally used, often originate from human activities such as road traffic, rail traffic, aircraft, discos, electric power generators, festivals, firecrackers and toys. In general, however, data on noise pollution in South east Asian countries are not available. For example, there are no comprehensive statistical data regarding the incidence and etiology of hearing impairment. Consequently, it is difficult to estimate the exact percentage of the population affected by community noise.

Excessive noise is the major contributor to many stress conditions. It reduces resistance to illness by decreasing the efficiency of the immune system, and is the direct cause of some gastrointestinal problems. Noise also increases the use of drugs, disturbs sleep and increases proneness to accidents. An increased incidence of mental illness and hospital admissions, increases in absenteeism from work and lethargy from sleep disturbance all result from noise pollution and cause considerable loss of industrial production.

Noise Exposure in India

India is rapidly becoming industrialized and more mechanized, which directly affects noise levels. However, no general population study regarding the magnitude of the noise problem in India has been performed.

Road Traffic Noise

Exposure. A study by the Indian Institute of Road Traffic (IRT) reported that Delhi was the noisiest city in India, followed by Calcutta and Bombay (IRT 1996; Santra & Chakrabarty 1996). The survey examined whether road-traffic noise affected people with respect to annoyance, sleep disturbance, interference with communication and hearing impairment. It showed that 35% of the population in four major cities have bilateral sensory neural hearing loss at noise emission levels above 82 dBA. This is of particular concern in light of a second study, showing that LAeq,24h levels at 24 kerbside locations in Calcutta were 80–92 dBA (Chakrabarty et al. 1997) The mean noise emission levels of four different vehicle categories are presented in Table A2.1.

Table A2.1: Mean noise emission levels of vehicles

Type of vehicle	Mean sound pressure level
2 wheelers (motor cycle)	82 dBA
3 wheelers (auto rickshaw)	87 dBA
Motor car (taxi, private cars)	85 dBA
Heavy vehicles (trucks)	92 dBA

Control Measures. Only recently has noise pollution been considered an offence in India, under the Environmental (Protection) Act 1986. Several measures are being taken to reduce traffic-noise exposure. These include:

a. Planting trees, shrubs and hedges along roadsides.

b. Mandatory, periodic vehicle inspections by road traffic control.

c. Reintroduction of silent zones, such as around schools, nursing homes and hospitals that face main roads.

d. Regulation of traffic discipline, and a ban on the use of pressure horns.

e. Enforcement of exhaust noise standards.

f. Mandating that silencers be effective in three-wheeled vehicles.

g. The use and construction of bypass roads for heavy vehicles.

h. Limiting night-time access of heavy vehicles to roads in residential neighbourhoods

i. Installation of sound-proof windows.

j. Proper planning of new towns and buildings.

Air Traffic Noise

Many airports were originally built at some distance from the towns they served. But due to growing populations and the lack of space, buildings are now commonly constructed alongside airports in India.

Exposure. A survey revealed that aircraft produced a high level of noise during take-off, with sound pressure levels of 97–109 dBA for the Airbus, and 109 dBA for Boeing aircraft (SB Ogale, unpublished observations). During landing, the aircraft produced a sound pressure level of 108 dBA. Although exposure to aircraft noise is considered to be less of a problem than exposure to traffic noise, the effects of air-traffic noise are similar to those of road traffic, and include palpitations and frequent awakenings at night.

Control measures. The use of ear muffs must be made obligatory at the airport. This can reduce noise exposure to a safe level. An air-traffic control act should also enforce the use and introduction of low-noise aircraft, and mandate fewer night-time flights.

Rail Traffic Noise

Very little attention has been paid to the problems of railway noise.

Exposure. In Bombay, where the majority of residential buildings are situated on either side of railway tracks, residents are more prone to suffer from acoustic trauma. More than 14% of the population in Bombay suffer from sleep disturbances during night, due to high-speed trains and their whistling. A study on surface railways (SB Ogale, unpublished observations) revealed that platform noise was 71–73 dBA in the morning and 78–83 dBA in the evening. The noise from loudspeakers mounted in the platform was 87–90 dBA. At a distance of 1 m from the engine, the whistle noise was 105–108 dBA for a train with an electric engine, up to 110 dBA for a train with diesel engine and 118 dBA for steam engine trains. Vacuum brakes produced noise levels as high as 95 dBA. This suggests that unprotected railway staff on platforms are at risk of permanent noise induced hearing loss.

Festival noise

Festival noise in India was first surveyed in Bombay in late 1970, during the Ganpati festival period. A similar study (Santra et al. 1996) was conducted soon after in Calcutta at the Durga Pooja festival during evening hours (18:00–22:00). The music from loudspeakers produces sound pressure levels of more than 112 dBA. During the festival period the residents experienced a noisy environment for 8–10 h at a stretch, with noise level of 85–95 dBA. This level is above the 80 dBA limit set by WHO for industrial workers exposed to noise for a maximum period of 8 hours.

Control measures. In a religious country, it is politically difficult to restrict religious music, even in the interests of public health. A ban on all music from loudspeakers after 22:00 would decrease the sound pressure levels to below the permissible legal limit. A preventive programme is advocated to measure noise levels with sound level metres.

Fire crackers and toy weapons noise

Exposure. A study conducted by Gupta & Vishvakarma (1989) at the time of Deepawali, an Indian festival of fireworks, determined the auditory status of 600 volunteers from various age groups, before and after exposure to firecrackers. The study also measured the acoustical output of representative samples of toy weapons and firecrackers, and the noise intensity level at critical spectator points. The average sound level at a distance of 3 m from the noise source was 150 dBA, exceeding the 130 dBA level at which adults are at risk for hearing damage. On average, 2.5% of the people surveyed during Deepawali had persistent sensory neural hearing loss of 30 dBA, with those in the 9–15 year old age group being most affected.

Control Measures. A judicious approach in the manufacture and use of toy weapons and firecrackers is encouraged, in addition to legal restraints. Fireworks should be more a display of light, rather than sound.

Generator Noise

Diesel generators are often used in India to produce electric power. Big generators produce sound pressure levels exceeding 96 dBA (SB Ogale, unpublished observations).

Conclusions

No comprehensive statistical data are available for community noise in India, however, the main sources of environmental noise are road traffic, air traffic, rail traffic, festivals, firecrackers and diesel generators. The adverse effects of noise are difficult to quantify, since tolerance to noise levels and to different types of noise varies considerably between people. Noise intensity also varies significantly from place to place. It should also be noted that noise data from different countries are often not obtained by the same method, and in general models have been used which are based on data from a limited number of locations. Noise control measures could be taken at several levels, including building design, legal measures, and educating the people on the health dangers of community noise. In India, what is needed now is noise control legislation and its strict enforcement, if a friendly, low-noise environment is to be maintained.

Noise Exposure in Indonesia

According to a report by the WHO, the noise exposure and control situation in Indonesia is as follows (Dickinson 1993).

Exposure. No nationwide data are available for Indonesia. However, during the last three decades there has been rapid growth in transportation, industry and tourism in Indonesia.

Control Measures. With the large majority of people having little income, protection of the physical environment has not been a first-order priority. The following recommendations have been made with respect to community noise (Dickinson 1993):

a. The cities of Indonesia have relatively large populations and each provincial government will need the staff and equipment to monitor and manage the environment.

b. Sound level meters with noise analysis computer programmes should be purchased.

c. Training courses and adequate equipment should be provided.

d. Noise management planning for airports should be promoted.

e. Reduction measures should be taken for road-traffic noise.

Noise Exposure in Bangladesh

Exposure. In Bangladesh no authentic statistical data on the effects of community noise on deafness or hearing impairment are available (Amin 1995).

Control Measures. Governments have meager resources, a vast population to contend with and high illiteracy rates; consequently, priorities are with fighting hunger, malnutrition, diseases and various man-made and natural calamities. The governments are unable to give the necessary attention towards the prevention, early detection and management of noise disabilities in the country. Close cooperation is needed between the national and international organizations, to exchange ideas, skills and knowledge (Amin 1995).

Noise Exposure in Thailand

Exposure. Noise from traffic, construction, and from factories and industry has become a big problem in the Bangkok area. The National Environmental Board of Thailand was set up two decades ago and has been active in studying the pollution problems in Thailand. Indeed, a committee on noise pollution control was set up to study the noise pollution in Bangkok area and its surroundings. Although regulations and recommendations were made for controlling various sources of noise, the problem was not solved due to a lack of public awareness, the difficulty of proving that noise had adverse effects on health and hearing, and the difficulty of getting access to control noise. A general survey revealed that 21.4% of the Bangkok population is suffering from sensory neural hearing loss (Prasanchuk 1997). Noise sources included street noise, traffic noise, industrial noise and leisure noise.

Control Measures. In 1996, regulations for noise pollution control set LAeq,24h levels at 70 dBA for residential areas, and less than 50 dBA to avoid annoyance. The National Committee on Noise Pollution Control has been asked to study the health effects of noise in the Bangkok area and its surroundings, and determine whether these regulations are realistic and feasible.

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WESTERN PACIFIC REGION.

In this section, information on noise pollution and control will be given for three countries in the Western Pacific Region, namely Australia, the People's Republic of China and Japan. From a noise pollution point of view China may be viewed as a developing country, whereas Japan and Australia, with their high level of industrialization, represent developed countries.

Australia (Andrew Hede & Michinori Kabuto)

Exposure. Australia has a population of 18 million with the majority living in cities that have experienced increasing noise pollution from a number of sources. The single most serious source of noise is road traffic, although in major cities such as Sydney, Melbourne and Perth, large communities are exposed to aircraft noise as well. Other important sources of noise pollution are railway noise and neighbourhood noise (including barking dogs, lawn mowers and garbage collection). A particular problem in Australia is that the climate encourages most residents to live with open windows, and few houses have effective noise insulation.

A study of road-traffic noise was conducted at 264 sites in 11 urban centres with populations in excess of 100 000 people (Brown et al. 1994). Noise was measured one metre from the façade of the most exposed windows and at window height. From the results, it was estimated that over 9% of the Australian population is exposed to LA10,18h levels of 68 dB or greater, and 19% of the population is exposed to noise levels of 63 dB or greater. In terms of LAeq values for daytimes, noise exposure in Australia is worse than in the Netherlands, but better than in Germany, France, Switzerland or Japan.

Control. In the mid-1990's, when a third runway was built at Sydney Airport, the government funded noise insulation of high-exposed dwellings. Increasingly, too, major cities are using noise barriers along freeways adjacent to residential communities. In most states barriers are mandatory for new freeways and for new residential developments along existing freeways and major motorways. There has been considerable testing of noise barriers by state agencies, to develop designs and materials that are cost effective.

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China (Chen Ming)

Introduction

Urban noise pollution has become a contemporary world problem. Urban noise influences people's living, learning and working. People exposed to noise feel disagreeable and cannot concentrate on work. Rest and sleep are also disturbed. People exposed to high-intensity noise do not hear alarm signals and cannot communicate with each other. This can result in injury and, indeed, with the modernization of China, construction accidents related to noise are increasing. According to statistics for several cities in China, including Beijing, Shanghai, Tientsin and Fuzhou, the proportion of total accidents that were noise related was 29.7% in 1979, 34.6% in 1980, 44.8% in 1981 and 50% in 1990. It is therefore very important to control noise pollution in China.

Long-term exposure to urban environmental noise can lead to temporary hearing loss (assessed by temporary threshold shift), permanent hearing loss (assessed by permanent threshold shift) or deafness. Microscopy studies have shown that in people exposed to noise for long periods, hair cells, nerve fibers and ganglion cells were absent in the cochleae, especially in the basal turns. The primary lesion is in the 8–10 mm region of the cochlea, which is responsible for detecting sound at a frequency of 4 000 Hz. People chronically exposed to noise may first complain about tinnitus and, later on, about hearing loss. This is especially true for patients who have bilateral hearing loss at 4 000 Hz, but who have relatively good hearing other frequencies. Non-auditory symptoms of noise include effects on the nervous system, cardiovascular system and blood system. These symptoms were rarely observed in China in the past, but today more and more people complain about hearing damage and non-auditory physiological effects.

Urban environmental noise has thus become a common concern of all members of society. A key to resolving the complex noise issue lies in the effective control of urban noise sources. Control measures include reducing noise at its source, changing noise transmission pathways, building design, community planning and the use of personal hearing protection.

Urban environmental noise sources can be divided into industrial noise, traffic noise, building architecture noise and community district noise sources. Only the last three types are of concern here.

Traffic Noise

There are four sources of traffic noise: road traffic, railway transport, civil aviation and water transport; of these, road traffic is the main source of urban noise. The sound emission levels of heavy-duty trucks are 82–92 dBA and 90–100 dBA for electric horns; air horns are even worse, with sound emission levels of 105–110 dBA. Most urban noise from automobiles is in the 70–75 dB range, and it has been estimated that 27% of all complaints are about traffic noise. When a commercial jet takes off, speech communication is interrupted for up to 1 km on both sides of the runway, but people as far away as 4 km are disturbed in their sleep and rest. If a supersonic passenger plane flies at an altitude of 1 500 m, its sound pressure waves can be heard on the ground in a 30–50 km radius.

Building Noise

As a result of urban development in China, construction noise has become an increasingly serious problem. It is estimated that 80% of the houses in Fuzhou were built in the past 20 years. According to statistics, the noise from ramming in posts and supports is about 88 dB and the noise from bulldozers and excavators is about 91 dB, 10 m from the equipment. About 98% of industrial noise is in the 80–105 dB range, and it is estimated that 20% of all noise complaints is about industrial noise.

Community Noise

The main sources of community noise include street noise, noise from electronic equipment (air conditioners, refrigerators, washing machines, televisions), music, clocks, gongs and drums. Trumpets, gongs, drums and firecrackers, in particular, seriously disturb normal life and lead to annoyance complaints.

In conclusion, urban noise pollution in China is serious and is getting worse. To control noise pollution, China has promulgated standard sound values for environmental noise. These are summarized in table A2.2.

Table A2.2: LAeq standard values in dB for environmental noise in urban areas.

Applied area	day	night
Special residential quarters[1]	45	35
Residential and cultural education area[2]	50	40
Type 1 mixed area[3]	55	45
Type 2 mixed area[4] or commercial area	60	50
Industrial area	65	55
Arterial roads[5]	70	55

1 Special residential quarters: quiet residential area
2 Residential and cultural education area: residential quarters, cultural, educational offices
3 Type 1 mixed area: mixture of commercial area and residential quarters
4 Type 2 mixed area: mixture of industrial area, commercial area, residential quarters and others
5 Roads with traffic volume of more than 100 cars per hour

The peak sound levels for frequent noises emitted during the night-time are not allowed to exceed standard values by more than 10 dBA. Single, sudden noises during the night-time are not allowed to exceed standard values by more than 15dBA.

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Japan (Michinori Kabuto)

Environmental Quality Standards

Noise standards for both general and roadside areas were set in Japan in 1967, through the "Basic Law for Environmental Pollution." This law was updated in September 1999. Each standard is classified according to the type of land use and the time of day. In ordinary residential areas, the night-time standard is 45 dB LAeq, but in areas that require even lower noise exposure, such as hospitals, this is lowered to 40 dB LAeq. In contrast, the daytime levels for commercial and industrial areas is as high as 60 dBA. Standards for roadside areas are 70 dB LAeq for daytime and 65 dB LAeq for nighttime. Between 1973–1997 noise standards for aircraft noise, super-express train noise and conventional railway train noise were also implemented. Standards for aircraft noise were set in terms of the weighted equivalent continuous perceived noise level (WECPNL). For residential areas, the WECPNL standard is 70 dBA, and is 75 dBA for areas where it is necessary to maintain a normal daily life.

For super-express trains, the Environmental Agency required noise levels to be below 75 dBA in densely populated residential areas, such as along the Tokaido and Sanyo Shinkansen lines, as well as in increasingly populated areas, such as along the Tohoku and Joetsu Shinkansen lines. The standards were to be met by 1990, but by 1991 this level had been achieved at only 76% of the measuring sites on average. Noise countermeasures included the installation of new types of sound-proof walls, and laying ballast mats along densely populated stretches of the four Shinkansen lines. Noise and vibration problems can also result from conventional trains, such as occurred with the opening of the Tsugaru Strait and Seto Ohashi railway lines in 1988. Various measures have since been taken to address the problems.

Complaints About Community Noise.

In Japan, complaints to local governments about environmental problems have been summarized annually and reported by Japan Environmental Agency. Thirty-seven percent of all complaints was due to factory (machinery) noise; 22% to construction noise; 3% to road traffic noise; 4% to air traffic noise; 0.8% to rail traffic noise; 9% to night-time business; 6% to other commercial activities; 2.5% to loudspeaker announcements; 9% to domestic noise; and 8% was due to miscellaneous complaints.

Sources of Noise Exposure and their Effects

Road-traffic noise. The number of automobiles in Japan has increased from 20 million in 1971 to 70 million in 1994, a 3.5-fold increase. One-third of this increase was due to heavy-duty vehicles. Since 1994, out of a total of 1 150 000 km of roads in Japan, only 29 930 km have been designed according to noise regulations. According to 1998 estimates by the Environmental Agency, 58% of all roads passed through residential areas. Daytime noise limits were exceeded in 92% of all cases, and night-time limits were exceeded in 87% of all cases. The study also estimated that 0.5 million houses within 10 m of the roads were exposed to excessive traffic noise. In a recent lawsuit, the Japanese Supreme Court ruled that people should be compensated when exposed to night-time noise levels exceeding 65 dB Laeq. This would apply to people living alongside 2 000 km of roads in Japan.

A recent epidemiological study examined insomnia in 3 600 women living in eight different roadside areas exposed to night-time traffic. Insomnia was defined as one or more of the following symptoms: difficulty in falling asleep; waking up during sleep; waking up too early; and feelings of sleeplessness one or more days a week over a period of at least a month. The data were adjusted for confounding variables, such as age, medical care, whether the subjects had young children to care for, and sleep apnea symptoms. The results showed that the odds ratio for insomnia was significantly correlated with the average night-time traffic volume for each of the eight areas and suggested that insomnia could be attributed solely to night-time road traffic.

From the most noisy areas in the above study 19 insomnia cases were selected for a further in-depth examination. The insomnia cases were matched in age and work with 19 control subjects. Indoor and outdoor sound levels during sleep were measured simultaneously at 0.6 s intervals. For residences facing roads with average night-time traffic volume of 6 000 vehicles per hour, the highest sound levels observed were 78–93 dBA. The odds ratios for insomnia in each of the quartiles for LAmax,1min; L50,1min; L10,1min and LAeq,1min generally showed a linear trend and ranged between 1 (lowest quartile) and 6–7 (highest quartile). It was concluded that insomnia was likely to result when night-time indoor LAeq, 1min sound levels exceeded 30 dBA.

Air-traffic noise At the larger Japanese airports (Osaka, Tokyo, Fukuoka), jet airplanes have rapidly increased in number and have caused serious complaints and lawsuits from those living nearby. Complaints about jet-fighter noise are also common from residents living in the vicinity of several U.S. airbases located in Japan. In the case of Kadena and Futemma airbases on Okinawa, a recent study by the Okinawa Prefecture Government suggested that hearing loss, child misbehaviour and low birth-weight babies were possible health effects of the noise associated with these bases (RSCANIH 1997). Using measurements taken in 1968 during the Vietnam War, it was estimated that the WECPNL was 99–108 dBA at the Kadena village fire station. Similar WECPNL estimates of 105 dBA were also obtained for Yara (Kadena-cho) and Sunabe (Chatan-cho) bases. These levels correspond to a LAeq,24h value of 83 dB, and are of serious concern in light of recommendations by the Japan Association of Industrial Health that occupational noise exposure levels should not exceed 85 dB for an 8-h work day if hearing loss is to be avoided.

Audiogrammes of subjects living in areas surrounding Kadena airport indicated that they had progressive hearing loss at higher frequencies. Eight subjects had hearing impairment in the 3–6 kHz range, which strongly suggested that the hearing loss was due to excessive noise exposure. Since the examiners confirmed the subjects had not been exposed to repeated intense noise at their residences or workplaces, the most likely cause of their hearing loss was the intense aircraft noise during take-offs, landings and tune-ups at Kadena airport.

The effects of noise were examined in children from nursery schools and kindergartens in towns surrounding Kadena airport. The children were scored with respect to seven variables: cold symptoms, emotional instability, discontentment-anxiety, headache-stomachache, passivity, eating problems and urination problems. Confounding factors, such as sex, age, birth order, the number of parents living together, the mother's age when the child was born, reaction to noise and the extent of noise exposure, were taken into account. The results showed that children exposed to noise had significantly more problems with respect to their behaviour, physical condition, character and reaction to noise, when compared to a control group of children that had not been exposed to airport noise. This was especially true of for children exposed to a WECPNL of 75 or more. Thus, small children acquire both physical and mental disorders from chronic exposure to aircraft noise.

Chronic exposure to aircraft noise also affects the birth-weight of children. The birth-weights of infants were analyzed using records from 1974 to 1993 in the Okinawa Prefecture. Confounding factors such as the mother's age, whether there were single or multiple embryos, the child's sex, and the legitimacy of the child were considered. The results showed that 9.1 % of all infants born in Kadena-cho, located closest to Kadena airport, had low birth-weights. This was significantly higher than the 7.6 % rate seen in other municipalities around Kadena and Futemma airfields, and much higher than the 7 % rate in cities, towns and villages on other parts of Okinawa Island.

Rail-traffic noise. Commuter trains and subway cars expose Tokyo office workers to much higher noise levels than do other daily activities (Kabuto & Suzuki 1976). Exposure to indoor noise may vary according to railway line or season (there are more open windows in good weather), but the levels range from 65–85 dBA. In general, these values exceeded the LAeq,24h level of 70 dBA for auditory protection (US EPA 1974).

Neighbourhood noise. Neighbourhood noise, including noise from late-night business operations, noise caused by loudspeaker announcements, and noise from everyday activities, have accounted for approximately 39% of all complaints about noise in recent years. At present, noise controls for late-night business operations have been enforced by ordinances in 39 cities and prefectures, and in 42 cities for loudspeaker announcements.

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Appendix 3 : Glossary

Acoustic	Pertaning to sound or to the sense of hearing (CMD 1997)
Acoustic dispersion	Change of speed of sound with frequency (ANSI 1994)
Acoustic trauma	Injury to hearing by noise, especially loud noise (CMD 1997)
Adverse effect	(of noise:) A change in morphology and physiology of an organism which results in impairment of functional capacity or impairment of capacity to compensate for additional stress or increase in susceptibility to the harmful effects of other environmental influences. This definition includes any temporary or long term lowering of physical, psychological or social functioning of humans or human organs (WHO 1994)
Annoyance	A feeling of displeasure associated with any agent or condition known or believed by an individual or a group to be adversely affecting them" (Lindvall and Radford 1973; Koelega 1987). Any sound that is perceived as irritating or a nuisance (ANSI 1995)
Anxiety	A feeling of apprehension, uncertainty, and fear without apparent stimulus, and associated with physiological changes (tachycardia, sweating, tremor, etc.) (DIMD 1985). A vaguer feeling of apprehension, worry, uneasiness, or dread, the source of which is often nonspecific or unknown to the individual (CMD 1997).
Audiometry	Testing of the hearing sense (CMD 1997). Measurement of hearing, including aspects other than hearing sensitivity (ANSI 1995)
Auditory	Pertaining to the sense of hearing (CMD 1997)
Auditory threshold	Minimum audible sound perceived (CMD 1997)
A-weighting	A frequency dependent correction that is applied to a measured or calculated sound of moderate intensity to mimick the varying sensitivity of the ear to sound for different frequencies

Ambient noise	All-encompassing sound at a given place, usually a composite of sounds from many sources near and far (ANSI 1994)
Articulation index	Numerical value indicating the proportion of an average speech signal that is understandable to an individual (ANSI 1995)
Bel	Unit of level when the base of the logarithm is ten, and the quantities concerned are proportional to power; unit symbol B (ANSI 1994)
Cardiovascular	Pertaining to the heart and blood vessels (DIMD 1985)
Cochlea	A winding cone-shaped tube forming a portion of the inner ear. It contains the receptor for hearing (CMD 1997)
Cognitive	Being aware with perception, reasoning, judgement, intuition, and memory (CMD 1997)
Community noise	Noise emitted from all noise sources except noise at the industrial workplace (WHO 1995a)
Cortisol	A glucocortical hormone of the outer layer of the adrenal gland (CMD 1997)
Critical health effect	Health effect with lowest effect level
C-weighting	A frequency dependent correction that is applied to a measured or calculated sound of high intensity to mimick the varying sensitivity of the ear to sound for different frequencies
dB	Decibel, one-tenth of a bel
dBA	A-weighted frequency spectrum in dB, see A-weighting
dBC	C-weighted frequency spectrum in dB, see C-weighting
dBlin	Unweighted frequency spectrum in dB
Decibel	Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power; unit symbol dB (ANSI 1994)

Ear plug	Hearing protector that is inserted into the ear canal (ANSI 1994)
Ear muff	Hearing protector worn over the pinna (external part) of an ear (ANSI 1994)
Effective perceived noise level	Level of the time integral of the antilogarithm of one tenth of tone-corrected perceived noise level over the duration of an aircraft fly-over, the reference duration being 10 s (ANSI 1994)
Emission	(of sounds). Sounds generated from all types of sources
Epinephrine	A hormone secreted by the adrenal medulla (inner or central portion of an organ) in response to stimulation of the sympathetic nervous system (CMD 1997)
Equal energy principle	Hypothesis that states that the total effect of sound is proportional to the total amount of sound energy received by the ear, irrespective of the distribution of that energy in time
Equivalent sound pressure level	Ten times the logarithm to the base ten of the ratio of the time-mean-square instantaneous sound pressure, during a stated time interval T, to the square of the standard reference sound pressure (ANSI 1994)
Exposure-response curve	Graphical representation of exposure-response relationship
Exposure-response relationship	(With respect to noise:) Relationship between specified sound levels and health impacts
Frequency	For a function periodic in time, the reciprocal of the period (ANSI 1994)
Frequency-weighting	A frequency dependent correction that is applied to a measured or calculated sound (ANSI 1994)
Gastro-intestinal	Pertaining to the stomach and intestines (CMD 1997)
Hearing impairment, hearing loss	A decreased ability to perceive sounds as compared which what the individual or examiner would regard as normal (CMD 1997)
Hearing threshold	For a given listener and specified signal, the minimum (a) sound pressure level or (b) force level that is capable of

	evoking an auditory sensation in a specified function of trials (ANSI 1994)
Hertz	Unit of frequency, the number of times a phenomenon repeats itself in a unit of time; abbreviated to Hz
Hysteria	A mental disorder, usually temporary, presenting somatic (pertaining to the body) symptoms, stimulating almost any type of physical disease. Symptoms include emotional instability, various sensory disturbations, and a marked craving for sympathy (CMD 1997)
Immission	Sounds impacting on the human ear.
Impulsive sound	Sound consisting of one or more very brief and rapid increases in sound pressure
Incubator	An enclosed crib, in which the temperature and humidity may be regulated, for care of premature babies (CMD 1997)
Isolation, insulation	(With respect to sound:) Between two rooms in a specified frequency band, difference between the space-time average sound presssure levels in the two enclosed spaces when one or more sound sources operates in one of the rooms (ANSI 1994). (With respect to vibrations:) Reduction in the capacity of a system to respond to excitation, attained by use of resilient support (ANSI 1994).
Ischaemic Heart Disease	Heart disease due to a local and temporary deficiency of blood supply due to obstruction of the circulation to a part (CMD 1997)
Loudness level	Of a sound, the median sound pressure level in a specified number of trials of a free progressive wave having a frequency of 1000 Hz that is judged equally loud as the unknown sound when presented to listeners with normal hearing who are facing the source; unit phon (ANSI 1994)
Level	Logarithm of the ratio of a quantity to a reference quantity of the same kind; unit Bel (ANSI 1994)
Maximum sound level	Greatest fast (125 milliseconds) A-weighted sound level, within a stated time interval (ANSI 1994)

Mental Health	The absence of identifiable psychiatric disorder according to current norms (Freeman 1984). In noise research, mental health covers a variety of symptoms, ranging from anxiety, emotional stress, nervous complaints, nausea, headaches, instability, argumentativeness, sexual impotency, changes in general mood and anxiety, and social conflicts, to more general psychiatric categories like neurosis, phychosis and hysteria (Berglund and Lindvall 1995).
Morphological	Pertaining to the science of structure and form of organisms without regard to function (CMD 1997)
Nausea	An unpleasant sensation usually preceding vomiting (CMD 1997)
Neurosis	An emotional disorder due to unresolved conflicts, anxiety being its chief characteristic (DIMD 1985)
Noise	Undesired sound. By extension, noise is any unwarranted disturbance within a useful frequency band, such as undesired electric waves in a transmission channel or device (ANSI 1994).
Noise induced temporary threshold shift	Temporary hearing impairment occurring as a result of noise exposure, often phrased temporary threshold shift (adapted from ANSI 1994)
Noise induced permanent threshold shift	Permanent hearing impairment occurring as a result of noise exposure, often phrased permanent threshold shift (adapted from ANSI 1994)
Noise level	Level of undesired sound
Norepinephrine	A hormone produced by the adrenal medulla (inner or central portion of an organ), similar in chemical and pharmacological properties to epinephrine, but chiefly a vasoconstrictor with little effect on cardiac output (CMD 1997)
Oscillation	Variation, usually with time, of the magnitude of a quantity with respect to a specified reference when the magnitude is alternately greater and smaller than the reference (ANSI 1994)

Ototoxic	Having a detrimental effect on the organs of hearing (CMD 1997)
Paracusis	Any abnormality or disorder of the sense of hearing (CMD 1997)
Pascal	Unit of pressure, equal to one newton per square meter, abbreviated to Pa
Peak sound pressure	Greatest absolute instantaneous sound pressure within a specified time interval (ANSI 1994)
Peak sound pressure level	Level of peak sound pressure with stated frequency weighting, within a specified time interval (ANSI 1994)
Perceived noise level	Frequency-weighted sound pressure level obtained by a stated procedure that combines the sound pressure levels in the 24 one-third octave bands with midband frequencies from 50 Hz to 10 kHz (ANSI 1994)
Permanent threshold shift, permanent hearing loss	Permanent increase in the auditory threshold for an ear (adapted from ANSI 1995) (see also: noise induced permanent threshold shift)
Presbyacusia, presbycusis	The progressive loss of hearing ability due to the normal aging process (CMD 1997)
Psychiatric disorders	Mental disorders
Psychosis	Mental disturbance of a magnitude that there is a personality disintegration and loss of contact with reality (CMD 1997)
Psychotropic drug	A drug that affects psychic function, behaviour or experience (CMD 1997)
Reverberation time	Of an enclosure, for a stated frequency or frequency band, time that would be required for the level of time-mean-square sound pressure in the enclosure to decrease by 60 dB, after the source has been stopped (ANSI 1994)
Sensorineural	Of or pertaining to a sensory nerve; pertaining to or affecting a sensory mechanism and/or a sensory nerve (DIMD 1985)

Signal	Information to be conveyed over a communication system (ANSI 1994)
Signal-to-noise ratio	Ratio of a measure of a signal to the same measure of the noise (ANSI 1995) (see also: noise –in its extended meaning)
Silencer	Duct designed to reduce the level of sound; the sound-reducing mechanisms may be either absorptive or reactive, or a combination (ANSI 1994)
Sound absorption	Change in sound energy into some other form, usually heat, in passing through a medium or on striking a surface (ANSI 1994)
Sound energy	Total energy in a given part of a medium minus the energy that would exist at that same part with no sound waves present (ANSI 1994)
Sound exposure	Time integral of squared, instantaneous frequency-weighted sound pressure over a stated time interval or event (ANSI 1994)
Sound exposure level	Ten times the logarithm to the base ten of the ratio of a given time integral of squared, instantaneous A-weighted sound pressure, over a stated time interval or event, to the product of the squared reference sound pressure of 20 micropascals and reference duration of one second (ANSI 1994)
Sound intensity	Average rate of sound energy transmitted in a specified direction at a point through a unit area normal to this direction at the point considered (ANSI 1994)
Sound level meter	Device to be used to measure sound pressure level with a standardized frequency weighting and indicated exponential time weighting for measurements of sound level, or without time weighting for measurement of time-average sound pressure level or sound exposure level (ANSI 1994)
Sound pressure	Root-mean-square instantaneous sound pressure at a point, during a given time interval (ANSI 1994), where the *instantaneous* sound pressure is the total instantaneous pressure in that point minus the static pressure (ANSI 1994)

Sound pressure level	Ten times the logarithm to the base ten of the ratio of the time-mean-square pressure of a sound, in a stated frequency band, to the square of the reference sound pressure in gases of 20 μPa (ANSI 1994)
Sound reduction index	Single-number rating of airborne sound insulation of a partition (ANSI 1994)
Sound transmission class	Single-number rating of airborne sound insulation of a building partition (ANSI 1994)
Speech interference level	One-fourth of the the sum of the band sound pressure levels for octave-bands with nominal midband frequencies of 500, 100, 2000 and 4000 Hz (ANSI 1994)
Speech intelligibility	That property which allows units of speech to be identified (ANSI 1995)
Speech perception	Psychological process that relates a sensation caused by a spoken message to a listener's knowledge of speech and language (ANSI 1995)
Speech comprehension	(a) Highest level of speech perception. (b) Knowledge or understanding of a verbal statement (ANSI 1995)
Speech transmission index	Physical methgod for measuring the quality of speech-transmission channels accounting for nonlinear distortions as well as distortions of time (ANSI 1995)
Stereocilia	Nonmotile protoplasmic projections from free surfaces on the hair cells of the receptors of the inner ear (CMD 1997)
Stress	The sum of the biological reactions to any adverse stimulus, physical, mental or emotional, internal or external, that tends to disturb the organism's homeostasis (DIMD 1985)
Temporary threshold shift, temporary hearing loss	Temporary increase in the auditory threshold for an ear caused by exposure to high-intensity acoustic stimuli (adapted from ANSI 1995) (see also: noise induced temporary threshold shift).
Tinnitus	A subjective ringing or tinkling sound in the ear (CMD 1997). Otological condition in which sound is perceived by

	a person without an external auditory stimulation. The sound may be a whistling, ringing, buzzing, or cricket type sounds, but auditory hallucinations of voices are excluded (ANSI 1995).
Vibration	Oscillation of a parameter that defines the motion of a mechanical system (ANSI 1994)

For references see Appendix A.

Appendix 4 : Acronyms

AAP	American Academy of Pediatrics
AI	Articulation Index
AMIS	Air Management Information System (WHO, Healthy Cities)
ANEF	Australian Noise Exposure Forecast
ANSI	American National Standard Institute, Washington DC, USA
ASCII	American Standard Code for Information Interchange
ASHA	American Speech-Language-Hearing Association, Rockville, MD, USA
ASTM	American Society for Testing and Materials, West Conshohocken, PA, USA
CEN	Comité Européen de Normalisation, Brussels, Belgium (European Committee for Standardization)
CFR	Code of Federal Regulations (United States)
CIAL	Centro de Investigaciones Acústicas y Luminotécnicas, Córdoba, Argentina (Centre of acoustical and light-technical investigations)
CMD	Cyclopedic Medical Dictionary
CNRC	Conseil National de Recherches du Canada (National Research Council)
COPD	Chronic Obstructive Pulmonary Disease
CSD	Commission for Sustainable Development
CSIRO	Commonwealth Scientific and Industrial Research Organization
CVS	Cardiovascular System
DNL	Day-Night Average Sound Level (United States)
EC DG	European Commission Directorate General
ECE	Economic Commission for Europe
ECMT	European Conference of Ministers of Transport
EHIAP	Environmental Health Impact Assessment Plan
EIAP	Environmental Impact Assessment Plan
EMRO	WHO Regional Office of the Eastern Mediterranean
ENIA	Environmental Noise Impact Analysis
EPNL	Effective Perceived Noise Level measure
EU	European Union
FAA	Federal Aviation Administration (United States)
FFT	Fast Fourier Transform technique
GIS	Geographic Information System
Hz	Hertz, the unit of frequency
ICAO	International Civil Aviation Organization
ICBEN	International Commission on the Biological Effects of Noise
IEC	International Electrotechnical Commission
ILO	International Labour Office, Geneva, Switzerland
INCE	Institute of Noise Control Engineering of the United States of America
INRETS	Institut National de REcherche sur les Transports et leur Sécurité, Arcueil, France (National Research Institute for Transport and their Safety)
ISO	International Standards Organization
I-INCE	International Institute of Noise Control Engineering
L10	10 percentile of sound pressure level

L50	Median sound pressure level
L90	90-percentile of sound pressure level
LA	Latin America
LAeq,T	A-weighted equivalent sound pressure level for period T
LAmax	Maximum A-weighted sound pressure level in a stated interval
L_{dn}	Day and night continuous equivalent sound pressure level
Leq,T	Equivalent sound pressure level for period T
LEQ(FLG)	Descriptor used for aircraft noise (Germany)
LNIP	Low Noise Implementation Plan
Lp	Sound pressure level
MTF	Modulation Transfer Function
NASA	National Aeronautics and Space Administration (United States)
NC	Noise Criterion
NCA	Noise Control Act (United States)
NCB	Balanced Noise Criterion procedure system
NEF	Noise Exposure Forecast
NEPA	National Environmental Policy Act (United States)
NGO	Non Governmental Organization
NIHL	Noise Induced Hearing Loss
NIPTS	Noise Induced Permanent Threshold Shift
NITTS	Noise Induced Temporary Threshold Shift
NNI	Noise and Number Index
NR	Noise Rating
NRC	National Research Council (United States, Canada)
OECD	Organisation for Economic Co-operation and Development, Paris, France.
ONAC	Office of Noise Abatement and Control of the US EPA
OSHA	Occupational Safety and Health Administration
Pa	Pascal, the unit of pressure
PAHO	Pan American Health Organization
PHE	Department for Protection of the Human Environment, WHO, Geneva
PNL	Perceived Noise Level
PSIL	Preferred Speech Interference Level
PTS	Permanent Threshold Shift
RASTI	Rapid Speech Transmission Index
RC	Room Criterion
SABS	South African Bureau of Standards
SEL	Sound Exposure Level
STC	Sound Transmission Class
STI	Speech Transmission Index
TTS	Temporary Threshold Shift
UK	United Kingdom
UN	United Nations
UNCED	United Nations Conference on Environment and Development (Rio de Janeiro, June 1992)
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe

UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
US EPA	United States Environmental Protection Agency
USA	United States of America
WCED	World Commission on Environment and Development (Brundtland Commission)
WECPNL	Weighted Equivalent Continuous Perceived Noise Level
WHO	World Health Organization
WWF	World Wildlife Fund

Appendix 5 : Equations and other technical information

Basic acoustical measures

Sound Pressure Level

The time-varying sound pressure will completely define a sound in a given location. The sound pressure range is wide within which human listeners can receive (10^{-5} - 10^{2} N/m^2). Therefore, it is practical to measure sound pressure level on a logarithmic scale. Sound intensity level is defined as 10 times the logarithm (to the base 10) of the ratio of the sound intensity of a target sound to the sound intensity of another (reference) sound. Sound intensity is proportional to the squared sound pressure because the static mass density of the sound medium as well as the speed of sound in this medium are invariant. The sound pressure level (L_p) of a sound may be expressed as a function of sound pressure (p) and is, thus, possible to measure:

$$L_p = 10 \log_{10} (p/p_{ref})^2$$

For the purpose of measuring sound pressure level in a comparative way, the reference pressure, p_{ref}, has an internationally agreed value of $2 \cdot 10^{-5}$ N/m^2 (earlier 20 μPa). Sound pressure level is then expressed in decibel (dB) relative to this reference sound.

Sound Pressure Level of Combined Sounds

Whereas sound intensities or energies or pressures are additive, non-correlated time-varying sound pressure levels have first to be expressed as mean square pressure, then added, and then transferred to a sound pressure value again. For example, if two sound sources are combined, each of a sound pressure level of 80 dB, then the sound pressure level of the resulting combined sound will become 83 dB:

$$L_p = 10 * \log_{10} (10^8 + 10^8) = 10 * \log_{10} (2 * 10^8) = 10 * (\log_{10} 2 + \log_{10} 10^8) = 10 * (0.3 + 8) = 83$$

It is only sounds with similar sound pressure levels that when combined will result in a significant increase in sound pressure level relative to the louder sound. In the example given above, a doubling of the sound energy from two sources will only result in a 3-dB increase in sound pressure level. For two sound sources that emit non-correlated time-varying sound pressures, this represents the maximum increase possible. The sound pressure level outcome, resulting from combining two sound pressure levels in dB, is displayed in Figure A.5.1.

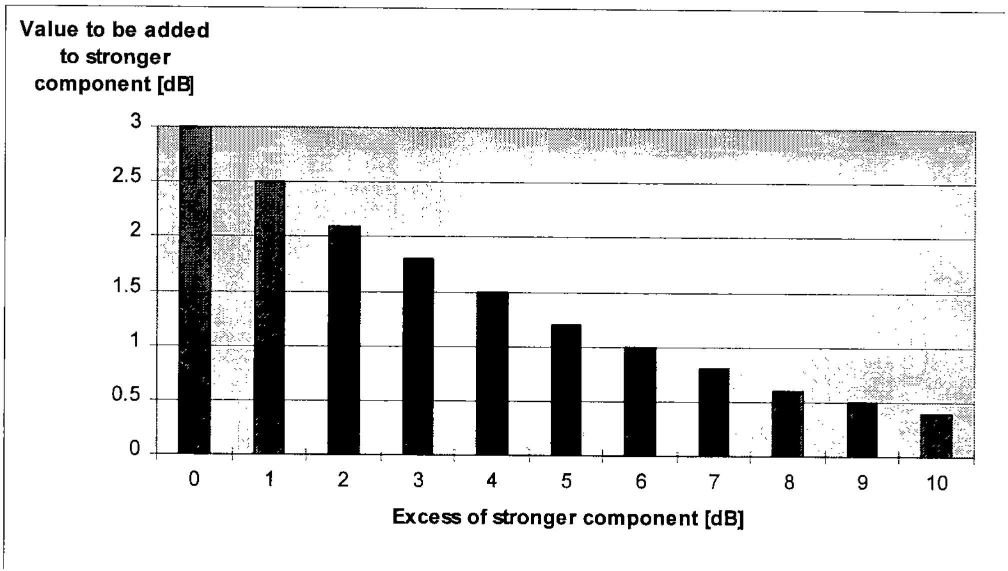

Figure A.5.1: Estimate of combined sound levels

Equivalent Continuous Sound Pressure Level

Average sound pressure level is determined for a time period of interest, T, which may be an interval in seconds, minutes, or hours. This gives a dB-value in Leq that stands for equivalent continuous sound pressure level or simply sound level. It is derived from the following mathematical expression in which A-weighting has been applied:

$$LAeq,T = 10 \log_{10}\{(1/T) \int_0^T 10^{Lp(t)/10} dt\} \text{ [dBA]}$$

Because the integral is a measure of the total sound energy during the period T, this process is often called "energy averaging". For similar reasons, the integral term representing the total sound energy may be interpreted as a measure of the total noise dose. Thus, Leq is the level of that steady sound which, over the same interval of time as the fluctuating sound of interest, has the same mean square sound pressure, usually applied as an A-frequency weighting. The interval of time must be stated.

Sound exposure level

Individual noise events can be described in terms of their sound exposure level (SEL). SEL is defined as the constant sound level over a period of 1 s that would have the same amount of energy as the complete noise event (Ford 1987). For a single noise event occurring over a time interval T, the relationship between SEL and LAeq,T is,

$$SEL = LAeq,T + 10 \log_{10} (T/T_0)$$

In this equation T_0 is 1 s.

Day and night continuous sound pressure level

There are different definition in different countries. One definition is (von Gierke 1975; Ford 1987):

L_{dn} = LAeq,16h + LAeq,8h – 10 dBA

Where LAeq,16h is the day equivalent sound pressure level and LAeq,8h is the night equivalent sound pressure level.

Sound Transmission into and within buildings

An approximate relationship between sound reduction index (R), the frequency (f), the mass per unit area of the panel (m) in kg/m^2, and the angle of incidence (θ) is given by

$$R(\theta) = 20 \log\{f\, m\, \mathrm{COS}(\theta)\} - 42.4, \text{ (dB)}$$

This relationship indicates that the sound reduction index will increase with the mass of a panel and with the frequency of the sound as well as varying with the angle of incidence of the sound. It is valid for limp materials but is a good approximation to the behaviour of many real building materials at lower frequencies.

The sound reduction index versus frequency characteristics are usually complicated by a coincidence dip which occurs around the frequency where the wavelength of the incident sound is the same as the wavelength of bending waves in the building façade material. The frequency at which the coincidence dip occurs is influenced by the stiffness of the panel material. Thicker, and hence stiffer materials, will have coincidence dips that are lower in frequency than less stiff materials. Figure A.5.2 plots measured sound reduction index values versus frequency for 4 mm thick glass and illustrates the coincidence dip for this glass at a frequency centered just above 3 kHz.

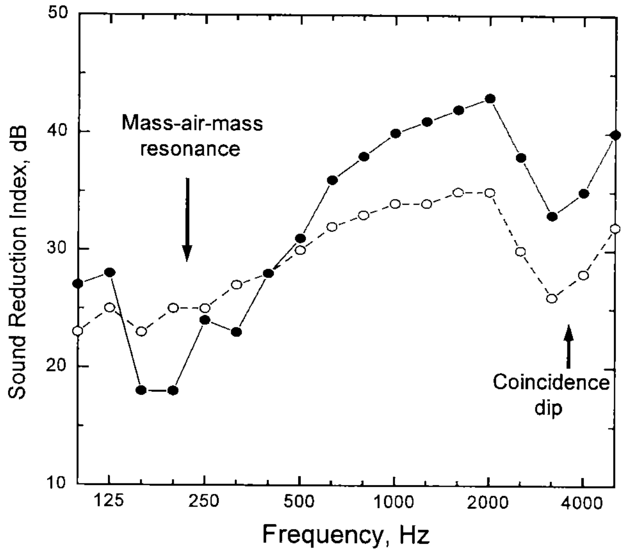

Figure A.5.2: Sound reduction index versus frequency for single and double layers of 4 mm glass (air separation 13 mm).

As also illustrated in Figure A.5.2 for two layers of 4 mm glass, the low frequency sound reduction can be severely limited by the mass-air-mass resonance. This resonance is due to the combination of the masses of the two layers and the stiffness of the enclosed air space. As the Figure A.5.2 example shows, this resonance can often dramatically reduce the low frequency sound reduction of common double window constructions.

The sound reduction of various building constructions can be calculated as the difference between the average sound levels in the two rooms ($L_1 - L_2$) plus a correction involving the area of the test panel (S) in m^2 and the total sound absorption (A) in m^2 in the receiving room,

$$R = L_1 - L_2 + 10\log\{S/A\} \text{ [dB]}.$$

For outdoor-to-indoor sound propagation, the measured sound reduction index will also depend on the angle of incidence of the outdoor sound as well as the position of the outdoor measuring microphone relative to the building façade,

$$R = L_1 - L_2 + 10\log\{4S\,COS(\theta)/A\} + k \text{ [dB]}.$$

When the outdoor incident sound level L_1 is measured with the outdoor microphone positioned against the external façade surface, measured incident sound pressures will be 6 dB higher due to pressure doubling. This occurs because the incident sound and reflected sound arrive at the microphone at the same time. If the external microphone is located 2 m from the façade, there will not be exact pressure doubling but an approximate doubling of the measured sound energy corresponding to a 3 dB increase in sound level. The table below indicates the appropriate values of k to be used in the above equation, depending on the location of the outdoor microphone, to account for sound reflected from the façade.

$k = 0$, dB	L_1 does not include reflected sound.
$k = -3$, dB	L_1 measured 2 m from façade and includes reflected energy.
$k = -6$, dB	L_1 measured at the façade surface and includes pressure doubling effect.

Appendix 6 : Participant list of THE WHO Expert Task Force meeting on Guidelines For Community Noise, 26-30 April 1999, MARC, London, UK

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FTA

FEDERAL TRANSIT ADMINISTRATION

Transit Noise and Vibration Impact Assessment Manual

SEPTEMBER 2018

FTA Report No. 0123
Federal Transit Administration

PREPARED BY
John A. Volpe National Transportation Systems Center

U.S. Department of Transportation
Federal Transit Administration

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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14. ABSTRACT
This report is the third edition of a guidance manual originally issued in 1995. It includes clarifications to existing policy and updates to outdated references where applicable. Topics presented in this manual include procedures for predicting and assessing noise and vibration impacts of proposed transit projects for different stages of project development and different levels of analysis. Additional topics include descriptions of noise and vibration mitigation measures, construction noise and vibration, and how to present these analyses in the Federal Transit Administration's environmental documents. This guidance is for technical specialists who conduct the analyses, as well as project sponsor staff, Federal agency reviewers, and members of the general public who may be affected by the projects.

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Transit noise and vibration analysis, noise and vibration impact criteria, noise and vibration mitigation measures, environmental impact assessment, Nation Environmental Policy Act compliance.

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Abstract

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The original 1995 version of this manual was developed by the firm Harris Miller Miller & Hanson Inc. (HMMH) and peer-reviewed by a group of specialists in the fields of acoustics and environmental planning and analysis. HMMH updated the original manual in 2006.

The updates for this current version were provided by the John A. Volpe National Transportation Systems Center, Cross Spectrum Acoustics, and FTA, and it was peer-reviewed by a panel of experts.

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SECTION

1

Introduction

1.1 Purpose

The Council on Environmental Quality (CEQ) regulations for implementing the procedural provisions of the National Environmental Policy Act of 1969 (NEPA)[1,2] require that a federally-funded project be assessed for its impact on the human and natural environment prior to implementation. The Federal Transit Administration (FTA), in conjunction with the Federal Highway Administration (FHWA), has issued detailed regulations implementing NEPA for transit and highway projects. The regulations are codified in part 771 of title 23, Code of Federal Regulations, and are titled "Environmental Impact and Related Procedures." (23 CFR part 771).[3]

The Federal Transit Administration (FTA) provides financial assistance for a range of public transportation projects from new rail rapid transit (RRT) systems to bus maintenance facilities and vehicle purchases. As required by NEPA and its implementing regulations, each project must undergo environmental review.

Noise and vibration are sometimes among the major concerns regarding the effects of a transit project on the surrounding community and are key elements of the environmental impact assessment process for public transportation projects. A transit system is often placed near population centers by necessity and may cause noise and vibration at nearby residences and other sensitive types of land use.

This manual provides technical guidance for conducting noise and vibration analyses for transit projects, as well as direction regarding preparation of the information for FTA's environmental documents. Some situations may not be explicitly covered in this manual; the exercise of professional judgment may be required to extend the basic methods in these cases and frequent consultation with FTA staff is important to ensure the methods used meet the requirements for environmental reviews. See Appendix G for information on using non-standard modeling procedures.

In general, the noise and vibration impact assessment process for projects includes the following steps:

1. Determine appropriate impact criteria (Section 4.1).
2. Conduct screening and determine appropriate level of noise analysis, analyze project noise impacts, and evaluate mitigation options if appropriate (Sections 4.2–4.5).
3. Determine appropriate level of vibration analysis, analyze project vibration impacts, and evaluate mitigation options if appropriate (Sections 6.1–6.5).
4. Analyze construction noise and vibration impacts (Section 7).
5. Document findings (Section 8).

1.2 Organization of the Manual

This guidance manual is organized by the following recommended analysis workflow. A glossary of terms used throughout this manual is available in Appendix A. Detailed information on the fundamentals of noise, noise impact criteria, clustering receivers, determining existing noise, computing source levels from measurements, and using non-standard methodology is available in the appendices.

Section 2: Project Class of Action and Planning – This section describes the first step in the analysis process that is applicable to both noise and vibration analyses.

Section 3: Transit Noise – This section provides the reader with background information specific to transit noise.

Section 4: Noise Impact Analysis – This section provides a general outline of the entire noise impact analysis process: guidelines on determining noise impact criteria, methods for choosing the appropriate level of noise analysis ("Screening," "General," or "Detailed"), steps for evaluating noise impacts with the Noise Screening Procedure (a simplified method of evaluating the potential for noise impact from transit projects), steps for evaluating noise impact with the General Noise Assessment procedure (a simplified assessment method to estimate noise impact and compare alternatives for transit projects), and steps for evaluating noise impact with the Detailed Noise Analysis procedure (a comprehensive assessment method to produce the most accurate estimates of noise impact intended for certain major public transportation projects).

Section 5: Transit Vibration – This section contains background information specific to transit vibration.

Section 6: Vibration Impact Analysis – This section provides a general outline of the entire vibration impact analysis process: guidelines on determining vibration impact criteria, methods for choosing the appropriate level of vibration analysis ("Screening," "General," or "Detailed"), steps for evaluating vibration impact with the vibration screening procedure (a simplified method of evaluating the potential for vibration impact from transit projects), steps for evaluating vibration impact with the general vibration assessment procedure (a simplified assessment method to estimate vibration impact and compare alternatives for transit projects), and steps for evaluating vibration impact with the detailed vibration analysis procedure (a comprehensive assessment method to produce the most accurate estimates of vibration impact intended for certain major public transportation projects).

Section 7: Noise and Vibration During Construction – This section presents the process of assessing noise and vibration impact during construction, including determination of level of assessment, source levels, impact criteria, and mitigation.

Section 8: Documentation of Noise and Vibration Assessment – This section includes guidance for documenting the noise and vibration assessment in technical reports and environmental documents.

SECTION

2

Project Class of Action and Planning

The level of environmental analysis and review depends on the significance of any potential associated environmental impacts, which in turn depends in part on the scope and complexity of the proposed project. The goals of a transit noise and vibration impact assessment are to:

1. Determine existing noise and vibration levels.
2. Assess project noise and vibration for potential impact.
3. Evaluate the effect of mitigation options on impacts.

The class of action determination will inform the required level of analysis. The FTA Regional office[i] determines the class of action based on project information provided by the project sponsor. The following types of information can assist the FTA Regional office in an initial class of action determination for a project:

- Project description
- Project-specific graphics, including:
  - Project location/sizes
  - Known land use and environmental features
- Additional information, as appropriate:
  - Summary of prior planning
  - Draft purpose and need statement

Project classes of action are described in Section 2.1. Project planning and development guidelines are presented in Section 2.2.

2.1 Project Class of Action

FTA's environmental regulations classify projects by level of environmental analysis. The class of action will determine the appropriate level of analysis and documentation for a project. Details of each class are described in the following sections. For more information, review FTA's environmental impact and related procedures at 23 CFR part 771.

Environmental Impact Statements
Environmental impact statements (EISs) apply to projects that are expected to cause significant environmental effects in the NEPA context. Typical examples include new or extensions of fixed-guideway projects, such as heavy rail, light rail, commuter rail, and automated guideway transit (AGT) systems that are not located within existing transportation right-of-way (ROW). It is likely that for major infrastructure projects requiring an EIS, the most detailed treatment of noise and vibration impacts will often be required.

Categorical Exclusions
Categorical exclusions (CEs) cover actions that are excluded from requiring an EIS or environmental assessment (EA) because FTA has determined that they do

[i] http://www.fta.dot.gov/12926.html.

not routinely cause significant environmental impacts. FTA's CEs are located at 23 CFR §§ 771.118(c) and (d), commonly referred to as the c-list and d-list, respectively. Examples of projects that would normally be CEs include vehicle purchases, maintenance of equipment, vehicles, or facilities, and ROW acquisition.
In general, CEs for transit capital construction projects often require at least a screening of noise impacts.

Environmental Assessments
When a proposed project is presented to FTA and it is uncertain whether the project requires an EIS or qualifies for a CE, FTA will normally direct the project sponsor to prepare an environmental assessment (EA) to assist in making the determination. An EA may be prepared for any type of project if uncertainty exists about the magnitude or extent of the impacts. Generally, an EA is selected over a CE if FTA determines that several types of potential impacts require further investigation, for example, air quality, noise, wetlands, historic sites, and/or traffic, but FTA's environmental regulation does not list typical projects that require EAs.
Experience shows that most of the EAs prepared for transit projects require at least a general assessment of noise impacts.

2.2 Project Planning and Development

Capital transit projects are ordinarily developed initially from a comprehensive transportation planning process conducted in metropolitan areas (see 23 CFR § 450.300).(4) The metropolitan planning process often includes some early consideration of social, economic, and environmental effects of proposed major infrastructure improvements. At this stage, environmental effects are usually considered on a broad scale—for example, overall development patterns, impacts on green space, and regional air quality. Noise and vibration assessments are not typically performed at this stage because the proposed infrastructure improvements lack the necessary detail.

Once the need for a capital transit project in a corridor is established in the metropolitan transportation plan, the transit mode and general alignment best suited for the corridor are identified. The Screening and General noise assessment procedures and the vibration screening procedure described in this manual may be used to compare noise and vibration effects among different transit modes and alignments at an early stage of the project planning. The analysis that results is documented through the environmental review process.

NEPA establishes a broad policy regarding mitigation as a means of accomplishing its environmental objectives. Other Federal laws, such as Section 4(f) (49 U.S.C. 303) and Section 404 (33 U.S.C. 1344), have explicit mitigation requirements for certain resources. The decision to include noise or vibration mitigation for a project is made by FTA and the project sponsor after public review of the environmental document, as appropriate. If mitigation measures are deemed necessary to protect the environment or to satisfy 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. Through that process, FTA ensures that the project sponsor complies with all design and mitigation commitments contained in the environmental record.

Once the project enters construction, noise or vibration may need to be reassessed in some circumstances. Some large construction projects in densely populated residential areas may require noise monitoring to ensure agreed-upon noise limits are not exceeded. Vibration testing may be needed in the final stages of construction to determine whether vibration control measures have the predicted effect.

Considering that transit projects must be located amid or very close to concentrations of people, noise and vibration impacts can be a concern throughout the environmental review process, design, and construction phases. This manual offers the flexibility to address noise and vibration at different stages in the development of a project and in different levels of detail.

2.3 Mitigation Policy Considerations

Because noise is frequently among the greatest environmental concerns of planned transit projects, FTA and the project sponsor should make reasonable efforts to reduce predicted noise to levels considered acceptable for affected noise-sensitive land uses. The need for noise mitigation is determined based on the magnitude of impact and consideration of factors specifically related to the proposed project and affected land uses.

The goal of providing noise mitigation is to gain substantial noise reduction, not simply to reduce the predicted levels to just below the "severe" impact threshold. For FTA to determine whether the mitigation is reasonable, the evaluation of specific mitigation measures should include the noise reduction potential, the cost, the effect on transit operations and maintenance, and any other relevant factors, such as any new environmental impacts that may be caused by the implementation of a noise reduction measure. A thorough evaluation enables FTA to make the findings required by NEPA and other statutes, such as Section 4(f) or Section 106 requirements and their implementing regulations.

Severe impacts have the greatest adverse impact on the community, and mitigation should be strongly considered. Areas with "moderate" impacts also have potential for effects on the community and therefore should also include consideration and possible adoption of mitigation measures when considered reasonable.

Since reasonableness is not strictly defined, FTA recommends that project sponsors work with the affected public and FTA staff during the environmental review process to decide appropriate mitigation strategies. A project sponsor may also consider developing and formally adopting a mitigation policy to aid in the determination of appropriate and applicable mitigation measures for current and proposed projects and anticipated impacts. Having such a policy in place can aid in the project planning up front and help to expedite mitigation decisions.

The following considerations can assist in determining circumstances that trigger the need for mitigation and include examples of how they can be applied in a noise mitigation policy:

- **Number of Noise-Sensitive Sites Affected**
  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. Single residences may not be able to meet a cost-effectiveness criterion for mitigation.

  Example Mitigation Policy Consideration: Set a minimum number of noise-sensitive sites as a threshold, combined with a reference to a cost-effectiveness criterion.

- **Increase over Existing Noise Levels**
  Since the noise impact criteria are delineated as bands or ranges, project noise can vary 5 to 7 decibels (dB) within the band of moderate impact at any specific ambient noise level. If the project and ambient noise plot falls just below the severe range, the need for mitigation is strongest for a moderate impact. Similarly, if the plot falls within the moderate range just above the no impact threshold, the impacts are expected to be less, so the justification for mitigation would not be as strong.

  Example Mitigation Policy Consideration: Set a strong need for mitigation when a moderate impact is 2 dB (for example) over the no impact threshold.

- **Noise Sensitivity of the Property**
  Section 4.1 includes 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.

  Example Mitigation Policy Consideration: Cite the use of the property as a determination of sensitivity for parks and recreational areas.

- **Effectiveness of the Mitigation Measure(s)**
  Determine the magnitude of the noise reduction that can be achieved, and consider whether there are conditions that limit effectiveness, such as noise barrier effectiveness for a multi-story apartment building.

  Example Mitigation Policy Consideration: Set a minimum reduction in noise level to be considered effective. A 5-dB reduction is typically considered an effective reduction from mitigation.

- **Feasibility of the Mitigation Measure(s)**
  Determine if the mitigation measure is feasible from an engineering, operations or safety perspective. In some cases, it may not be possible to construct mitigation (noise barriers) due to physical or structural limitations

or because of safety concerns, especially related to sight lines for pedestrians and vehicles.

Example Mitigation Policy Consideration: State that the engineering design of the mitigation must be feasible, that it must be implementable in light of operations, and that mitigation must not compromise safety.

- **Fairness and Equity of the Mitigation Measure(s)**
  Ensure that mitigation measures are applied in a fair and equitable manner. In many cases, small differences in distances or operations can result in small differences in projected noise levels. For example, all the residences in a row could have a projected moderate impact except for one residence at the end of the row that falls just under the moderate criteria due to being set slightly further back from the alignment. In a case like this, mitigation should be applied for the entire row of residences if possible.

  Example Mitigation Policy Consideration: State that mitigation should be applied equitably.

- **Existing Transportation Noise**
  Neighborhoods with ambient noise levels already heavily influenced by transportation noise, especially the same type of noise source as the project, should be considered. Often adding a new similar noise source will not add to the ambient noise levels or only slightly increase it to within acceptable levels. Whereas, impacts would be more likely, if the new noise was added to a neighborhood with minimal transportation noise. However, it is important to note that per (Section 4.1, Step 3) the higher the existing noise, the lower the allowable noise increase from new sources. A new cumulative noise environment may be very objectionable because people will not be compartmentalizing the existing noise versus the new noise and reacting only to the new noise. In this circumstance, impacts predicted in the moderate range could be treated as if they were severe.

  Example Mitigation Policy Consideration: Set a policy that moderate impacts under these circumstances be treated as severe and cite the potential for reducing noise from existing transportation noise, as well as from project noise.

- **Community Views**
  This manual provides the methodology to make an objective assessment of the need for noise mitigation. However, the views of the community should be considered where there are potential noise impacts predicted through this manual. 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 moderate impact range and, where possible, decisions regarding mitigation should be made 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 noise barrier, was not preferable to community members because of perceived adverse visual effects.

Example Mitigation Policy Consideration: State that community input in determining the need for mitigation will be included whenever possible.

- **Implementation Cost**
  Cost is an important consideration in reaching decisions about noise mitigation measures. One guideline for gauging the reasonableness of the cost of mitigation is the state DOT's procedures on the subject. Many states have established their own cost threshold per benefited residence for determining whether installation of noise barriers for noise reduction is a reasonable expenditure. Several airport authorities have placed limits on the costs they will incur for sound insulation per residence for homes, and FTA assesses cost in a similar manner by benefited residence. Higher costs may be justified depending on the specific set of circumstances of a project.

  Example Mitigation Policy Consideration: State the adopted cost threshold per benefited receiver for typical circumstances.

SECTION 3

Transit Noise

This section presents the basic concepts of transit noise as background for computation methods and transit noise assessment procedures presented in Section 4. An overview of fundamental noise topics, including amplitude, frequency, time pattern, and decibel addition, is presented in Appendix B.

The Source-Path-Receiver framework for noise illustrated in Figure 3-1 is central to all environmental noise studies. Each transit source generates noise that depends upon the type of source and its operating characteristics. Along the propagation path, between all sources and receivers, noise levels can be reduced (attenuated) by distance depending on ground type, intervening obstacles, and other factors. Finally, noise combines from multiple sources at each receiver and potentially interferes with activities at that location.

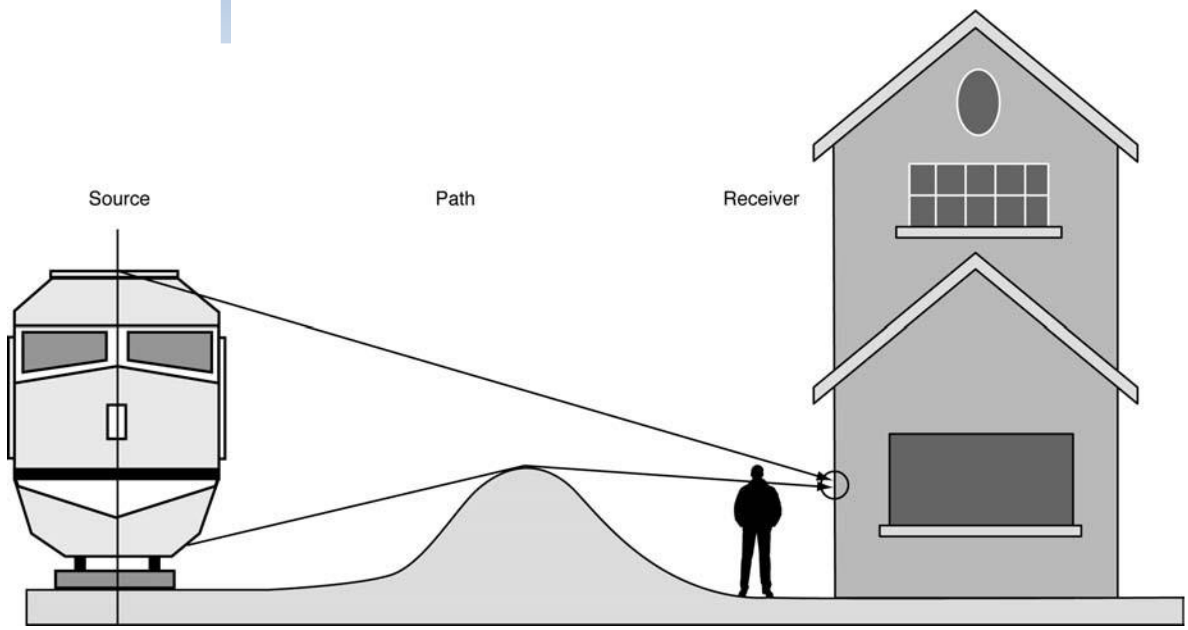


Figure 3-1 Source-Path-Receiver Framework

This section contains the following:

- Section 3.1 presents the noise metrics used in this manual.
- Section 3.2 provides an overview of transit noise sources, including a listing of major sources and a discussion of noise-generation mechanisms.
- Section 3.3 provides an overview of noise paths, including a discussion of the various attenuating mechanisms on the path between source and receiver.
- Section 3.4 provides an overview of receiver response to transit noise, including a discussion of the technical background for transit noise criteria and the distinction between absolute and relative noise impact.

3.1 Noise Metrics

This manual uses the noise metrics outlined in Table 3-1 for transit noise measurements, computations, and assessment. The terminology is consistent with common usage in the United States. All of these noise metrics are expressed in units of A-weighted decibels (dBA). A-weighted sound levels represent the overall noise at a receiver that is adjusted in frequency to approximate typical human hearing sensitivity. This is the basic noise unit for transit noise analyses.

Table 3-1 Noise Metrics

Metric	Abbreviation	Definition
A-weighted Sound Level	dBA	A-weighted sound levels represent the overall noise at a receiver that is adjusted in frequency to approximate typical human hearing sensitivity. This is expressed as A-weighted decibels (dBA), the basic noise unit for transit noise analyses.
Sound Exposure Level	*SEL*	SEL is the cumulative noise exposure from a single noise event, normalized to one second. SEL contains the same overall sound energy as the actual varying sound energy during the event. It is the primary metric for the measurement of transit vehicle noise emissions, and is an intermediate metric in the measurement and calculation of both $L_{eq(t)}$ and L_{dn}.
Equivalent Sound Level	$L_{eq(t)}$	The equivalent sound level $L_{eq(t)}$ describes a receiver's cumulative noise exposure from all events normalized to a specified period of time "t". $L_{eq(t)}$ represents a hypothetical, constant sound level and contains the same overall sound energy as the actual varying sound energy during the time period "t". For transit noise impact assessments, the equivalent sound level metric is A-weighted and all events are normalized over a one-hour time period, $L_{eq(1hr)}$. For transit noise assessments, this metric is appropriate for non-residential land uses and is computed for the loudest hour of project related activity during hours of noise sensitivity.
Day-Night Sound Level	L_{dn}	L_{dn} describes a receiver's cumulative noise exposure from all events over 24 hours. Events between 10 p.m. and 7 a.m. are increased by 10 dB to account for humans' greater nighttime sensitivity to noise. L_{dn} is used to assess transit noise for residential land uses.
Maximum Sound Level	L_{max}	The maximum level describes the maximum noise level reached during a single noise event. For transit noise impact assessments, it is appropriate to consider the A-weighted maximum level (L_{max}) to understand the full context of the scenario. It is not appropriate to use this metric for transit noise impact assessments. This metric is commonly used in vehicle noise specifications and commonly measured for individual vehicles.

The noise metrics, including their application to transit noise and vibration impact assessment, are described in more detail in Appendix B.1.4. Mathematical definitions and graphic illustrations are presented to facilitate understanding and the interrelationships among metrics.

3.2 Sources of Transit Vehicle Noise

This section discusses major characteristics of the sources of transit noise. Transit noise can be generated by transit vehicles in motion, stationary transit vehicles, and fixed-transit facilities. Procedures for computing nearby noise levels for major sources as a function of operating parameters such as vehicle speed are given in Sections 4.4 and 4.5.

Transit Vehicles in Motion

Transit vehicles most noticeably create noise when in motion. Noise from transit vehicles in motion can come from multiple sources, including the propulsion unit (i.e., the engine and engine components), the interaction of the wheels and/or tires and the running surface, and warning bells and horns.

Vehicle propulsion units generate:

- Whine from electric control systems and traction motors that propel rapid transit cars
- Diesel-engine exhaust noise from both diesel-electric locomotives and transit buses
- Air-turbulence noise generated by cooling fans
- Gear noise

Noise is also generated by the interaction of wheels and/or tires with their running surfaces. Tire noise from rubber-tired vehicles is generated at normal operating speeds. The interaction of steel wheels and rails generates:

- Rolling noise due to continuous rolling contact
- Impact noise when a wheel encounters a discontinuity in the running surface such as a rail joint, turnout or crossover (where the train or rail vehicle switches off one track and onto another)
- Impact noise from the wheel and running surface if the wheel is not completely round (wheel flat) or if the running surface is not completely flat
- Squeal generated by friction between wheels and rail on tight curves

Transit vehicles are equipped with horns and bells for use in emergency situations and as a general audible warning to track workers and trespassers within the ROW, pedestrians, and motor vehicles at highway grade crossings. Horns and bells on the moving transit vehicle combined with stationary bells at-grade crossings can generate high noise levels for nearby residents and are often sources of complaints.

For many noise sources, such as transit vehicles, the sound level is dependent on the speed of the noise source. In other cases, such as for stationary sources or horns mounted on vehicles, the sound level is not dependent on speed. Figure 3-2 illustrates sound level dependence on speed for a diesel-powered commuter rail train and an electric-powered transit train assuming all other parameters, such as weight, are equal. Plotted vertically in this figure is a notional indication of the maximum sound level during a passby. Speed dependence is strong for electric-powered transit trains because wheel/rail noise is the dominant noise source and noise from this type of source increases strongly with speed. Diesel-powered commuter rail train noise is dominated by the locomotive exhaust noise at slower speeds. As speed increases, wheel-rail noise becomes the dominant noise source and diesel- and electric-powered trains generate similar noise levels. Similarly, speed dependence is also strong for automobiles, city buses (two-axle), and non-accelerating highway buses (three-axle), because tire/pavement noise is the dominant noise source for these vehicles. Accelerating highway bus noise is dominated by exhaust noise.

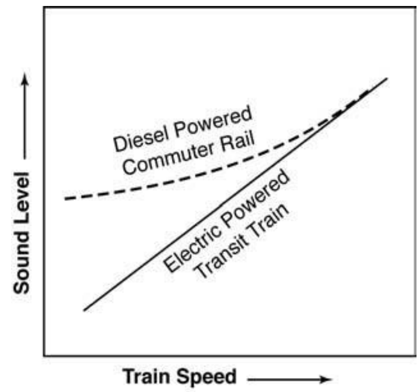


Figure 3-2 Sound Level Dependence on Speed

Sound levels close to the source are also dependent on vehicle acceleration, vehicle length, running surface type, and running surface condition. For high-speed rail vehicles (vehicles with an operating speed of 90–250 mph are typically beyond the scope of this manual), air turbulence can also be a source of noise. In addition, for an elevated structure, the guideway can radiate noise as it vibrates in response to the dynamic loading of the moving vehicle.

Stationary Transit Vehicles

Noise can be generated by transit vehicles even when they are stationary. For example, auxiliary equipment such as cooling fans on motors, radiator fans, plus hydraulic, pneumatic, and air-conditioning pumps, often continue to run when vehicles are stationary. Transit buses are also often left idling in stations or storage yards.

Fixed-transit Facilities

Noise can also be generated by sources at fixed-transit facilities. Such sources include ventilation fans in transit stations, subway tunnels, and electric power substations, as well as equipment in chiller plants, and many activities within maintenance facilities and shops.

Common Noise Sources

Table 3-2 summarizes common sources of transit noise by vehicle and facility type.

Table 3-2 Sources of Transit Noise

Vehicle or Facility*	Dominant Components	Comments
RRT or Light Rail Transit (LRT) on exclusive ROW	Wheel/rail interaction and guideway amplification	Depends on condition of wheels and rails
	Propulsion system	When accelerating and at higher speeds
	Brakes	When stopping
	Auxiliary equipment	When stopped
	Wheel squeal	On tight curves
	In general	Noise increases with speed and train length
LRT in Mixed Traffic	Wheel squeal	On tight curves
	Auxiliary equipment	When stopped
	Horns and crossing bells	At-grade crossings and stations
	In general	Traveling at lower speeds in mixed traffic produces less noise than when traveling at higher speeds in exclusive ROW
Commuter Rail	Diesel exhaust	On diesel-hauled trains
	Cooling fans	On both diesel and electric-powered trains
	Wheel/rail interaction	Depends on condition of wheels and rails
	Horns and crossing gate bells	At-grade crossings and stations
	In general	Noise is usually dominated by locomotives and horns/bells at-grade crossings
Low and Intermediate Capacity Transit	Propulsion systems, including speed controllers	At low speeds
	Ventilation systems	At low speeds
	Tire/guideway interaction	For rubber-tired vehicles, including monorails
	Wheel/rail interaction	Depends on condition of wheels and rails
	In general	Wide range of vehicles: monorail, rubber-tired, steel-wheeled, linear induction. Noise characteristics depend upon type
Diesel Buses	Cooling fans	While idling
	Engine casing	While idling
	Diesel exhaust	At low speeds and while accelerating
	Tire/roadway interaction	At moderate and high speeds
	In general	Includes city buses (generally two-axle) and commuter buses (generally three-axle)
Electric Buses and Trackless Trolleys	Tire/roadway interaction	At moderate speeds
	Electric traction motors	At moderate speeds
	In general	Much quieter than diesel buses
Bus Storage Yards	Buses starting up	Usually most disruptive in the early morning
	Buses accelerating	Usually near entrances/exits and/or locations that require buses to accelerate (tight turns)
	Buses idling	Warm-up areas
	In general	Site specific: often peak periods with considerable noise
Rail Transit Storage Yards	Wheel squeal	On tight curves
	Wheel impacts	On joints and switches
	Wheel rolling noise	On tangent track
	Auxiliary equipment	Throughout day and night; includes air-break release noise
	Coupling/uncoupling	On storage tracks
	Signal horns	Throughout yard site
	In general	Site specific: often early morning and peak periods with considerable noise

Maintenance Facilities	Signal horns	Throughout facility
	Intercoms	Throughout facility
	Impact tools	Shop buildings
	Car/bus washers/driers	Wash facility
	Vehicle activity	Throughout facility
	In general	Site specific: considerable activity throughout day and night, some outside.
Stations	Automobiles	Patron arrival/departure, especially in early morning
	Buses idling	Bus loading zone
	Intercoms	Platform area
	Locomotive idling	At commuter rail terminal stations
	Auxiliary systems	At terminal stations and layover facilities
	Horns	At stations, if applicable
	In general	Site specific, with peak activity periods
Subways	Fans	Noise through vent shafts/structures
	Buses/trains in tunnels	Noise through vent shafts/structures
	In general	Noise is not a problem, except in the immediate vicinity of vent shafts/structures.

* Refer to Appendix A for additional information.

3.3 Paths of Transit Noise from Source to Receiver

This section contains a qualitative overview of noise-path characteristics from source to receiver, including attenuation along these paths. Equations for specific noise-level attenuations along source-receiver paths are included in Sections 4.4 and 4.5.

Sound paths from source to receiver are predominantly through the air. Along these paths, sound reduces with distance due to divergence, absorption/diffusion, and shielding. These mechanisms of sound attenuation are discussed below.

Divergence

Sound levels naturally attenuate with distance, as shown in Figure 3-3. The plot shows attenuation at the receiver relative to the sound level 50 ft from the source. This type of attenuation is called divergence and is dependent upon source configuration (line or point source) or other source-emission characteristics. Localized sources (point sources) grouped closely together attenuate greatly with distance at a rate of approximately 6 dB per doubling of distance. Examples of point sources include highway grade-crossing signals along rail corridors, intercoms in maintenance yards and other closely grouped sources of noise. Vehicles passing along a track or roadway forming a line are called line sources. Line sources attenuate less than point sources with distance. Rate of attenuation for line sources varies depending on the noise metric. $L_{eq(1hr)}$ and L_{dn} noise levels attenuate at a rate of 3 dB per doubling of distance and L_{max} noise levels attenuate at a rate of 3 to 6 dBs per doubling of distance.

Figure 3-3 illustrates approximate attenuation with distance between the source and receiver for point and line sources. The line source curve for the L_{max} noise metric separates into three curves because it is dependent on the length of the line source. Equations for the curves in Figure 3-3 are included in Section 4.5.

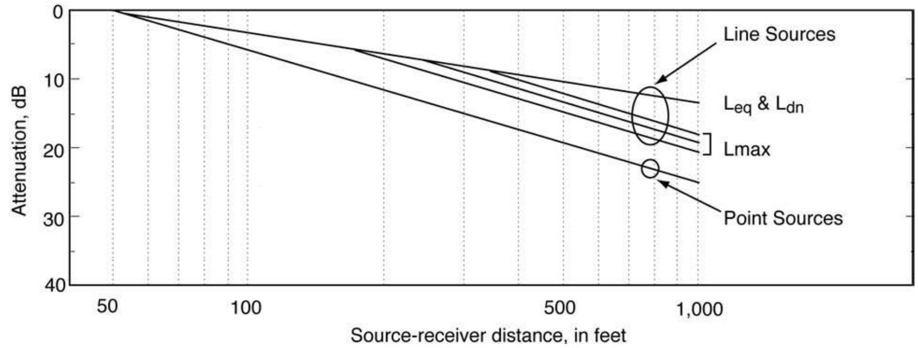


Figure 3-3 Attenuation Due to Distance (Divergence)

Absorption/Diffusion

In addition to distance, sound levels can be attenuated depending on the type of ground between the source and receiver. A portion of the sound energy is absorbed by the ground and only the remaining energy travels to the source. How much energy the ground absorbs is dependent on the ground type (characterized as acoustically "hard" or "soft") and geometry. Example absorptive ground types include freshly-plowed or vegetation-covered ground. Figure 3-4 illustrates approximate attenuation due to ground type by source to receiver path distance and height. Ground attenuation can be as large as 5 dB over a path distance of several hundred ft. At very large distances, wind and temperature gradients could modify the expected ground attenuation. However, these variable atmospheric effects are not included in this manual because they generally occur beyond the range of typical transit-noise impact. Equations for the curves in this figure are included in Section 4.5.

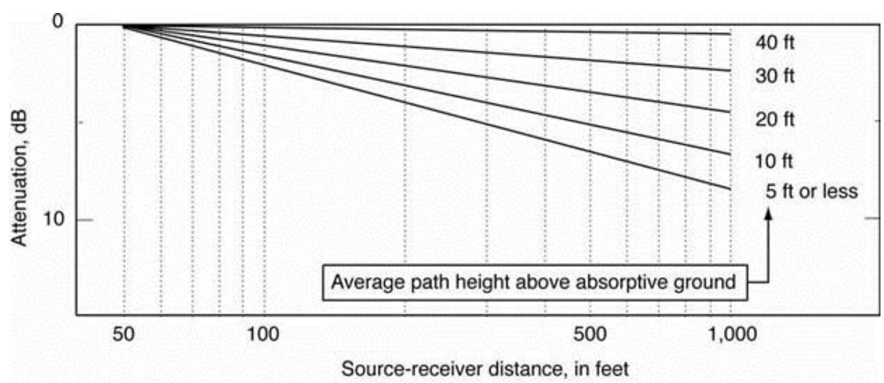


Figure 3-4 Attenuation due to Soft Ground

Shielding

Sound paths are sometimes interrupted by terrain, human-constructed noise barriers, rows of buildings, or other objects. Noise barriers are one of the most effective means of mitigating noise (Section 4.5, Step 7). A noise barrier reduces sound levels at a receiver by breaking the direct line-of-sight between source and receiver with a solid wall (in contrast to vegetation which hides the source from view but does not reduce sound levels substantially over short distances). Sound energy reaches the receiver only by bending (diffracting) over the top of the barrier, as shown in Figure 3-5. This diffraction over the barrier reduces the sound level that reaches the receiver. One important consideration in using noise barriers to mitigate noise impacts is safety. Noise barriers, if not designed and sited carefully, can reduce visibility of trains for pedestrians and motorists, leading to less safe conditions. It is important to consult with safety experts when choosing and siting a noise barrier.

Noise barriers for transportation systems are typically used to attenuate noise at the receiver, potentially reducing received sound levels by 5 to 15 dB, depending upon barrier height, length, and distance from both source and receiver. Barriers on structures close to the transportation noise source may provide less attenuation than barriers located farther from the source due to reverberation (multiple reflections) between the barrier and the body of the vehicle or noise source. This reverberation can be offset by increased barrier height and/or acoustical absorption on the source side of the barrier. Further discussion and equations on acoustical absorption and barrier attenuation is provided in Section 4.5.

Source-to-receiver sound paths may not always travel through the air, but rather through the ground or through structural components of the receiver's building. Discussion of such ground-borne and structure-borne propagation is included in Section 5.

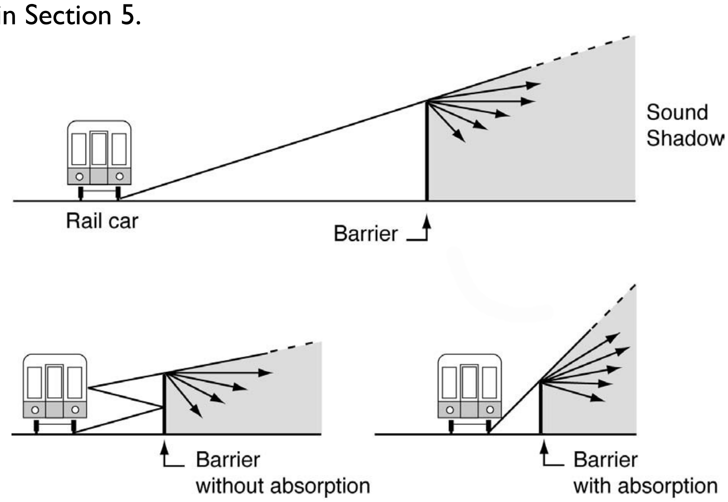


Figure 3-5 Noise Barrier Geometry

3.4 Receiver Response to Transit Noise

This section contains an overview of human receiver response to noise. It serves as background information for the noise impact criteria in Section 4.1.

Noise can interrupt ongoing activities causing community annoyance, especially in residential areas. In general, most residents become highly annoyed when noise interferes considerably with activities such as sleeping, talking, noise-sensitive work, and audio entertainment. In addition, some land uses, such as outdoor concert pavilions, are inherently incompatible with high noise levels.

Annoyance from noise has been investigated and approximate dose-response relationships have been quantified by the U.S. Environmental Protection Agency (EPA).[5] The selection of noise metrics in this manual is largely based upon this EPA work. Beginning in the 1970s, the EPA undertook a number of research and synthesis studies relating to community noise of all types. Results of these studies have been widely published, discussed, and refereed by many professionals in acoustics. Basic conclusions of these studies have been adopted by the Federal Interagency Committee on Noise (FICON),[ii] the U.S. Department of Housing and Urban Development (HUD), the American National Standards Institute, and even internationally[6][7][8][9]. Conclusions from this seminal EPA work remain scientifically relevant today.

Figure 3-6 contains a synthesis of actual case studies of community reaction to newly introduced sources of noise in a residential urban neighborhood.[10] Plotted horizontally in the figure is the increase in noise from new sources above existing noise levels expressed as Day-Night Sound Levels, L_{dn}, discussed in Appendix B.1.4.5. Plotted vertically is the community reaction to this newly introduced noise. As shown in the figure, community reaction varies from no reaction to vigorous action for newly introduced noises averaging from 10 dB below existing to 25 dB above existing. Note the assumptions included in the graphic are associated with the specific data points from the study. These assumptions are generally appropriate to give context to most transit projects, but community reaction may differ for conditions specific to each project.

In many community attitudinal surveys, transportation noise has been ranked among the greatest causes of community dissatisfaction. A synthesis of many such surveys on annoyance is shown in Figure 3-7.[11][12] Noise exposure levels are plotted against the percentage of people who are highly annoyed by the particular level of neighborhood noise. As shown in the figure, the percentage of high annoyance is approximately 0 percent at 45 dB, 10 percent around 60 dB, and increases quite rapidly to approximately 70 percent around 85 dB. The scatter about the synthesis line is due to community variation and wording differences in the surveys. An update of the original research containing additional railroad, transit and street traffic noise surveys generally follows the shape of the original response curve shown in Figure 3-7.[12][13]

As indicated by Figure 3-6 and Figure 3-7, introduction of certain levels of transit noise into a community may have two undesirable effects. First, it may substantially increase noise levels above existing noise levels in a community. This effect is called a relative noise impact. Evaluation of this effect compares new noise levels to the existing levels. Criteria for a relative noise impact evaluation are based upon noise increases above existing levels. Second, newly introduced transit noise may interfere with community activities independent of existing noise levels. For example, it may be too loud to converse or sleep. This effect is called absolute noise impact and is expressed as a fixed level threshold that is not to be exceeded. The fixed level threshold is determined independently of existing noise levels. Relative and absolute noise impacts are discussed in terms of transit noise criteria in Section 4.1, Step 3.

[ii] The Federal Interagency Committee on Aviation Noise (FICAN) is the current version of this group.

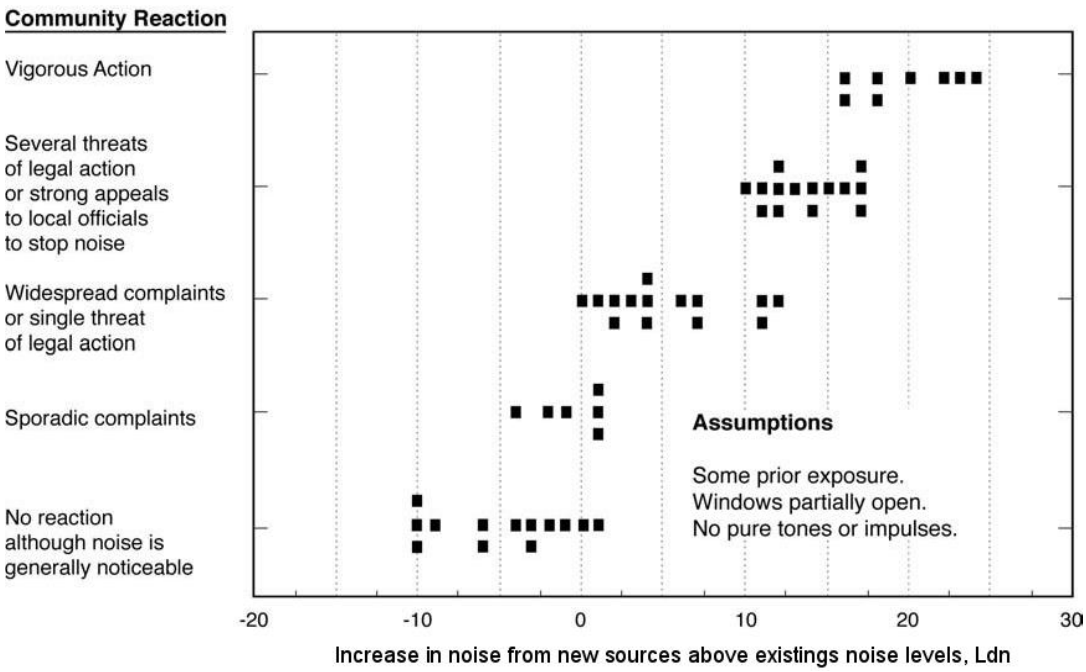


Figure 3-6 Community Reaction to New Noise, Relative to Existing Noise in a Residential Urban Environment

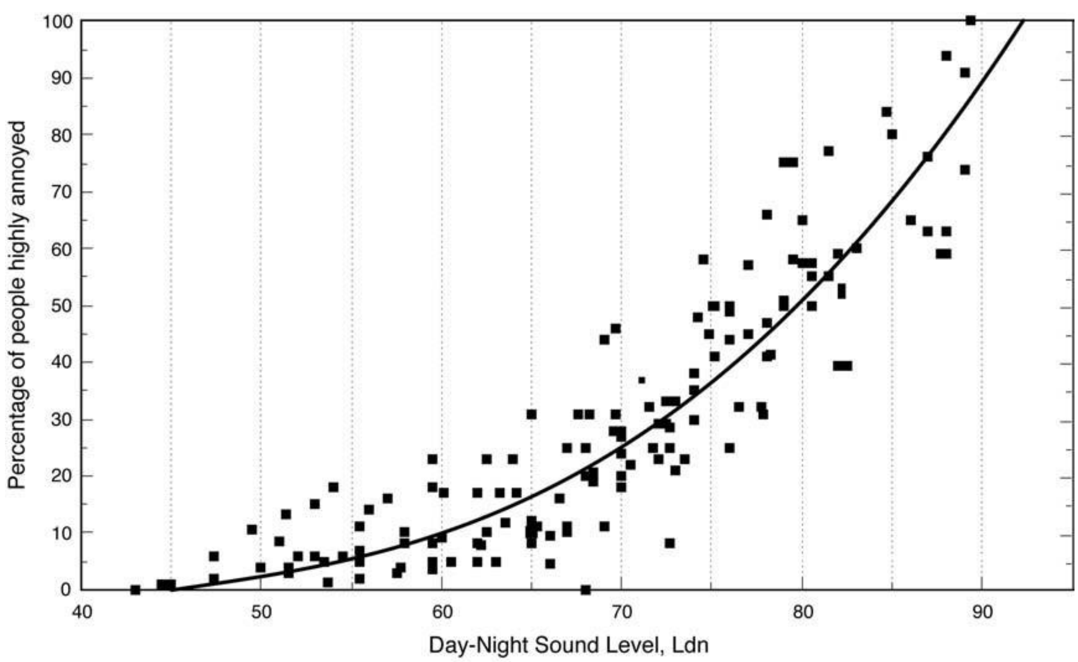


Figure 3-7 Community Annoyance Due to Noise

SECTION 4

Noise Impact Analysis

The FTA noise impact analysis process is a multi-step process used to evaluate the project for potential noise impacts for FTA NEPA approvals. If impact is determined, measures necessary to mitigate adverse impacts must be considered for incorporation into the project.(4) It is recommended that project sponsors develop and formally adopt a policy for determining the need for mitigation for situations that are loosely covered by the impact criteria. Considerations for mitigation policies are included in Section 2.3. The FTA noise impact analysis steps are summarized as follows and are described in the subsequent subsections:

4.1: Determine noise impact criteria.
- **Step 1:** Identify the type of project/dominant noise source (transit or multimodal).
- **Step 2:** Choose land use category for FTA criteria.

4.2: Determine the highest appropriate level of noise analysis for the current stage of project planning or development.

4.3: Evaluate for the potential of impact according to the Noise Screening Procedure.
- **Step 1:** Identify project type.
- **Step 2:** Determine the screening distance.
- **Step 3:** Identify the study area.
- **Step 4:** Locate noise-sensitive land uses.

4.4: Evaluate impact according to the General Noise Assessment and evaluate preliminary mitigation options if impact is found.
- **Step 1:** Identify noise-sensitive receivers.
- **Step 2:** Determine the project noise source reference levels.
- **Step 3:** Estimate project noise exposure by distance.
- **Step 4:** Combine noise exposure from all sources.
- **Step 5**: Measure existing noise exposure.
- **Step 6:** Inventory noise impacts.
- **Step 7:** Determine noise mitigation needs.

4.5: Evaluate for impact according to the Detailed Noise Analysis and evaluate mitigation options if impact is found.
- **Step 1:** Identify noise-sensitive receivers.
- **Step 2:** Determine noise source levels for detailed analysis.
- **Step 3:** Calculate project noise exposure by distance.
- **Step 4:** Combine noise exposure from all sources.
- **Step 5:** Determine existing noise exposure.
- **Step 6:** Assess noise impact.
- **Step 7:** Determine noise mitigation measures.

In addition to analyzing for potential noise impacts, analyze the project for potential vibration impacts according to the process presented in Section 6. After both the noise and vibration analyses have been completed, assess construction noise and vibration according to Section 7 and document findings according to Section 8.

4.1 Determine Noise Impact Criteria

This section describes the procedure for determining the appropriate criteria for assessing project noise impact based on the type of project and project noise source. Project noise is the new noise or change in noise introduced by the project. Noise impact criteria may vary for different segments of the project. Project segments can be portions of a project with similar characteristics.

The procedure to determine the appropriate impact criteria is described in this section and shown more simply as a flow chart in Figure 4-1. If there is uncertainty in how to determine the appropriate criteria, contact the FTA Regional office.

The selected criteria are used in the analysis procedures discussed in Sections 4.3, 4.4, and 4.5 to identify potential impacts and the level of impact.

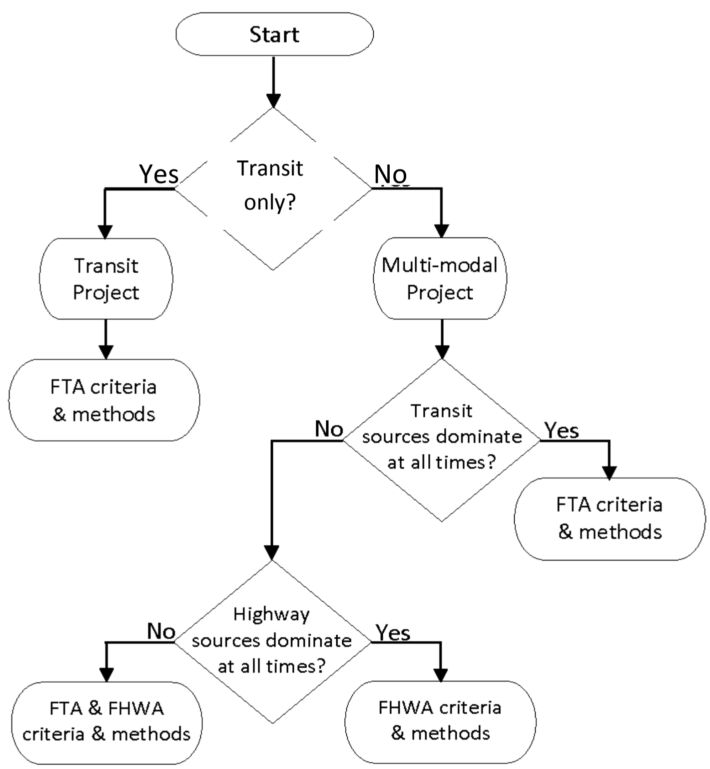


Figure 4-1 Noise Impact Criteria Flow Chart by Project Segment

Step 1: Identify Project Type

Identify the type of project as transit, multimodal (transit and highway), or other multimodal according to the dominant noise source.

Option A: Transit Project (Transit Noise Only) – The transit project category includes all transit projects where the project noise is exclusively due to new transit sources, no changes are made to the highway or to existing highway noise barriers, and the existing noise levels generated by roadway sources will not change because of the project. For these transit projects, FTA is the lead agency conducting the environmental review in cooperation with the transit agency.

Typical examples of transit projects include:

- RRT, LRT, commuter rail, and AGT
- Rail projects built within an existing highway or railroad corridor that do not alter the existing noise levels generated by roadway sources
- Bus facility projects with operations on local streets and highways used to access the facility, where the project does not include roadway construction or modification that changes roadway capacity substantially
- Fixed facilities including storage and maintenance yards, passenger stations and terminals, parking facilities, and substations
- Portions of transit projects not adjacent to highway corridors

FTA impact criteria are appropriate for transit projects, proceed to Step 2.

Option B: Multimodal Project (Transit and Highway Noise) – In this manual, "multimodal" refers to projects that include changes to both transit and highway components, resulting in project noise comprised of both highway and transit noise sources.

Typical examples of multimodal projects include:

- New highway construction providing general-purpose lanes as well as dedicated bus and high occupancy vehicle (HOV) lanes
- Rail transit projects that involve changes to the highway travel lanes or existing highway noise barriers

Evaluate multimodal projects for impact according to the project noise source by project segment. FHWA's noise assessment methods are used to inform FTA's NEPA evaluation only for segments where highway noise levels change due to the transit project. These projects are not necessarily subject to FHWA's procedures at 23 CFR part 772 (*see call out box below*). For segments of the project outside the highway corridor, use FTA's criteria and methods. Use Table 4-1 to determine multimodal project noise.

Once the project noise source(s) is identified**,** determine the appropriate assessment method according to Table 4-2.

Note that a separate noise analysis may be required for FHWA approval of a multimodal project pursuant to 23 CFR part 772. For these projects, it is important to work with FHWA early in the environmental review process to determine how a noise assessment will be completed where FHWA approval is needed for the project.

The determination of whether a project is subject to FHWA procedures at 23 CFR part 772 depends upon the specific circumstances of a project. A proposed transit project that would share an existing highway ROW is not necessarily a FHWA-defined multimodal project. A transit project that meets all three of the following criteria is not considered a multimodal project subject to 23 CFR part 772:

- FTA is the lead agency in the NEPA process and FHWA's limited participation is as a cooperating agency.
- The main transportation purpose of the project, as stated in the purpose and need statement of the environmental document, is transit-related and not highway-related.
- No Federal-aid highway funds are being used to fund the project.

Table 4-1 Multimodal Project Noise Factors

Factor	Description
Volume of Traffic	Major freeways and interstate highways often carry large volumes of traffic throughout the day and night such that the highway noise dominates at all times. Transit noise in this case may be unimportant by comparison, but must still be evaluated using FTA's noise criteria for a potential impact.
Traffic Patterns	Some highways and arterials serve primarily as commuter routes such that nighttime traffic diminishes considerably, while transit systems continue to operate well into the late hours. Here the dominant noise source at times of maximum sensitivity may be transit.
Type of Traffic	Some highways and arterials may serve commuters during the daytime hours, but provide access to business centers by trucks at night. In this case, the roadway noise would likely continue to dominate.
Alignment Configuration	Elevation of the transit mode in the median or beside a busy highway may result in transit noise contributing more noise to nearby neighborhoods than a highway that may be partially shielded by rows of buildings adjacent to the ROW. In this case, both transit and highway noise may be considered dominant.

Table 4-2 Multimodal Project Assessment Methods

Dominant Noise Source	Assessment Method
Transit, at All Times	Use FTA criteria and methods. *Proceed to Step 2.*
Highway, at All Times	Use FHWA criteria and methods to inform FTA's NEPA evaluation. *Contact FHWA directly for assistance using FHWA noise analysis methods and FHWA noise impact criteria.*
Transit and Highway at Different Times	Use both the FHWA and FTA methods to determine if one, both, or neither method determines impact due to the project noise for these segments. Note that the project noise includes both highway and transit sources associated with the project. Both methods are used because the FTA methods consider nighttime sensitivity while the FHWA methods consider the peak traffic hour. *Proceed to Step 2 for FTA criteria. Contact FHWA directly for assistance using FHWA noise analysis methods and FHWA noise impact criteria.*

Option C: Other Multimodal Projects – For projects with components from other modes, contact the FTA Regional office. Additional information on high-speed rail vibration and noise can be found in the Federal Railroad Administration (FRA) "High-Speed Ground Transportation Noise and Vibration Impact Assessment" guidance manual.[14]

Step 2: Choose Land Use Category for FTA Criteria

Determine the appropriate noise-sensitive land use category for the project segment using Table 4-3 and the descriptions below then, proceed to Step 3. FTA criteria are presented by land use.

Table 4-3 Land Use Categories and Metrics for Transit Noise Impact Criteria

Land Use Category	Land Use Type	Noise Metric, dBA	Description of Land Use Category
1	High Sensitivity	Outdoor $L_{eq(1hr)}$*	Land where quiet is an essential element of its intended purpose. Example land uses include preserved land for serenity and quiet, outdoor amphitheaters and concert pavilions, and national historic landmarks with considerable outdoor use. Recording studios and concert halls are also included in this category.
2	Residential	Outdoor L_{dn}	This category is applicable all residential land use and buildings where people normally sleep, such as hotels and hospitals.
3	Institutional	Outdoor $L_{eq(1hr)}$*	This category is applicable to institutional land uses with primarily daytime and evening use. Example land uses include schools, libraries, theaters, and churches where it is important to avoid interference with such activities as speech, meditation, and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds, and recreational facilities are also included in this category.

* $L_{eq(1hr)}$ for the loudest hour of project-related activity during hours of noise sensitivity.

Noise-sensitive land use categories are described in in order of sensitivity. Most commercial or industrial uses are not considered noise-sensitive because activities within these buildings are generally compatible with higher noise levels. Business can be considered noise-sensitive if low noise levels are an important part of operations, such as sound and motion picture recording studios.

For residential land use (category 2), apply the noise criteria at the nearest façade of the occupied portion of the building, e.g., not at a garage or porch. The residential criteria should be applied at locations with nighttime sensitivity. For major noise-sensitive outdoor use at non-residential locations, apply the noise criteria at the point of noise-sensitive use nearest the noise source.

Land use categories are evaluated using noise metrics that reflect the noise-sensitive time of day:

- **Categories 1 and 3** – The noise metric, $L_{eq(1hr)}$ is used for all category 1 and 3 land uses where nighttime sensitivity is not a factor. Category 3 land uses are considered less noise-sensitive than category 1 land uses. For transit analyses, $L_{eq(1hr)}$ is computed for the noisiest hour of transit-related activity during which human activities occur at the noise-sensitive location. See Appendix B.1.4.4 for more information on this metric.

- **Category 2** – The noise metric L_{dn} is a used for all category 2 land uses where nighttime sensitivity is a factor. This noise metric includes a 10-dB penalty for nighttime noise. See Appendix B.1.4.5 for more information on this metric.

Land Use Categories: Special Cases

Historic sites, parks, indoor-only land use, and undeveloped land require special consideration. In addition to NEPA, noise impacts may need to be considered under other environmental laws such as Section 106[15] or Section 4(f).[16] Indoor-only use and undeveloped land should be evaluated on a case-by-case basis to determine noise sensitivity based on how each facility is used or the reason it is protected under the applicable requirement.

Historic Sites – Section 106 requires Federal agencies to evaluate potential effects from projects on historic properties. Per the regulations at 36 CFR part 800,[17] historic properties are defined as any prehistoric or historic district, site, building, structure, or object included in, or eligible for the National Register of Historic Places (NRHP). An adverse effect determination under Section 106 is made when a project may alter, directly or indirectly, any of the characteristics of a historic property that qualify the property for inclusion in the National Register in a manner that would diminish the integrity of the property's location, design, setting, materials, workmanship, feeling, or association.

Under FTA environmental reviews, some structures may be evaluated as noise-sensitive resources per this noise manual and evaluated as historic properties under Section 106. However, because this manual and Section 106 regulations have different criteria for effect, identifying a severe noise impact for a structure under this manual does not necessarily mean there would be an adverse effect under Section 106. It is important to thoroughly document the characteristics of historic properties that qualify for inclusion in the NRHP for evaluation of effect under Section 106.

If a property, for example, is listed on the NRHP under criterion C because the structure possesses high artistic values, but lacks integrity of setting, feeling, or association, it is unlikely that a change in the noise environment would affect the features that qualify the property for listing or eligibility for inclusion in the NRHP.

In the assessment of effects on historic properties, consideration should be given to not just the proposed transit project, but any associated mitigation measures with the transit project. For example, if a transit project would involve noise walls or berms as mitigation, the effect of those structures on the visual setting may need to be considered in a Section 106 analysis.

Parks – Most parks used primarily for active recreation such as sports complexes and bike or running paths are not considered noise-sensitive.

However, some parks (even some in dense urban areas) are primarily used for passive recreation such as reading, conversation, or meditation. These places, which may be valued as havens from the noise and rapid pace of everyday city life, are treated as noise-sensitive, and are included in land use category 3. Consult the state or local agency with jurisdiction over the park on questions about how the park is used, and visit the park to observe its use, if possible.

Indoor-Only Use – The land use categories described in this section correspond with noise impact criteria that provide protection for both outdoor and indoor land uses. For locations where noise impact will be evaluated but there is no outdoor land use such as apartment buildings, hotels or upper levels of multi-story buildings, indoor criteria can be used. In these cases, the criterion for indoor noise levels from project sources is a L_{dn} of 45 dBA.(18) This criterion is consistent with the Federal Aviation Administration (FAA). See Section 4.5 for more information on how indoor criteria apply to noise mitigation consideration.

Undeveloped Land – Undeveloped land may also need to be considered for noise impact assessment and mitigation if plans are under way to develop the land for noise-sensitive use. The policy for considering such land for assessment and mitigation should be determined on a project-specific basis by the project sponsor in consultation with the FTA Regional office.

Step 3: Determine Appropriate FTA Criteria Presentation

FTA criteria for noise impact were developed specifically for transit noise sources operating on fixed-guideways or at fixed facilities in urban areas. These criteria are based on well-documented research on human response to community noise and represent a reasonable balance between community benefit and project costs. These criteria do not reflect specific community attitudinal factors. See Appendix C for additional background information on the development of FTA noise criteria.

The criteria specify a comparison of future project noise with existing noise. Note that projections of future noise exposure without the project (no-build scenario) are not included in this analysis. The criteria also consider land use which is an important factor that reflects noise sensitivity based on activity and time period of concern. The criteria are defined with the expectation that communities already exposed to high levels of noise can only tolerate a small increase. In contrast, if the existing noise levels are low, it is reasonable to allow a greater change in the community noise.

The levels of impact are described in Table 4-4. The criteria at which the levels of impact occur are presented in two ways depending on the relationship of project and existing noise sources.

If the project noise source is a new source of transit noise in the community, such as a new project in an area currently without transit, use the criteria as presented in Option A. If the project noise adds to or changes existing transit noise in the community, use the criteria as presented in Option B.

Table 4-4 Levels of Impact

Level of Impact	Description
No Impact	Project-generated noise is not likely to cause community annoyance. Noise projections in this range are considered acceptable by FTA and mitigation is not required.
Moderate Impact	Project-generated noise in this range is considered to cause impact at the threshold of measurable annoyance. Moderate impacts serve as an alert to project planners for potential adverse impacts and complaints from the community. Mitigation should be considered at this level of impact based on project specifics and details concerning the affected properties.
Severe Impact	Project-generated noise in this range is likely to cause a high level of community annoyance. The project sponsor should first evaluate alternative locations/alignments to determine whether it is feasible to avoid severe impacts altogether. In densely populated urban areas, evaluation of alternative locations may reveal a trade-off of affected groups, particularly for surface rail alignments. Projects that are characterized as point sources rather than line sources often present greater opportunity for selecting alternative sites. This guidance manual and FTA's environmental impact regulations both encourage project sites which are compatible with surrounding development when possible. If it is not practical to avoid severe impacts by changing the location of the project, mitigation measures must be considered.

Option A: Project Noise Impact Criteria Presentation – The impact criteria presentation for evaluating existing noise independently to project noise is presented in this option.

The noise levels at which impacts occur are presented in Figure 4-2 and Table 4-5. Equations for the impact criteria are presented in Appendix C. If impact is determined, measures necessary to mitigate impacts are to be considered for incorporation into the project.(3)

Figure 4-2 presents the existing noise exposure on the horizontal axis and project noise on the vertical axis. Category 1 and 2 land uses have the same criteria for project noise and are on the primary vertical axis. Category 3 land use criteria are presented on the secondary vertical axis. Note that project noise for category 1 and 3 land uses is expressed as $L_{eq(1hr)}$, whereas project noise for category 2 land use is expressed as L_{dn}. Also, note that project noise criteria are 5 dB higher for category 3 land uses in Figure 4-2 since these types of land use are less noise-sensitive than those in categories 1 and 2.

Note that for projects in locations with existing noise levels below 55 dBA, the project noise exposure is allowed some increase over the existing noise exposure before it is considered to cause impact. For category 1 and 2 land uses, the maximum project noise level to be considered to cause no impact is 65 dBA ($L_{eq(1hr)}$ or L_{dn}) regardless of the existing noise. Note that no impact at 65 dBA aligns with other Federal agencies in that a L_{dn} of 65 dBA is a standard limit for an acceptable living environment among some Federal agencies.(19) (20) Project noise levels above the top curve are considered to cause severe impact. The upper limit of the severe impact range is 75 dBA for category 1 and 2 land uses. The upper limit of 75 dBA is associated with an unacceptable living environment. Project noise between the two curves is considered to have moderate impact on the community.

The criteria are also tabulated in Table 4-5. Figure 4-2 and the equations that correspond with this figure in Appendix C are the precise definition of the criteria. The values in Table 4-5 can be used for illustrative purposes and should only be used if all numbers are rounded up to the nearest decibel.

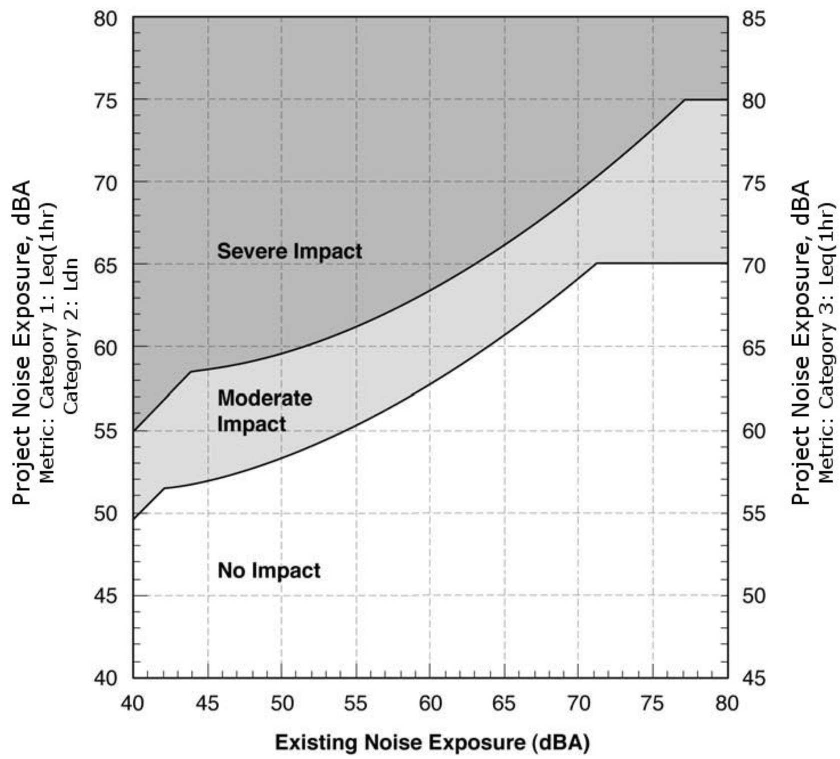


Figure 4-2 Noise Impact Criteria for Transit Projects

Table 4-5 Noise Levels Defining Impact for Transit Projects

Existing Noise Exposure, dBA	Project Noise Impact Exposure, dBA					
	Category 1 ($L_{eq(1hr)}$) or 2 (L_{dn}) Sites			Category 3 Sites ($L_{eq(1hr)}$)		
$L_{eq(1hr)}$ or L_{dn}	No Impact	Moderate Impact	Severe Impact	No Impact	Moderate Impact	Severe Impact
<43	< Ambient+10	Ambient +10 to 15	> Ambient+15	< Ambient+15	Ambient +15 to 20	> Ambient+20
43	<52	52-58	>58	<57	57-63	>63
44	<52	52-58	>58	<57	57-63	>63
45	<52	52-58	>58	<57	57-63	>63
46	<53	53-59	>59	<58	58-64	>64
47	<53	53-59	>59	<58	58-64	>64
48	<53	53-59	>59	<58	58-64	>64
49	<54	54-59	>59	<59	59-64	>64
50	<54	54-59	>59	<59	59-64	>64
51	<54	54-60	>60	<59	59-65	>65
52	<55	55-60	>60	<60	60-65	>65
53	<55	55-60	>60	<60	60-65	>65
54	<55	55-61	>61	<60	60-66	>66
55	<56	56-61	>61	<61	61-66	>66
56	<56	56-62	>62	<61	61-67	>67
57	<57	57-62	>62	<62	62-67	>67
58	<57	57-62	>62	<62	62-67	>67
59	<58	58-63	>63	<63	63-68	>68
60	<58	58-63	>63	<63	63-68	>68
61	<59	59-64	>64	<64	64-69	>69
62	<59	59-64	>64	<64	64-69	>69
63	<60	60-65	>65	<65	65-70	>70
64	<61	61-65	>65	<66	66-70	>70
65	<61	61-66	>66	<66	66-71	>71
66	<62	62-67	>67	<67	67-72	>72
67	<63	63-67	>67	<68	68-72	>72
68	<63	63-68	>68	<68	68-73	>73
69	<64	64-69	>69	<69	69-74	>74
70	<65	65-69	>69	<70	70-74	>74
71	<66	66-70	>70	<71	71-75	>75
72	<66	66-71	>71	<71	71-76	>76
73	<66	66-71	>71	<71	71-76	>76
74	<66	66-72	>72	<71	71-77	>77
75	<66	66-73	>73	<71	71-78	>78
76	<66	66-74	>74	<71	71-79	>79
77	<66	66-74	>74	<71	71-79	>79
>77	<66	66-75	>75	<71	71-80	>80

Option B: Cumulative Noise Impact Criteria Presentation

The impact criteria presentation for evaluating existing noise to project noise cumulatively is presented in this option.

In certain cases, the cumulative form of the noise criteria shown in Figure 4-3 can be used. These cases involve projects where changes are proposed to an existing transit system, as opposed to a new project in an area previously without transit. Such changes might include operations of a new type of vehicle, modifications of track alignments within existing transit corridors, or changes in facilities that dominate existing noise levels. In these cases, the existing noise sources change because of the project, and so it is not possible to define project noise separately from existing noise. An example would be a commuter rail corridor where the existing noise along the alignment is dominated by diesel locomotive-hauled trains, and where the project involves electrification with the resulting replacement of some of the diesel-powered locomotives with electric trains operating at increased frequency of service and higher speeds on the same tracks. In this case, the existing noise can be determined and a new future noise can be calculated, but it is not possible to describe what constitutes the "project noise." For example, if the existing noise dominated by trains was measured to be an L_{dn} of 63 dBA at a particular location, and the new combination of diesel and electric trains is projected to be an L_{dn} of 65 dBA, the change in the noise exposure due to the project would be 2 dB. Referring to Figure 4-3, a 2-dB increase with an existing noise exposure of 63 dBA would be rated as a moderate impact. Normally the project noise is added to the existing noise to come up with a new cumulative noise, but in this case, the existing noise was dominated by a source that changed due to the project, so it would be incorrect to add the project noise to the existing noise. Consequently, the existing noise determined by measurement is compared with a new calculated future noise, but a description of what constitutes the actual project is complex.

Another example would be a rail corridor where a track is added and grade crossings are closed, potentially resulting in a change in train location and horn operation. Here the "project noise" results from moving some trains closer to some receivers, away from others, and elimination of horns. In this case, the change in noise level is more readily determined than the noise from the actual project elements. In all cases, Figures 4-3 and 4-4 for changes in a transit system results in the same assessment of impact as Figure 4-2 for development of transit facilities in a new area.

The noise impact criteria in Figure 4-3 and Figure 4-4 are presented as an increase in cumulative noise level between the existing and project conditions. The horizontal axis represents the existing noise exposure and the vertical axis is the increase in cumulative noise level due to the transit project. Note that noise exposure is expressed as $L_{eq(1hr)}$ for category 1 and 3 land uses and L_{dn} for category 2 land use. Since $L_{eq(1hr)}$ and L_{dn} are measures of total acoustic energy, any new noise sources in a community will cause an increase, even if the new source level is the same or less than the existing noise level (refer to decibel addition in Appendix B). As shown in Figure 4-3, the criterion for moderate impact is a noise exposure increase of 10 dB for an existing noise exposure level of 42 dBA or less, but only a 1-dB increase when the existing noise exposure is 70 dBA.

As the existing level of ambient noise increases, the allowable level of transit noise increases, but the total amount that community noise exposure is allowed to increase is reduced. This accounts for the unexpected result that a project exposure which is less than the existing noise exposure can still cause impact. This is clearer from the examples listed in Table 4-6 which indicate the level of transit noise allowed for different existing levels of exposure. Any increase greater than shown in the table will cause moderate impact.

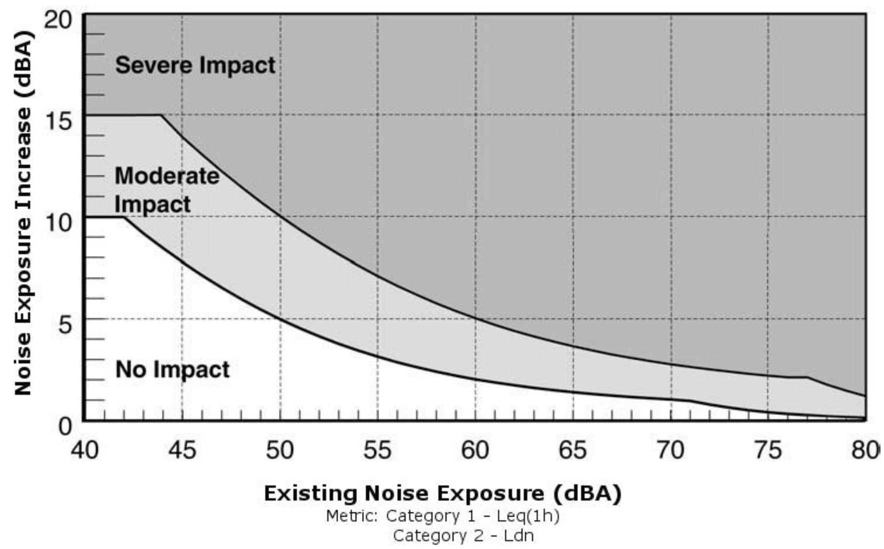


Figure 4-3 Increase in Cumulative Noise Levels Allowed by Criteria (Land Use Cat. 1 & 2)

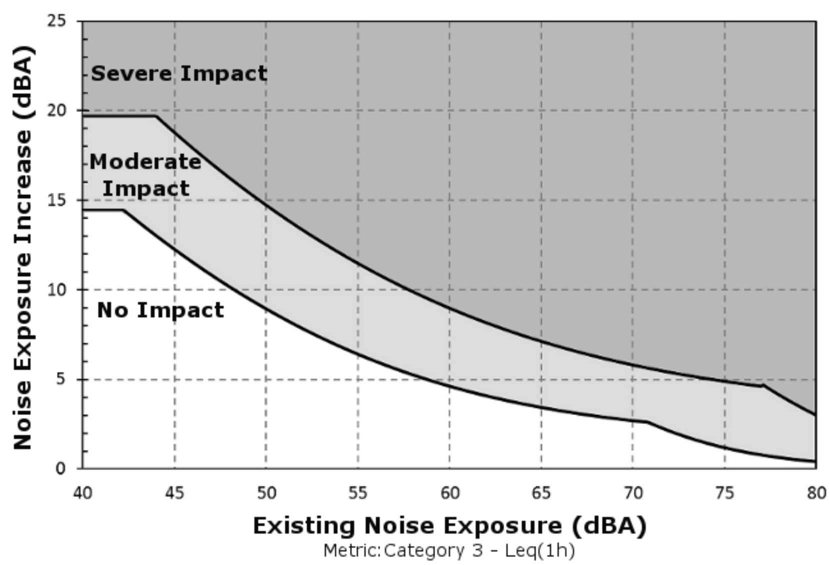


Figure 4-4 Increase in Cumulative Noise Levels Allowed by Criteria (Land Use Cat. 3)

This table shows that as the existing noise exposure increases from 45 dBA to 75 dBA, the allowed project noise exposure increases from 51 dBA to 65 dBA. However, the allowed increase in the cumulative noise level decreases from 7 dB to 0 dB (rounded to the nearest whole decibel). The justification for this is that people already exposed to high levels of noise should be expected to tolerate only a small increase in the amount of noise in their community. In contrast, if the existing noise levels are quite low, it is reasonable to allow a greater change in the community noise for the equivalent difference in annoyance.

Note that Table 4-6 was developed for illustrative purposes and the official criteria are included in Figure 4-3 and Figure 4-4 and the associated equations.

Table 4-6 Noise Impact Criteria: Effect on Cumulative Noise Exposure

L_{dn} or $L_{eq(1hr)}$ in dBA (rounded to nearest whole decibel)			
Existing Noise Exposure	**Allowable Project Noise Exposure Before Moderate Impact**	**Allowable Combined Total Noise Exposure**	**Allowable Noise Exposure Increase Before Moderate Impact**
45	51	52	7
50	53	55	5
55	55	58	3
60	57	62	2
65	60	66	1
70	64	71	1
75	65	75	0

4.2 Determine Noise Analysis Level

There are three levels of analysis to evaluate noise on a transit project based on the type and scale of the project, stage of project development, and environmental setting. These levels, described below, are the Noise Screening Procedure, the General Noise Assessment and the Detailed Noise Analysis.

The Noise Screening Procedure, conducted first, defines the study area of any subsequent noise impact assessment. Where there is potential for noise impact, the General Noise Assessment and Detailed Noise Analysis procedures are used to determine the extent and severity of impact. In some cases, a General Noise Assessment may be all that is needed. However, if the proposed project is near noise-sensitive land uses, and it appears at the outset that the impact would be substantial, it is prudent to conduct a Detailed Noise Analysis.

Conduct the noise screening procedure and then determine the appropriate noise analysis option.

Noise Screening Procedure – The Noise Screening Procedure is a simplified method of identifying study area receivers or locations where a project may have the potential for noise impacts from transit projects. This procedure accounts for impact criteria, the type of project, and noise-sensitive land uses. If no noise-sensitive land uses or receivers are present in the analysis area, then no further noise assessment is needed. If noise-sensitive receivers are identified, then proceed to conduct a General Assessment and/or a Detailed Assessment.

The Noise Screening Procedure steps are provided in Section 4.3.

General Noise Assessment – The General Noise Assessment is used to examine potentially impacted areas identified in the screening step by examining the location and estimated severity of noise impacts. This procedure considers noise source and land use information likely to be available at an early stage in the project development process. Estimates are made of project noise levels and of existing noise conditions to model the location of a noise impact contour that defines the outer limit of an impact corridor or area. This modeling method uses transit-specific noise and adjustment data (in tabular and graphical form) for the noise computations.

For many smaller projects, this assessment may be sufficient to define impacts and determine whether noise mitigation is necessary. The procedure can be used in conjunction with established highway noise prediction procedures to compare highway, transit, and multimodal alternatives. If an assessment is needed to inform the decision on transit mode and general alignment in a corridor, the General Noise Assessment procedures should be used, and not the Detailed Noise Analysis, which requires more detailed information.

The General Noise Assessment procedure is provided in Section 4.4. FTA has also developed an Excel spreadsheet to more simply conduct the General Noise Assessment. It is on FTA's website at http://www.fta.dot.gov/12347_2233.html.

Detailed Noise Analysis – The Detailed Noise Analysis procedure is a comprehensive assessment method that produces the most accurate estimates of noise impacts for a proposed project. It is important to recognize that use of the Detailed Noise Analysis methods will not provide more accurate results than the General Noise Assessment unless more detailed and case-specific input data are used.

The project must be defined to the extent that location, alignment, transit mode, 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) are determined. A detailed Noise Analysis is often accomplished at the development of the final environmental impact statement (FEIS), record of decision (ROD), or combined FEIS/ROD in the NEPA process, when the preferred alternative is undergoing refinements to mitigate its adverse impacts. However, these project details may not be available until the final design phase, requiring that the detail noise analysis be conducted after the NEPA process is complete. However, it is recommended that the detailed analysis be conducted earlier for controversial projects or projects with highly noise-sensitive sites close to tracks.

A Detailed Noise Analysis may be warranted as part of the development of an environmental assessment (EA) if there are potentially severe impacts due to the proximity of noise-sensitive land uses.

In some cases, decisions on appropriate noise mitigation measures can be made based on the results of the General Noise Assessment. But if costly measures may be needed, it is generally recommended that a Detailed Noise Analysis be conducted to verify the need and design of the noise mitigation. The Detailed Noise Analysis is always appropriate under two sets of circumstances:

- For a major transit project with likely noise impacts after the preferred alternative has been selected.
- For any other transit project where potentially severe impacts are identified at an early stage.

Noise impacts may occur for relatively minor transit projects when the project is near noise-sensitive sites, particularly residences. In this case, completing a Detailed Noise Analysis is recommended. Some examples include:

- A terminal or station sited adjacent to a residential neighborhood
- A maintenance facility located near a school
- A storage yard adjacent to residences
- An electric substation located adjacent to a hospital

The Detailed Noise Analysis procedure is provided in Section 4.5.

4.3 Evaluate Impact: Noise Screening Procedure

Identify the potential for impact using the Noise Screening Procedure described below.

Step 1: Identify Project Type

Identify the project type using Table 4-7 and confirm the assumptions in Table 4-8 are appropriate for the project.

The noise screening procedure is intended to be conservative to broadly capture the potential for impact with minimal effort. To make the procedure conservative, the project system must be assumed to be operating under relatively high-capacity conditions, which would produce more noise than normal operating conditions. In addition, the assumptions in Table 4-8 were made using the lowest threshold of impact (50 dBA) from the criteria curves in Figure 4-2. Clarification can be obtained from FTA on special cases that are not represented in this section.

If the assumptions in Table 4-8 are not appropriate for the project, make adjustments to the screening distances in Table 4-8 according to the methodology in Section 4.4 or the FTA spreadsheet model.

Step 2: Determine the Screening Distance

Determine the appropriate screening distance considering the type of project and shielding from intervening buildings.

2a. Determine the appropriate screening distance column in Table 4-7.

Option A: Buildings in the Sound Paths – Use the screening distances in the "Intervening Buildings" column.

Option B: Buildings Not in the Sound Paths – Use the distances in the "Unobstructed" column.

2b. Adjust these distances according to the methodology in Section 4.4, or the FTA spreadsheet model, if the assumptions in Table 4-8 are not appropriate for the project. The appropriate screening distance is where the project noise reaches 50 dBA for the appropriate metric. If the assumptions in Table 4-8 are not appropriate for a commuter rail grade crossing project where horns and warning bells are used, use the FRA horn noise model available from the FRA website to develop the screening distance distance (49 CFR § 222).[21]

Step 3: Identify Study Area

Apply the screening distances as follows to identify the study area. The study area is intended to be sufficiently large to encompass all potentially impacted locations.

Option A: Fixed Guideway Transit Sources – Apply the screening distance from the guideway centerline.

Option B: Highway/Transit Sources (e.g., Bus) – Apply the screening distance from the nearest ROW line on both sides of a highway or access road.

Option C: Small Stationary Facilities – Apply the screening distance from the center of the noise-generating activity.

Option D: Stationary Facility Spread Over a Large Area – Apply the screening distance from the outer boundary of the proposed project site.

Step 4: Locate Noise-Sensitive Land Uses

Locate all noise-sensitive land uses within the study area using Table 4-3.

See Section 4.1 for more information on noise-sensitive land uses. Include all categories of noise-sensitive land uses in this step.

If no noise-sensitive land uses are identified, no further noise analysis is needed. If one or more of the noise-sensitive land uses are in the study area, proceed to Section 4.4 and complete a General Noise Assessment.

Table 4-7 Screening Distance for Noise Assessments

Project Systems		Screening Distance, ft*	
		Unobstructed	Intervening Buildings
Fixed-Guideway Systems			
Commuter Rail Mainline		750	375
Commuter Rail Station	With Horn Blowing	1,600	1,200
	Without Horn Blowing	250	200
Commuter Rail Road Crossing with Horns and Bells		1,600	1,200
RRT		700	350
RRT Station		200	100
LRT		350	175
Streetcar		200	100
Access Roads to Stations		100	50
Low and Intermediate Capacity Transit	Steel Wheel	125	50
	Rubber Tire	90	40
	Monorail	175	70
Yards and Shops		1000	650
Parking Facilities		125	75
Access Roads to Parking		100	50
Ancillary Facilities: Ventilation Shafts		200	100
Ancillary Facilities: Power Substations		250	125
Bus Systems			
Busway		500	250
Bus Rapid Transit (BRT) on exclusive roadway		200	100
Bus Facilities	Access Roads	100	50
	Transit Mall	225	150
	Transit Center	225	150
	Storage & Maintenance	350	225
	Park & Ride Lots w/Buses	225	150
Ferry Boat Terminals		300	150

*Measured from centerline of guideway for fixed-guideway sources, from the ROW on both sides of the roadway for highway/transit sources, from the center of noise-generating activity for stationary sources, or from the outer boundary of the proposed project site for fixed facilities spread out over a large area.

Table 4-8 Assumptions for Screening Distances for Noise Assessments

Type of Project		Operations	Speeds*	Metric**
Fixed-Guideway Systems				
Commuter Rail Mainline		66 day /12 night; 1 loco, 6 cars	55 mph	L_{dn}
Commuter Rail Station	With Horn Blowing	22 day / 4 night	N/A	L_{dn}
	Without Horn Blowing	22 day / 4 night	N/A	L_{dn}
Commuter Rail-Highway Crossing with Horns and Bells		22 day / 4 night	55 mph	L_{dn}
RRT		220 day / 24 night; 6-car trains	50 mph	L_{dn}
RRT Station		220 day / 24 night	20 mph	L_{dn}
LRT		150 day / 18 night; 2 artic veh.	35 mph	L_{dn}
Streetcar		150 day / 18 night	25 mph	L_{dn}
Access Roads to Stations		1000 cars, 12 buses	35 mph	$L_{eq(1hr)}$
Low and Intermediate Capacity Transit	Steel Wheel	220 day / 24 night	30 mph	L_{dn}
	Rubber Tire	220 day / 24 night	30 mph	L_{dn}
	Monorail	220 day / 24 night	30 mph	L_{dn}
Yards and Shops		20 train movements	N/A	$L_{eq(1hr)}$
Parking Facilities		1000 cars	N/A	$L_{eq(1hr)}$
Access Roads to Parking		1000 cars	35 mph	$L_{eq(1hr)}$
Ancillary Facilities: Ventilation Shafts		Rapid Transit in Subway	50 mph	L_{dn}
Ancillary Facilities: Power Substations		Sealed shed, air conditioned	N / A	L_{dn}
Bus Systems				
Busway		30 buses, 120 automobiles	50 mph	$L_{eq(1hr)}$
BRT on exclusive roadway		30 buses	35 mph	$L_{eq(1hr)}$
Bus Facilities	Access Roads	1000 cars	35 mph	$L_{eq(1hr)}$
	Transit Mall	20 buses	N/A	$L_{eq(1hr)}$
	Transit Center	20 buses	N/A	$L_{eq(1hr)}$
	Storage & Maintenance	30 buses	N/A	$L_{eq(1hr)}$
	Park & Ride Lots w/Buses	1000 cars, 12 buses	N/A	$L_{eq(1hr)}$
Ferry Boat Terminals		8 boats with horns used in normal docking cycle	N/A	$L_{eq(1hr)}$

*N/A = not applicable

**$L_{eq(1hr)}$ = the loudest hour of project related activity during hours of noise sensitivity.

4.4 Evaluate Impact: General Noise Assessment

The General Noise Assessment should be completed after the Noise Screening Procedure (Section 4.3), through which noise-sensitive receivers have been identified. This can be completed either by using the General Noise Assessment Procedure described below or using the FTA General Noise Assessment Spreadsheet found on the following FTA website: http://www.fta.dot.gov/12347_2233.html.

Assumptions are used throughout the General Noise Assessment. If the listed assumptions are not appropriate for the project and good engineering judgement cannot be used by following the General Noise Assessment procedure, proceed to a Detailed Noise Analysis or consult with the FTA Regional office.

Major steps in the General Noise Assessment procedure and recommended workflow are shown in Figure 4-5 and listed below. Four examples of General Noise Assessments are given at the end of this section. Many of these concepts are explained in greater detail in the context of a Detailed Noise Analysis in Section 4.5.

Step 1: Identify Noise-Sensitive Receivers – Identify noise-sensitive receivers (Section 4.3) and their proximity to the project and major noise sources.

Step 2: Determine Project Noise Source Reference Levels – Determine the project noise sources and reference levels. Then, estimate the project noise exposure at the reference distance of 50 ft considering operational characteristics with preliminary estimations of the effect of mitigation.

Step 3: Estimate Project Noise Exposure by Distance – Estimate project noise exposure at distances beyond 50 ft considering propagation characteristics using a simplified procedure.

Step 4: Combine Noise Exposure from All Sources – Combine all sources associated with the project to predict the total project noise at the receivers.

Step 5: Measure Existing Noise Exposure – Measure the existing noise or estimate the existing noise exposure using a simplified procedure.

Step 6: Inventory Impacts

> **Option A:** Tabulate the change in noise (existing vs. estimated project noise) at each noise-sensitive receiver or cluster, identifying all moderate and severe impacts.
>
> **Option B:** Take inventory of noise-sensitive receivers that fall within the moderate and severe noise contours.

Step 7: Determine Noise Mitigation Needs – Evaluate the need for mitigation and repeat the General Noise Assessment with proposed mitigation.

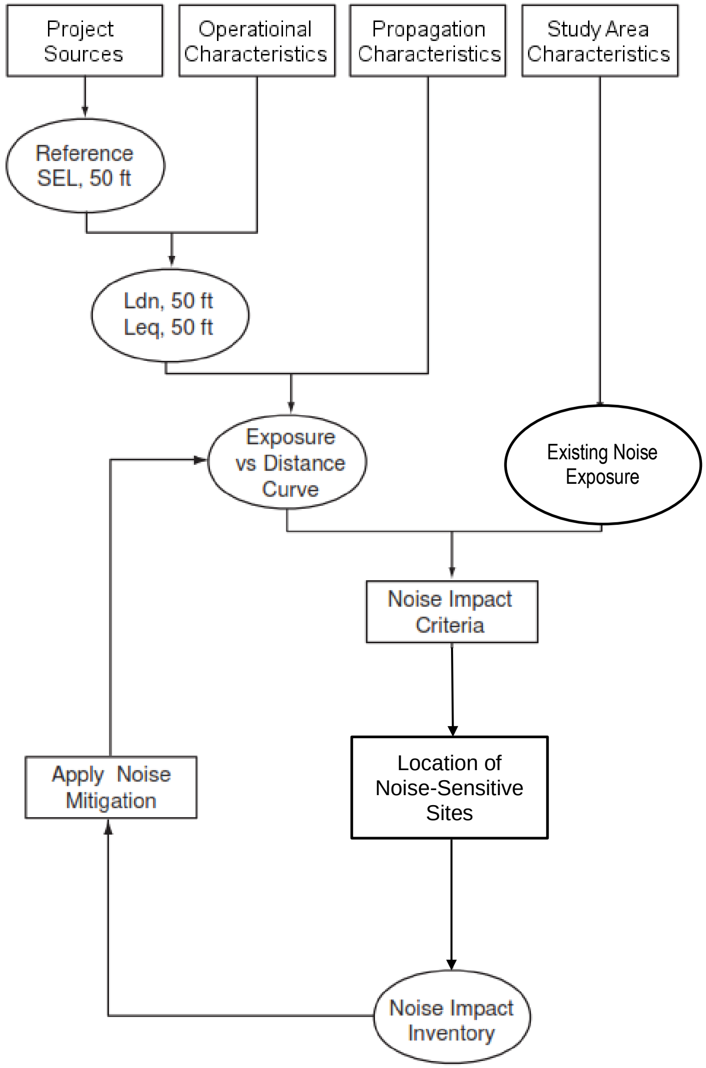


Figure 4-5 Procedure for General Noise Assessment

Step 1: Identify Noise-Sensitive Receivers

Determine the proximity of noise-sensitive land uses identified in Section 4.3 to the project and to the nearest major roadways and railroad lines.

1a. When necessary, use windshield surveys or detailed land use maps to confirm the location of noise-sensitive land uses.

1b. For land uses more than 1,000 ft from major roadways or railroad mainlines, obtain an estimate of the population density in the immediate area, expressed in people per square mile. Distances to roadways or railroads, or population density, will be used later to estimate the existing noise level. Coordinate with the Metropolitan Planning Organization (MPO) for population densities at an appropriate level of detail.

Step 2: Determine Project Noise Source Reference Levels

Determine the general source reference level for each project noise source.

Classify all project noise sources as fixed-guideway transit, highway/transit, or stationary facility and determine the source reference levels. 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.

Option A: Fixed-guideway Transit Sources – For this manual, fixed-guideway transit sources include commuter rail, RRT, LRT, streetcar, AGT, monorail, and magnetically levitated vehicles (maglev). For commuter railroads and LRT systems, the crossing of streets and highways at-grade is likely, and in that case, warning devices should be included in the assessment. At an early project stage, the information available for a General Noise Assessment includes:

- Candidate transit mode
- Guideway options
- Time of operation
- Operational headways
- Design speed
- Alternative alignments

This information is not sufficient to predict noise levels at all locations along the ROW. Therefore, use conservative estimates (e.g., maximum (expected) design speeds and operations at design capacities) to estimate worst-case noise levels.

First choose the appropriate fixed-guideway transit source reference level and then predict the noise exposure at 50 ft in terms of $L_{eq(1hr)}$ and L_{dn}.

A.i. Choose the reference source noise levels 50 ft from the track for one vehicle in terms of Sound Exposure Level (SEL) using Table 4-9. See Appendix B for a detailed explanation of SEL. Note that the SEL reference speed is 50 mph, unless otherwise noted.

Table 4-9 Reference SEL's 50 ft from Track and at 50 mph, One Vehicle

Source	Type	Reference Conditions	Reference SEL (SEL_{ref}), dBA
Commuter Rail, At-Grade	*Locomotives*	Diesel-electric, 3000 hp, throttle 5	92
		Electric	90
	Diesel Multiple Unit (DMU)	Diesel-powered, 1200 hp	85
	Horns	Within ¼ mile of grade crossing	110
	Cars	Ballast, welded rail	82
Rail Transit and Streetcars at 50 mph		At-grade, ballast, welded rail	82
Rail Transit and Streetcars at 25 mph		At-grade, ballast, welded rail	76
Transit whistles / warning devices		Within 1/8 mile of grade crossing	93
AGT	*Steel Wheel*	Aerial, concrete, welded rail	80
	Rubber Tire	Aerial, concrete guideway	78
Monorail		Aerial straddle beam	82
Maglev		Aerial, open guideway	72

A.ii. Collect the following data:

- Number of train passbys during the day (7 a.m. to 10 p.m.) and night (10 p.m. to 7 a.m.) for category 2 land uses
- Maximum number of train passbys during hours that category 1 or category 3 land uses are normally in use (typically the peak hour train volume)
- Number of vehicles per train for each time period for category 2 land uses (if this number varies during the day or night, take the average)
- Maximum number of vehicles per train during hours that category 1 or category 3 land uses are normally in use (typically the peak hour train volume)
- Train speed in mph (maximum expected)
- Guideway configuration
- Location of highway and street grade crossings, if any
- If this process is repeated to estimate the effect of proposed noise mitigation, include the noise barrier location

A.iii. Calculate the noise exposure at 50 ft in terms of $L_{eq(1hr)}$:

- Calculate $L_{eq(1hr)}$ for each source using the appropriate equations in Table 4-10.
- Compute $L_{eq(1hr).Combo}$ using Eq. 4-6. It may be necessary to compute the combined totals with and without warning horns. Some neighborhoods along the corridor may be exposed to horn noise, but some may not.

A.iv. Calculate the noise exposure at 50 ft in terms of L_{dn}:

- If the project noise will affect any residential receivers, calculate the L_{dn} using the combined $L_{eq(1hr)}$ for both the daytime and nighttime periods separately, using the appropriate equations in Table 4-10.
- It may be necessary to calculate L_{dn} with and without warning horns, as in the previous step.

Note that the equations in Table 4-10 include terms to account for a difference in speed from the 50 mph reference speed and a numerical adjustment to account for the one-hour time period for this metric. For more information on the numerical adjustment to represent the time period of interest, see Appendix B.1.4.4.

Table 4-10 presents an estimate of the noise reduction potentially provided by wayside noise barriers that can be used when assessing mitigation options in a General Noise Assessment. If impact is determined during the General Noise Assessment, repeat the procedure and include proposed mitigation according to Section 4.4, Step 7. See Section 4.5, Step 7 for a complete description of the benefits resulting from various noise mitigation measures that can be evaluated with a Detailed Noise Analysis.

Table 4-10 Computation of Noise Exposure at 50 ft for Fixed-Guideway General Noise Assessment

Locomotives* $L_{eq(1hr)}$ at 50 ft	$L_{eq.Loco(1hr)} = SEL_{ref} + 10\,log(N_{Loco}) + K log(\frac{S}{50}) + 10\,log(V) - 35.6$	**Eq. 4-1**
Locomotive Warning Horns** $L_{eq(1hr)}$ at 50 ft	$L_{eq.LHorns(1hr)} = SEL_{ref} + 10\,log(V) - 35.6$	**Eq. 4-2**
Rail Vehicles† $L_{eq(1hr)}$ at 50 ft	$L_{eq.RCars(1hr)} = SEL_{ref} + 10\,log(N_{Cars}) + 20\log(\frac{S}{50}) + 10\,log(V) - 35.6 + Adj_{track}$	**Eq. 4-3**
Streetcars (25 mph or slower) $L_{eq(1hr)}$ at 50 ft	$L_{eq.SCars(1hr)} = SEL_{ref} + 10\,log(N_{Cars}) + 2\log(\frac{S}{25}) + 10\,log(V) - 35.6 + Adj_{track}$	**Eq. 4-4**
Transit Warning Horns $L_{eq(1hr)}$ at 50 ft	$L_{eq.THorns(1hr)} = SEL_{ref} - 10\,log(\frac{S}{50}) + 10\,log(V) - 35.6$	**Eq. 4-5**
Combined Locomotive and transit†† $L_{eq(1hr)}$ at 50 ft	$L_{eq.Combo(1hr)} = 10\log(10^{(L_{eq.Loco(1hr)}/10)} + 10^{(L_{eq.RCars(1hr)}/10)} + 10^{(L_{eq.SCars(1hr)}/10)} + 10^{(L_{eq.LHorns(1hr)}/10)} + 10^{(L_{eq.THorns(1hr)}/10)}$	**Eq. 4-6**
Daytime L_d at 50 ft	$L_d = L_{eq(1hr)}$ where V = V_d, N_{Loco} = N_d (loco events), and N_{Cars} = N_d (car events)	**Eq. 4-7**
Nighttime L_n at 50 ft	$L_n = L_{eq(1hr)}$ where V = V_n, N_{Loco} = N_d (loco events), and N_{Cars} = N_d (car events)	**Eq. 4-8**
Day/Night L_{dn} at 50 ft	$L_{dn} = 10log(15 \times 10^{(L_d/10)} + 9 \times 10^{((L_n+10)/10)}) - 13.8$	**Eq. 4-9**

N_{Loco} = average number of locomotives per train

K = constant
- -10 for passenger diesel
- 0 for DMUs
- +10 for electric

S = train speed, mph

V = average hourly volume of train traffic, trains per hour

N_{Cars} = average number of cars per train

Adj_{track} = constant
- +5 for jointed track or for a crossover within 300 ft
- +4 for aerial structure with slab track (except AGT and monorail)
- +3 for embedded track on grade
- -5 if a noise barrier blocks the line of sight

V_d = average hourly daytime volume of train traffic, trains per hour

$$= \frac{number\ of\ trains, 7\ a.m.\ to\ 10\ p.m.}{15}$$

N_d = average hourly number of events that occur during daytime (7 a.m. to 10 p.m.)

$$= \frac{number\ of\ events\ between\ 7\ a.m.\ to\ 10\ p.m.}{15}$$

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

$$= \frac{number\ of\ trains, 10\ p.m.\ to\ 7 a.m.}{9}$$

N_n = average hourly number of events that occur during nighttime (10 p.m. to 7 a.m.)

$$= \frac{number\ of\ events\ between\ 10\ p.m.\ to\ 7\ a.m.}{9}$$

* Assumes a diesel locomotive power rating at approximately 3000 hp.
** Based on FRA's horn noise model (http://www.fra.dot.gov/eLib/Details/L04091).
† Includes all commuter rail cars, transit cars, streetcars above 25 mph, AGT and monorail.
† † Only include appropriate terms.

Option B: Highway/Transit Sources – The highway/transit type sources include most transit modes that do not require a fixed-guideway. Examples are high-occupancy vehicles, such as buses, commuter vanpools and carpools. Use the instructions below to estimate source noise levels for projects that involve these types of vehicles and are using FTA's environmental review procedures. At an early project stage, the information available for a General Noise Assessment includes:

- Vehicle type
- Transitway design options
- Time of operation
- Typical headways
- Design speed
- Alternative alignments

This information is not sufficient to predict noise levels at all locations along the ROW; therefore, use of conservative estimates (e.g., maximum (expected) design speeds and operations at design capacities) to estimate worst-case noise impact levels is recommended. The procedure is consistent with FHWA's highway noise prediction method. The reference SEL levels in Table 4-11 correspond to FHWA's source emission levels and speed coefficients for buses and automobiles.[22]

B.i. Using Table 4-11, choose the appropriate reference source noise levels 50 ft from the roadway in terms of SEL. Note that the SEL reference speed is 50 mph, unless otherwise noted.

Table 4-11 Source Reference Levels at 50 ft from Roadway, 50 mph

Source*	Reference SEL, dBA
Automobiles and Vans	74
Buses (diesel-powered)	82
Buses (electric)	80
Buses (hybrid)	83**

* Assumes normal roadway surface conditions.
** For hybrid buses, determine Reference SEL on a case-by-case basis because they vary, and data are scarce.

B.ii. Collect the following data:

- Number of vehicle passbys during the day (7 a.m. to 10 p.m.) and night (10 p.m. to 7 a.m.) for each vehicle type in Table 4-11, if a category 2 land use is present
- Number of vehicle passbys during hours that category 1 or category 3 land uses are normally in use, each vehicle type in Table 4-11
- Speed (maximum expected)
- Transitway configuration (with or without noise barrier)

B.iii. Calculate the noise exposure at 50 ft in terms of $L_{eq(1hr)}$. Calculate $L_{eq(1hr)}$ for each source using the appropriate equations in Table 4-12.

B.iv. Calculate the noise exposure at 50 ft in terms of L_{dn}. If the project noise will affect any residential receivers, calculate the L_{dn} using the combined $L_{eq(1hr)}$ for both the daytime and nighttime periods separately, using the appropriate equations in Table 4-12.

Note that the equations in Table 4-12 include terms to account for a speed other than the 50 mph reference speed and a numerical adjustment to account for the one-hour time period for this metric. For more information on the numerical adjustment to represent the time period of interest, see Appendix B.1.4.4.

Table 4-12 presents an estimate of noise reduction potentially provided by wayside noise barriers. This is considered illustrative given that barriers are the most common noise mitigation measure. See Section 4.5, Step 7 for a complete description of the benefits resulting from noise mitigation. If impact is determined during the General Noise Assessment without mitigation, repeat the procedure and include proposed mitigation.

Table 4-12 Computation of $L_{eq(1hr)}$ and L_{dn} at 50 ft for Highway/Transit General Noise Assessment

$L_{eq(1hr)}$ at 50 ft	$L_{eq(1hr)} = SEL_{ref} + 10\,log(V) + C_S log(\frac{S}{50}) - 35.6$	**Eq. 4-10**
Daytime L_d at 50 ft	$L_d = L_{Aeq(1hr)}$ where $V = V_d$	**Eq. 4-11**
Nighttime L_n at 50 ft	$L_n = L_{Aeq(1hr)}$ where $V = V_n$	**Eq. 4-12**
L_{dn} at 50 ft	$L_{dn} = 10log(15 \times 10^{(L_d/10)} + 9 \times 10^{((L_n+10)/10)}) - 13.8$	**Eq. 4-13**
Barrier Adjustment	= -5 for noise barriers	
V	= hourly volume of vehicles, vehicles per hour	
C_S	= Speed constant 15 for diesel buses 28 for electric buses 21 for hybrid buses[23] 30 for automobile and van pools	
S	= average vehicle speed, mph	
V_d	= average hourly daytime volume of vehicles, vehicles per hour $= \frac{total\ number\ of\ vehicles, 7\ a.m.\ to\ 10\ p.m.}{15}$	
V_n	= average hourly nighttime volume of vehicles, vehicles per hour $= \frac{total\ number\ of\ vehicles, 10\ p.m.\ to\ 7\ a.m.}{9}$	

Option C: Stationary Sources – Stationary sources include fixed transit system facilities. New transit facilities undergo a site review for best location that considers the noise sensitivity of surrounding land uses. Although many facilities such as bus maintenance garages are usually located in industrial and commercial areas, some facilities such as bus terminals, ferry terminals, train stations, and park-and-ride lots may be placed near residential neighborhoods where noise impact may occur. Access roads to some of these facilities may also pass through noise-sensitive areas. Noise from access roads is treated according to the procedures described in the Highway/Transit Sources category. In a General Noise Assessment, only the prominent features of each fixed facility are considered in the noise analysis.

C.i. For small facilities, using Table 4-13, determine the reference source noise levels 50 ft from the center of the site in terms of SEL. The source reference levels given in the table are based on measurements for the peak hour of operation of a typical stationary source of the noted type and size.

A large facility, such as a rail yard, is spread out over considerable area with various noise sources with different noise levels depending on the layout of the facility. Specifying a single reference SEL for the facility at 50 ft from the center of the site could be misleading if all of these different noise sources are not represented. Therefore, the reference distance should be the equivalent distance of 50 ft, which is determined by estimating the noise levels from the center of the site at a distance far enough to capture all noise sources and projecting back to 50 ft from the center of the site. This approach allows for a conservative estimate of noise for all surrounding areas and the equivalent noise can be considered as concentrated at the center of the site. If the location of noise sources is known, then the distance should be taken from the point of the noisiest activity on the site (e.g., the dock in the case of ferry boat operations) instead of the center of the site.

Table 4-13 Source Reference Levels at 50 ft from Center of Site, Stationary Sources

Source	Reference SEL, dBA	Reference Conditions
Rail System		
Yards and shops	118	20 train movements in peak activity hour
Layover tracks (commuter rail)	109	1 train with diesel locomotive idling for 1 hour
Crossing signals	109	3600 second duration
Bus System		
Storage yard	111	100 buses accessing facility in peak activity hour
Operating facility	114	100 buses accessing facility, 30 buses serviced and cleaned in peak activity hour
Transit center	101	20 buses in peak activity hour
Ferry Terminal		
Ferry boat (no fog horn sounded)	97	4 ferry boat landings in 1 hour
Ferry boat (fog horn sounded)	100	
Parking Garage	92	1000-car capacity in peak activity hour
Park & Ride Lot	101	12 buses, 1000 cars in peak activity hour

C.ii. Collect the following data:

- Number of layover tracks and hours of use
- Number of buses, if different from assumed reference conditions (if this number varies during the day or night, take the average)
- Number of ferry boat landings, if different from assumed reference conditions (if this number varies during the day or night, take the average)
- Actual capacity of parking garage or lot

C.iii. Calculate $L_{eq(1hr)}$ at 50 ft. Calculate $L_{eq(1hr)}$ for each source using the appropriate equations in Table 4-14.

C.iv. Calculate L_{dn} at 50 ft. If the project noise will affect any residential receivers, calculate the L_{dn} using the combined $L_{eq(1hr)}$ for both the daytime and nighttime periods separately, using the appropriate equations in Table 4-14.

The equations in Table 4-14 include a numerical adjustment to account for the one-hour time period for this metric. See Appendix B.1.4.4 for more information on the numerical adjustment.

Table 4-14 presents an estimate of noise reduction potentially provided by noise barriers at the property line. Only approximate locations and lengths for barrier or other noise mitigation measures are developed during a General Noise Assessment to provide a preliminary indication of the costs and benefits of mitigation. A Detailed Noise Analysis of the preferred alternative is usually warranted following the General Noise Assessment (if it predicts any impacts) to verify impacts and design the mitigation.

Table 4-14 Computation of $L_{eq(1hr)}$ and L_{dn} at 50 ft for Stationary Source General Noise Assessment*

$L_{eq(1hr)}$ at 50 ft	$L_{eq(1hr)} = SEL_{ref} + C_N - 35.6$	**Eq. 4-14**
Daytime L_d at 50 ft	$L_d = 10\log\left(\left(\frac{1}{15}\right) \sum_{7am-10pm} 10^{\left(L_{Aeq(1hr)}/10\right)}\right)$	**Eq. 4-15**
Nighttime L_n at 50 ft	$L_n = 10\log\left(\left(\frac{1}{9}\right) \sum_{10pm-7am} 10^{\left(L_{Aeq(1hr)}/10\right)}\right)$	**Eq. 4-16**
L_{dn} at 50 ft	$L_{dn} = 10\log\left(15 \times 10^{\left(L_d/10\right)} + 9 \times 10^{\left((L_n+10)/10\right)}\right) - 13.8$	**Eq. 4-17**
Barrier Adjustment	= -5 for noise barrier at property line	
Volume Adjustment	$= C_N$ $= 10\log(\frac{N_T}{20})$ Rail yards and shops $= 10\log(N_T)$ Layover tracks $= 10\log(\frac{N_B}{100})$ Bus storage yard $= 10\log(\frac{N_B}{200} + \frac{N_S}{60})$ Bus operating facility $= 10\log(\frac{N_B}{20})$ Bus transit center $= 10\log(\frac{N_F}{4})$ Ferry terminal $= 10\log(\frac{N_A}{1000})$ Parking garage $= 10\log(\frac{N_A}{2000} + \frac{N_B}{24})$ Park & ride lot $= 10\log(\frac{E}{3600})$ Crossing signals N_T = average number of trains per hour during the day (7AM to 10PM) or night (10PM to 7AM) N_B = average number of buses per hour during the day or night N_F = average number of ferry boat landings per hour during the day or night N_S = average number of buses serviced and cleaned per hour during the day or night N_A = average number of automobiles per hour during the day or night E = average hourly duration of events, sec during the day or night	

* If any of these numbers is zero, omit that term.

Step 3: Estimate Project Noise Exposure by Distance

Estimate the project noise exposure for locations beyond the reference distance, such as for noise-sensitive land uses.

In the previous step, noise exposure at the reference distance of 50 ft was calculated for the various noise sources. This step describes how to estimate the project noise exposure beyond (or, if needed, closer than) the reference distance, such as at noise-sensitive land uses locations. This procedure estimates the source's noise exposure as a function of distance. Adjustments are provided to account for shielding attenuation from rows of buildings.

3a. Select the appropriate distance correction curve (Fixed-Guideway & Highway or Stationary) from Figure 4-6. The Fixed-Guideway & Highway curve refers to line sources while the Stationary curve is refers to point sources. The distance correction factor ($C_{distance}$) is 0 dB at 50 ft.

3b. Choose a distance other than 50 ft, such as the distance to a receiver. Determine the correction factor using Figure 4-6 or calculate using the equations in Table 4-15.[iii] For distances beyond 1,000 ft, the equations in Table 4-15 can be used; however, ground effects have an upper limit and atmospheric conditions may affect propagation characteristics. More detailed calculation methods may be required to account for those effects beyond 1,000 ft.

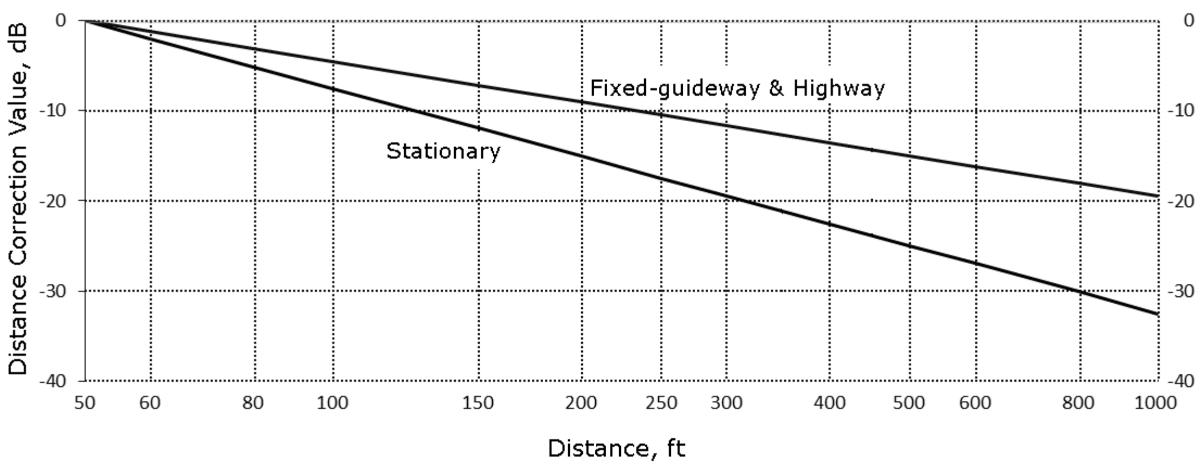


Figure 4-6 Curves for Estimating Exposure vs. Distance in General Noise Assessment

[iii] Note that the curves and equations assume acoustically soft ground beyond a distance of 50 ft. See Table 4-27 for more detailed calculation of ground attenuation.

Table 4-15 Distance Correction Factor Equations for General Noise Assessment

Source	Equation	
Stationary Sources	$C_{distance} = -25\log(\frac{D}{50})$	**Eq. 4-18**
Fixed-guideway and Highway	$C_{distance} = -15\log(\frac{D}{50})$	**Eq. 4-19**
D = distance, ft		

3c. Apply the distance correction ($C_{distance}$) to the project noise exposure at 50 ft (Section 4.4, Step 2) using the following equation:

$$L_{distance} = L_{50} + C_{distance} \quad \textbf{Eq. 4-20}$$

where:

$L_{distance}$ = L_{dn} or $L_{eq(1hr)}$ at the new distance in feet
L_{50} = L_{dn} or $L_{eq(1hr)}$ at 50 ft

3d. Repeat Step 3c for each source-receiver distance from the project. A noise exposure vs. distance curve can be created, if desired, by calculating the noise exposure for all distances of interest and plotting a curve. This curve can be used to assist in determining the noise impact contour for the first row of unobstructed buildings. This plot can be used to display noise from both unmitigated and mitigated conditions to assess the potential benefits from mitigation measures.

For second row receivers and beyond, it is necessary to account for shielding attenuation from rows of intervening buildings. Without accounting for shielding, impacts may be substantially overestimated. Use the following general rules to account for the effect of shielding from intervening rows of buildings:

- Assign 4.5 dB of shielding attenuation for the first row of intervening buildings only.
- Assign 1.5 dB of shielding attenuation for each subsequent row, up to a maximum total attenuation of 10 dB.

Step 4: Combine Noise Exposure from All Sources

Combine all sources to predict the total project noise at the receivers using the equations in Table 4-16, once propagation adjustments have been made for the noise exposure from each source separately (fixed-guideway, highway/transit, and stationary).

Table 4-16 Computing Total Noise Exposure

Total $L_{eq(t)}$ from all sources for the hour of interest:	$L_{eq.total(1hr)} = 10\log(\sum_{all\ sources} 10^{L_{eq}/10})$	**Eq. 4-21**
Total L_{dn} from all sources	$L_{dn.total} = 10\log(\sum_{all\ sources} 10^{L_{dn}/10})$	**Eq. 4-22**

Step 5: Estimate Existing Noise Exposure

Measure the existing noise or estimate the existing noise exposure using a simplified procedure.

Existing noise in the project vicinity must be quantified and compared to the project noise to determine the potential noise impact. It is generally recommended to measure existing noise, especially at locations known to be noise-sensitive, but if measurement results are not available then they must be estimated. In the Detailed Noise Analysis, the existing noise exposure is usually based on noise measurements at representative locations in the community.

It is not necessary or recommended that existing noise exposure be determined by measuring at every noise-sensitive location in the project area. Rather, the recommended approach is to characterize the noise environment for "clusters" of sites based on measurements or estimates at representative locations in the community. Because of the sensitivity of the noise criteria to the existing noise exposure, careful characterization of pre-project ambient noise is important. Guidelines for selecting representative receiver locations and determining ambient noise are provided in Appendix D and Appendix E, respectively.

Changes to Existing Transit

For projects that propose changes to an existing transit system, such as a rehabilitation project, the project noise can include changes to the existing noise because of the project, and so it is not possible to define project noise separately. For these projects, refer to Section 4.1, Step 3 – Option B, on using the cumulative noise criteria.

This section describes how to estimate the existing noise in the project study area from general data available early in project planning. The procedure uses Table 4-17, where a neighborhood's existing noise exposure is based on proximity to nearby major roadways or railroads, or on population density. For areas near major airports, published aircraft noise contours can also be used to estimate the existing noise exposure. The process is as follows:

5a. Obtain scaled mapping and aerial photographs showing the project location and alternatives. A scale of 1 inch = 200 or 400 ft is convenient for the accuracy needed in the noise assessment. The size of the base map should be sufficient to show distances of at least 1000 ft from the center of the alignment or property center, depending on whether the project is a line source (fixed guideway/ roadway) or a stationary facility. These data are commonly available from local transit agencies and a number of publicly available online tools.

5b. Estimate the existing noise exposure by estimating the noise from major roads and railroad lines or by population density. First, evaluate the site's proximity to major roads and railroad lines including those that are included in the project. If these noise sources are far enough away that ambient noise is dominated by local streets and community activities, estimate the existing noise based on population density. To choose the appropriate existing noise exposure, compare noise levels from each of the three categories—Roadways, Railroads, and Population Density—and select the lowest level. In case of a lightly used railroad (one train per day or less) select the Population Density category. Existing noise levels are presented in Table 4-17. Refer to Section 4.1, Step 3 – Option B, on using the cumulative noise criteria for projects that propose changes to an existing transit system, such as a rehabilitation project.

Option A: Roadways – Major roadways are separated into two categories for a general noise assessment. Roadways that cannot be described by these two categories are not considered major roadways and would use the Population Density method described below. The roadway categories are as follows:

- Interstate highway—roadways with 4 or more lanes that allow trucks
- Other roadway—parkways without trucks and city streets with the equivalent of 75 or more heavy trucks per hour or 300 or more medium trucks per hour

The estimated roadway noise levels in Table 4-17 are based on data for light to moderate traffic on typical highways and parkways using FHWA highway noise prediction procedures. Where a range of distances is given, the noise exposure estimates are given at the larger distance (note that the traffic noise at the smaller distance is underestimated). For highway noise, distances are measured from the centerline of the near lane for roadways with two lanes, while for roadways with more than two lanes the distance is measured from the geometric mean of the roadway. This distance is computed as follows:

$$D_{GM} = \sqrt{(D_N)(D_F)}$$ **Eq. 4-23**

where:

D_{GM} = distance to the geometric mean in feet
D_N = distance to the nearest lane centerline in feet
D_F = distance to the farthest lane centerline in feet

Option B: Railroad Lines – For railroads, the estimated noise levels are based on an average train traffic volume of 5–10 trains per day at 30–40 mph for main line railroad corridors and the noise levels are provided in terms of L_{dn} only. Distances are referenced to the track centerline, or in the case of multiple tracks, to the centerline of the rail corridor. Because of the intermittent nature of train operations, train noise will affect the $L_{eq(1hr)}$ only during certain hours of the day, and these hours may vary from day to day. Therefore, to avoid underestimating noise impact when using $L_{eq(1hr)}$, it is recommended that sites near rail lines are estimated based on nearby roadways or population density unless very specific train information is available.

Option C: Population Density – In areas away from major roadways, noise from local streets or in neighborhoods is estimated using a relationship determined during a research program by EPA.[24] EPA determined that ambient noise can be related to population density in locations away from transportation corridors, such as airports, major roads and railroad tracks, according to the following relation:

$$L_{dn} = 22 + 10\log(p)$$ **Eq. 4-24**

where:

L_{dn} = in dBA
p = population density in people per square mile

In areas near major airports, published noise contours can be used to estimate the existing noise exposure. The L_{dn} from such contours should be applied if greater than the estimates of existing noise from other sources at a given location.

Table 4-17 Estimating Existing Noise Exposure for General Noise Assessment

Dominant Existing Noise Source	Distance from Major Noise Source, ft*	Population Density, people per sq. mi.	*Noise Exposure Estimates*			
			L_{eq} Day	L_{eq} Evening	L_{eq} Night	L_{dn}
Interstate Highway**	10–50		75	70	65	75
	50–100		70	65	60	70
	100–200		65	60	55	65
	200–400		60	55	50	60
	400–800		55	50	45	55
	800 and up		50	45	40	50
Other Roadway†	10–50		70	65	60	70
	50–100		65	60	55	65
	100–200		60	55	50	60
	200–400		55	50	45	55
	400 and up		50	45	40	50
Railway††	10–30		--	--	--	75
	30–60		--	--	--	70
	60–120		--	--	--	65
	120–240		--	--	--	60
	240–500		--	--	--	55
	500–800		--	--	--	50
	800 and up		--	--	--	45
Population		1–100	35	30	25	35
		100–300	40	35	30	40
		300–1000	45	40	35	45
		1000–3000	50	45	40	50
		3000–10000	55	50	45	55
		10000–30000	60	55	50	60
		30000 and up	65	60	55	65

* Distances do not include shielding from intervening rows of buildings. Generally, for estimating shielding attenuation in populated areas, assume 1 row of buildings every 100 ft, 4.5 dB for the first row, and 1.5 dB for every subsequent row up to a maximum of 10 dB attenuation.
** Roadways with 4 or more lanes that permit trucks, with traffic at 60 mph.
† Parkways with traffic at 55 mph, but without trucks, and city streets with the equivalent of 75 or more heavy trucks per hour and 300 or more medium trucks per hour at 30 mph.
†† Main line railroad corridors typically carrying 5-10 trains per day at speeds of 30-40 mph.

Step 6: Inventory Noise Impacts

Inventory the potential noise impacts either by comparing the project and existing noise at each noise-sensitive land use or by developing noise impact contours.

Use land use information and assumptions for shielding attenuation from rows of buildings. In some cases, it may be necessary to supplement the land use information or determine the number of dwelling units within a multi-family building with a visual survey. If the objective is to compare major alignment options, it may not be necessary to identify every different type of noise-sensitive land use. The inventory may include a subset of land uses, including residential and public institutional uses.

Option A is the preferred method as it quantifies the noise impact at each noise-sensitive land use indicating the severity of the impact. Option B may be useful for comparing and narrowing down major alignment options with numerous noise-sensitive land uses.

Option A: Compare existing noise to project noise at each noise-sensitive land use.

A1. Tabulate each individual noise-sensitive land use building and site within the identified screening distance (Section 4.3).

A2. Determine for each noise-sensitive land use the existing noise (Section 4.4, Step 5), the project noise (Section 4.4, Step 3) and the resulting change in noise.

A3. Designate each noise-sensitive land use with either a no, moderate, or severe noise impact based on the criteria in Section 4.1.

A4. Identify all moderate and severe impacts on a project map.

Option B: Develop noise impact contours.

B1. Determine the noise level thresholds at which the project noise would cause moderate and severe impacts using the estimated existing noise exposure from Section 4.4, Step 5 and the noise impact criteria in Figure 4-2.

B2. Determine the distances from the project boundary to the two impact levels using the noise exposure vs. distance curves or equations in Section 4.4, Step 3.

B3. Plot points on a project land use map that correspond to the distances determined in Section 4.4, Step 3. Continue this process for all areas surrounding the project. Connect the plotted points to represent the noise impact contours.

B4. Tabulate all noise-sensitive land use buildings and sites that lie between the impact contours and the project boundary. For residential buildings, an estimate of the number of dwelling units is satisfactory.

B5. Prepare summary tables showing the number of buildings (and estimated dwelling units, if available) within both impact categories.

Specific decibel level noise contours, for example, 65 dBA, can also be plotted if desired. The distances can be determined using the procedure in Section 4.4, Step 3 by substituting the desired decibel level for the impact threshold.

Locations of points will change with respect to the project boundary as the existing ambient exposure changes, the project source levels change, and as shielding effects change. It is recommended to plot points close together to draw a smooth curve. For a General Noise Assessment, the contours may be drawn through buildings and terrain features as if they were not present. This practice is acceptable considering the level of detail associated with a project in its early stages of development. Example 4-1 and Example 4-4 describe the development of noise contours with illustrations.

Step 7: Determine Noise Mitigation Needs

Apply estimates of the noise reduction from proposed mitigation measures (Section 4.4, Step 2), where the assessment shows either severe or moderate impact, and repeat the tabulation of noise impacts.

Note that noise barriers are the only form of mitigation available in a General Noise Assessment. The other mitigation measures are available for a Detailed Noise Analysis. The approximate noise barrier lengths and locations developed in a General Noise Assessment provide a preliminary basis for evaluating the costs and benefits of impact mitigation. This evaluation will provide a conservative estimate of the effect of the mitigation on the identified impacts.

In general, it is recommended to complete a Detailed Noise Analysis for final mitigation measures. However, if impact is identified through a General Noise Assessment and can be mitigated to a level of no impact using the noise reduction estimates included in the General Noise Assessment, a Detailed Noise Analysis may not be needed. Mitigation assumed in the assessment used for the NEPA evaluation must be included in the project as a commitment. Consult with the FTA Regional office to determine if a Detailed Noise Analysis is required for final mitigation measures.

The following examples illustrate how to complete general noise assessments for varying project types including commuter rail, highway/transit, BRT system, and a transit center.

Example 4-1 General Noise Assessment – Commuter Rail

General Noise Assessment for a Commuter Rail System in an Existing Abandoned Railroad Right-of-Way

The following example illustrates the General Noise Assessment procedure for a new fixed-guideway project. The hypothetical project is a commuter rail system to be built within the abandoned ROW of a railroad. The example covers a segment of the corridor that passes through a densely developed area with population density of 25,000 people per square mile in mixed single- and multi-family residential land uses as shown in Figure 4-7. The example is presented in two parts: first, a segment where the rail line is grade-separated and a horn is not sounded; and second, an at-grade street-rail crossing where the horn is sounded.

Assumptions

- **Project Corridor**
  Existing population density is 25,000 people per square mile.
- **Commuter Rail System**
  Commuter train with one locomotive and a three-car consist on a double-track at-grade system with welded rail. Trains operate with 20-minute headways during peak hours and 1-hour headways during off-peak. Speeds are approximately 40 mph along the corridor.

Operating Schedule

	Period	Headway (minutes) Inbound	Headway (minutes) Outbound	Trains per hour Inbound	Trains per hour Outbound	Trains per hour Total	Period Total
Daytime	7 a.m. – 8 a.m.	20	20	3	3	6	6
	8 a.m. – 4 p.m.	60	60	1	1	2	16
	4 p.m. – 6 p.m.	20	20	3	3	6	12
	6 p.m. – 10 p.m.	60	60	1	1	2	8
Nighttime	10 p.m. – 11 p.m.	60	60	1	1	2	2
	11 p.m. – 5 a.m.	--	--	--	--	--	--
	5 a.m. – 6 a.m.	60	60	1	1	2	2
	6 a.m. – 7 a.m.	20	20	1	1	2	2

Part 1: Grade-Separated Street Crossing

Determine Project Source Reference Levels at 50 ft

Classify the noise source: Fixed-Guideway Transit
Determine noise source reference level from Table 4-9:
Locomotive: 92 dBA
Cars: 82 dBA

Estimate Project Noise Exposure at 50 ft

Determine average hourly daytime and nighttime volumes of train traffic.

Daytime (7 a.m. – 10 p.m.)

$$V_d = \frac{42\ trains}{15\ hours} = 2.8\ trains/hour$$

Nighttime (10 p.m. – 7 a.m.)

$$V_n = \frac{6\ trains}{9\ hours} = 0.7\ trains/hour$$

Use Eq. 4-1 and Eq. 4-3 to calculate the daytime $L_{eq(1hr)}$ at 50 ft for the locomotives and rail cars.

$$L_{d.Locos} = SEL_{ref} + 10log(N_{Locos}) + Klog(\frac{S}{50}) + 10log(V_d) - 35.6$$
$$= 92 + 10log(1) - 10log(\frac{40}{50}) + 10log(2.8) - 35.6$$
$$= 61.8\ dBA \text{ at 50 ft}$$

$$L_{d.RCars} = SEL_{ref} + 10log(N_{Cars}) + 20log(\frac{S}{50}) + 10log(V_d) - 35.6$$
$$= 82 + 10log(3) + 20log(\frac{40}{50}) + 10log(2.8) - 35.6$$
$$= 53.7\ dBA \text{ at 50 ft}$$

Calculate the total daytime L_d for the locomotive and rail cars using Eq. 4-7.

$$L_{d.Combo} = 10log(10^{L_{d.Loco}/10} + 10^{L_{d.RCars}/10})$$
$$= 10log(10^{61.8/10} + 10^{53.7/10})$$
$$= 62.4\ dBA \text{ at 50 ft}$$

Calculate the nighttime $L_{eq(1hr)}$ at 50 ft for the locomotives and rail cars.

$$L_{n.Locos} = SEL_{ref} + 10\log(N_{Locos}) + K\log(\frac{S}{50}) + 10\log(V_n) - 35.6$$
$$= 92 + 10\log(1) - 10\log(\frac{40}{50}) + 10\log(0.7) - 35.6$$
$$= 55.8\ dBA \text{ at 50 ft}$$

$$L_{n.RCars} = SEL_{ref} + 10\log(N_{Cars}) + 20\log(\frac{S}{50}) + 10\log(V_n) - 35.6$$
$$= 82 + 10\log(3) + 20\log(\frac{40}{50}) + 10\log(0.7) - 35.6$$
$$= 47.7\ dBA \text{ at 50 ft}$$

Calculate the total nighttime L_n for the locomotive and rail cars using Eq. 4-8.

$$L_{n.Combo} = 10log(10^{L_{n.Locos}/10} + 10^{L_{n.RCars}/10})$$
$$= 10log(10^{55.8/10} + 10^{47.7/10})$$
$$= 56.4\ dBA \text{ at 50 ft}$$

Calculate L_{dn} at 50 ft for the project using Eq. 4-9.

$$L_{dn.Combo} = 10log\ (15 \times 10^{(L_{d.Combo}/10)} + 9 \times 10^{((L_{n.Combo}+10)/10)}) - 13.8$$

Estimate Existing Noise Exposure

Estimate existing noise at noise-sensitive sites. Since the existing alignment is on an abandoned railroad, the dominant existing noise source can be described by a generalized noise level to characterize a large area. Use Table 4-17 and population density of 25,000 people per square mile to determine the existing noise level. Unobstructed residences range from 100 to 200 ft from the rail line.

According to Table 4-17: L_{dn} = 60 dBA

Determine Noise Level and Distance for the Onset Of Impact

Determine the noise level for the onset of moderate and severe impact using Figure 4-2 and the existing noise level of 60 dBA. Note that this project is land use category 2 and the appropriate metric is L_{dn}.

Existing Noise L_{dn}	Onset of Moderate Impact L_{dn}	Onset of Severe Impact L_{dn}
60 dBA	58 dBA	64 Dba

Determine the distance from the project noise sources to the noise impact contours using the fixed-guideway curve in Figure 4-6 (or the equations in Table 4-15) and the project impact thresholds obtained above. The project noise level at 50 ft is approximately 64 dBA.

Moderate impact (58 dBA)

$$58 - 64 = -6\ dB$$

According to Figure 4-6, the distance correction is approximately -6 dB at 120 ft.

Severe Impact (64 dBA)

$$64 - 64 = 0\ dB$$

According to Figure 4-6, the distance correction is less than 0 dB at approximately 51 ft.

Project Level L_{dn}	Onset of Moderate Impact Distance	Onset of Severe Impact Distance
64 dBA	120 ft	51 ft

Develop Noise Impact Contours

Draw contours for each affected land use, based on the above table and its distance from the rail line (Figure 4-7). Note that the impact distances listed are in terms of distance to the centerline of the Commuter Rail corridor.

Inventory of Noise Impact

There are six residential buildings within the contours defining moderate impact (shaded in Figure 4-7).

Noise Mitigation

The procedure is repeated assuming a noise barrier to be placed at the railroad ROW line. The barrier serves to reduce project noise from the commuter rail by at least 5 dB. Note that the barrier does not affect the project criteria to be used in determining impact, and the same existing noise levels (as the case without a barrier) are used to determine these thresholds.

In this example, the noise barrier decreases the distance to moderate impact from 120 to 60 ft and eliminates all residential noise impact for this segment of the project area.

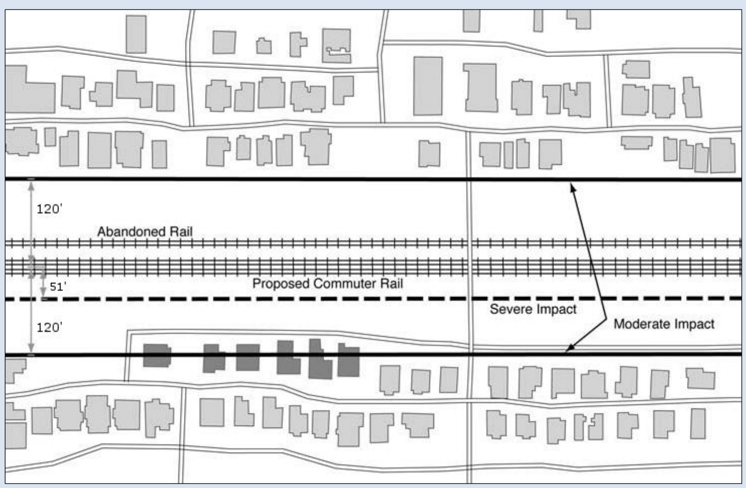


Figure 4-7 Noise Impacts of Hypothetical Commuter Rail

Part 2: At-Grade Crossing with Horn Blowing

Now consider the case of an active street crossing of the commuter railroad tracks. The General Noise Assessment method includes source reference levels for horns on moving trains and warning bells (crossing signals) at the street crossing. According to Table 4-9, the horn noise applies to track segments within ¼ mile of the grade crossing.

Estimate Project Noise Exposure at 50 ft

Using the train volumes from Part 1 and the information in Table 4-9 and Table 4-10, determine the day and nighttime $L_{eq(1hr)}$ from sounding the horns at 50 ft.

$$L_{d.LHorns} = SEL_{ref} + 10\log(V_d) - 35.6$$
$$= 110 + 10\log(2.8) - 35.6$$
$$= 78.9\ dBA$$

$$L_{n.LHorns} = SEL_{ref} + 10\log(V_n) - 35.6$$
$$= 110 + 10\log(0.7) - 35.6$$
$$= 72.9\ dBA$$

Calculate the L_{dn} at 50 ft from train horns using Eq. 4-9 :

$$L_{dn.LHorns} = 10\log(15 \times 10^{\left(L_{d.LHorns}/10\right)} + 9 \times 10^{\left((L_{n.LHorns}+10)/10\right)})\text{-}13.8$$
$$= 81\ dBA$$

At-grade street crossings will have warning bells, typically sounding for 20 seconds for every train passby. The total daytime and nighttime durations are as follows:

E_d = average daytime hourly duration
=20 seconds X 2.8 trains/hour = 56 seconds/hour
E_n = average nighttime hourly duration
=20 seconds X 0.7 trains/hour = 14 seconds/hour

From Table 4-14:

$$L_{d.WBell} = SEL_{ref} + 10\log(\frac{E_d}{3600}) - 35.6$$
$$= 109 + 10\log(\frac{56}{3600}) - 35.6$$
$$= 55.3\ dBA$$

$$L_{n.WBell} = SEL_{ref} + 10\log(\frac{E_n}{3600}) - 35.6$$
$$= 109 + 10\log(\frac{14}{3600}) - 35.6$$
$$= 49.3\ dBA$$

Calculate L_{dn} at 50 ft. from the warning bells using Eq. 4-17:

$$L_{dn.WBell} = 10\log(15 \times 10^{\left(L_{d.WBell}/10\right)} + 9 \times 10^{\left((L_{n.WBell}+10)/10\right)})\text{-}13.8$$
$$= 57.3\ dBA$$

Compared to horn blowing, the crossing signal warning bell noise is negligible, but still must be included in the evaluation.

Estimate Existing Noise Exposure

From Part 1, the existing noise level is 60 dBA.

Determine Noise Level and Distance for the Onset Of Impact

As in Part 1, the existing noise level (60 dBA) is used to determine the onset of moderate and severe impacts:

Existing Noise L_{dn}	Onset of Moderate Impact L_{dn}	Onset of Severe Impact L_{dn}
60 dBA	58 dBA	64 dBA

Determine the distance from the project noise sources to the impact contours using the fixed-guideway curve in Figure 4-6 (or the equations in Table 4-15) and the project impact thresholds obtained above. The project noise at 50 ft is approximately 81 dBA. However, there are at least two intervening rows of buildings, which will provide 6 dB (4.5 dB for the first row and 1.5 dB for the second row) of shielding.

Moderate impact (58 dBA)

$$58 - (81 - 6) = -17\ dB$$

According to Figure 4-6, the distance correction is approximately -17 dB at 715 ft.

Severe Impact (64 dBA)

$$64 - (81 - 6) = -11\ dB$$

According to Figure 4-6, the distance correction is approximately -11 dB at 265 ft.

Project Level L_{dn}	Onset of Moderate Impact Distance	Onset of Severe Impact Distance
81 dBA	715 ft	265 ft

Draw Noise Impact Contours

Contours can be drawn as in Part 1 for ¼ mile on either side of the grade crossing.

Example 4-2 General Noise Assessment – Highway/Transit

General Noise Assessment Example of Highway/Transit Corridor Projects

This example illustrates a highway/transit project where the highway noise dominates and the FHWA assessment methods should be used to inform the FTA process according to the impact criteria in Section 4.1.

Case 1: Highway Dominates

A new LRT system is planned for the median of a major highway that carries heavy traffic both day and night. The noise levels at the first row of houses along the highway were measured during peak hour, mid-day and nighttime with hourly $L_{eq(1hr)}$ readings of 65 dBA, 63 dBA, and 60 dBA, respectively. The LRT tracks will be 125 ft from the first row of houses. The LRT operations during peak hour will be 4-car trains at 45 mph, with 5-minute headways in both directions. Nighttime service decreases to 2-car trains and 20 minute headways.

FTA is providing a share of the funding for the LRT project, but the State DOT and the FHWA are co-lead agencies because the median requires considerable preparation for the tracks, including replacing bridge piers of street crossings and moving some highway lanes.

Assumptions

SEL_{ref} = 82 dBA
Nd = 4 cars per train
Nn = 2 cars per train
S = 45 mph
V_d = 24 trains per hour
V_n = 6 trains per hour

Estimate Project Noise Exposure at 50 ft

Use Table 4-9 and Table 4-10 to determine the peak hour $L_{eq(1hr)}$ for the rail vehicles.

Use Eq. 4-3 to calculate the LRT peak-hour noise level.

$$L_{d.RCars}(h) = SEL_{ref} + 10\,log(N_{cars}) + 20\log(\frac{S}{50}) + 10\,log(V) - 35.6$$

$$= 82 + 10\,log(4) + 20\log(\frac{45}{50}) + 10\,log(24) - 35.6$$

= 65 dBA at 50 ft

Use Eq. 4-3 to calculate the LRT late evening hourly noise level.

$$L_{n.RCars}(h) = SEL_{ref} + 10\,log(N_{cars}) + 20\log(\tfrac{S}{50}) + 10\,log(V) - 35.6$$
$$= 82 + 10\,log(2) + 20\log(\frac{45}{50}) + 10\,log(6) - 35.6$$
= 56 dBA at 50 ft

Estimate Project Noise Exposure at 125 ft

Since the LRT tracks will be 125 ft from the first row of houses, use Figure 4-6 to determine the level at 125 ft.

At 125 ft, the distance correction is 5 dB.
Peak hour:

$$65 - 5 = \ 60\ dBA\ at\ 125\ ft$$

Night hourly:

$$56 - 5 = \ 51\ dBA\ at\ 125\ ft$$

In this case, the highway dominates the noise environment in the area both day and night, by 5 dB during peak hour and 9 dB at night. According to Section 4.1 and Table 4-2, use the FHWA assessment methods.

Example 4-3 General Noise Assessment – BRT System

General Noise Assessment for a BRT System in an Existing Railroad Right-of-Way

This example for a simple BRT project illustrates using the FTA procedures for a new BRT corridor planned in an existing abandoned railroad ROW.

Assumptions

SEL_{ref} = 82 for buses
S = 25 mph
V_d = (344 buses) / (15 hours) = 22.9 buses per hour
V_n = (116 buses) / (9 hours) = 12.9 buses per hour

Estimate Project Noise Exposure

Use the information and equations in Table 4-12 to calculate the daytime and nighttime $L_{eq(1hr)}$ at 50 ft.

C_S = 15 for buses

$$L_{d.Bus} = \ SEL_{ref} + 10\,log(V_d) + C_S\log(\frac{S}{50}) - 35.6$$
$$= \ 82 + 10\,log(22.9) + 15log(\frac{25}{50}) - 35.6$$
= 55 dBA at 50 ft

$$L_{n.Bus} = \ SEL_{ref} + 10\,log(V_n) + C_S\log(\frac{S}{50}) - 35.6$$
$$= 82 + 10\,log(12.9) + 15log(\frac{25}{50}) - 35.6$$
= 53 dBA at 50 ft

Calculate L_{dn} at 50 ft for the project using Eq. 4-13.

$$L_{dn.Bus} = \ 10\log(15 \times 10^{(L_{d.Bus}/10)} + 9 \times 10^{((L_{n.Bus}+10)/10)}) - 13.8$$
= 60 dBA at 50 ft

Estimate Existing Noise Exposure

The surrounding area is residential with 2,500 people per square mile starting approximately 100 ft away from the proposed alignment. Determine the existing noise using Table 4-17.

L_{dn} = 50 dBA

Determine Noise Level and dIstance for the Onset of Impact

Determine the noise level for the onset of moderate and severe impact using Figure 4-2 and the existing noise level of 50 dBA. Note that this project is land use category 2 and the appropriate metric is L_{dn}.

Existing Noise L_{dn}	Onset of Moderate Impact L_{dn}	Onset of Severe Impact L_{dn}
50 dBA	54 dBA	59 dBA

Determine the distance to the noise impact contours using the fixed-guideway & highway curve in Figure 4-6 (or the equations in Table 4-15) and the project impact thresholds obtained above. The project noise level at 50 ft is approximately 60 dBA.

Moderate impact (54 dBA)

$$54 - 60 = -6\ dB$$

According to Figure 4-6, the distance correction is approximately -6 dB at 125 ft.

Severe Impact (59 dBA)

$$59 - 60 = -1\ dB$$

According to Figure 4-6, the distance correction is less than -1 dB at approximately 60 ft.

Project Level L_{dn}	Onset of Moderate Impact Distance	Onset of Severe Impact Distance
60 dBA	125 ft	60 ft

Inventory of Noise Impact

Since there are residential land uses approximately 100 ft away from the proposed alignment and the onset of moderate impact is at 125 ft, there are possible moderate impacts to the residences.

Noise Mitigation

A barrier is proposed for mitigation between the BRT system and the residences. The analysis is repeated and results in a predicted new project level of 55 dBA and the following impact distances:

Mitigated Project Level L_{dn}	Onset of Moderate Impact Distance	Onset of Severe Impact Distance
55 dBA	60 ft	N/A

With a noise barrier in place between the BRT system and the residences, it is predicted that the onset of moderate impact would occur approximately 60 ft away from the BRT system. Since the residential area begins approximately 100 ft away from the BRT system, which is beyond the distance of moderate impact (60 ft), a noise barrier would provide the appropriate noise mitigation for the predicted moderate impact. The onset of severe impact is listed as N/A because with a noise barrier, the severe impact criterion is not exceeded by the project.

Example 4-4 General Noise Assessment – Transit Center

General Noise Assessment for a Transit Center

The following example illustrates the procedure for performing a General Noise Assessment for a stationary source. The example represents a typical FTA-assisted project in an urban area, the siting of a busy transit center in a mixed commercial and residential area, as shown in Figure 4-8.

Assume that the Noise Screening Procedure has already been done for this project and the nearest residence has been identified approximately 140 ft from the center of the proposed transit center. Recall that if any residential or other noise-sensitive land use is identified within 150 ft of a transit center during the Noise Screening Procedure, additional analysis is required.

Assumptions

- **Main Street Traffic**
  Peak hour traffic of 1200 autos, 20 heavy trucks, 300 medium trucks.

- **Population Density**
  12 houses per block, single family homes, 3 people per family.
  - Block area 78,750 square ft.
  - Population density = 9,750 people/square mile.

- **Bus Traffic**

Period	Hours	Buses per Hour
Peak, Morning	7 a.m.–9 a.m.	30
Peak, Afternoon	4 p.m.–6 p.m.	30
Mid-day	9 a.m.–4 p.m.	15
Evening	6 p.m.–10 p.m.	12
Early Morning (Night)	6 a.m.–7 a.m.	15
Late Night	10 p.m.–1 a.m.	4

Estimate Project Noise Exposure at 50 ft

Determine the hourly volume of buses during day and night.

Daytime (7 a.m. – 10 p.m.)

$$V_d = \frac{273\ buses}{15\ hours} = 18.2\ buses/hour$$

Nighttime (10 p.m. – 7 a.m.)

$$V_n = \frac{27\ buses}{9\ hours} = 3\ buses/hour$$

Calculate the daytime and nighttime $L_{eq(1hr)}$ at 50 ft for the bus transit center using the reference levels in Table 4-13 and the equations in Table 4-14.

$$\begin{aligned} L_{d.BTCenter} &= SEL_{ref} + C_N - 35.6 \\ &= 101 + 10\log\left(\frac{18.2}{20}\right) - 35.6 \\ &= 65\ dBA \text{ at 50 ft} \end{aligned}$$

$$L_{n.BTCenter} = SEL_{ref} + C_N - 35.6$$

$$= 101 + 10\log(\frac{3}{20}) - 35.6$$
$$= 57\ dBA \text{ at 50 ft}$$

Calculate L_{dn} at 50 ft for the project using Eq. 4-17.

$$L_{dn.BTCenter} = 10\log(15 \times 10^{(L_{d.BTCenter}/10)} + 9 \times 10^{((L_{n.BTCenter}+10)/10)}) - 13.8$$
$$= 66\ dBA \text{ at 50 ft}$$

Estimate Existing Noise Exposure

Estimate existing noise at noise-sensitive sites from the dominant noise source, and either major roadways or local streets (population density).

Roadway Noise Estimate – The traffic on Main Street qualifies this street for the Other Roadway category in Table 4-17. According to the map, the nearest residence is 275 ft from the edge of Main Street. The table shows existing L_{dn} = 55 dBA at this distance for representative busy city street traffic.
Population Density Noise Estimate – Noise from local streets is estimated from the population density of 9,750 people/square mile. Table 4-17 confirms that the L_{dn} is approximately 55 dBA.

In this example, the existing noise level by both the roadway and population density estimates are the same, but that is not always the case. If the levels are different, use the lower noise level. The existing noise level associated with the residential neighborhood in this example is L_{dn} = 55 dBA.

Determine Noise Level and Distance for the Onset of Impact

Determine the noise level for the onset of moderate and severe impact using Figure 4-2 and the existing noise level of 55 dBA. Note that this project is land use category 2 and the appropriate metric is L_{dn}.

Existing Noise L_{dn}	**Onset of Moderate Impact** L_{dn}	**Onset of Severe Impact** L_{dn}
55 dBA	56 dBA	62 dBA

Determine the distances from the center of the property to the noise impact contours using the stationary curve in Figure 4-6. The project noise level at 50 ft is 66 dBA.

<u>Moderate impact (56 dBA)</u>

$$56 - 66 = -10\ dB$$

According to Figure 4-6, the distance correction is approximately -10 dB at 125 ft.

<u>Severe impact (62 dBA)</u>

$$62 - 66 = -4\ dB$$

According to Figure 4-6, the distance correction is -4 dB at approximately 70 ft.

Project Noise L_{dn}	**Onset of Moderate Impact** Distance	**Onset of Severe Impact** Distance
66 dBA	125 ft	70 ft

Draw Noise Impact Contours

Draw lines at 70 ft and 125 ft from the center of the property of the proposed transit center. These lines represent the noise impact contours. (Note that in Figure 4-8 the severe impact contour is not drawn for clarity. The contour is just within the dashed line representing the moderate impact contour after mitigation).

Inventory of Noise Impact

Within, or touching, the contour defining moderate impact are three residential buildings (shaded in Figure 4-8). No residences are within the severe impact contour.

Noise Mitigation

The process is repeated with a hypothetical noise barrier at the property line on the residential side of the transit center. This would consist of a wall approximately 15 ft high partially enclosing the transit center, sufficient to screen the residences but not the commercial block facing Main Street. According to Table 4-14, the approximate noise barrier effect is -5 dB. Repeating the procedure above, the noise barrier will reduce the moderate impact contour to 80 ft and the severe impact contour to 45 ft (note that at 50 ft the distance correction is 0), which in this example eliminates all potential impacts on the residences.

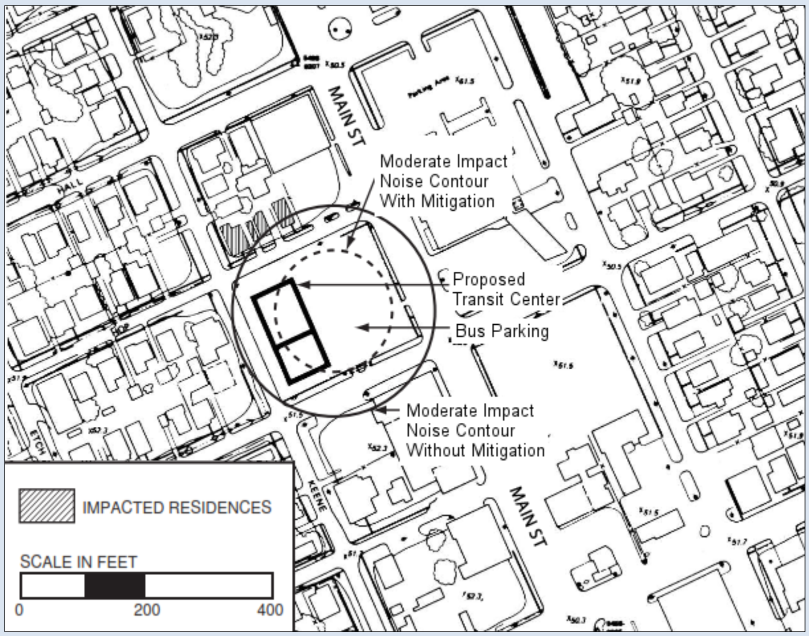


Figure 4-8 Example of Project for General Noise Assessment: Siting of Transit Center in Mixed Commercial/Residential Area

4.5 Evaluate Impact: Detailed Noise Analysis

Evaluate for impact using the Detailed Noise Analysis procedure in this section, if appropriate. For guidelines on when the Detailed Noise Analysis is appropriate, review Section 4.2.

The steps in the Detailed Noise Analysis (Figure 4-9) parallel the steps in the General Noise Assessment, though the Detailed Noise Analysis employs equations for computations rather than graphs or tables. Each step in the Detailed Noise Analysis is more refined in the prediction of project noise and subsequent evaluation of mitigation measures. Noise projections from the project must be determined for each receiver.

- **Step 1: Identify Noise-Sensitive Receivers**
  Identify the noise-sensitive receivers of interest in the impact analysis study, including clustering noise-sensitive areas. This identification is usually based

on the Screening Procedure and General Noise Assessment previously conducted.

- **Step 2: Determine Project Noise Source Reference Levels**
  Determine the project noise sources and reference levels. Then, estimate the project noise exposure at the reference distance of 50 ft, considering operational characteristics. When appropriate, measurements may be used to determine noise source reference levels.

- **Step 3: Determine Propagation Characteristics**
  Estimate project noise exposure as a function of distance, accounting for shielding and propagation along the path.

- **Step 4: Combine Noise Exposure from All Sources**
  Combine all sources to predict the total project noise at receivers.

- **Step 5: Determine Existing Noise Exposure**
  Determine the existing noise exposure. Measurements are used to determine the existing noise exposure. When measurements are unavailable, a simplified procedure to estimate existing noise exposure may be used with a clear justification to and approval by the FTA Regional office.

- **Step 6: Assess Noise Impact**
  Assess the noise impact at each receiver of interest using separate procedures for transit only and multimodal transportation projects.

- **Step 7: Determine Noise Mitigation Measures**
  Evaluate the need for mitigation and repeat the Detailed Noise Analysis with proposed mitigation.

When situations arise that are not explicitly covered in the Detailed Noise Analysis, professional judgment, in consultation with the FTA Regional office, may be used to extend these methods to cover these unique cases, when appropriate. Appendix G provides information on developing and using non-standard modeling procedures.

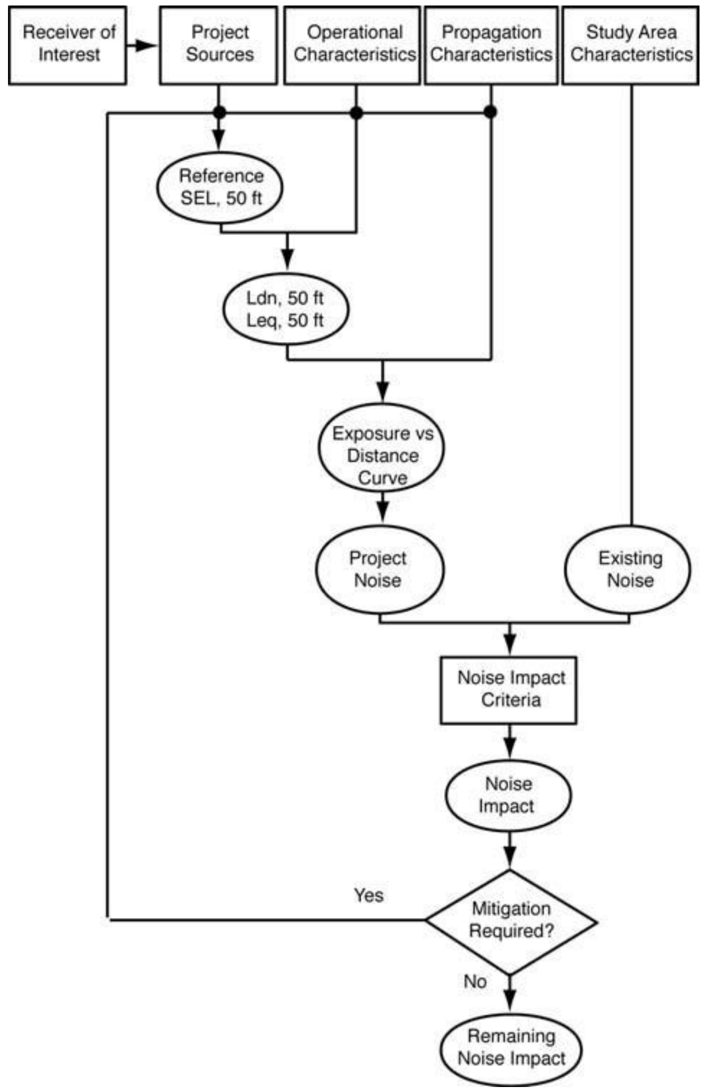


Figure 4-9 Procedure for Detailed Noise Analysis

Step 1: Identify Noise-Sensitive Receivers

Select the noise-sensitive receivers of interest, the number of which will depend upon the land use in the vicinity of the proposed project and the extent of the study area defined by the Noise Screening Procedure in Section 4.3 and the results of the General Noise Assessment in Section 4.4.

The steps in identifying the noise-sensitive receivers of interest, both the number of receivers needed and their locations, shown in Figure 4-10, include:

- **1a.** Identify all noise-sensitive land uses.
- **1b.** Select individual receivers of interest.
- **1c.** Cluster residential neighborhoods and other large noise-sensitive areas.

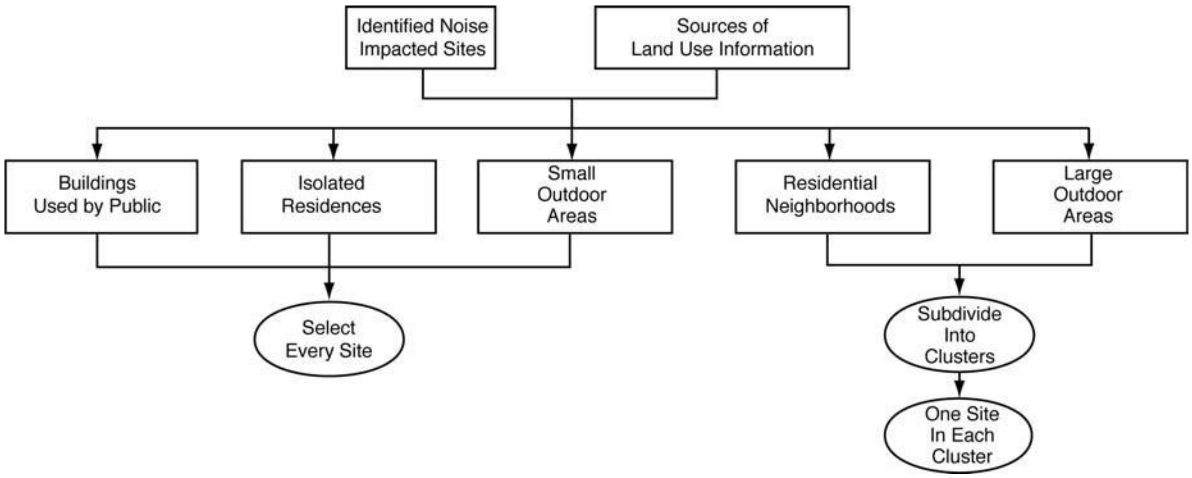


Figure 4-10 Guide to Selecting Noise-Sensitive Receivers of Interest

1a. Identify all noise-sensitive land uses where impact is identified by the General Noise Assessment in Section 4.4. If a General Noise Assessment has not been done, include all noise-sensitive sites according to the Noise Screening Procedure in Section 4.3. In areas where ambient noise is low, include land uses that are farther from the proposed project than for areas with higher ambient levels.

Recommended materials and methods that can assist in locating noise-sensitive land uses near 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. But they can provide broad guidance and may suggest residential pockets hidden within otherwise commercial zones. Of more use are project-specific maps that provide building-by-building detail on the land near the proposed project.

- **Road and town maps** can supplement other maps, are generally more up-to-date, and may be of larger scale.

- **Aerial photographs,** when current, especially those of 400-ft scale or better, 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,** in which the corridor is driven and land uses are annotated on base maps, may be used for definitive identification of noise-sensitive sites. 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. In addition, maps and aerial photos typically reveal only horizontal distances, not vertical distances. Houses on a hill overlooking the project may need a barrier of unacceptable height for its attenuation to be effective, and the greater vertical distance between source and receiver may eliminate the impact entirely. The windshield survey would reveal where vertical contour maps or other means may be needed so that vertical distances can be determined**.**

- **Geographic Information Systems (GIS)** provides electronic mapping needed for identifying noise-sensitive land uses. GIS data may include land parcels, building structures, aerial photography, and project-specific information. These data may be obtained during the project study or from local or regional agencies that store and maintain GIS data. Using electronic GIS data has advantages over paper mapping with respect to automating the process of identifying noise-sensitive land uses and accurately being able to determine their distances to the project alignment

Table 4-18 contains three types of *land uses of interest* and provides guidelines as to when receivers should be analyzed individually and when they can be clustered.

Table 4-18 Land Uses of Interest

Land Uses	Specific Use	Selecting Receivers
Residences	Isolated single family residences Neighborhoods (single and 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 (closest to the project noise source and at an intermediate distance from the predominant sources of existing noise) in each cluster (i.e., Balance the distance between the receiver and the new noise source and the receiver and the existing noise source). Multiple clusters in one location may be needed to fully characterize the area.
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.
Outdoor noise-sensitive areas	Certain parks Historic sites used for interpretation Amphitheaters Passive recreation areas Cemeteries Other outdoor noise-sensitive areas	For relatively small noise-sensitive areas, select noise-sensitive sites as separate receivers of interest. For relatively large areas (e.g. a cemetery, etc.), cluster by proximity to project noise sources, proximity to ambient-noise sources, and location along project line. Choose one receiver of interest (closest to the project noise source and at an intermediate distance from the predominant sources of existing noise) in each cluster.

1b. Select the following types of noise-sensitive receivers within the noise study area, per Table 4-18, to be evaluated as individual receivers:

- Every major noise-sensitive public building
- Every isolated residence
- Every relatively small outdoor noise-sensitive area

Use judgment to avoid analyzing noise where such analysis is obviously not needed. Areas that are considered particularly noise-sensitive by the community, but do not meet the criteria in Table 4-3, should be considered on a case-by-case basis as discussed in Section 4.1.

1c. 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. Subdivide all such neighborhoods/areas into clusters of approximately uniform noise, each containing a collection of noise-sensitive sites. Strive to obtain uniformity of both project noise and ambient noise using the following guidelines:

- In general, project noise reduces (drops off) with distance from the project. For this reason, project noise uniformity requires nearly equal distances between the project noise source and all sites within the cluster. Clusters are typically shaped as long narrow strips parallel to the transit corridor and/or circling project point sources such as maintenance facilities. It is suggested to cluster sites where the project noise varies over a range of 5 dB or less.

- Note that noise drops off approximately 3 dB per doubling of distance for line sources and approximately 6 dB per doubling of distance for point sources over open terrain. This reduction in noise will occur over a shorter distance in areas containing obstacles blocking the path of sound propagation, such as rows of buildings.

- Ambient noise usually drops off from non-project sources in the same manner as 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 manufacturing facilities. It is suggested to cluster sites where the ambient noise varies over a range of 5 dB or less. Ambient noise levels may be difficult to judge without measurements. In areas without predominant sources of noise, like highways, ambient noise can be considered to vary with population density, which is often uniform along the corridor. In situations where ambient noise tends to be uniform, the clusters can encompass relatively large areas.

After defining clusters, select one representative receiver in each cluster. It is recommended to choose the receiver closest to the project noise source and at an intermediate distance from the predominant sources of existing noise. See Appendix D for additional guidance and examples on clustering receivers, as well as an example.

Assess each identified cluster representative and individual noise-sensitive receiver of interest using the Detailed Noise Analysis as presented in the following steps.

Step 2: Determine Project Noise Source Reference Levels

Identify the major project noise sources near the noise-sensitive receivers of interest, group them by source type, and determine reference levels to compute project noise at 50 ft, as shown in Figure 4-11.

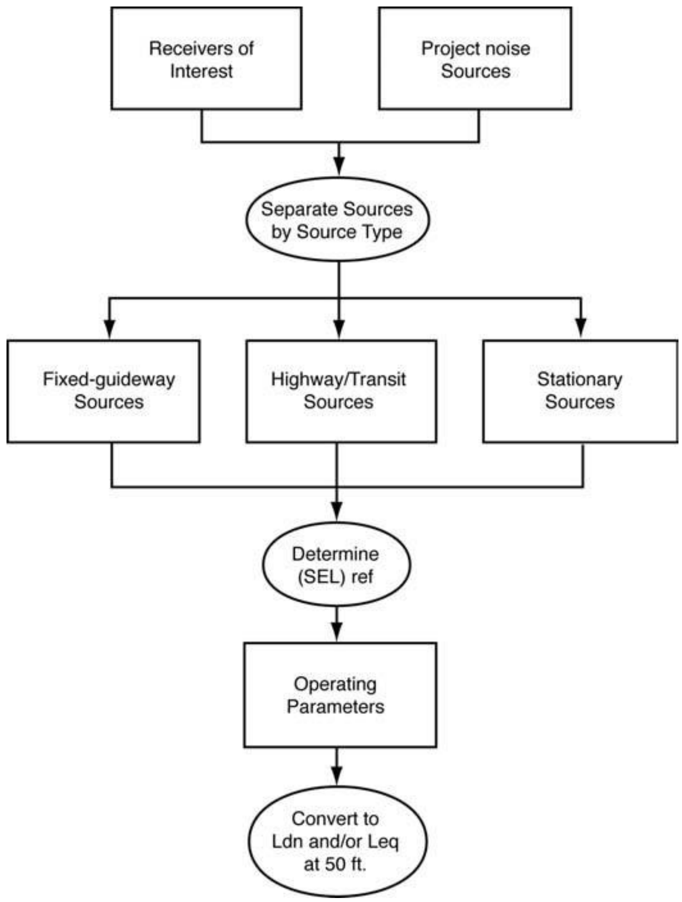


Figure 4-11 Flow Diagram for Determining Project Noise at 50 ft

2a. Identify the major project noise sources near receivers of interest according to Table 4-19. The right-hand column of the table indicates if each source is considered as a major contributor to the overall noise impact. Note that some noise sources can create high noise levels but are not indicated as major contributors. 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.

Table 4-19 Sources of Transit Noise

Project Type	Source Type	Actual Source	Major?
Commuter Rail Light Rail Streetcars RRT	Fixed-Guideway	Locomotive and rail car passbys Horns and whistles Crossing signals Crossovers/switches Squeal on tight curves Track-maintenance equipment	Yes Yes Yes Yes Yes No
	Stationary	Substations Chiller plants	Yes No
Busways Bus Transit Malls	Highway/Transit	Bus passbys Buses parking	Yes No
	Stationary	Buses idling	Yes
AGT Monorail	Fixed-Guideway	Vehicle passbys	Yes
	Miscellaneous	Line equipment	No
Terminals Stations Transit Centers	Fixed-Guideway	Locomotive and rail car passbys Crossovers/switches Squeal on tight curves	Yes Yes Yes
	Highway/Transit	Bus passbys Buses parking Automobile passbys	Yes No No
	Stationary	Locomotives idling Buses idling Ferry boats landing, idling, and departing at dock HVAC equipment Cooling towers P/A systems	Yes Yes Yes No No No
Park-and-Ride Lots	Highway/Transit	Bus passbys Buses idling Automobile passbys	Yes Yes 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 Locomotives idling Squeal on tight curves Horns, warning signals, coupling/ uncoupling, auxiliary equipment, crossovers/ switches, brake squeal, and air release	Yes Yes Yes Yes
	Highway/Transit	Bus passbys	Yes
	Stationary	Buses idling Yard/shop activities Car washes HVAC Equipment P/A Systems	Yes No No No No

2b. Separate the major noise sources by source type: fixed-guideway transit, highway/transit or stationary facility. Note that a major fixed-guideway system will usually have stationary facilities associated with it, and that a stationary facility may have highway/transit elements associated with it. Then use the instructions in the following source type options below to:

2c. Determine the source reference levels for the all project noise sources. Each source reference level pertains to reference operating conditions for stationary sources or one vehicle passby under reference operating conditions.

These reference levels should incorporate source-noise mitigation only if such mitigation will be considered for incorporation into the system specifications. 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. If special features that result in noise reductions are included in any of the predictions, the Federal environmental documents must include a commitment by the project sponsor to adopt such treatments before the project is approved for construction. For example, if the specifications include vehicle noise limits that may not be exceeded, 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.

2d. Convert the source reference level to noise exposure in terms of $L_{eq(1hr)}$ or L_{dn} under project operating conditions using the appropriate equations depending upon the type of source. The noise exposure is determined at the reference distance of 50 ft.

Option A. Fixed-guideway Sources – Compute project noise at 50 ft for fixed-guideway sources as identified in the second column of Table 4-19.

A.i. Reference SEL Levels
Determine the reference SEL at 50 ft for each major fixed-guideway noise source, either by measurement according to Appendix F or by referencing Table 4-20. The table provides guidance on which method is preferred for each source type. The "NO" designation implies that the source levels given in the table are appropriate to use in the analysis, and the "YES" designation implies that measurements are preferred over the data given in the table. In general, measurements are preferred for source types that vary considerably from project to project, including any emerging technology sources. The data in the table are adequate for source types that do not vary considerably from project to project.

For sources where measurements are preferred, refer to Appendix F for guidance on measurement procedures and methods for conversion of these measurements to the reference conditions of Table 4-20. 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 using the equations in Appendix F. This is only appropriate when there is a firm commitment to adopt the noise specifications in the vehicle procurement documents during the engineering phase and to adhere to the specifications throughout the procurement, delivery, and testing of the vehicles.

Approximate L_{max} values are provided in the table for general user information. As discussed in Appendix B.1.4.2, L_{max} is not used directly in the evaluation of noise impact.

Table 4-20 Source Reference SELs at 50 ft: Fixed-Guideway Sources at 50 mph

Source	Reference SEL, dBA	Approximate L_{max}, dBA	Prefer Measurements? *
Rail cars	82	80	No
Streetcars**	76	74	No
Locomotives – diesel	92	88	No
Locomotives – electric	90	86	No
Diesel multiple unit (DMU)	85	81	Yes
Agt – steel wheel	80	78	Yes
Agt – rubber tire	78	75	Yes
Monorail	82	80	Yes
Maglev	72	70	Yes
Transit car horns (emergency)	93	90	No
Transit car whistles	81	78	No
Locomotive horns			
At-grade crossing	113	110	No
From crossing to 1/8 mile	†	110	
From 1/8 mile to 1/4 mile	110	110	

* "No" implies that the source levels given in the table are appropriate to use in the analysis and "Yes" implies that measurements are preferred over the data given in the table.
** The reference speed for streetcars is 25 mph. For streetcar speeds above 25 mph, use the "Rail Cars" reference level and 50 mph for the reference speed.
† Use the following equation for locomotive horns from crossing to 1/8 mile:

$$SEL_{Ref} = 113 - 3 \times (\frac{D_P}{660})$$

where:
D_P= distance from grade crossing parallel to tracks

A.ii. Estimate Noise Exposure at 50 ft – Use the reference SELs in Table 4-20, operating conditions, and the equations in Table 4-21 to predict the noise exposure at 50 ft expressed in terms of $L_{eq(1hr)}$ and L_{dn}. Follow the steps below:

1. **Identify operating conditions** – Trains with different numbers of cars or operating conditions produce different noise exposure levels and should be converted from SEL to L_{dn} separately. Use the following guidelines to determine if sources should be converted separately. These differences 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).

2. **Establish relevant time periods** – For each of these source types and conditions, determine the relevant time periods for all receivers that may be affected by this source.
   - For residential receivers, the time periods of interest for computation of L_{dn} are: daytime (7 a.m. to 10 p.m.) and nighttime (10 p.m. to 7 a.m.).
   - If the source will affect non-residential receivers, the time period of interest is the loudest hour of project-related activity during hours of noise sensitivity. 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.
   - Number of rail cars in the train (if this number varies during the day, take the average for the daytime and nighttime periods separately for category 2 land uses, and use the maximum number during the period of interest for category 1 or 3 land uses).
   - Number of locomotives in the train, if any.
   - Train speed, in miles per hour (maximum expected).
   - Average throttle setting of the train's locomotive(s) for diesel-powered locomotives and DMU's only.[iv] If this input is not available, assume a throttle setting of 8 for locations where the vehicle would accelerate and 5 for all other locations.[25]
   - For residential receivers of interest:
     - Average hourly train volume during daytime hours (the total number of train passbys between 7 a.m. and 10 p.m., divided by 15 hours);
     - Average hourly train volume during nighttime hours (the total number of train passbys between 10 p.m. and 7 a.m., divided by 9 hours);
   - For non-residential receivers of interest, number of events that occur during each hour of interest in trains per hour; and
   - Track type (continuously welded or jointed) and profile (at-grade or elevated).

4. **Calculate $L_{eq(1hr)}$ at 50 ft**
   - Calculate $L_{eq(1hr)}$ using the appropriate equations in Table 4-21 for each hour of interest.
   - Compute the combined $L_{eq(1hr)}$. It may be necessary to compute the combined totals with and without the warning horns; some neighborhoods along the corridor may be exposed to the horn noise and some may not.

5. **Calculate L_{dn} at 50 ft**
   - If the project noise will affect any residential receivers, calculate the L_{dn} using the combined day $L_{eq(1hr)}$ and the combined night $L_{eq(1hr)}$.
   - It may be necessary to calculate L_{dn} with and without the warning horns, as above.

[iv] Omit this term if not applicable from the equation in Table 4-21 for other vehicle types.

Note that the equations in Table 4-21 include terms to account for a difference in speed from the reference speed of 50 mph and a numerical adjustment to account for the one-hour time period for this metric. For more information on the numerical adjustment to represent the time period of interest, see Appendix B.1.4.4.

Table 4-21 Computation of $L_{eq(1hr)}$ and L_{dn} at 50 ft: Fixed-Guideway Sources

Locomotives* $L_{eq(1hr)}$ at 50 ft	$L_{eq.Loco(1hr)} = SEL_{ref} + 10\,log(N_{Loco}) + C_T + Klog(\frac{S}{50}) + 10\,log(V) - 35.6$	**Eq. 4-25**
Locomotive Warning Horns** $L_{eq(1hr)}$ at 50 ft	$L_{eq.LHorns(1hr)} = SEL_{ref} + 10\,log(V) - 35.6$	**Eq. 4-26**
Rail Vehicles† $L_{eq(1hr)}$ at 50 ft	$L_{eq.RCars(1hr)} = SEL_{ref} + 10\,log(N_{Cars}) + 20\log(\frac{S}{50}) + 10\,log(V) - 35.6 + Adj_{track}$	**Eq. 4-27**
Streetcar (25 mph or slower) $L_{eq(1hr)}$ at 50 ft	$L_{eq.SCars(1hr)} = SEL_{ref} + 10\,log(N_{Cars}) + 2\log(\frac{S}{25}) + 10\,log(V) - 35.6 + Adj_{track}$	**Eq. 4-28**
Transit Warning Horns** $L_{eq(1hr)}$ at 50 ft	$L_{eq.THorns(1hr)} = SEL_{ref} - 10\,log(\frac{S}{50}) + 10\,log(V) - 35.6$	**Eq. 4-29**
Combined Locomotive and transit†† $L_{eq(1hr)}$ at 50 ft	$L_{eq.Combo(1hr)} = 10\log(10^{(L_{eq.Loco(1hr)}/10)} + 10^{(L_{eq.RCars(1hr)}/10)} + 10^{(L_{eq.SCars(1hr)}/10)} + 10^{(L_{eq.LHorns(1hr)}/10)} + 10^{(L_{eq.THorns(1hr)}/10)})$	**Eq. 4-30**
Daytime L_d at 50 ft	$L_d = L_{eq(1hr)}$ where V = V_d, N_{Loco} = N_d (loco events), and N_{Cars} = N_d (car events)	**Eq. 4-31**
Nighttime L_n at 50 ft	$L_n = L_{eq(1hr)}$ where V = V_n, and N_{Loco} = N_d (loco events), and N_{Cars} = N_d (car events)	**Eq. 4-32**
Day/Night L_{dn} at 50 ft	$L_{dn} = 10\log(15 \times 10^{(L_d/10)} + 9 \times 10^{((L_n+10)/10)}) - 13.8$	**Eq. 4-33**

N_{Loco} = average number of locomotives per train

C_T = $0\ for\ T < 6$
$2(T-5)\ for\ T \geq 6$
where
T = average throttle setting for diesel-powered locomotives and DMUs only

K = -10 for passenger diesel
0 for DMUs[Ŧ]
+10 for electric

N_{Cars} = average number of cars per train

V = average hourly volume of train traffic, trains per hour

S = train speed, mph

Adj_{track} = constant
+5 for jointed track or for a crossover within 300 ft
+4 for aerial structure with slab track (except AGT and monorail)
+3 for embedded track on grade

V_d = average hourly daytime volume of train traffic, trains per hour

$$= \frac{number\ of\ trains, 7\ a.m.\ to\ 10\ p.m.}{15}$$

N_d = average hourly number of events that occur during daytime (7 a.m. to 10 p.m.)

$$= \frac{number\ of\ events\ between\ 7\ a.m.\ to\ 10\ p.m.}{15}$$

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

$$= \frac{number\ of\ trains, 10\ p.m.\ to\ 7 a.m.}{9}$$

N_n = average hourly number of events that occur during nighttime (10 p.m. to 7 a.m.)

$$= \frac{number\ of\ events\ between\ 10\ p.m.\ to\ 7\ a.m.}{9}$$

* Assumes a diesel locomotive power rating at approximately 3000 hp ** Based on FRA's horn noise model (www.fra.dot.gov/Elib/Document/2681)
† Includes all commuter rail cars, transit cars, streetcars above 25 mph, AGT and monorail. †† Only include appropriate terms.
Ŧ Because of the wide range of vehicle types that qualify as a DMU, measurements are preferred for the reference level and speed coefficient. If no measurements are conducted, use the reference level in Table 4-20 and a speed coefficient of 0.

Example 4-5 Detailed Noise Analysis – Fixed Guideway Noise Sources

Computation of $L_{eq(1hr)}$ and L_{dn} at 50 ft for Fixed-Guideway Source

A commuter train with 1 diesel locomotive and 6 cars will pass close to a residential area at a grade crossing. The track is jointed.

Assumptions

SEL_{ref} = 92 for diesel locomotives
= 82 for rail cars
= 113 for locomotive warning horns at-grade crossing
N_{Cars} = 6
N_{Loco} = 1
S = 43 mph
T = 8
$V_d = 40\ trains/15\ hours = 2.667\ trains\ per\ hour$
$V_n = 2\ trains/9\ hours = 0.222\ trains\ per\ hour$

Use the equations in Table 4-21 to determine the daytime $L_{eq(1hr)}$ for each source and the combined daytime $L_{eq(1hr)}$ at 50 ft.

$$L_{d.Locs(1hr)} = SEL_{ref} + 10\,log(N_{Loco}) + C_T + Klog(\frac{S}{50}) + 10\,log(V_d) - 35.6$$
$$= 92 + 10\,log(1) + 6 + (-10)log(\frac{43}{50}) + 10\,log(2.667) - 35.6$$
$$= 67.3\ dBA \text{ at 50 ft}$$

$$L_{d.RCars(1hr)} = SEL_{ref} + 10\,log(N_{Cars}) + 20log\left(\frac{S}{50}\right) + 10\,log(V_d) - 35.6 + Adj_{track}$$
$$= 82 + 10\,log(6) + 20log\left(\frac{43}{50}\right) + 10\,log(2.667) - 35.6 + 5$$
$$= 62.1\ dBA \text{ at 50 ft}$$

$$L_{d.LHorn(1hr)} = SEL_{ref} + 10\,log(V_d) - 35.6$$
$$= 113 + 10\,log(2.667) - 35.6$$
$$= 81.7\ dBA \text{ at 50 ft}$$

$L_{d.Combo(1hr)}$ With horn:
$$= 10log\left[10^{\left(L_{d.Locos(1hr)}/10\right)} + 10^{\left(L_{d.RCars(1hr)}/10\right)} + 10^{\left(L_{d.LHorn(1hr)}/10\right)}\right]$$
$= 81.9\ dBA$ in neighborhoods where the horn is sounded

Without horn:
$$= 10log\left[10^{\left(L_{d.Locos(1hr)}/10\right)} + 10^{\left(L_{d.RCars(1hr)}/10\right)}\right]$$
$= 68.4\ dBA$ in neighborhoods where the horn is not sounded

Use the same equations as above to determine the nighttime $L_{eq(1hr)}$ at 50 ft. Use V_n instead of V_d.

$L_{n.Locos(1hr)}$ = 56.5 for locomotives
$L_{n.RCars(1hr)}$ = 51.3 for cars
$L_{n.LHorn(1hr)}$ = 70.9 for horns
$L_{n.Combo(1hr)}$ = 71.1 in neighborhoods where the horn is sounded
= 57.6 in neighborhoods where the horn is not sounded

Calculate the L_{dn} with and without horns.

$$L_{dn.Combo} = 10log\left[15 \times 10^{\left(L_{d.Combo}/10\right)} + 9 \times 10^{\left((L_{n.Combo}+10)/10\right)}\right] - 13.8$$

With horn: = 81.6 at 50 ft in neighborhoods where horns are sounded
Without horn: = 68.1 at 50 ft in neighborhoods where horns are not sounded

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

Option B. Highway/Transit Sources – Compute project noise at 50 ft for highway/transit noise sources as identified in the second column of Table 4-19. Use the instructions below to estimate source noise levels for projects following FTA's procedures that involve highway vehicles.

This method is based on the original FHWA highway noise prediction model, with updated noise emission levels.(26) The vehicle equations are applicable to speeds typical of freely-flowing traffic on city streets and access roads.

B.i. Reference SEL Levels – Determine the reference SEL at 50 ft for each major highway/transit source, either by measurement according to Appendix F or by using Table 4-22.[v] The table provides guidance on which method is preferred for each source type. "NO" implies that the source levels given in the table are appropriate to use in the analysis, and "YES" implies that measurements are preferred over the data given in the table. For sources where measurements are preferred, refer to Appendix F for guidance on measurement procedures and methods for conversion of measurement data to the reference conditions in Table 4-20.

Approximate L_{max} values are provided in the table for general user information. As discussed in Appendix B.1.4.2, L_{max} is not used directly in the evaluation of noise impact.

Table 4-22 Source Reference SELs at 50 ft: Highway/Transit Sources at 50 mph

Source	Reference SEL, dBA	Approximate L_{max}, dBA	Prefer Measurements?*
Automobiles	74	70	No
Buses (diesel)	82	79	No
Buses (electric trolleybus)	80	77	No
Buses (hybrid)**	83	80	Yes

* "No" implies that the source levels given in the table are appropriate to use in the analysis and "Yes" implies that measurements are preferred over the data given in the table.
** Hybrid bus with full-time diesel engine and electric drive motors.

[v] Idling buses are considered stationary sources.

B.ii. Noise Exposure at 50 ft – Use the reference SELs in Table 4-22, operating conditions, and the equations in Table 4-23 to predict the noise exposure at 50 ft expressed in terms of $L_{eq(1hr)}$ and L_{dn}. Follow the steps below:

1. **Identify operating conditions** – Noise emission from most transit buses is not dependent upon whether the buses are accelerating or cruising. However, accelerating suburban buses are substantially louder than cruising suburban buses. For this reason, suburban buses require separate calculation along roadway stretches where they are accelerating. Separate calculation is also needed for all highway/transit vehicles at different speeds, since speed affects noise emissions. Use the following guidelines to determine if sources should be calculated separately. These differences 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}); or
   - 15 percent change in vehicle speed.

2. **Establish relevant time periods** – For each of these source types and conditions, determine the relevant time periods for all receivers that may be affected by this source.
   - For residential receivers, the time periods of interest for computation of L_{dn} are: daytime (7 a.m. to 10 p.m.) and nighttime (10 p.m. to 7 a.m.).
   - If the source will affect non-residential receivers, the time period of interest is the loudest hour of project related activity during hours of noise sensitivity. 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 the vehicle types of concern
   - Average running speed in miles per hour
   - For residential receivers of interest:
     - Average hourly vehicle volume during daytime hours (total number of vehicle passbys between 7 a.m. and 10 p.m., divided by 15).
     - Average hourly vehicle volume during nighttime hours (total number of vehicle passbys between 10 p.m. and 7 a.m., divided by 9).
   - For non-residential receivers of interest, number of events that occur during each hour of interest, in vehicles per hour

4. **Calculate $L_{eq(1hr)}$ at 50 ft – Calculate $L_{eq(1hr)}$ using the appropriate** equations in Table 4-23 for each hour of interest.

5. **Calculate L_{dn} at 50 ft –** If the project noise will affect any residential receivers, calculate the L_{dn} using the day $L_{eq(1hr)}$ and night $L_{eq(1hr)}$.

Note that the equations in Table 4-23 include terms to account for a difference in speed from the reference speed of 50 mph and a numerical adjustment to account for the one-hour time period for this metric. For more information on the numerical adjustment to represent the time period of interest, see Appendix B.1.4.4.

Table 4-23 Computation of $L_{eq(1hr)}$ and L_{dn} at 50 ft: Highway/Transit Sources

$L_{eq(1hr)}$ at 50 ft	$L_{eq(1hr)} = SEL_{ref} + 10\,log(V) + C_{emissions} - 10\log(\frac{S}{50}) - 35.6$	**Eq. 4-34**
Daytime L_d at 50 ft	$L_d = L_{eq(1hr)}$ where V = V_d	**Eq. 4-35**
Nighttime L_n at 50 ft	$L_n = L_{eq(1hr)}$ where V = V_n	**Eq. 4-36**
L_{dn} at 50 ft	$L_{dn} = 10log(15 \times 10^{(L_d/10)} + 9 \times 10^{((L_n+10)/10)}) - 13.8$	**Eq. 4-37**
Adjustments	= -3 for automobiles, open-graded asphalt = +3 for automobiles, grooved pavement	
V	= average hourly volume of vehicles, vehicles per hour	
$C_{emissions}$	= $25\log(\frac{S}{50})$ for buses $31\log(\frac{S}{50})$ for hybrid buses (23) 1.6 for accelerating 3-axle commuter buses $40\log(\frac{S}{50})$ for automobiles	
S	= average vehicle speed, mph (distance divided by time, excluding stop time at red lights)	
V_d	= average hourly daytime volume of vehicles of this type, vehicles per hour $= \frac{total\ vehicle\ volume,\ 7\ a.m.\ to\ 10\ p.m.}{15}$	
V_n	= average hourly nighttime volume of vehicles, vehicles per hour $= \frac{total\ vehicle\ volume,\ 10\ p.m.\ to\ 7\ a.m.}{9}$	

Example 4-6 Detailed Noise Analysis – Highway Transit Noise Sources

Computation of $L_{eq(1hr)}$ and L_{dn} at 50 ft for Highway/Transit Source

A bus route with city buses will pass close to a school that is in session from 8 a.m. to 4 p.m. on weekdays. Within this time period, the hour of greatest activity for this bus route is 8 a.m. to 9 a.m.

Assumptions

SEL_{ref} = 82 dBA

S = 40 mph

V = 30 buses per hour

Use the equations in Table 4-23 to determine the hourly $L_{eq(1hr)}$ at 50 ft.

$$L_{d.Bus} = SEL_{ref} + 10\,log(V) + C_{emissions} - 10\log(\frac{S}{50}) - 35.6$$

$$= 82 + 10\,log(30) + 6 + 25 \times log(\frac{40}{50}) - 10\log(\frac{40}{50}) - 35.6$$

$= 59.7\ dBA$ at 50 ft

This same bus also passes close to a residential area with the following operating conditions:

$$V_d = 200\ buses/15\ hours = 13.33\ buses\ per\ hour$$
$$V_n = 20\ buses/9\ hours = 2.22\ buses\ per\ hour$$

Calculate the daytime and nighttime $L_{eq(1hr)}$ at 50 ft.

$$L_{d.Bus} = 82 + 10\,log(13.33) + 6 + 25 \times log(\frac{40}{50}) - 10\log(\frac{40}{50}) - 35.6$$
$$= 56.2\ dBA \text{ at 50 ft}$$

$$L_{n.Bus} = 82 + 10\,log(2.22) + 6 + 25 \times log(\frac{40}{50}) - 10\log(\frac{40}{50}) - 35.6$$
$$= 48.4\ dBA \text{ at 50 ft}$$

Calculate L_{dn} at 50 ft.

$$L_{dn.Bus} = 10log(15 \times 10^{\left(L_{d.Bus}/_{10}\right)} + 9 \times 10^{\left((L_{n.Bus}+10)/_{10}\right)}) - 13.8$$
$$= 57.2\ dBA \text{ at 50 ft}$$

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

Option C. Stationary Sources – Compute project noise at 50 ft for stationary sources as identified in the second column of Table 4-19.

C.i. Determine Reference SEL Levels – Determine the reference SEL at 50 ft for each major stationary source, either by measurement according to Appendix F or by using Table 4-24. The table provides guidance on which method is preferred for each source type. "NO" implies that the source levels given in the table are appropriate to use in the analysis, and "YES" implies that measurements are preferred over the data given in the table. In general, measurements are preferred for source types that vary considerably from project to project. For example, curve squeal is highly variable depending on weather conditions, curve radius, and train speed. The data in the table are adequate for source types that do not vary considerably from project to project (crossing signals, for example). For sources where measurements are preferred, refer to Appendix F for guidance on measurement procedures and methods for conversion of these measurements to the reference conditions of Table 4-24.

Layover facilities and transit centers can be the sources of low-frequency noise from idling diesel engines. Sounds with considerable low-frequency components can cause greater annoyance than would be expected based on their A-weighted levels. Low-frequency sounds often cause windows and walls to vibrate resulting in secondary effects in buildings such as rattling of dishes in cupboards and wall-mounted pictures. The reference levels in Table 4-24 are adjusted to take increased annoyance into account. For a Detailed Noise Analysis at locations where such idling takes place for an extended period, use the method described in ANSI Standard S12.9-Part 4, Annex D.[27]

Approximate L_{max} values are provided in the table for general user information. As discussed in Appendix B.1.4.2, L_{max} is not used directly in the evaluation of noise impact.

Table 4-24 Source Reference SELs at 50 ft: Stationary Sources

Source	Reference SEL, dBA	Approximate L_{max}, dBA	Prefer Measurements?*
Auxiliary Equipment	101	65	Yes
Locomotive Idling	109	73	No
Rail Transit Idling	106	70	No
Buses Idling	111	75	No
Ferry Boat Landing**, Idling, and Departing	91	78	No
Ferry Boat Fog Horn	90	84	No
Track Curve Squeal	136	100	Yes
Car Washes	111	75	Yes
Crossing Signals	109	73	No
Substations	99	63	No

* "No" implies that the source levels given in the table are appropriate to use in the analysis, and "YES" implies that measurements are preferred over the data given in the table.

**Ferry boat landings are included in the stationary source category because the noise from the landing remains in one area even though the boats move in and out.

C.ii. Estimate Noise Exposure at 50 ft – Use the reference SELs in Table 4-24, operating conditions, and the equations in Table 4-25 to predict the noise exposure at 50 ft expressed in terms of $L_{eq(1hr)}$ and L_{dn}. Follow the steps below:

1. **Identify operating conditions** – Identify actual source durations and numbers of events. Sources with different operating conditions should be converted from SEL to L_{dn} separately. Use the following guidelines to determine if sources should be converted separately. These differences in operating conditions will produce an approximate 2-dB change in noise exposure:
   - 40 percent change in event duration (e.g., from 30 to 42 minutes), or
   - 40 percent change in number of events per hour (e.g., from 10 to 14 events per hour).

2. **Establish relevant time periods** – For each of these source types and conditions, determine the relevant time periods for all receivers that may be affected by this source.
   - For residential receivers, the time periods of interest for computation of L_{dn} are: daytime (7 a.m. to 10 p.m.) and nighttime (10 p.m. to 7 a.m.).
   - If the source will affect non-residential receivers, the time period of interest is the loudest hour of project related activity during hours of noise sensitivity. 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 each relevant source
   - Average duration of one event, in seconds
   - For residential receivers of interest:
     - Average number of events per hour that occur during the daytime (the total number of events between 7 a.m. and 10 p.m., divided by 15).

  - Average number of events per hour that occur during the nighttime (the total number of events between 10 p.m. and 7 a.m., divided by 9).
- For non-residential receivers of interest, number of events that occur during each hour of interest in events per hour

4. **Calculate $L_{eq(1hr)}$ at 50 ft** – Calculate $L_{eq(1hr)}$ using the appropriate equations in Table 4-25 for each hour of interest.

5. **Calculate L_{dn} at 50 ft** – If the project noise will affect any residential receivers, calculate the L_{dn} using the day $L_{eq(1hr)}$ and night $L_{eq(1hr)}$.

Note that the equations in Table 4-25 include a numerical adjustment to account for the one-hour time period for this metric. For more information on the numerical adjustment to represent the time period of interest, see Appendix B.1.4.4.

Table 4-25 Computation of $L_{eq(1hr)}$ and L_{dn} at 50 ft: Stationary Sources

$L_{eq(1hr)}$ at 50 ft	$L_{eq(1hr)} = SEL_{ref} + 10\,log(N) + 10\log(\frac{E}{3600}) - 35.6$	**Eq. 4-38**
Daytime L_d at 50 ft	$L_d = L_{eq(1hr)}$ where N = N_d	**Eq. 4-39**
Nighttime L_n at 50 ft	$L_n = L_{eq(1hr)}$ where N = N_n	**Eq. 4-40**
L_{dn} at 50 ft	$L_{dn} = 10\log(15 \times 10^{\left(L_d/10\right)} + 9 \times 10^{\left((L_n+10)/10\right)}) - 13.8$	**Eq. 4-41**

N = number of events of this type that occur during one-hour

E* = duration of one event, sec

N_d = average hourly number of events that occur during daytime (7 a.m. to 10 p.m.)

$$= \frac{number\ of\ events\ between\ 7\ a.m.\ to\ 10\ p.m.}{15}$$

N_n = average hourly number of events that occur during nighttime (10 p.m. to 7 a.m.)

$$= \frac{number\ of\ events\ between\ 10\ p.m.\ to\ 7\ a.m.}{9}$$

*Omit the term containing E for ferry boat, and fog horn noise sources.

Example 4-7 Detailed Noise Analysis – Stationary Noise Sources

Computation of $L_{eq(1hr)}$ and L_{dn} at 50 ft for Stationary Sources

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

Assumptions

SEL_{ref} = 109 dBA
E = 25 seconds (counting both cycles of the signal)
N = 22

Use the equations in Table 4-25 to determine the hourly $L_{eq(1hr)}$ at 50 ft.

$$L_{d.Cross} = SEL_{ref} + 10log(N) + 10log\left(\frac{E}{3600}\right) - 35.6$$
$$= 109 + 10log(22) + 10log(\frac{25}{3600}) - 35.6$$
$$= 65.2\ dBA \text{ at 50 ft}$$

This same signal crossing lies close to a residential area with the following operating conditions:

N_d = $200\ /15\ hours = 13.3\ events\ per\ hour$
N_n =$12\ /9\ hours = 1.33\ events\ per\ hour$

Calculate the daytime and nighttime $L_{eq(1hr)}$ at 50 ft.

$$L_{d.Cross} = 109 + 10log(13.3) + 10log(\frac{25}{3600}) - 35.6$$
$$= 63.1\ dBA \text{ at 50 ft}$$
$$L_{n.Cross} = 109 + 10log(1.33) + 10log(\frac{25}{3600}) - 35.6$$
$$= 53.1\ dBA \text{ at 50 ft}$$

Calculate L_{dn} at 50 ft.

$$L_{dn} = 10log(15 \times 10^{\left(L_{d.Cross}/_{10}\right)} + 9 \times 10^{\left((L_{n.Cross}+10)/_{10}\right)}) - 13.8$$
$$= 63.1\ dBA \text{ at 50 ft}$$

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

Step 3: Determine Propagation Characteristics

Determine the combined propagation characteristics between each source and receiver of interest.

3a. Calculate project noise exposure as a function of distance. *Calculate the project noise exposure at distances other than 50 ft, such as at receiver locations, as a function of distance accounting for shielding and ground effects along the path*. See Example 4-8 below.

1. Determine the topography of the ground within the transit corridor using the figures in Table 4-26 as a guide. It is not necessary to represent the transit corridor with an extreme number of changes in topography. Often, several typical sections will suffice throughout the transit corridor.

2. Use the equations in Table 4-26 to determine ground factor (G) based on the effective path height (Heff) for each identified terrain feature. Standard source heights are included at the bottom of the table. Assume receiver heights of 5 ft for both outdoor receivers and first-floor receivers. Note that larger ground factors correspond to larger amounts of ground attenuation with increasing distance from the source. For acoustically "hard" (e.g., non-absorptive) ground conditions, G should be taken to be zero.

3. Determine the distance correction factor using the ground factor and another distance, such as the distance to a receiver, and the equations in Table 4-27.

4. Apply the distance correction ($C_{distance}$) to the project noise exposure at 50 ft (Section 4.5, Step 2) using the following equation:

$$L_{distance} = L_{50ft} + C_{distance} \quad \textbf{Eq. 4-42}$$

where:

$L_{distance}$ = L_{dn} or $L_{Aeq(1hr)}$ at the new distance, ft

L_{50ft} = L_{dn} or $L_{Aeq(1hr)}$ at 50 ft

5. Plot noise exposure as a function of distance if desired.

Table 4-26 Ground Factor G, for Ground Attenuation

Ground Factor

Soft Ground:

$$G = \begin{cases} 0.66, & H_{eff} \leq 5 \\ 0.75(1 - \frac{H_{eff}}{42}), & 5 < H_{eff} < 42 \\ 0, & H_{eff} \geq 42 \end{cases}$$ **Eq. 4-43**

H_{eff} = sum of average path heights on either side of the barrier, see below.

Hard Ground: $G = 0$

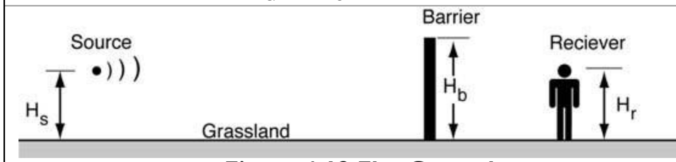


Figure 4-12 Flat Ground

$$H_{eff} = \frac{H_s + 2H_b + H_r}{2}$$ **Eq. 4-44**

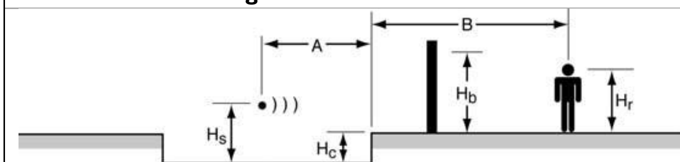


Figure 4-13 Source in Shallow Cut

$$H_{eff} = \frac{H_s + 2H_b + H_c + H_r}{2} \quad for\ B \leq \frac{A}{2}$$

Use **Eq. 4-44** $\quad for\ B > \frac{A}{2}$

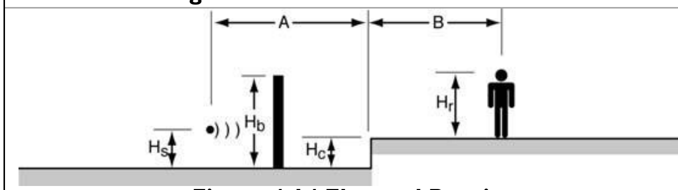


Figure 4-14 Elevated Receiver

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

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

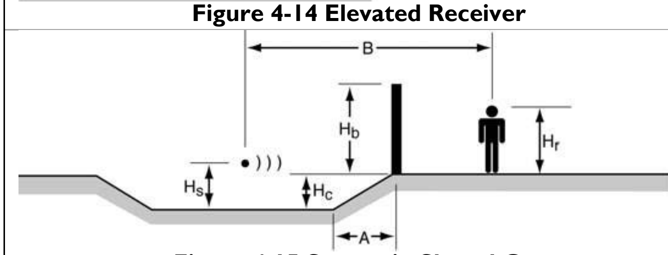


Figure 4-15 Source in Sloped Cut

Use **Eq. 4-44** $\quad for\ A \leq \frac{B}{2}$

$$H_{eff} = \frac{H_s + 2H_b + H_c + H_r}{2} \quad for\ A > \frac{B}{2}$$

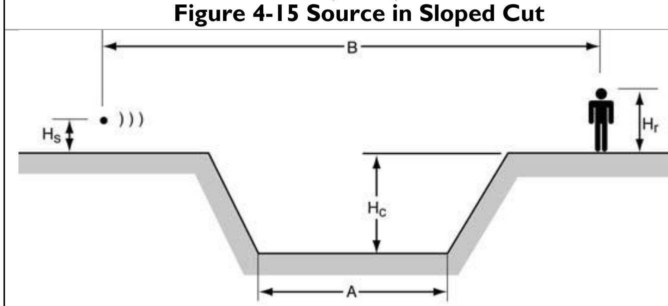


Figure 4-16 Source and Receiver Separated by Trench

$$H_{eff} = \frac{H_s + H_r}{2} \quad for\ A \leq \frac{B}{2}$$

$$H_{eff} = \frac{H_s + 2H_c + H_r}{2} \quad for\ A > \frac{B}{2}$$

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

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

Table 4-27 Distance Correction Factor Equations for Detailed Noise Analysis

Source	Equation*	
Stationary Sources	$C_{distance} = -20\log(\frac{D}{50}) - 10G\log(\frac{D}{50})$	**Eq. 4-45**
Fixed-guideway rail car passbys	$C_{distance} = -10\log(\frac{D}{50}) - 10G\log(\frac{D}{42})$	**Eq. 4-46**
Fixed-guideway locomotive and rubber-tired vehicle passbys, highway vehicle passbys and horns	$C_{distance} = -10\log(\frac{D}{50}) - 10G\log(\frac{D}{29})$	**Eq. 4-47**
$D =$ distance, ft $G =$ ground factor, see Table 4-26		

*These equations assume the distance between the source and receiver is approximately 300 ft or less. At longer distances, ground effects have an upper limit and atmospheric conditions may affect propagation characteristics. Therefore, more detailed calculation methods may be required to account for those effects.

Example 4-8: Detailed Noise Analysis – Exposure vs. Distance Curve

Exposure vs. Distance Curve for Fixed-Guideway Source

Plot an exposure vs. distance curve for a diesel-electric commuter train that does not sound the horn in this area.

Assumptions

The terrain is flat grassland without a noise barrier.

$L_{eq.Loco}\ (8-9am)$ = 72 dBA at 50 ft

$L_{dn.Loco}$ = 68 dBA at 50 ft

H_r = 5 ft

H_b = 0 ft (for a "no noise barrier" case)

H_s = 8 ft (for a diesel-electric commuter train)

Calculate H_{eff} using the equations in Table 4-26.

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

$$= \frac{8+0+5}{2}$$

= 6.5 ft

Determine the ground factor using Eq. 4-43.

$$G = 0.75(1 - \frac{H_{eff}}{42})$$

$$= 0.63$$

Use Eq. 4-45 to determine noise vs. exposure equations for $L_{d.loco}$ and $L_{dn.loco}$.

$$L_{eq.Loco} = 72 - 10\log(\frac{D}{50}) - 6.3\log(\frac{D}{42})$$

$$L_{dn.Loco} = 68 - 10\log(\frac{D}{50}) - 6.3\log(\frac{D}{42})$$

Plot the two equations (see example in Figure 4-17). From these curves, the noise levels due to this train operation can be determined for a receiver of interest at any distance without shielding.

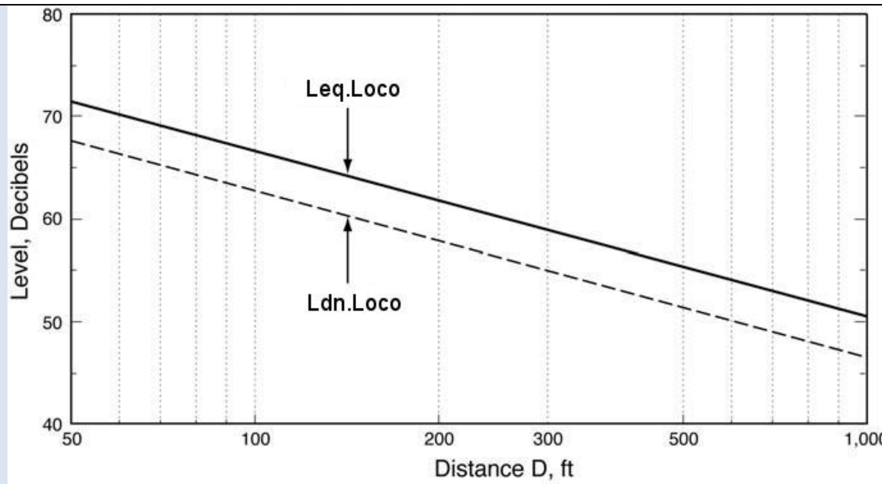


Figure 4-17 Example Exposure vs. Distance Curves

3b. Calculate the attenuation due to shielding for each distance of interest from Step 3a, using the following equation and Tables 4-26 through 4-30 and as illustrated in Example 4-9. If the conditions described in the tables are not met, the attenuation due to shielding is considered zero. Shielding can be due to intervening noise barriers, terrain features, rows of buildings, and dense tree zones.

$$A_{shielding} = \max\{IL_{barrier} \text{ or } A_{buildings} \text{ or } A_{trees}\}$$ **Eq. 4-48**

where:

$IL_{barrier}$ = barrier insertion loss, see Table 4-28

$A_{buildings}$ = attenuation due to buildings, see Table 4-29

A_{trees} = attenuation due to trees, see Table 4-30

Table 4-28 Barrier Insertion Loss

Barrier Insertion Loss	$IL_{barrier} = \max\{0 \text{ or } (A_{barrier} - 10(G_{NB} - G_B)\log(\frac{D}{50}))\}$	**Eq. 4-49**
$A_{barrier}$	$= \min\{12 \text{ or } [5.3\log(P) + 6.7]\}$	For non-absorptive transit barriers within 5 ft of the rail
	$= \min\{15 \text{ or } (5.3\log(P) + 9.7)\}$	For absorptive transit barriers within 5 ft of the rail
	$= \min\{15 \text{or} (20\log(\frac{2.51\sqrt{P}}{\tanh(4.46\sqrt{P})}) + 5)\}$	For all other barriers, and for protrusion of terrain above the line of sight
P	= path length difference, ft (see figure 4-18)*	
D	= closest distance between the receiver and the source, ft	
G_{NB}	= ground factor G computed without barrier (see Table 4-26)	
G_B	= ground factor G computed with barrier (see Table 4-26)	

* If the source height (exhaust outlet) for diesel-electric locomotives is not available, assume 15 ft.

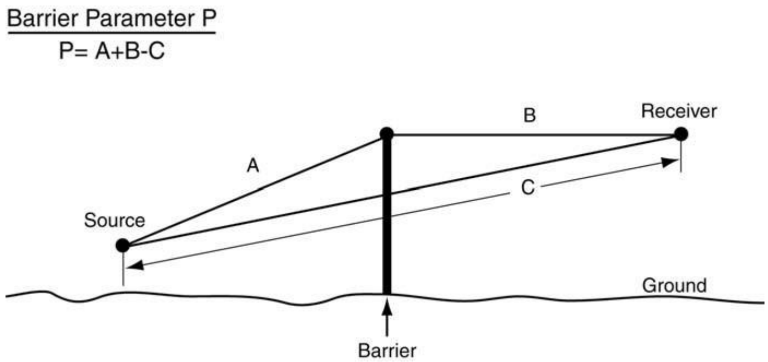


Figure 4-18 Noise Barrier Parameter "P"

Table 4-29 Attenuation due to Buildings

Condition	Equation	
Gaps in the row of buildings constitute less than 35% of the length of the row	$A_{buildings} = \min\{10\ or\ [1.5\ (R-1)+5]\}$	**Eq. 4-50**
Gaps in the row of buildings constitute 35 to 65% of the length of the row	$A_{buildings} = \min\{10\ or\ [1.5\ (R-1)+3]\}$	**Eq. 4-51**
Gaps in the row of buildings constitute more than 65% of the length of the row	$A_{buildings} = 0$	
R = number of rows of houses that intervene between the source and receiver		

Table 4-30 Attenuation due to Trees

Condition	Equation	
At least 100 ft of trees intervene between the source and receiver with no clear line-of-sight between source and receiver, and the trees extend 15 ft or more above the line-of-sight	$A_{trees} = \min\left\{10\ or\ \frac{W}{20}\right\}\ where\ W \geq 100ft$ $= 0\ where\ W < 100ft$	**Eq. 4-52**
W = width of tree zone along the line-of-site between the source and receiver in feet		

Example 4-9: Detailed Noise Analysis – Shielding

Computation of Shielding

The following features are between the rail corridor and a receiver of interest. Calculate the attenuation due to shielding.

1. A 15-foot high noise barrier is 40 ft from the closest track and 130 ft from the receiver
2. A dense tree zone 100 ft thick that extends 15 ft above the line-of-sight

Assumptions

H_s = 8 ft
H_r = 5 ft

Barrier dimensions

A = 40.61 ft
B = 130.38 ft
C = 170.03 ft

Barrier

Calculate H_{eff} with and without the barrier using the equations in Table 4-26.

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

$$= \frac{8+0+5}{2}$$
= 6.5 ft

$$H_{eff.Barrier} = \frac{H_s + 2H_b + H_r}{2}$$
$$= \frac{8+15+5}{2}$$
= 21.5 ft

Determine the ground factor with and without the barrier using Eq. 4-43**.**

$$G_{NoBarrier} = 0.75(1 - \frac{H_{eff}}{42})$$
$$= 0.63$$

$$G_{Barrier} = 0.75(1 - \frac{H_{eff}}{42})$$
$$= 0.37$$

Calculate the barrier insertion loss using Table 4-28 and Figure 4-18.

$$P = A + B - C$$
$= 0.96$ ft

$$A_{barrier} = \min\{15 \text{or} (20 \log(\frac{2.51\sqrt{P}}{\tanh(4.46\sqrt{P})}) + 5)\}$$
= 12.8 dB
= min { $15\ or\ 12.8\}$
= 12.8 dB

$$IL_{barrier} = \max\{0 \text{ or } (A_{barrier} - 10(G_{NoBarrier} - G_{Barrier}) \log(\frac{D}{50}))\}$$
$$= 12.8 - 10(0.63 - 0.37) \log(\frac{170}{50})$$
= 11.4 dB

Trees
Determine the attenuation due to trees using Table 4-30.

$$A_{trees} = \min\{10\ or\ \frac{W}{20}\}$$
$= 5$ dB

Total Shielding
The total shielding is the maximum of the barrier and tree zone shielding, 11.4 dB.

$$A_{shielding} = \max\{IL_{barrier}\ or\ A_{buildings}\ or\ A_{trees}\}$$
$$= \max\{11.4\ or\ 0\ or\ 5\}$$
= 11.4 dB

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

3c. Combine the two propagation characteristics.
Combine the results from Steps 3a and 3b to determine the noise at the receiver considering the propagation characteristics of distance and shielding by applying the distance correction and attenuation due to shielding to the project noise exposure level at 50 ft.

The equations in Table 4-31 combine the equations in Steps 3a and 3b.

Table 4-31 Calculate L_{dn} or $L_{eq(1hr)}$

Source	Equation*	
Stationary Sources	$L_{DistShield} = L - 20\log(\frac{D}{50}) - 10G\log(\frac{D}{50}) - A_{shielding}$	**Eq. 4-53**
Fixed-guideway rail car passbys	$L_{DistShield} = L - 10\log(\frac{D}{50}) - 10G\log(\frac{D}{42}) - A_{shielding}$	**Eq. 4-54**
Fixed-guideway locomotive and rubber-tired vehicle passbys, highway vehicle passbys and horns	$L_{DistShield} = L - 10\log(\frac{D}{50}) - 10G\log(\frac{D}{29}) - A_{shielding}$	**Eq. 4-55**
L = L_{dn} or L_{eq} D = distance, ft G = ground factor, see Section 4.5, Step 3a $A_{shielding}$ = attenuation due to shielding, see Section 4.5, Step 3b.		

*These equations assume the distance between the source and receiver is approximately 300 ft or less. At longer distances, ground effects have an upper limit and atmospheric conditions may affect propagation characteristics. Therefore, more detailed calculation methods may be required to account for those effects.(28, 29)

Step 4: Combine Noise Exposure from All Sources

Combine all sources to predict the total project noise at the receivers using the equations in Table 4-32 after propagation adjustments have been made for the noise exposure from each source separately.

Table 4-32 Computing Total Noise Exposure

Total $L_{eq(1hr)}$ from all sources for the hour of interest:	$L_{eq.total(1hr)} = 10\log(\sum_{all\ sources} 10^{L_{Aeq(1hr)}/10})$	**Eq. 4-56**
Total L_{dn} from all sources	$L_{dn.total} = 10\log(\sum_{all\ sources} 10^{L_{dn}/10})$	**Eq. 4-57**

Example 4-10 Detailed Noise Analysis – Combine Sources

Computation of Total Exposure from Combined Sources

Combine the noise exposure from the commuter train and light rail system to estimate the total noise exposure at the receiver.

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

$L_{eq.Commuter}$ = 72 dBA
$L_{dn.Commuter}$ = 68 dBA

A light rail system produces the following levels at the same receiver:

$L_{eq.LightRail}$ = 69 dBA

$L_{dn.LightRail}$ = 70 dBA

No other project sources affect this receiver.

Calculate the total noise exposure at the receiver using the equations in Table 4-32.

$$L_{eq.total} = 10\log(10^{(72/10)} + 10^{(69/10)})$$
$$= 73.8 \text{ dBA}$$
$$L_{dn.total} = 10\log(10^{(68/10)} + 10^{(70/10)})$$
$$= 72.1 \text{ dBA}$$

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

Step 5: Determine Existing Noise Exposure

Choose the appropriate method for characterizing noise and then determine the existing noise at each identified noise-sensitive receiver. The existing noise is needed to determine the noise impact according to the criteria described in Section 4.1, Step 2. Recall that impact is assessed based on a comparison of the existing ambient noise exposure and the additional noise exposure that will be caused by the project. The existing noise exposure must be estimated for all receivers of interest identified in Section 4.5, Step 1.

For a Detailed Noise Analysis, it is recommended to measure existing noise at each receiver of interest identified in Section 4.5, Step 1, for the most precise assessment of existing noise and conclusions concerning noise impact. However, measurements are expensive, often thwarted by weather, and take considerable time in the field. If taking measurements at each identified receiver is not possible, other less precise methods are available. Different methods may be used at different receivers along the project. However, it is important to recognize the correlation between the precision of measurements and the confidence in the impact assessment. Especially in a Detailed Noise Analysis, avoid using less precise methods of measuring existing noise just for the sake of convenience or expediency. The use of less precise methods must be clearly justified.

Option A. Noise Exposure Measurements – Full one-hour measurements are the most appropriate way to determine ambient noise exposure for non-residential receivers with the level of precision expected in a Detailed Noise Analysis**.** For residential receivers, full 24-hour measurements are more appropriate. These full-duration measurements are preferred over other methods of characterizing existing noise where time and study funds allow.

Follow the procedures below for these full-duration ambient noise exposure measurements:

Ai. Non-residential land uses – Measure a full hour $L_{eq(1hr)}$ at the receiver of interest on at least two non-successive weekdays (generally between noon on Monday and noon on Friday). Select the hour of the day when the maximum project activity is expected to occur.

A.ii. Residential land uses – Measure a full 24-hour L_{dn} at the receiver of interest for a single weekday (generally between noon on Monday and noon on Friday).

A.iii. Microphone position – The location of the microphone at the receiver depends upon the proposed location of the transit noise source, so use good technical judgment in positioning the measurement microphone. If, for example, a new rail line will be in front of the house, do not locate the microphone in the backyard behind the house where the line of sight between the noise source and receiver is obstructed. Figure 4-19 illustrates recommended measurement positions for various locations of the project, with respect to the house and the existing source of ambient noise.

A.iv. Measurement guidelines – Undertake all measurements in accordance with good engineering practice following guidelines given in ASTM and ANSI standards.[30][31]

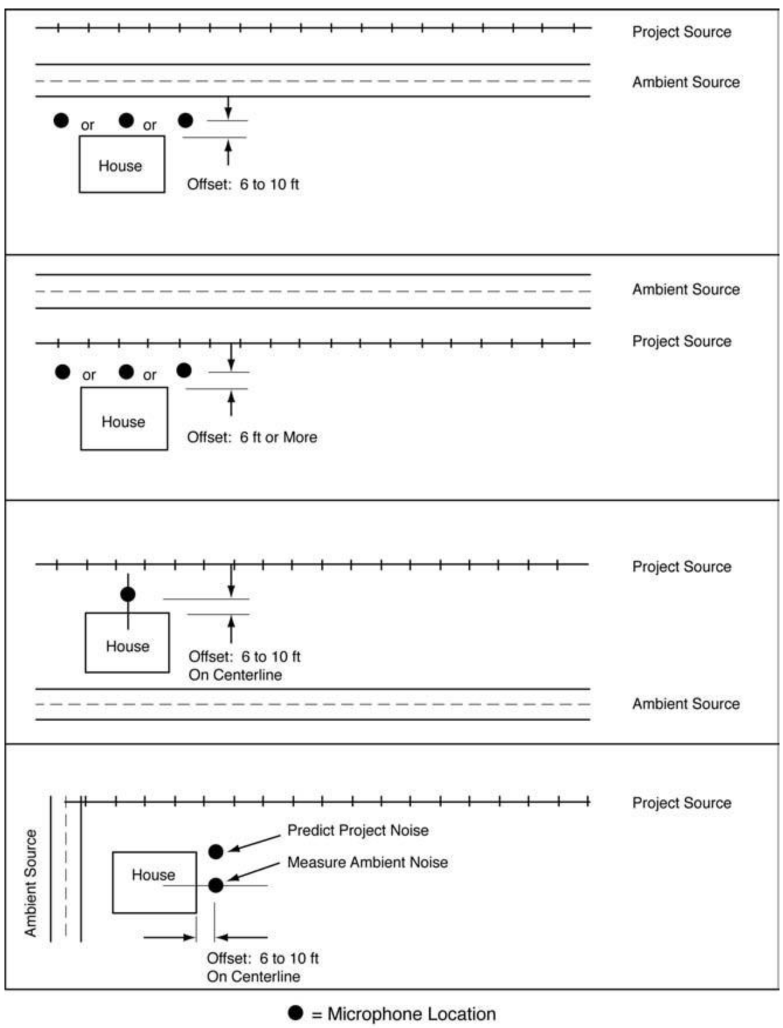


Figure 4-19 Recommended Microphone Locations for Existing Noise Measurements

Option B. Noise Exposure Computations from Partial Measurements – Often, measurements can be made at some of the receivers of interest and used to estimate noise exposure at nearby receivers. In other situations, several $L_{eq(1hr)}$ measurements can be taken at a receiver and then the L_{dn} computed from these. Both options require experience and knowledge of acoustics to select representative measurement sites. If using this method to compute an Ldn, a minimum time period of one hour should be used for each measurement period. It is unacceptable to extrapolate a one hour measurement from a shorter measurement period.

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. Residential neighborhoods with otherwise similar homes may have greatly varying noise environments. For example, one area of the neighborhood may be located where the ambient noise is clearly due to highway traffic. A second area toward the interior of the neighborhood may have highway noise as a factor, but also include other noise sources from the community. A third area located deep into the residential area could 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:

- 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 to use their experience and judgment in fully utilizing the measurements in their computations. This does necessitate a conservative estimate (underestimate) of existing noise to account for reduced precision from partial data as compared to full noise measurements.

Those without a background in acoustics are encouraged to use the procedures in Appendix E to compute existing noise from partial measurements. These methods include a factor to conservatively estimate (underestimate) existing noise to account for reduced precision from partial data as compared to full noise measurements.

Option C. Estimating Existing Noise Exposure – The least precise way to determine noise exposure is to estimate it from a table. This method is often used for the General Noise Assessment, but it is not recommended for a Detailed Noise Analysis. It can be used, however, in the absence of better data for locations where roadways or railroads are the predominant ambient noise source. Table 4-17 presents these existing levels. The levels in Table 4-17 are conservative and underestimate existing noise to account for reduced precision compared to full noise measurements. If a simplified procedure to estimate existing noise exposure is chosen it must be clearly justified and receive approval by the FTA Regional office.

While measurements are considered the most precise method, there is one situation where it may be more accurate to estimate rather than measure the existing noise exposure, which is in areas near major airports where aircraft noise is dominant. Because airport noise is highly variable based on weather conditions and corresponding runway usage, it is preferable in such cases to base the existing noise exposure on published aircraft noise contours in terms of Annual Average L_{dn}.

Step 6: Assess Noise Impact

Assess noise impact at each receiver of interest identified in Section 4.5, Step 1 using the noise impact criteria in Section 4.1 and the procedures in this step. Choose the appropriate noise impact assessment procedure for a transit project or multimodal project.

Option A. Transit Projects – For transit projects, noise impact is assessed at each receiver of interest using the criteria for transit projects described in Section 4.1. The noise impact assessment procedure is as follows:

A.i. Tabulate existing ambient noise exposure (rounded to the nearest whole decibel) at all receivers identified Section 4.5, Step 1. In cases where large residential buildings are exposed to noise on one side only, the receivers on that side are included in the analysis.

A.ii. Tabulate project noise exposure at these receivers from Section 4.5, Step 4.

A.iii. Determine the level of noise impact (no impact, moderate impact, or severe impact) according to Section 4.1.

A.iv. Document the results in noise-assessment inventory tables. Include the following 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, moderate impact, or severe impact)
- A sum of the total number of receivers and numbers of dwelling units predicted to experience moderate impact or severe impact

A.v. Illustrate the areas of moderate impact and severe impact. Two methods of displaying impact are labeling and contouring.

- In a Detailed Noise Analysis, the most accurate indication of impact is to label each impacted building or cluster identified in the inventory table.
- A less precise illustration of impacted areas is a plot of project noise contours on the maps or aerial photographs, along with shaded impact areas. Use the procedures in Section 4.4, Step 6 and the levels from Section 4.5, Step 2 to develop these contours.

Note that it is difficult to position noise contours in urban areas due to shielding, terrain features, and other propagation anomalies. If noise contours are used, they should be considered illustrative rather than definitive. If desired to conform to 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 dBA.

A.vi. Including information on 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 moderate impact and severe impact.

Option B. Multimodal Projects – For multimodal projects, project noise comprised of both highway and transit noise sources that are assessed according to the FTA noise impact criteria (see Table 4-2), use the procedure in Option A above. For multimodal projects that require FHWA's noise assessment methods to inform FTA's evaluation (see Section 4.1, Step 1 - Option B), follow the FHWA guidance.(32) In general, the appropriate calculation method is to use the current version of FHWA's Traffic Noise Model (TNM).(22) TNM is a state-of-the-art computer program used for predicting noise impacts near highways.

TNM allows for a detailed assessment at each receiver of interest by separately calculating the noise contribution of each roadway segment. For each roadway segment, the noise from each vehicle type is computed from reference noise levels, adjusted for:

- Vehicle volume
- Vehicle speed
- Grade
- Roadway segment length
- Source-to-receiver distance

Further adjustments needed to accurately model the sound propagation from source to receiver include:

- Shielding provided by rows of buildings,
- Effects of different ground types,
- Source and receiver elevations, and
- Effect of any intervening noise barriers.

TNM sums the noise contributions of each vehicle type for a given roadway segment at the receiver. TNM then repeats this process for all roadway segments, summing their contributions to generate the predicted noise level at each receiver.

Step 7: Determine Noise Mitigation Measures

Evaluate alternative mitigation measures where the Detailed Noise Analysis shows either severe or moderate impact, and it is not feasible to change the alignment or location of the project to avoid impact. Project noise that is found to cause no impact does not generally require any mitigation.

Mitigation of noise impact from transit projects may involve treatments at the three fundamental components of the noise problem: at the noise source, along the source-to-receiver propagation path, or 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 at the receiver. After mitigation options have been determined, repeat the project noise computations including the adopted mitigation and reassess the remaining noise impact.

Approximate costs for noise control measures are documented in a report from the Transit Cooperative Research Program (TCRP)(33) and are also presented in this section. These costs reflect the noise mitigation costs available in 1997 (unless otherwise noted), which are the most recent data available as of this publication, and should only be used as representative estimates when considering noise mitigation options. Current noise mitigation costs should be researched before decisions on noise mitigation options are finalized, and then they should be documented according to Section 8.

7a. Evaluate Source Treatments – The most effective noise mitigation treatments are applied at the noise source. This is the preferred approach to mitigation when possible. Common source treatments and their estimated acoustical effectiveness are included in Table 4-33 and described below. It is important to note that the values below are estimates and should be applied with good engineering judgement. It also important to note that these mitigation measures should not be applied as a reduction in the reference SEL values for a vehicle that already incorporates that measure as a feature, such as vehicle skirts. Measurements to determine the reference SEL source level are required in those instances.

Table 4-33 Transit Noise Mitigation Measures – Source Treatments

Mitigation Measure		Effectiveness
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
Quiet Fan Design and Fan Placement*		Varied
Preventative Maintenance on Rail Systems*		Varied
Resurfacing Roads**		10 dB
Guideway Support for Buses**		10 dB
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		6-10 dB
Quiet Zones*		Reduces occurrence of horn noise

†FTA does not normally accept operational restrictions as a noise mitigation measure – see below.
* Applies to rail projects only.
** Applies to bus projects only.

- **Stringent Vehicle and Equipment Noise Specifications**
  - **Vehicles** – Among the most effective noise mitigation treatments is noise control 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 considering the noise reduction benefits and costs.

    Effective enforcement includes penalties for non-compliance with the specifications. The noise mitigation achieved by source treatment is dependent on the quality of installation and maintenance. Vehicles failing to meet the noise specification could result in complaints from the public and require additional noise mitigation measures applied along the path or at receivers.

  - **Stationary sources** – Stringent but achievable noise specifications for stationary sources are also an effective approach for mitigating noise impacts. Typical equipment includes fixed plant equipment such as transformers and mechanical equipment, as well as grade-crossing signals. For example, it may be possible to reduce noise impact from grade-crossing signals in some areas by specifying equipment that sets the level of the warning signal lower in locations where ambient noise is lower to minimize the signal noise in the direction of noise-sensitive receivers.

- **Operational Restrictions** – Changes in operations that can mitigate noise include the lowering of speed, the reduction of nighttime (10 p.m. to 7 a.m.) operations, and reduction of warning horns and signals.

  - **Speed reduction** – Because noise from most transit vehicles is dependent 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 $L_{eq(1hr)}$ and L_{dn} (Table 4-21) results in a 6-dB reduction when reducing the speed to half of the original speed.

    Although there are tangible benefits from speed reductions during the most noise-sensitive time periods, FTA does not ordinarily accept speed reduction as a noise mitigation measure for two important reasons: speed reduction is unenforceable and negated if vehicle operators do not adhere to established policies, and it is contrary to the purpose of the transit investment by FTA, which is to move as many people as possible as efficiently and safely as possible.

  - **Reduction of nighttime operations** – Complete elimination of nighttime operations has a strong effect on reducing the L_{dn}, because nighttime noise is increased by 10 dB when calculating L_{dn}. But restrictions on operations are usually not feasible because of service demands. FTA generally does not pursue restrictions on operations as a noise reduction measure. However, if early morning idling can be curtailed to the minimum necessary, however, this can have a measurable effect on L_{dn}.

While there are tangible benefits from limits on operations during the most noise-sensitive time periods, FTA does not recommend limits on operations as a way to reduce noise impacts because it is contrary to the purpose of the transit investment by FTA which is to move as many people as possible as efficiently and safely as possible.

  - **Reduction of warning horns and signals** – Minimizing or eliminating horns and other warning signals at gate crossings can reduce noise impact for light rail and commuter rail systems. Although these mitigation options are limited by safety considerations, they can be effective in the right circumstances. For examples, see quiet zones below and wayside horns in Step 7b.

- **Wheel Treatments (Rail)** – A major source of noise from steel-wheel and steel-rail systems is the wheel/rail interaction that can produce three distinctive sounds: roar, impact, and squeal (as discussed in Section 3.2). 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 spot on the wheels. Squeal occurs when a steel-wheel tread or its flange rubs across the rail, resulting in resonant vibrations in the wheel that creates a screeching sound. Various wheel designs and other mitigation measures exist to reduce the noise from each of these three mechanisms.

  - **Resilient wheels** – Resilient wheels are effective in eliminating wheel squeal on tight turns with reductions of 10 to 20 dB in the high-frequency range where squeal noise occurs. Rolling noise is also slightly reduced with resilient wheels and typically achieves a 2-dB reduction on tangent track. The costs for resilient wheels are approximately $2000 to $3000 per wheel, as compared to about $400 to $700 for standard steel wheels.[(vi)]

  - **Damped wheels** – Damped wheels, like resilient wheels, are effective in eliminating wheel squeal on tight turns with reductions of 5 to 15 dB in the high-frequency range where squeal occurs. Rolling noise is also slightly reduced by approximately 2 dB on tangent track. This treatment involves attaching vibration absorbers to standard steel wheels. The costs for damped wheels add approximately $500 to $1000 to the normal $700 for each steel wheel.

[vi] Assumes 8 wheels per vehicle.

- **Vehicle Treatments** – 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. The mitigation options for these systems include:

  - **Quiet fan design and placement** – Fan noise can be reduced by installation 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 considerable difference in the noise radiated to the wayside or to patrons on the station platforms.

  - **Vehicle skirts and undercar absorption** – 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 dB 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 dB of mitigation. By carrying their own noise barriers, vehicles with these features can provide cost-effective noise reduction. The cost for vehicle skirts will add approximately $5000 to $10000 per vehicle. Undercar absorption will add approximately $3500 per vehicle, assuming that 50% of the underside of the floor is treated.

- **Preventative Maintenance (Rail)** – Preventative maintenance is the best strategy to minimize rail and wheel deterioration. While these are not mitigation measures in the traditional sense and should not be included as mitigation in an environmental document, they can help to keep both noise and vibration levels at a "like-new" level or reduce both noise and vibration in systems with deferred maintenance. This can be accompanied by considerable life cost benefits for the transit system.

  - **Spin-slide control systems** – Similar to anti-locking brake systems (ABS) on automobiles, spin-slide control systems reduce the incidence of wheel flats, a major contributor of impact noise. Trains with smooth wheel treads can be up to 20 dB 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. The cost of slip-slide control may be incorporated in the new vehicle costs, but may be between $5,000 and $10,000 per vehicle with a maintenance cost of $200 per year.

- **Wheel truing** – 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. As a guideline, it is recommended that wheel sets match within approximately ±0.01 inch and all wheels on the same truck should match within ±0.02 inches to minimize damage and wear to wheels and rails.(34) A wheel truing machine costs approximately $1 million, including associated maintenance materials and labor costs. The TCRP report estimates a system with 700 vehicles would incur a yearly cost of $300,000 to $400,000 for a wheel truing program.

  It is recommended to install wheel-flat detector systems to identify vehicles that are most in need of wheel truing. These systems are becoming more common on railroads and intercity passenger systems, but are relatively rare on transit systems.

- **Rail grinding** – The smoothness of the running surface is critical in the mitigation of noise from a moving vehicle. Mill scale grinding before commencement of pre-revenue service train operations is critical. Experience shows that grinding new rails after approximately 3 months of train operations and scheduling routine grinding at approximate intervals of 2 years in the problem areas would minimize noise problems related to corrugation in most cases. Grinding with small machines when the corrugation depth is still small is a reasonable approach. As a guideline, it is recommended to spot-grind at locations where corrugation occurs before corrugation grows to 0.02 inches (32).

  Periodic rail grinding can result in a net savings per year on wheel and rail wear. Most transit systems contract out rail grinding, although some of the larger systems make the investment of approximately $1 million for the equipment and do their own grinding. Contractors typically charge a fixed amount per day for the equipment on site, plus an amount per pass-mile (one pass of the grinding machine for one mile). Typical rail grinding cost would be approximately $7,000 to $10,000 per pass-mile.

- **Wheel and rail profile matching** – It is important to consider the wheel and rail profile compatibility when truing wheels and grinding rails. If the profiles do not match, the benefits of this kind of preventative maintenance will not be achieved.

  It is equally important to consider initial wheel and rail profile compatibility. Work with track designers and vehicle suppliers early in the design process to ensure wheel and rail profile compatibility. Profiles should be defined during the design phase and should be in place when system opens.[32] The cost of wheel and rail profile matching may be incorporated in the new vehicle and new rail costs.

Profile grinding of the rail head in combination with a wheel truing program may be the most practical approach to controlling and reducing noise and vibration where such practices are not normally conducted.

  - **Maintenance program** – Clearly defined maintenance specifications should be developed during design phase of the project. The specifications should define rail and wheel profiles, include detailed guidance for pre-revenue mill scale grinding, address issues related to healthy rail-wheel interface, and include a mechanism for periodic monitoring of wheel and rail condition and verification for compliance.[32] A diligent maintenance program can often resolve or reduce rail noise issues before they occur. Vehicle reconditioning programs should also be developed particularly for components such as suspension system, brakes, wheels, and slip-slide detectors.

- **Guideway Support (Bus)** – The smoothness of the running surface is critical in the mitigation of noise from a moving vehicle.
  - **Resurfacing roads** – Roughness on the guideway can be eliminated by resurfacing roads, thereby reducing noise levels by up to 10 dB.
  - **Bridge expansion joint angles and design** – 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.

- **Turn Radii and Rail Lubrication** – For steel-wheel/steel-rail systems with non-steerable trucks and sharp turns, squeal can typically be eliminated by designing all turn radii to be greater than 1000 ft, or 100 times the truck wheelbase, whichever is less. If this is not possible, squeal can be mitigated by installation of lubricators (though the potential environmental impacts of lubricant application should be factored into this decision).Rail lubricators cost approximately $10,000 - $40,000 per curve.

- **Movable-point and Spring-rail Frogs** – Frogs with spring-loaded mechanisms and frogs with movable points can reduce impact noise near crossovers. According to the TCRP report, a spring frog costs approximately $12,000, twice the cost of a standard frog. A movable point frog involves elaborate signal and control circuitry resulting in higher costs of approximately $200,000.

- **Use of Locomotive Horns at-grade Crossings and Quiet Zones** – In cases where commuter rail operations share tracks or ROW with freight or intercity passenger trains that are part of the general railroad system, the safety rules of the FRA, including the Train Horn Rule, apply.[35] The Train Horn Rule requires that locomotive horns be sounded at public highway grade crossings, although some exceptions are allowed in carefully defined circumstances. Locomotive horns are often a major contributor in projections of adverse noise impact, in the community from proposed commuter rail projects. Since noise barriers are not feasible at highway-rail grade crossings, the establishment of quiet zones could be considered.

Quiet zones can be established in which supplemental safety measures (SSMs) are used in place of the locomotive horn to provide an equivalent level of safety at-grade crossings.[vii] By adopting an approved SSM at each public grade crossing, a quiet zone of at least a half-mile long can be established. These measures are in addition to the standard safety devices required at most public grade crossings (e.g., stop signs, reflectorized crossbucks, flashing lights with gates that do not completely block travel over the tracks). Below are four SSMs that have been predetermined by the FRA to fully compensate for the lack of a locomotive horn:

- **Temporary closure of a public highway-rail grade crossing** – This measure requires closure of the grade crossing for one period each 24 hours, and the closure must occur at the same time each day.
- **Four-quadrant gate system** – This measure involves the installation of at least one gate for each direction of traffic to fully block vehicles from entering the crossing.
- **Gates with medians or channelization devices** – This measure keeps traffic in the proper travel lanes as it approaches the crossing. This denies the driver the option of circumventing the gates by traveling in the opposing lane.
- **One-way street with gates** – This measure consists of one-way streets with gates installed, so that all approaching travel lanes are completely blocked.

In addition to the pre-approved SSMs, the FRA rule also identifies a range of other measures that may be used in establishing a quiet zone. These could include modified SSMs or non-engineering types of measures, such as increased monitoring by law enforcement for grade crossing violations or instituting public education and awareness programs that emphasize the risks associated with grade crossings and applicable requirements. These alternative safety measures (ASMs) require approval by FRA based on a demonstration that public safety would not be compromised by eliminating horn usage.

The lead agency for designating a quiet zone is the local public authority responsible for traffic control and law enforcement on the roads crossing the tracks. To satisfy the FRA regulatory requirements, the public transit agency must work closely with this agency while also coordinating with any freight or passenger railroad operator sharing the ROW. The final environmental document should discuss the main considerations in adopting the quiet zone including: the engineering feasibility, receptiveness of the local public authority, consultation with the railroad, preliminary cost estimates, and evidence of the planning and interagency coordination that has occurred to date. If a quiet zone will be relied on as a mitigation measure, the final environmental document should provide reasonable

[vii] For more information on quiet zones, visit: https://www.fra.dot.gov/Page/P0889.

assurance that any remaining issues can and will be resolved. For more information on documentation requirements see Section 8.

The cost of establishing a quiet zone varies considerably, depending on the number of intersections that must be treated and the specific SSMs, ASMs, or combination of measures that are used. The FRA gives a cost estimate of $15,000 per crossing for installing two 100-foot-long, non-traversable medians that prevent motorists from driving around closed gates. A typical installation of a four-quadrant gate system is in the range of $175,000–$300,000 per crossing.(36) Who pays for the installation of modifications can become a major consideration in a decision to pursue a quiet zone designation, especially in cases where noise from preexisting railroad operations is controversial in the community. In many cases where a quiet zone would mitigate a severe impact caused by the proposed transit project, the costs are covered by the project sponsor and FTA in the same proportion as the overall cost-sharing for the project.

7b. Evaluate Path Treatments – When noise mitigation treatments cannot be applied at the noise source or additional mitigation is required after treating the source, the next preferred placement of noise mitigation is along the noise propagation path between the source and receiver. Common path treatments and their estimated acoustical effectiveness are included in Table 4-34 and described below.

Table 4-34 Transit Noise Mitigation Measures – Path Treatments

Mitigation Measure	Effectiveness
Noise barriers close to vehicles	6-15 dB
Noise barriers at row line	3-15 dB(37)
Alteration of horizontal & vertical alignments	Varied
Wayside horns	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
Vegetation and trees	Varied, see Table 4-30

* Applies to rail projects only.

- **Noise Barriers** – Noise 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 Section 3.3. The necessary height of a barrier depends on the source height and the distance from the source to the barrier, see Table 4-28 and Figure 4-18.
    - **Noise barriers close to vehicles** – Barriers located very close to a rapid transit train, for example, may only need to be approximately 3 to 4 ft above the top of rail to be effective. Standard barriers close to vehicles can provide noise reductions of 6 to 10 dB.
    - **Noise barriers at ROW line –** Barriers on the ROW line or for trains on the far track, the height must be increased to provide equivalent effectiveness to barriers located close to the vehicles. Otherwise, the effectiveness can drop to 3 dB or less, even if the barrier breaks the line-of-sight.

All barrier effectiveness can be increased by as much as 5 dB by applying sound-absorbing material to the inner surface of the barrier. The length of the barrier wall is also important to its effectiveness. The barrier must be long enough to block noise from 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 noise-sensitive locations. The barrier length can be refined in the engineering phase, closely examining the predicted sound level exceedances at specific receivers, site geometries, and the contribution of barrier flanking noise, then adjusting the length as appropriate.

Noise barriers can be made of any outdoor weather-resistant solid material that meets the minimum sound transmission loss required by the project. Materials that are commonly used for noise barriers include 16-gauge steel, 1-inch thick plywood, and any reasonable thickness of concrete. Typically, a surface density of 4 pounds per square foot is required. Areas with strong winds may require more stringent structural requirements. It is critical to seal any gaps between barrier panels and between the barrier and the ground or elevated guideway deck for maximum performance.

Costs for noise barriers (based on highway installations) range from $20 to $25 per square foot of installed noise barrier at-grade with additional cost for design and inspection.[38] Installation on aerial structures could be twice the amount of installation at-grade, especially if the structure has to be strengthened to accommodate the added weight and wind load.

As described in Section 3.3, noise barriers, if not designed and sited carefully, can reduce visibility of trains for pedestrians and motorists, which causes safety concerns. It is important to consult with safety experts in choosing and siting a noise barrier.

- **Alteration of Horizontal and Vertical Alignments** – Transit alignment in a 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.

- **Wayside Horns** – The sounding of a locomotive horn as the train approaches an at-grade intersection produces a very wide noise footprint in the community. Using wayside horns at these intersections instead of the locomotive horn can substantially reduce the noise footprint without compromising safety at the grade crossing.

  A wayside horn does not need to be as loud as a locomotive horn, and the warning sound is focused only on the area where it is needed. These are pole-mounted horns used in conjunction with flashing lights and gates at the intersection, with a separate horn oriented toward each direction of oncoming vehicle traffic. Noise levels in nearby residential and business areas can be reduced substantially with wayside horns, depending on the location with respect to the grade crossing.

A plan to use wayside horns in place of the locomotive horn at public grade crossings must be coordinated with several public and private entities, notably the local agency having responsibility for traffic control and law enforcement on the road crossings, the state agency responsible for railroad safety, any railroads that share the ROW, and FRA. Public notification must also be given. Preliminary cost information from testing programs indicates a wayside horn system at a railroad/highway grade crossing costs approximately $50,000.

- **Buffer Zones** – Because noise levels attenuate with distance, one noise mitigation option is to increase the distance between noise sources and the closest noise-sensitive receivers. This can be accomplished by locating alignments away from noise-sensitive sites. Acquisition of land or purchasing easements for noise buffer zones is an option that may be considered if appropriate for the project.

- **Ground Absorption – Ballast on Guideways** – 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 substantial effect on the propagation of noise to greater distance. 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 dB at-grade and up to 5 dB on an aerial structure.

- **Vegetation and Trees** – In almost all cases, vegetation and trees are ineffective at providing noise mitigation. Vegetation and Trees can provide some mitigation if at least 100 ft of trees intervene between the source and receiver, if no clear line-of-sight exists between the source and receiver, and if the trees extend 15 ft or more above the line-of-sight as described in Section 4.5, Step 3b. This is generally not a recommended form of mitigation to pursue.

7c. Evaluate Receiver Treatments – Consider treatments to the receivers when noise mitigation treatments cannot be applied at the source or along the propagation path, or if combinations of treatments are required. Common receiver treatments and their estimated acoustical effectiveness are included in Table 4-35 and are described in this section.

Table 4-35 Transit Noise Mitigation Measures – Receiver Treatments

Mitigation Measure	Effectiveness
Acquisition of Property Rights for Construction of Noise Barriers	5-10 dB
Building Noise Insulation	5-20 dB

- **Noise Barriers** – In certain cases, it may be possible to acquire limited property rights for the construction of noise 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. See Section 3.3 for more information on noise barriers.

- **Building Insulation** – In cases where noise barriers are not feasible—such as multi-story buildings, buildings very close to the ROW, or grade crossings—the only practical noise mitigation measure may be to provide sound insulation for the buildings. In these cases, the need for mitigation at locations where impact has been identified will depend on the use (outdoor vs. indoor), any existing outdoor to indoor reduction in noise levels, and the feasibility of constructing effective noise barriers for second stories and above.

  Depending on the quality of the original building façade, especially windows and doors, sound insulation treatments can improve the noise reductions from transit noise by 5 to 20 dB. To be considered cost-effective, a treatment should provide a minimum reduction of 5 dB in the interior of the building and meet the L_{dn} 45 dBA interior criterion. For more information, see Section 4.1.

  In many cases, especially in locations with high ambient noise levels, the existing sound insulation of a building may already meet the 45 dBA L_{dn} interior noise criterion. It is recommended that sound insulation testing be conducted to determine if the existing sound insulation is sufficient or what additional measures would be required to meet the interior criterion. Effective treatments include:
  - Caulking and sealing gaps in the building façade; and
  - Installation of new doors and windows that are specially designed to meet acoustical transmission-loss requirements:
    - Exterior doors facing the noise source should be replaced with well-gasketed, solid-core wood doors and well-gasketed storm doors.
    - Acoustical windows are typically made of multiple layers of glass with air spaces between to provide noise reduction. Acoustical performance ratings are published in terms of Sound Transmission Class (STC) for these windows. It is recommended to use a minimum STC rating of 39 on any window exposed to the noise source.

  These treatments are beneficial for heat insulation as well as for sound insulation, but acoustical windows are typically non-operable and central ventilation or air conditioning is needed. Residents' preferences should be considered.

  If needed, additional building sound insulation can be provided by sealing vents and ventilation openings and relocating them to a side of the building away from the noise source. In cases where the noise sources is low-frequency noise from diesel locomotives, it may be necessary to increase the mass of the building façade for wood-frame houses by adding a layer of sheathing to the exterior walls.

Examples of residential sound insulation for rail or highway projects are limited. However, much practical experience with sound insulation of buildings has been gained through grants for noise mitigation to local airport authorities by FAA.

SECTION 5

Transit Vibration

This section presents the basic concepts of transit ground-borne vibration, also referred throughout this manual as simple "vibration," and low-frequency groundborne-noise that sometimes results from vibration. The steps for the screening and assessing of potential vibration impacts of transit projects for FTA NEPA approval are described in the following sections.

The Source-Path-Receiver framework for ground-borne vibration for a rail system illustrated in Figure 5-1 is central to all environmental vibration studies. The train wheels rolling on the rails create vibration energy that is transmitted through the track support system into the transit structure. The vibration of the transit structure excites the adjacent ground, creating vibration waves that propagate through the ground and into nearby buildings creating ground-borne vibration effects that potentially interfere with activities. The vibrating building components may radiate sound, which this manual refers to as ground-borne noise. Airborne noise from transit sources is covered in Sections 2.3–4.5 of this manual. Ground-borne noise refers to the noise generated by ground-borne vibration.

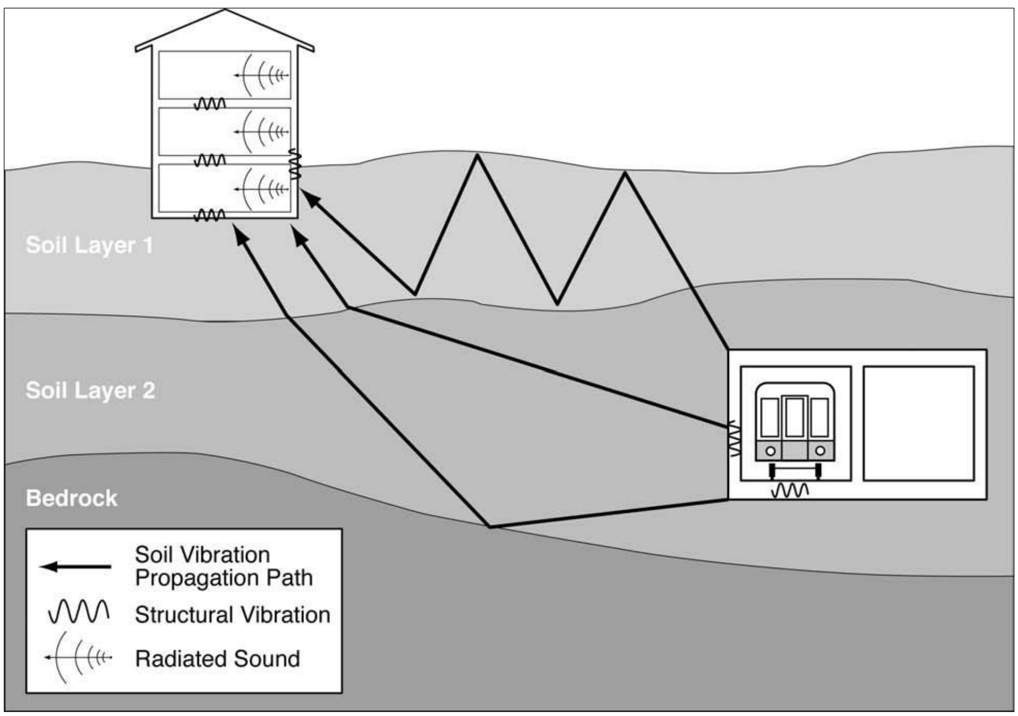


Figure 5-1 Propagation of Ground-Borne Vibration into Buildings

This section contains the following:

- Section 5.1 The ground-borne vibration and noise metrics used in this manual
- Section 5.2 An overview of transit vibration sources

- Section 5.3 An overview of transit vibration paths
- Section 5.4 An overview of receiver factors of transit vibration and a discussion of the technical background for ground-borne noise criteria

5.1 Ground-Borne Vibration and Noise Metrics

Vibration is an oscillatory motion that can be described in terms of the displacement, velocity, or acceleration. Because the motion is oscillatory, there is no net movement of the vibration element and the average of any of the motion metrics is zero. Displacement is the most intuitive metric. For a vibrating floor, the displacement is simply the distance that a point on the floor moves away from its static position. The velocity represents the instantaneous speed of the floor movement and acceleration is the rate of change of the speed.

Although displacement is easier to understand than velocity or acceleration, it is rarely used for describing ground-borne vibration. Most transducers used for measuring ground-borne vibration use either velocity or acceleration. Furthermore, the response of humans, buildings, and equipment to vibration is more accurately described using velocity or acceleration.

This manual uses the metrics outlined in Table 5-1 for transit ground-borne vibration and noise measurements, computations, and assessment. These metrics are consistent with common usage in the United States.

Table 5-1 Ground-borne Vibration and Noise Metrics

Metric	Abbreviation	Definition
Vibration Decibels	VdB	The vibration velocity level in decibel scale.
Peak Particle Velocity	PPV	The peak signal value of an oscillating vibration velocity waveform. Usually expressed in inches/second in the United States.
Root Mean Square	rms	The square root of the arithmetic average of the squared amplitude of the signal.
A-weighted Sound Level	dBA	A-weighted sound levels represent the overall noise at a receiver that is adjusted in frequency to approximate typical human hearing sensitivity. This unit is used to characterize ground-borne noise.

The metrics in the table above are illustrated in Figure 5-2. The components in the figure include:

- **Raw signal** – This curve shows the instantaneous vibration velocity, which fluctuates positively and negatively about the zero point.

- **Peak particle velocity (PPV)** – PPV is the maximum instantaneous positive or negative peak of the vibration signal. PPV is often used in monitoring of construction vibration (such as blasting) since it is related to the stresses that are experienced by buildings and is not used to evaluate human response.

- **Root mean square (rms) velocity** – Because the net average of a vibration signal is zero, the rms amplitude is used to describe smoothed vibration amplitude. The rms of a signal is the square root of the average of the squared amplitude of the signal. The average is typically calculated over a one-second period. The rms amplitude is always less than the PPV[viii] and is always positive. The rms amplitude is used to convey the magnitude of the vibration signal felt by the human body, in inches/second.

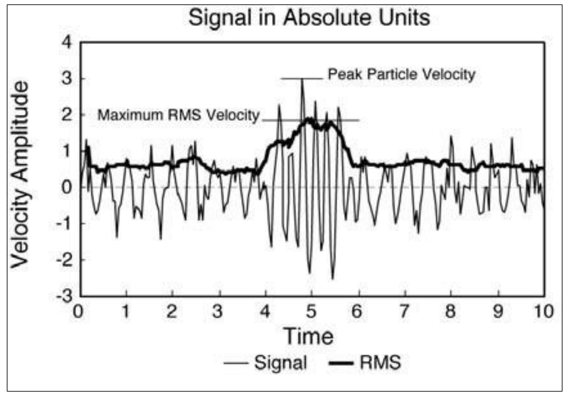


Figure 5-2 Vibration Signal in Absolute Units

The PPV and rms velocity are described in inches per second in the United States and meters per second internationally (with several different reference values). Although it is not universally accepted, vibration is commonly expressed in decibel notation. The decibel scale compresses the range of numbers required to describe vibration.

The graph in Figure 5-3 shows the rms curve from Figure 5-2 expressed in decibels.

Vibration velocity level in decibels is defined as:

$$L_v = 20\log\left(\frac{v}{v_{ref}}\right) \quad \textbf{Eq. 5-1}$$

where:

L_v = velocity level, VdB
v = rms velocity amplitude
v_{ref} = 1×10^{-6} in/sec in the USA
= 1×10^{-8} m/sec internationally*

*Because of the variations in the reference quantities, it is important to be clear about what reference quantity is being used when specifying velocity levels. All vibration levels in this manual are referenced to 1×10^{-6} inches/second.

viii The ratio of PPV to maximum rms amplitude is defined as the crest factor for the signal. The crest factor is typically greater than 1.41, although a crest factor of 8 or more is not unusual for impulsive signals. For ground-borne vibration from trains, the crest factor is usually 4 to 5.

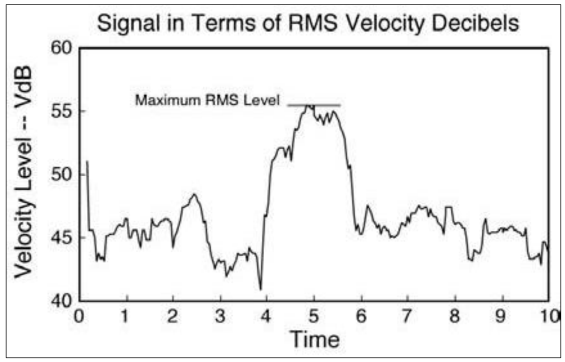


Figure 5-3 Vibration Signal in RMS Velocity Decibels

Ground-borne noise occurs when vibration radiates through a building interior and creates a low-frequency sound, often described as a rumble, as a train passes by. The annoyance potential of ground-borne noise is typically characterized with the A-weighted sound level. Although the A-weighted sound level is typically used to characterize community noise, characterizing low-frequency noise using A-weighting can be challenging because the non-linearity of human hearing causes sounds dominated by low-frequency components to seem louder than broadband sounds (sounds consisting of many frequency components, with no dominant frequencies) that have the same A-weighted level. The result is that ground-borne noise with a level of 40 dBA sounds louder than 40 dBA broadband noise. Because ground-borne noise sounds louder than broadband noise at the same noise level, the limits for ground-borne noise are lower (i.e., stricter) than would be the case for broadband noise.

5.2 Sources of Transit Ground-borne Vibration and Noise

Ground-borne vibration can be a concern for nearby neighbors of a transit system route or maintenance facility. However, in contrast to airborne noise, ground-borne vibration is not a common environmental problem. It is unusual for vibration from sources such as buses and trucks to be perceptible, even in locations close to major roads. This section discusses common sources of ground-borne vibration and noise.

Most perceptible indoor vibration is caused by sources within buildings such as operation of mechanical equipment, movement of people, or slamming of doors. Typical outdoor sources of vibration waves that propagate through the ground and create perceptible ground-borne vibration in nearby buildings include construction equipment, steel-wheeled trains, and traffic on rough roads. If the roadway is fairly smooth, the vibration from rubber-tired traffic is rarely perceptible. Building damage due to vibration is also rare for typical transportation projects; but in extreme cases, such as during blasting or pile-driving during construction, vibration could cause damage to buildings.

Figure 5-4 illustrates common vibration sources and the human and structural response to ground-borne vibration ranging from approximately 50 VdB (below perceptibility) to 100 VdB (the threshold of potential damage). The background vibration velocity level in residential areas is usually 50 VdB or lower,[ix] and the threshold of perception for humans is approximately 65 VdB. A vibration level of 85 VdB in a residence can result in strong annoyance.

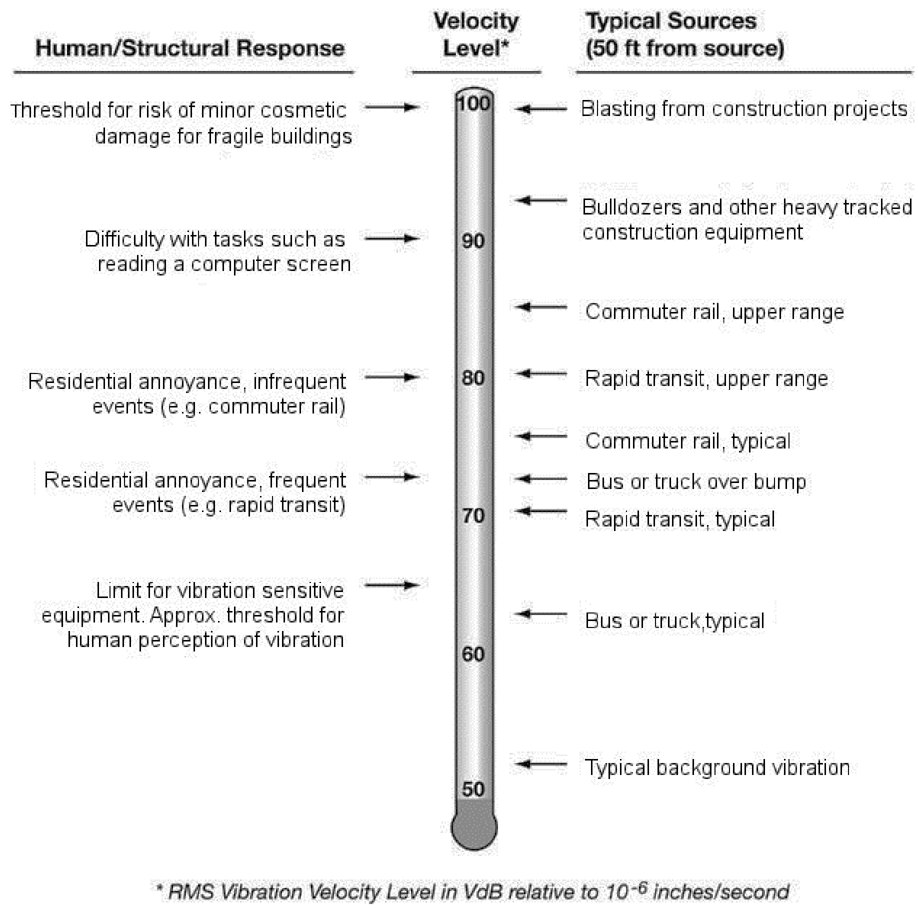


Figure 5-4 Typical Levels of Ground-Borne Vibration

Rapid transit or light rail systems typically generate vibration levels of 70 VdB or more near their tracks, while buses and trucks rarely create vibration that exceeds 70 VdB unless there are bumps due to frequent potholes in the road. Heavy locomotives on diesel commuter rail systems create vibration levels approximately 5 to 10 dB higher than rail transit vehicles.

Vibration from trains is strongly dependent on factors such as how smooth the wheels and rails are, as well as the resonance frequencies of the vehicle suspension system and the track support system. These systems, like all mechanical systems, have resonances that result in increased vibration response at certain frequencies, called natural frequencies. Unusually rough road or track, steel-wheel flats, geologic conditions that promote efficient propagation of vibration, or vehicles with very stiff suspension systems could increase typical

[ix] Background vibration is typically well below the threshold of human perception and is of concern only when the vibration affects very sensitive manufacturing or research equipment. Electron microscopes and high-resolution lithography equipment are examples of equipment that is highly sensitive to vibration.

vibration levels by approximately 10 VdB. Common factors that contribute to ground-borne vibration and noise at the source are presented in Table 5-2. These factors are discussed in more detail throughout this Section.

Table 5-2 Factors that Influence Levels of Ground-Borne Vibration and Noise at the Source

Category	Factors	Influence
Operations and Vehicles	Speed	Higher speeds result in higher vibration levels. Doubling speed results in a vibration level increase of approximately 4 to 6 dB.
	Vehicle Suspension	Stiff suspension in the vertical direction can increase the effective vibration forces. On transit cars, the primary suspension has the largest effect on vibration levels.
	Wheel Condition and Type	Wheel flats and general wheel roughness are major sources of vibration from steel wheel/steel rail systems. Resilient wheels on rail transit systems can provide some vibration reduction over solid steel wheels, but are usually too stiff to provide substantial reduction. For more information, see Section 6.4, Step 2.
Guideway	Track/Roadway Surface	Rough track or rough roads are often sources of excessive vibration. Maintaining a smooth surface will reduce vibration levels.
	Track Support System	On rail systems, the track support system is one of the major components in determining the levels of vibration. The highest vibration levels are created by track that is rigidly attached to a concrete trackbed (e.g., track on wood half-ties embedded in the concrete). The vibration levels are much lower when special vibration control track systems such as resilient fasteners, ballast mats, and floating slabs are used.
	Transit Structure	Heavier transit structures typically result in the lower vibration levels. The vibration levels from a lightweight bored tunnel will usually be higher than from a poured concrete box subway.
	Transit System Elevation	A rail system guideway will be either underground (subway), at-grade, or elevated, with substantial differences in the vibration characteristics at each elevation. ▪ Underground: vibration is typically the most important environmental factor of interest. ▪ At-grade: airborne noise is typically the dominant factor, although vibration and noise can be a problem, particularly at interior locations well isolated from exterior noise. ▪ Elevated: it is rare for vibration to be an issue with elevated railways except when guideway supports are located within 50 ft of buildings.

Brief discussions of ground-borne vibration and noise sources for different modes of transit are provided below.

At-Grade Heavy Rail and Light Rail

Ground-borne vibration and noise from urban heavy rail and LRT is common when there is less than 50 ft between the track and building foundations. Local geology and structural details of the building determine if the source of complaints is due to perceptible vibration or audible ground-borne noise. Complaints about ground-borne vibration from surface track are more common than ground-borne noise complaints. A substantial percentage of complaints about both ground-borne vibration and noise correlate with proximity of special track work, rough or corrugated track, or wheel flats. Light rail systems tend to generate fewer complaints than heavy rail due to lower operating speeds.

Commuter and Intercity Passenger Trains

There is the potential for vibration-related issues when new commuter or intercity rail passenger service (including electric multiple units (EMUs) and diesel multiple units (DMUs)) powered by either diesel or electric locomotives is introduced in an urban or suburban area. Commuter and intercity passenger trains have similar characteristics, but commuter trains typically operate on a more frequent schedule. These passenger trains often share track with freight trains, which have different vibration characteristics as discussed below.

Freight Trains

Local and long-distance freight trains are similar in that they both are diesel-powered and have the same types of cars. They differ in their overall length, number and size of locomotives, and number of heavily loaded cars. However, because locomotive suspensions are similar, the maximum vibration levels of local and long-distance freights are similar. Locomotives and rail cars with wheel flats are the sources of the highest vibration levels.

If the transit project does not in any way change the freight service, tracks, etc., then vibration from the freight line would be part of the existing conditions and need to be considered in terms of cumulative impacts (see Section 6.2, Step 3 on how to consider cumulative impacts). If the project results in changes to the freight path, operations, frequency, etc. (e.g., relocating freight tracks within the ROW to make room for the transit tracks) then those potential impacts and mitigation should be evaluated as part of the proposed project. However, note that vibration mitigation is very difficult to implement on tracks where freight trains with heavy axle loads operate.

High-Speed Passenger Trains

Passenger trains travelling at high speeds, 90 to 250 miles per hour, have the potential for creating high levels of ground-borne vibration. Ground-borne vibration should be anticipated as one of the major environmental impacts of any trains travelling at high speeds located in an urban or suburban area.[x] For projects that are specifically high-speed transportation refer to the FRA "High-Speed Ground Transportation Noise and Vibration Impact Assessment" guidance manual.[39]

AGT Systems

AGT systems include a wide range of transportation vehicles that provide local circulation in downtown areas, airports, and theme parks. Because AGT systems normally operate at low speeds, have lightweight vehicles, run on elevated structures, and rarely operate in vibration-sensitive areas, ground-borne vibration problems are very rare.

Subway and At-grade Track

While ground-borne vibration produced from trains operating subway and at-grade track have very different characteristics, they have comparable overall vibration velocity levels. Complaints about ground-borne vibration are often more common near subways than near at-grade track. This is not because

[x] Amtrak trains (branded Acela at the time of publication) on the Northeast Corridor between Boston and Washington, DC, which attain moderate to high speeds in some sections with improved track, fit into this category.

subways create higher vibration levels than at-grade systems, rather because subways are usually located in more densely developed areas in closer proximity to building foundations, and the airborne noise is usually a more serious problem for at-grade systems than the ground-borne vibration. Another difference between subway and at-grade track is that the ground-borne vibration from subways tends to be higher frequency than the vibration from at-grade track, which makes the ground-borne noise more noticeable.

Streetcars

Complaints about ground-borne vibration from street cars are uncommon given that streetcars typically operate at very low speeds (less than 25 mph).

Buses

Because the rubber tires and suspension systems of buses provide vibration isolation, it is unusual for buses to cause ground-borne vibration or noise problems. For most issues with bus-related vibration, such as rattling of windows, the cause is almost always airborne noise and directly related to running surface conditions such as potholes, bumps, expansion joints, or other discontinuities in the road surface (usually resolved by smoothing the discontinuities).

Buses operating inside buildings will likely cause vibration concerns for other building inhabitants. An example of this situation is a bus transfer station in the same building as commercial office space. Sudden loading of a building slab by a heavy moving vehicle or by vehicles running over lane divider bumps can cause intrusive building vibration.

5.3 Paths of Transit Ground-Borne Vibration and Noise

Vibration travels from the source through the transit structure and excites the adjacent ground, creating vibration waves that propagate through soil layers and rock strata to the foundations of nearby buildings. The vibration then propagates from the foundation throughout the remainder of the building structure. The vibration of the building structure and room surfaces can radiate a low-frequency rumble called ground-borne noise (Figure 5-1).

Soil and subsurface conditions are known to have a strong influence on the levels of ground-borne vibration. Among the most important factors are the stiffness and internal damping of the soil and the depth to bedrock. Vibration propagation is more efficient in stiff clay soils. Shallow rock may concentrate the vibration energy close to the surface, resulting in ground-borne vibration problems at large distances from the track. Factors such as soil layers and depth to water table can have substantial effects on the propagation of ground-borne vibration. These factors are summarized in Table 5-3.

Table 5-3 Factors that Influence Levels of Ground-borne Vibration and Noise along Path

Geology Factors	Influence
Soil type	Vibration levels are generally higher in stiff clay-type soil than in loose sandy soil.
Rock layers	Vibration levels are usually high near at-grade track when the depth to bedrock is 30 ft or less. Subways founded in rock will result in lower vibration amplitudes close to the subway. Vibration levels do not attenuate as rapidly in rock as in soil.
Soil layering	Soil layering can have a substantial effect on the vibration levels since each stratum can have considerably different dynamic characteristics.
Depth to water table	The presence of the water table may have a substantial effect on vibration, but a definite relationship has not been established.

5.4 Receiver Factors that Influence Ground-Borne Vibration and Noise

Ground-borne vibration is a concern almost exclusively inside buildings. Train vibration may be perceptible to people who are outdoors, but it is very rare for outdoor vibration to cause complaints.

The vibration levels inside a building are dependent on the vibration energy that reaches the building foundation, coupling of the building foundation to the soil, and propagation of the vibration through the building. In general, the heavier a building is, the lower the response will be to the incident vibration energy. Common factors that contribute to ground-borne vibration and noise at the receiver are presented in Table 5-4.

Table 5-4 Factors that Influence Levels of Ground-Borne Vibration and Noise at the Receiver

Receiver Building Factors	Influence
Foundation type	The heavier the building foundation, the greater the coupling loss as the vibration propagates from the ground into the building.
Building construction	Each building has different characteristics relative to structure-borne vibration, but, in general, the heavier the building, the lower the levels of vibration. The maximum vibration amplitudes of the floors and walls of a building will often occur at the resonance frequencies of the components of the building.
Acoustical absorption	The more acoustically absorptive materials in the receiver room, the lower the ground-borne noise level. Note that because ground-borne noise usually is a low-frequency phenomenon, it is affected by low-frequency absorption (e.g., below 250 Hz).

5.5 Human Response to Transit Ground-borne Vibration and Noise

This section contains an overview of human receiver response to ground-borne vibration and noise. It serves as background information for the vibration impact criteria in Section 6.2.

The effects of ground-borne vibration can include perceptible movement of floors in buildings, rattling of windows, shaking of items on shelves or hanging on walls, and low-frequency noise (ground-borne noise). Building damage is not a factor for typical transportation projects, but in extreme cases, such as during blasting or pile-driving during construction, vibration could cause damage to buildings. Although the perceptibility threshold is approximately 65 VdB, human response to vibration is not usually substantial unless the vibration exceeds 70 VdB (Figure 5-4). A vibration level that causes annoyance is well below the damage risk threshold for typical buildings (100 VdB).

Ground-borne vibration is almost never a problem outdoors. Although the motion of the ground may be perceived, without the effects associated with the shaking of a building, the motion does not provoke the same adverse human reaction. Ground-borne noise that accompanies the building vibration is usually perceptible only inside buildings and typically is only an issue at locations with subway or tunnel operations where there is no airborne noise path or for buildings with substantial sound insulation such as a recording studio.

One of the challenges in developing suitable criteria for ground-borne vibration is that there has been relatively little research into human response to vibration and, specifically, human annoyance with building vibration. The American National Standards Institute (ANSI) developed criteria for evaluation of human exposure to vibration in buildings in 1983,[(40)] and the International Organization for Standardization (ISO) adopted similar criteria in 1989[(41)] and revised them in 2003.[(42)] The 2003 version of ISO 2631-2 acknowledges that "human response to vibration in buildings is very complex." It further indicates that the degree of annoyance cannot always be explained by the magnitude of the vibration alone. In some cases, complaints are associated with measured vibration that is lower than the perception threshold. Other phenomena such as ground-borne noise, rattling, visual effects such as movement of hanging objects, and time of day (e.g., late at night) all play some role in the response of individuals. To understand and evaluate human response, which is often measured by complaints, all of these related effects need to be considered.

Figure 5-5 illustrates the relationship between the vibration velocity level measured in 22 homes and the general response of the occupants to the vibration from measurements performed for several transit systems along with subjective ratings by researchers and residents. These data are published in the "State-of-the-Art Review of Ground-borne Noise and Vibration."[(43)] The figure also includes a curve representing the percent of people annoyed by vibration from high-speed trains from a Japanese study for comparison.[(44)]

Both the occupants and the people who performed the measurements agreed that floor vibration in the Distinctly Perceptible range is unacceptable for a residence. The data indicates that residential vibration exceeding 75 VdB is unacceptable for a repetitive vibration source such as rapid transit trains that pass every 5 to 15 minutes. The results from the Japanese study confirm the conclusion that at a vibration velocity level of 75 to 80 VdB, many people will find the vibration annoying. A Transportation Research Board (TRB) study of human response to vibration from 2009 also supports this finding and indicates that incidence of complaints fall rapidly with a level decreasing below 72 VdB.[(42)(45)]

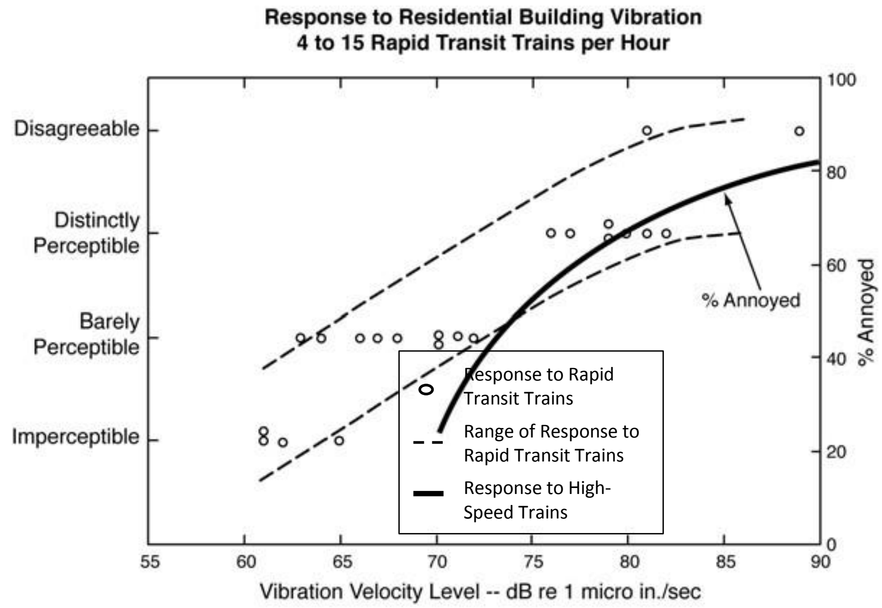


Figure 5-5 Response to Transit-Induced Residential Vibration

Table 5-5 presents the human response to different levels of ground-borne vibration and noise on which the criteria presented in Section 6.2 are based. The vibration level (VdB) is presented with the corresponding frequency assuming that the vibration spectrum peaks at 30 Hz or 60 Hz.[xi] The ground-borne noise levels (dBA) are estimated for the specified vibration velocity with a peak vibration spectrum of 30 Hz (Low Freq) and 60 Hz (Mid Freq). Note that the human response differs for vibration velocity level based on frequency. For example, the noise caused by vibrating structural components may cause annoyance even though the vibration cannot be felt. Alternatively, a low-frequency vibration can cause annoyance while the ground-borne noise level it generates does not.

[xi] The A-weighted level of ground-borne noise can be estimated by applying A-weighting to the vibration velocity spectrum and by subtracting an additional 5 dB for a room with average acoustical absorption. Since the A-weighting at 31.5 Hz is -39.4 dB, if the vibration spectrum peaks at 30 Hz, the A-weighted sound level will be approximately 40 dB lower than the velocity level. If the vibration spectrum peaks at 60 Hz, the A-weighted sound level will be approximately 25 dB lower than the velocity level.

Table 5-5 Human Response to Different Levels of Ground-Borne Vibration and Noise

Vibration Velocity Level	Noise Level		Human Response
	Low Freq*	Mid Freq**	
65 VdB	25 dBA	40 dBA	Approximate threshold of perception for many humans. Low-frequency sound: usually inaudible. Mid-frequency sound: excessive for quiet sleeping areas.
75 VdB	35 dBA	50 dBA	Approximate dividing line between barely perceptible and distinctly perceptible. Many people find transit vibration at this level annoying. Low-frequency noise: tolerable for sleeping areas. Mid-frequency noise: excessive in most quiet occupied areas.
85 VdB	45 dBA	60 dBA	Vibration tolerable only if there are an infrequent number of events per day. Low-frequency noise: excessive for sleeping areas. Mid-frequency noise: excessive even for infrequent events for some activities.

*Approximate noise level when vibration spectrum peak is near 30 Hz.
**Approximate noise level when vibration spectrum peak is near 60 Hz.

SECTION

6

Vibration Impact Analysis

The FTA vibration impact analysis process is a multi-step process used to evaluate a project for potential vibration impacts. If impact is determined, measures necessary to mitigate adverse impacts are to be considered for incorporation into the project.[(3)]

The FTA vibration impact analysis steps are summarized as follows and are described in the following sections:

6.1 Determine vibration analysis level.

6.2 Determine vibration impact criteria.
  Option A: General Vibration Assessment Criteria
  Option B: Vibration Impact Criteria for a Detailed Vibration Analysis

6.3 Evaluate Impact: Vibration Screening Procedure
  Step 1: Classify project vehicles.
  Step 2: Determine project type.
  Step 3: Determine screening distance.
  Step 4: Identify vibration-sensitive land uses.

6.4 Evaluate Impact: General Vibration Assessment.
  Step 1: Select base curve for ground surface vibration level.
  Step 2: Apply adjustments.
  Step 3: Inventory vibration impact.

6.5 Evaluate Impact: Detailed Vibration Analysis
  Step 1: Characterize Existing Vibration
  Step 2: Estimate Vibration Impact
  Step 3: Assess Vibration Impacts
  Step 4: Determine Vibration Mitigation Measures

A similar process for the noise impact analysis is presented in Section 4. After the noise and vibration analyses have been completed, assess construction noise and vibration according to Section 7 and document findings according to Section 8.

6.1 Determine Vibration Analysis Level

There are three levels of analysis to assess the potential ground-borne vibration and noise impacts resulting from a public transportation project. The appropriate level of analysis varies by project based on the type and scale of the project, the stage of project development, and its environmental setting. These three levels are: the Vibration Screening Procedure, the General Vibration Assessment, and the Detailed Vibration Analysis. These levels of vibration analysis mirror the levels of noise analysis discussed in Section 4.2.

The Vibration Screening Procedure, performed first, defines the study area of any subsequent vibration impact assessment. Where there is potential for impact, the General Vibration Assessment and Detailed Vibration Analysis procedures are used to determine the extent and severity of impact. In some cases, a General Vibration Assessment may be all that is needed. However, if the proposed project is near noise-sensitive land uses and it appears at the outset that the impact would be substantial, it is prudent to conduct a Detailed Vibration Analysis.

The methods for analyzing transit vibration are consistent with those described in recognized handbooks and international standards.[46][47]

Conduct the vibration screening procedure and then determine the appropriate vibration analysis option:

Vibration Screening Procedure – The Vibration Screening Procedure is a simplified method of identifying the potential for vibration impact from transit projects. The Vibration Screening Procedure is applicable to all types of transit projects and does not require any specific knowledge about the vibration characteristics of the system or the geology of the area. This procedure uses simplified assumptions and considers the type of project and the presence or absence of vibration-sensitive land uses within a screening distance that has been developed to identify most potential vibration impacts. If no vibration-sensitive land uses are present within the defined screening distance, then no further vibration assessment is necessary.

The Vibration Screening Procedure steps are provided in Section 6.3, Step 1.

General Vibration Assessment – The General Vibration Assessment is used to examine potential impacts to vibration-sensitive land use areas identified in the screening step more closely. It uses generalized information likely to be available at an early stage in the project development process and during the development of most environmental documents.

Vibration levels at receivers are determined by estimating the overall vibration velocity level and A-weighted ground-borne noise levels as a function of distance from the track and applying adjustments to account for factors such as track support systems, vehicle speed, type of building, and track and wheel conditions.

A General Vibration Assessment is sufficient for the environmental review of many projects, including projects that compare transit modal alternatives or relocate a crossover or turnout. The General Vibration Assessment may also be sufficient if it results in a commitment to mitigation that eliminates the vibration impacts, such as a change in transit mode or alignment. However, if impact is identified through the General Vibration Assessment procedures and not mitigated, a Detailed Vibration Analysis of the selected alternative must be completed. Most vibration mitigation measures can only be specified after a Detailed Vibration Analysis has been done.

The General Vibration Assessment procedure is provided in Section 6.3, Step 2.

Detailed Vibration Analysis – The Detailed Vibration Analysis procedure is a comprehensive assessment method that produces the most accurate estimates of vibration impact for a proposed project and is often accomplished during the engineering phase of a project when there are sufficient data identifying potential adverse vibration impacts from the project. However, a Detailed Vibration Analysis may be warranted earlier in the environmental review process if there are potentially severe impacts due to the proximity of vibration-sensitive land uses. This type of assessment requires professionals with experience in performing and interpreting vibration propagation tests.

A Detailed Vibration Analysis may not be necessary for all segments of a project. Generalized prediction curves from the General Vibration Assessment procedures may be sufficient for most of the alignment, and the Detailed Vibration Analysis procedure may only need to be applied to particularly sensitive receivers (Section 6.3). Note that a Detailed Vibration Analysis is typically required when designing special track-support systems such as floating slabs or ballast mats. These and other costly vibration mitigation measures can only be specified after a Detailed Vibration Analysis has been done in the engineering phase of the project.

The Detailed Vibration Analysis procedure is presented in Section 6.3, Step 3.

6.2 Determine Vibration Impact Criteria

Use the FTA criteria presented in this section when conducting a General Vibration Assessment or a Detailed Vibration Assessment. Like noise, the sensitivity to vibration varies by land use type, and the criteria represent these sensitivities. These criteria are based on national and international standards,[38][39][48] as well as experience on human response to building vibration. See Section 5.5 for additional background information on the development of FTA vibration criteria. The criteria for environmental impact from ground-borne vibration and noise are based on the maximum root-mean-square (rms) vibration velocity levels for repeated events of the same source.

Determine the appropriate criteria based on the level of analysis (Section 6.1). The impact criteria for the General Vibration Assessment are presented in Option A, and the impact criteria for the Detailed Vibration Analysis are presented in Option B.

Option A: General Vibration Assessment Criteria

Determine the land use according to Step 1 and the frequency of events according to Step 2. The impact criteria for the General Vibration Analysis are presented in Step 3.

Step 1: Land Use Categories

Determine the appropriate land use category for the receiver of vibration impacts of the project or project segment. Sensitive land use categories for vibration assessment are presented in Table 6-1 in order of sensitivity. Consider indoor use of the buildings when determining land use categories for ground-borne vibration and noise, since impact is experienced indoors.

Table 6-1 Land Use Categories for General Vibration Assessment Impact Criteria

Land Use Category	Land Use Type	Description of Land Use Category
-	Special Buildings	This category includes special-use facilities that are very sensitive to vibration and noise that are not included in the categories below and require special consideration. However, if the building will rarely be occupied when the source of the vibration (e.g., the train) is operating, there is no need to evaluate for impact. Examples of these facilities include concert halls, TV and recording studios, and theaters.
1	High Sensitivity	This category includes buildings where vibration levels, including those below the threshold of human annoyance, would interfere with operations within the building. Examples include buildings where vibration-sensitive research and manufacturing* is conducted, hospitals with vibration-sensitive equipment, and universities conducting physical research operations. The building's degree of sensitivity to vibration is dependent on the specific equipment that will be affected by the vibration. Equipment moderately sensitive to vibration, such as high resolution lithographic equipment, optical microscopes, and electron microscopes with vibration isolation systems are included in this category.** For equipment that is more sensitive, a Detailed Vibration Analysis must be conducted.
2	Residential	This category includes all residential land use and buildings where people normally sleep, such as hotels and hospitals. Transit-generated ground-borne vibration and noise from subways or surface running trains are considered to have a similar effect on receivers.***
3	Institutional	This category includes institutions and offices that have vibration-sensitive equipment and have the potential for activity interference such as schools, churches, doctors' offices. Commercial or industrial locations including office buildings are not included in this category unless there is vibration-sensitive activity or equipment within the building. As with noise, the use of the building determines the vibration sensitivity.

* Manufacturing of computer chips is an example of a vibration-sensitive process.

** Standard optical microscopes can be impacted at vibration levels below the threshold of human annoyance.

*** Even in noisy urban areas, the bedrooms will often be in quiet buildings with effective noise insulation. However, ground-borne vibration and noise are experienced indoors, and building occupants have practically no means to reduce their exposure. Therefore, occupants in noisy urban areas are just as likely to be exposed to ground-borne vibration and noise as those in quiet suburban areas.

- **Ground-borne Vibration** – Locations with equipment that is highly-sensitive to vibration should be included in category 1 or assessed using the Detailed Vibration Analysis procedures (Section 6.3, Step 3) and criteria (Section 6.2, Option B) or specific criteria of the equipment manufacturer.

  Most computer installations or telephone switching equipment is not considered sensitive to vibration. Although the owners of this type of equipment often are concerned with the potential for ground-borne vibration interrupting smooth operation of their equipment, it is rare for computer or other electronic equipment to be particularly sensitive to vibration. This type of equipment is typically designed to operate in common building environments where the equipment may experience occasional disturbances and continuous background vibration caused by other equipment.

- **Ground-borne Noise** – Ground-borne noise is typically only assessed at locations with subway or tunnel operations where there is no airborne noise path, or for buildings with substantial sound insulation such as a recording studio. For typical buildings with at-grade or elevated transit operations, the interior airborne noise levels are often higher than the ground-borne noise levels. For interior rooms or other special cases, ground-borne noise may need to be assessed.

Step 2: Identify Event Frequency

Determine the appropriate frequency of events for the project or project segment.

Community response to vibration correlates with the frequency of events and, intuitively, more frequent events of low vibration levels may evoke the same response as fewer high vibration level events. This effect is accounted for in the ground-borne vibration and noise impact criteria by characterizing projects by frequency of events. Event frequency definitions are presented in Table 6-2.

Table 6-2 Event Frequency Definitions

Category	Definition	Typical Project Types
Frequent Events	More than 70 events per day	Most rapid transit
Occasional Events	30–70 events per day	Most commuter trunk lines
Infrequent Events	Fewer than 30 events per day	Most commuter rail branch lines

Step 3: Apply Impact Criteria by Land Use and Event Frequency

Select the appropriate impact criteria for ground-borne vibration and noise based on the previously identified land use categories and frequency of events. It is also important to consider the time of vibration sensitivity. If the building is not typically occupied when the vibration source (e.g., train) is operating, it is not necessary to consider impact.

The criteria in this section are appropriate for assessing human annoyance or interference with vibration-sensitive equipment for common projects. While not typical, existing conditions, freight train operations, and building damage may require consideration.

- **Existing Conditions** – The criteria in this section do not consider existing conditions. In most cases, the existing environment does not include a substantial number of perceptible ground-borne vibration or noise events. However, existing conditions must be evaluated in some cases, such as for projects located in an existing rail corridor. For criteria considering existing conditions, see Step 3b.

- **Freight Train Operations** – The criteria are primarily based on experience with passenger train operations. Passenger train operations (rapid transit, commuter rail, and intercity passenger railroad) create vibration events that last approximately 10 seconds or less while a typical line-haul freight train event lasts approximately two minutes. This manual is oriented to transit projects. However, situations will occur when freight train operations must be evaluated, such as when freight train tracks are relocated for a transit project within a railroad ROW. Guidelines on applying these criteria to freight train operations are presented in Step 3c.

- **Building Damage** – It is extremely rare for vibration from train operations to cause substantial or even minor cosmetic building damage. However, damage to fragile historic buildings located near the ROW may be of concern. Even in these cases, damage is unlikely except when the track is located very close to the structure. Damage thresholds that apply to these structures are discussed in Section 7.2, Step 4 on Construction Vibration Impacts.

3a. Choose the impact criteria by land use category and event frequency. The criteria for ground-borne vibration and noise land use categories 1-3 are presented in Table 6-3. The criteria are presented in terms of acceptable indoor ground-borne vibration and noise levels. Impact will occur if these levels are exceeded. Criteria for ground-borne vibration are expressed in terms of rms velocity levels in VdB, and criteria for ground-borne noise are expressed in terms of A-weighted sound pressure levels in dBA.

Table 6-3 Indoor Ground-Borne Vibration (GBV) and Ground-Borne Noise (GBN) Impact Criteria for General Vibration Assessment

Land Use Category	GBV Impact Levels (VdB re 1 micro-inch /sec)			GBN Impact Levels (dBA re 20 micro Pascals)		
	Frequent Events	Occasional Events	Infrequent Events	Frequent Events	Occasional Events	Infrequent Events
Category 1: Buildings where vibration would interfere with interior operations.	65 VdB*	65 VdB*	65 VdB*	N/A**	N/A**	N/A**
Category 2: Residences and buildings where people normally sleep.	72 VdB	75 VdB	80 VdB	35 dBA	38 dBA	43 dBA
Category 3: Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB	40 dBA	43 dBA	48 dBA

* This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. For equipment that is more sensitive, a Detailed Vibration Analysis must be performed.
** Vibration-sensitive equipment is generally not sensitive to ground-borne noise; however, the manufacturer's specifications should be reviewed for acoustic and vibration sensitivity.

The criteria for ground-borne vibration and noise for special land uses are presented in Table 6-4. The criteria are presented in terms of acceptable indoor ground-borne vibration and noise levels. Impact will occur if these levels are exceeded. As for the other land uses, the criteria for ground-borne vibration are expressed in terms of rms velocity levels in VdB, and criteria for ground-borne noise are expressed in terms of sound pressure levels in dBA.

Table 6-4 Indoor Ground-Borne Vibration and Noise Impact Criteria for Special Buildings

Type of Building or Room	Ground-Borne Vibration Impact Levels (VdB re 1 micro-inch/sec)		Ground-Borne Noise Impact Levels (dBA re 20 micro-Pascals)	
	Frequent Events	Occasional or Infrequent Events	Frequent Events	Occasional or Infrequent Events
Concert halls	65 VdB	65 VdB	25 dBA	25 dBA
TV studios	65 VdB	65 VdB	25 dBA	25 dBA
Recording studios	65 VdB	65 VdB	25 dBA	25 dBA
Auditoriums	72 VdB	80 VdB	30 dBA	38 dBA
Theaters	72 VdB	80 VdB	35 dBA	43 dBA

3b. Consider the presence of existing vibration conditions.
When the project will cause vibration more than 5 dB above the existing vibration, the existing source can be ignored, and the standard vibration criteria in Step 3a are appropriate. When the project will cause vibration less than 5 dB above the existing vibration level, use the instructions presented in this section to determine the appropriate impact criteria for the project. For information on characterizing existing vibration conditions, see Section 6.2, Step 3.

Use Table 6-5 and Figure 6-1 to determine the appropriate impact criteria. Sources of existing vibration are typically longer in duration than the events introduced into the environment due to the project. The frequency of use in the rail corridor is also a factor in characterizing the existing conditions. Both factors are considered in the process of determining appropriate impact criteria in Table 6-5 and Figure 6-1.
Examples of projects considering the existing vibration conditions in Table 6-5 and Figure 6-1 include:

- An automated people mover system planned for a corridor with an existing rapid transit service with 220 trains per day that did not have a significant increase in events from the existing 220 trains per day and that is not 3 dB above the existing vibration level would cause no additional impact.
- Where a new commuter rail line shares a heavily-used corridor with a rapid transit system, the project vibration exceeds the existing vibration level, there is not a significant increase in the number of events, and the project vibration exceeds the existing vibration level by 3 dB or more, the projected vibration levels must be evaluated using the standard impact criteria to determine impact.
- If a new transit project will use an existing railroad ROW and the location of existing railroad tracks are shifted, existing vibration can be substantial. The track relocation and reconstruction can result in lower vibration levels that would benefit the receivers and not introduce any adverse impact. However, if the track relocation causes higher vibration levels at vibration-sensitive receivers, then the projected vibration levels must be evaluated using the standard impact criteria to determine impact.

Table 6-5 Impact Criteria Considering Existing Conditions

Category	Number of Operations (At present – without project)	Criteria
Heavily Used	More than 12 trains per day	Use the standard vibration criteria in Section 6.2, Step 3a for the following scenarios: ▪ The existing vibration does not exceed the standard vibration criteria. ▪ The existing vibration exceeds the standard vibration criteria and there is a significant increase in events.* ▪ The existing vibration exceeds the standard vibration criteria, and the project vibration is 3 dB or more above the existing vibration. The project has no impact if the existing vibration exceeds the standard vibration criteria, the number of events does not increase significantly, and the project vibration does not exceed the existing vibration by 3 dB or more.
Moderately Used	5 – 12 trains per day	Use the standard vibration criteria in Section 6.2 Step 3a for the following scenarios: ▪ The existing vibration does not exceed the standard vibration criteria. ▪ The existing vibration exceeds the standard vibration criteria, and the project vibration is not 5 dB or more below the existing vibration. The project has no impact if the existing vibration exceeds the standard vibration criteria and the project vibration is at least 5 dB below the existing vibration.
Infrequently Used	Fewer than 5 trains per day	The standard vibration criteria in Section 6.2, Step 3a apply.

* Approximately doubling the number of events is required for a significant increase.

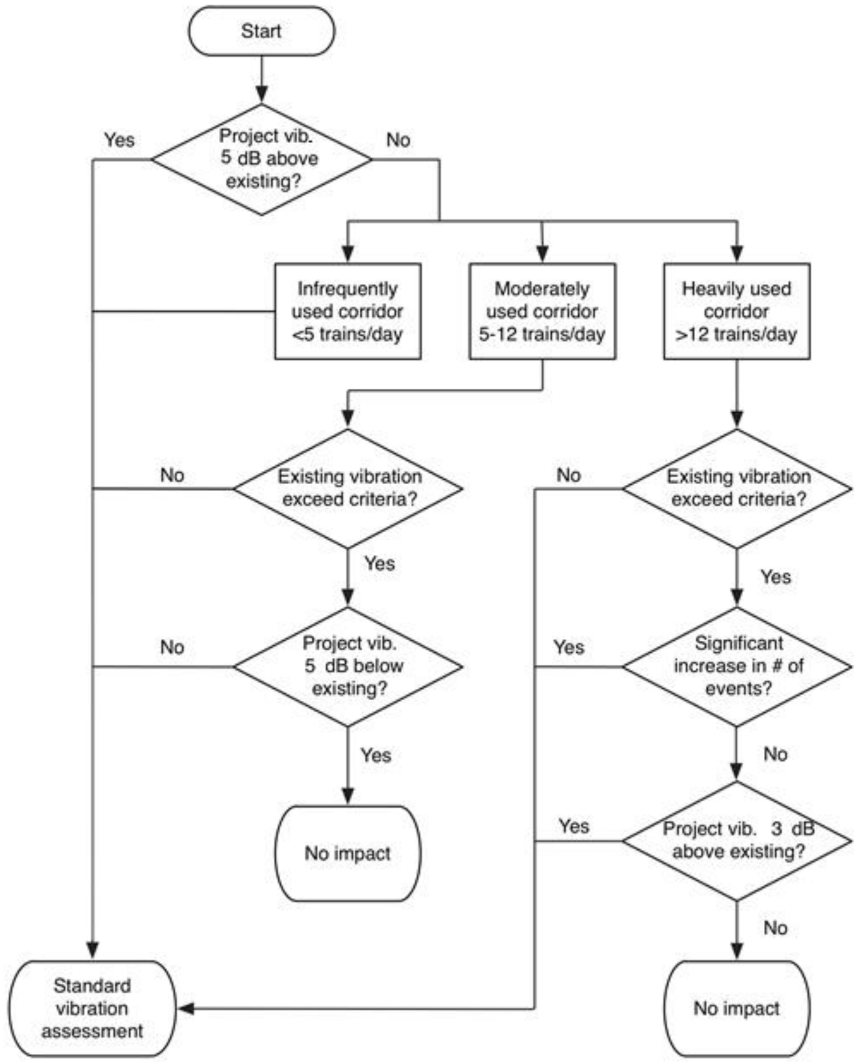


Figure 6-1 Existing Vibration[xii] Criteria Flow Chart

3c. Apply criteria to freight trains if part of the project.

Use the criteria presented in Step 3a to assess the vibration from freight trains in shared ROW scenarios because no specific impact criteria exist for freight railroads. It is important to consider that freight operations occur over substantially greater distances than passenger train operations and have different weight and axle loads.

When assessing vibration from freight train operations, consider the locomotive and rail car vibration separately. Since locomotive vibration lasts for a very short time, it can be characterized by the infrequent events category in Table 6-2. Rail car vibration from a typical line-haul freight train usually lasts for several minutes and can be characterized by the frequent events category in Table 6-2. Note

[xii] Vibration is abbreviated as "vib." in this flowchart.

that locomotives often create vibration levels that are 3 to 8 dB higher than those created by rail cars.

Use good engineering judgment to confirm the approach is reasonable for each project. For example, some spur rail lines carry very little rail traffic (sometimes only one train per week) or have short trains, in which case it may not be necessary to evaluate for impact. If there is uncertainty in how to determine the appropriate criteria, contact the FTA Regional office.

Decisions to relocate freight tracks closer to vibration-sensitive sites should be made with the understanding that increased vibration due to freight rail may not be possible to mitigate. Freight rail vibration may not always be successfully mitigated by the same methods as rail transit systems.

Option B: Vibration Impact Criteria for a Detailed Vibration Analysis

Determine the appropriate impact criteria for ground-borne vibration and ground-borne noise for a Detailed Vibration Analysis.

Step 1: Ground-Borne Vibration

Choose the appropriate criteria based on Figure 6-2 and Table 6-6.

Ground-borne vibration criteria presented in this section are more detailed than in the General Vibration Assessment. The criteria are based on international standards for the effects of vibration on people related to annoyance and interference with activities in buildings(39) as well as industry standards for vibration-sensitive equipment.(46) The criteria in this section are used to assess the potential for interference or annoyance from building response and to determine performance of vibration reduction methods. Note that for highly-sensitive equipment, specific vibration criteria provided by the manufacturer supersede the criteria in this section.

The criteria are presented by category in Figure 6-2 and are defined by international and industry standards.(39)(46) These criteria define limits for acceptable maximum rms vibration velocity level with a one-second averaging time at the floor of the receiving building in terms of a one-third octave band frequency spectrum. Band levels that exceed a particular criterion curve indicate impact; and therefore, mitigation options should be evaluated considering the specific frequency range in which the treatment is most effective. Interpretations of the criteria are presented in Table 6-6.

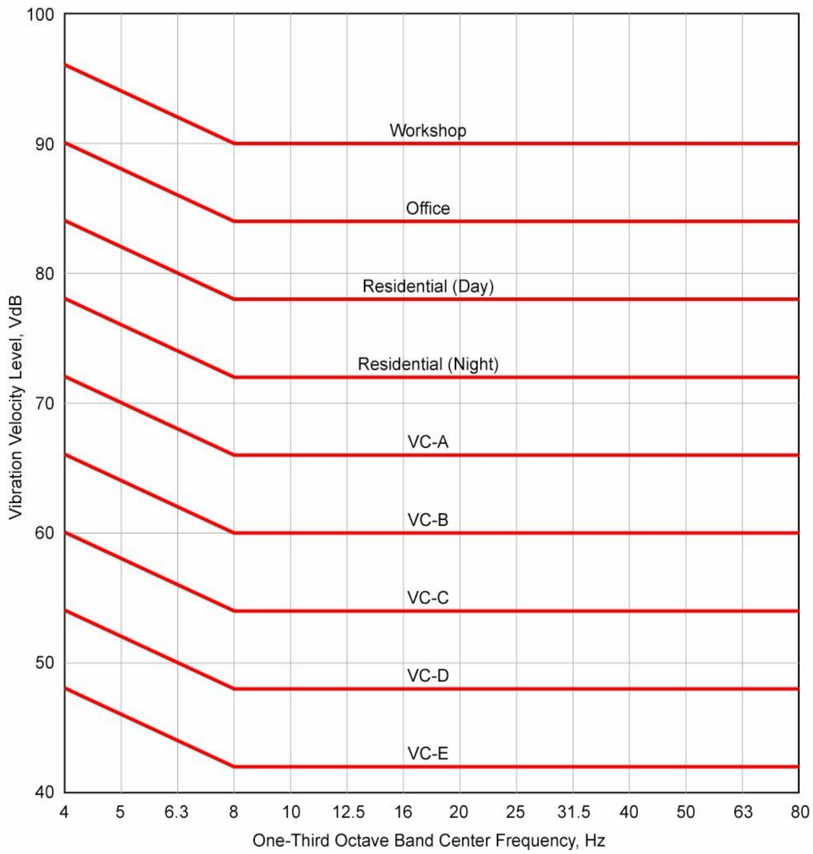


Figure 6-2 Criteria for Detailed Vibration Analysis

Table 6-6 Interpretation of Vibration Criteria for Detailed Vibration Analysis

Criterion Curve	Max Lv,* VdB	Description of Use
Workshop (ISO)	90	Vibration that is distinctly felt. Appropriate for workshops and similar areas not as sensitive to vibration.
Office (ISO)	84	Vibration that can be felt. Appropriate for offices and similar areas not as sensitive to vibration.
Residential Day (ISO)	78	Vibration that is barely felt. Adequate for computer equipment and low-power optical microscopes (up to 20X).
Residential Night, Operating Rooms (ISO)	72	Vibration is not felt, but ground-borne noise may be audible inside quiet rooms. Suitable for medium-power optical microscopes (100X) and other equipment of low sensitivity.
VC-A	66	Adequate for medium- to high-power optical microscopes (400X), microbalances, optical balances, and similar specialized equipment.
VC-B	60	Adequate for high-power optical microscopes (1000X) and inspection and lithography equipment to 3-micron line widths.
VC-C	54	Appropriate for most lithography and inspection equipment to 1-micron detail size.
VC-D	48	Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capabilities.
VC-E	42	The most demanding criterion for extremely vibration-sensitive equipment.

* As measured in 1/3-octave bands of frequency over the frequency range 8 to 80 Hz.

In addition to the uses described in Table 6-6, the detailed vibration criteria can be applied to the three land use categories presented in Table 6-3.

- For residential land uses (category 2), use the residential night criterion curve in Table 6-6.
- For institutional uses (category 3), use the residential day criterion curve in Table 6-6.
- For category 1, the specific use of the building should be matched to the appropriate criterion curve in Table 6-6.
- For special buildings, such as those found in Table 6-4, either the criteria in Table 6-4 or specific criteria presented by the building operator should be used.

These criteria use a frequency spectrum because vibration-related problems generally occur due to resonances of the structural components of a building or vibration-sensitive equipment. Resonant response is frequency-dependent. A Detailed Vibration Analysis can provide an assessment that identifies potential problems resulting from resonances.

The detailed vibration criteria are based on generic cases when people are standing or equipment is mounted on the floor in a conventional manner. Consequently, the criteria are less stringent at very low frequencies below 8 Hz. Where special vibration isolation has been provided in the form of pneumatic isolators, the resonant frequency of the isolation system is very low. Consequently, in this special case, the curves may be extended flat at lower frequencies.

Step 2: Ground-borne Noise

Ground-borne noise impacts are assessed based on criteria for human annoyance and activity interference. The Detailed Vibration Analysis procedure provides vibration spectra inside a building. To evaluate ground-borne noise, convert these vibration spectra to sound pressure level spectra in the occupied spaces using the method described in Section 6.5 and compare to the criteria as follows:

- For residential buildings, use the criteria presented in Table 6-3.
- For special buildings listed in Table 6-4, A-weighted noise may not be sufficient to assess activity interference for a Detailed Vibration Analysis. Each special building may have a unique specification for acceptable noise levels and criteria must be determined on a case-by-case basis. For example, a recording studio may have stringent requirements for allowable noise in each frequency band.

6.3 Evaluate Impact: Vibration Screening Procedure

Determine the potential for impact using the Vibration Screening Procedure by identifying any vibration-sensitive land uses (Table 6-1) within the appropriate screening distance.

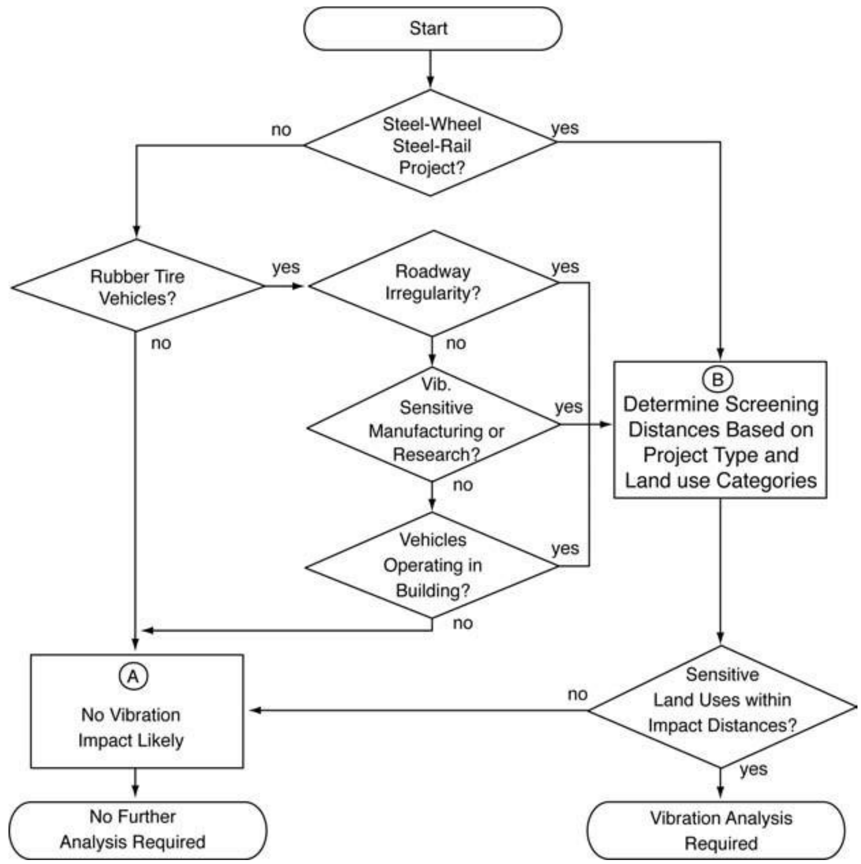


Figure 6-3 Flow Chart of Vibration Screening Process

Step 1: Classify Project Vehicles

Determine the project type and the next step based on the guidelines below.

Option A: No Vehicles – Transit projects that do not involve vehicles do not have potential for vibration impact and do not require further analysis (Box A in Figure 6-3).

Many smaller FTA-funded projects, such as bus terminals, park-and-ride lots, and station rehabilitation are in this category, and do not require further analysis of ground-borne vibration impact. However, if track systems are modified (e.g., tracks moved or switches modified), *proceed to Step 2*.

Option B: Steel-wheeled/Steel-rail Vehicles – Transit projects with steel-wheeled/steel-rail vehicles have potential for vibration impact (Box B in Figure 6-3); *proceed to Step 2*. These rail systems include urban rapid transit, LRT, commuter rail, and steel-wheel intermediate capacity transit (ICT) systems.

Option C: Rubber-tire Vehicles – For projects that involve rubber-tire vehicles and do not meet the following conditions, vibration impact is unlikely, and no further analysis is needed. *Proceed to Step 2* for projects that involve rubber-tire vehicles and meet the following conditions (Box A in Figure 6.3):

- **Roadway irregularity** – Expansion joints, speed bumps, or other design features that result in unevenness in the road surface can result in perceptible ground-borne vibration at distances up to 75 ft away.
- **Operation close to vibration-sensitive buildings** – Buses, trucks, or other heavy vehicles operating close to a vibration-sensitive building (within approximately 100 ft from the property line) may impact vibration-sensitive activities, such as research that uses electron microscopes or manufacturing of computer chips.
- **Vehicles operating within buildings** – Special considerations are often required for shared use facilities where vehicles operate inside or directly underneath buildings such bus stations located inside an office building complex.

Step 2: Determine Project Type

Determine the project type according to Table 6-7.

Table 6-7 Project Types for Vibration Screening Procedure

Project Type Number	Project Type	Description
1	Conventional Commuter Railroad	Both locomotives and passenger vehicles create vibration. For commuter trains, the highest vibration levels are typically created by the locomotives. Electric commuter rail vehicles create levels of ground-borne vibration that are comparable to electric rapid transit vehicles.
2	RRT	Ground-borne vibration impact from rapid transit trains is one of the major environmental issues for new systems. Ground-borne vibration is usually a major concern for subway operations. It is less common for at-grade and elevated rapid transit lines to create intrusive ground-borne vibration and noise since air-borne noise typically dominates.
3	LRT and Streetcars	The ground-borne vibration characteristics of light rail systems are very similar to those of rapid transit systems. Because the speeds of light rail systems are usually lower, typical vibration levels are usually lower. Steel-wheel/steel-rail AGT is included in either this category or the ICT category depending on the level of service and train speeds.
4	Intermediate Capacity Transit	Because of the low operating speeds of most ICT systems, vibration problems are not common. However, steel-wheel ICT systems that operate close to* vibration-sensitive buildings have the potential of causing intrusive vibration. With a stiff suspension system, an ICT system could create intrusive vibration.
5	Bus and Rubber-Tire Transit Projects	This category encompasses most projects that do not include steel-wheel trains of some type. Examples include diesel buses, electric trolley buses, and rubber-tired people movers. Most projects that do not include steel-wheel trains do not cause vibration impacts.**

*See the screening distances for category 1 land uses in Table 6-8.

****** Most complaints about vibration caused by buses and trucks are related to rattling of windows or items hung on the walls. These vibrations are usually the result of airborne noise and not ground-borne vibration. In the case where ground-borne vibration is the source of the complaint, the vibration can usually be attributed to irregularities in the road.

Step 3: Determine Screening Distance

Determine the appropriate screening distances based on land use and project type according to Table 6-8.

The distances are based on the criteria presented in Section 6.3, the procedures in Section 6.4 assuming normal vibration propagation, and include a 5-dB factor of safety. Even so, areas with very efficient vibration propagation can have substantially higher vibration levels.

Because of the 5-decibel safety factor, the screening distances will identify most of the potentially impacted areas, even for areas with efficient propagation. However, when there is evidence of efficient propagation, such as previous complaints about existing transit facilities or a history of problems with construction vibration, increase the distances in Table 6-8 by a factor of 1.5.

Table 6-8 Screening Distances for Vibration Assessments

Type of Project	Critical Distance for Land Use Categories* Distance from ROW or Property Line, ft		
	Land Use Cat. 1	Land Use Cat. 2	Land Use Cat. 3
Conventional Commuter Railroad	600	200	120
RRT	600	200	120
LRT and Streetcars	450	150	100
ICT	200	100	50
Bus Projects (if not previously screened out)	100	50	--

*For the Vibration Screening Procedure, evaluate special buildings as follows: Category 1 - concert halls and TV studios, Category 2 - theaters and auditoriums

Step 4: Identify Vibration-Sensitive Land Uses

Identify all vibration-sensitive land uses (Table 6-1) within the chosen screening distance. If no vibration-sensitive land uses are identified, no further vibration analysis is needed. If one or more of the vibration-sensitive land uses are in the screening distance, complete a General Vibration Assessment (Section 6.4) or a Detailed Vibration Analysis (Section 6.5).

6.4 Evaluate Impact: General Vibration Assessment

Evaluate for impact using the General Vibration Assessment procedure if the Vibration Screening Procedure (Section 6.3) identified vibration-sensitive receivers within the screening distance of the transit vibration source.

For guidelines on when the General Vibration Assessment is appropriate, review Section 6.1.

The basic approach for the General Vibration Assessment is to define a curve or set of curves that predicts the overall ground-borne vibration as a function of distance from the source, then apply adjustments to these curves to account for factors such as vehicle speed, geologic conditions, building type, and receiver location within the building. When the vehicle type is not covered by the curves included in this section, it will be necessary to define an appropriate curve either by extrapolating from existing information or performing measurements at an existing facility.

Step 1: Select Base Curve for Ground Surface Vibration Level

Select a standard vibration curve to represent general vibration characteristics for the source.

The curves presented in Figure 6-4 are based on measurements of ground-borne vibration at representative North American transit systems and can be used to represent vibration characteristics for standard transportation systems in the General Vibration Assessment.

These curves assume typical ground-borne vibration levels, equipment in good condition, and speeds of 50 mph for the rail systems and 30 mph for buses. Adjustments to account for differences in speed and geologic conditions are included in Step 2.

Select a base curve from Figure 6-4 according to the guidelines in Table 6-9. Equations for the curves in Figure 6-4 are included in Table 6-10. Additional considerations for selecting a base curve for systems not included in Table 6-9 are presented below by transit mode.

Table 6-9 Ground Surface Vibration Level Base Curve Descriptions

Curve	Description
Locomotive-Powered Passenger or Freight Curve	Appropriate for vehicles powered by diesel or electric locomotives including intercity passenger trains and commuter rail trains.
Rapid Transit or Light Rail Vehicles Curve	Appropriate for both heavy and light-rail vehicles on at-grade and subway track.
Rubber-Tired Vehicles Curve	Appropriate for rubber-tire vehicles. These types of vehicles rarely create ground-borne vibration problems unless there is a discontinuity or bump in the road that causes the vibration. This curve represents the vibration level for a typical bus operating on smooth roadway.

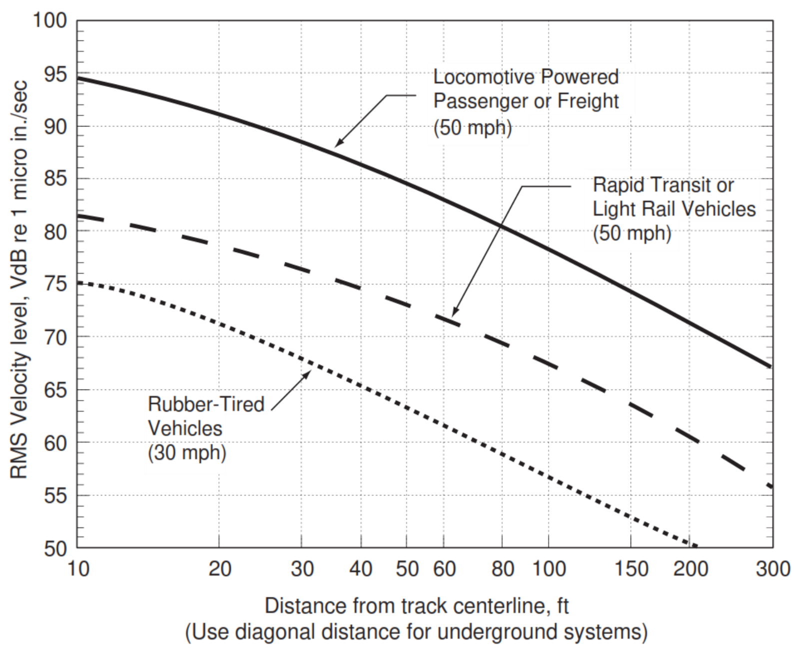


Figure 6-4 Generalized Ground Surface Vibration Curves

Table 6-10 Generalized Ground Surface Vibration Equations

Curve	Equation	
Locomotive Powered Passenger or Freight Curve	$L_v = 92.28 + 14.81\log(D) - 14.17\log(D)^2 + 1.65\log(D)^3$	**Eq. 6-1**
Rapid Transit or Light Rail Vehicles Curve	$L_v = 85.88 - 1.06\log(D) - 2.32\log(D)^2 - 0.87\log(D)^3$	**Eq. 6-2**
Rubber-Tired Vehicles Curve	$L_v = 66.08 + 34.28\log(D) - 30.25\log(D)^2 + 5.40\log(D)^3$	**Eq. 6-3**
L_v = velocity level, VdB D = distance, ft		

Considerations for selecting a base curve for different transit modes include:

- **Intercity passenger trains** – Although intercity passenger trains can be an important source of environmental vibration, it is rare that they are considered for FTA-funded projects unless a new transit mode uses an existing rail alignment. When a new transit line uses an existing rail alignment, changes in the intercity passenger traffic can result in either positive or negative impacts. Use the locomotive-powered passenger or freight curve for intercity passenger trains unless there are specific data available on the ground-borne vibration created by the new train operations.

- **Locomotive-powered commuter rail** – Use the locomotive-powered passenger or freight curve for all commuter rail system powered by either diesel or electric locomotives.

- **Electric multiple unit (EMU)** – Use the rapid transit or light rail vehicles curve for self-powered electric commuter rail trains.

- **Diesel multiple unit (DMU)** – Self-powered DMUs create vibration levels somewhere between rapid transit vehicles and locomotive-powered passenger trains. A vibration curve for DMUs can be estimated by lowering the locomotive-powered passenger or freight curve by 5 dB.

- **Subway heavy rail or light rail** – Use the rapid transit or light rail vehicles curve for subway heavy rail and subway light rail. Although vibrations from subway and at-grade tracks have very different characteristics, the overall vibration velocity levels are comparable. When applied to subways, the rapid transit or light rail vehicles curve assumes a relatively lightweight bored concrete tunnel in soil. The vibration levels will be lower for heavier subway structures such as cut-and-cover box structures and stations.

- **At-grade heavy rail or light rail** – Use the rapid transit or light rail vehicles curve for at-grade heavy rail or light rail. Heavy rail and LRT vehicles have similar suspension systems and axle loads and create similar levels of ground-borne vibration.

- **Elevated guideways or aerial structures** – Vibration from operations on an elevated structure is typically not an issue unless the guideway is supported by a building or located very close to buildings. Apply the appropriate adjustment for the aerial structures (Section 6.4, Step 2).

- **Streetcars** – Use the rapid transit or light rail vehicles curve for street cars.

- **ICT** – Use the rapid transit or light rail vehicles curve for ICT systems with steel wheels and the rubber-tired vehicles curve for ICT systems with rubber tires.

- **Other vehicle types** – For less common modes such as magnetically-levitated vehicles (maglev), monorail, or AGT, use good engineering judgment to choose a standard curve to best fit the mode or if a new curve needs to be developed, as a function of distance from the track. Examples include:
    - Vibration from a rubber-tire monorail operating on aerial guideway can be approximated using the rubber-tired vehicles curve with the appropriate adjustment for the aerial structure (Section 6.4, Step 2).
    - Most of the data available on the noise and vibration characteristics of maglev vehicles comes from high-speed systems intended for inter-city service. Even though there is no direct contact between the vehicle and the guideway, the dynamic loads on the guideway can generate ground-borne vibration. Measurements on a German high-speed maglev resulted in ground-borne vibrations at 75 mph which is comparable to the base curve for rubber-tired vehicles at 30 mph.(49)

Step 2: Apply Adjustments

Apply project-specific adjustments to the standard vibration curve.

Once the base curve has been selected, use the adjustments in the following instructions to develop project-specific vibration projections at each receiver. All adjustments are given as single numbers to add to, or subtract from, the base level.

Adjustments are separated by source, path, and receiver and include speed, wheel and rail type and condition, type of track support system, type of building foundation, and number of floors above the basement level. Calculate the appropriate adjustments to the base level. An example of the General Vibration Assessment is provided at the end of this Section.

It should be recognized that many of these adjustments are strongly dependent on the frequency spectrum of the vibration source and the frequency dependence of the vibration propagation. The adjustments in this section are suitable for generalized evaluation of the vibration impact and vibration mitigation measures because they are based on typical vibration spectra. However, these adjustments are not adequate for detailed evaluations of impact of vibration-sensitive buildings or for detailed specification of mitigation measures.

2a. Apply source adjustments to the base curve using Table 6-11 and the descriptions below to account for the project-specific source characteristics.

Table 6-11 Source Adjustment Factors for Generalized Predictions of GB Vibration and Noise

Source Factor	**Adjustment to Propagation Curve**			**Comment**
Speed		Reference Speed		Vibration level is approximately proportional to 20log(speed/speed$_{ref}$), see Eq. 6-4.
	Vehicle Speed	50 mph	30 mph	
	60 mph	+1.6 dB	+6.0 dB	
	50 mph	0.0 dB	+4.4 dB	
	40 mph	-1.9 dB	+2.5 dB	
	30 mph	-4.4 dB	0.0 dB	
	20 mph	-8.0 dB	-3.5 dB	
Vehicle Parameters (not additive, apply greatest value only)				
Vehicle with stiff primary suspension	+8 dB			Transit vehicles with stiff primary suspensions have been shown to create high vibration levels. Include this adjustment when the primary suspension has a vertical resonance frequency greater than 15 Hz.
Resilient Wheels	0 dB			Resilient wheels do not generally affect ground-borne vibration except at frequencies greater than about 80 Hz.
Worn Wheels or Wheels with Flats	+10 dB			Wheel flats or wheels that are unevenly worn can cause high vibration levels.
Track Conditions (not additive, apply greatest value only)				
Worn or Corrugated Track	+10 dB			Corrugated track is a common problem. Mill scale* on new rail can cause higher vibration levels until the rail has been in use for some time. If there are adjustments for vehicle parameters and the track is worn or corrugated, only include one adjustment.
Special Trackwork within 200 ft	+10 dB (within 100 ft) +5 dB (between 100 and 200 ft)			Wheel impacts at special trackwork will greatly increase vibration levels. The increase will be less at greater distances from the track. Do not include an adjustment for special trackwork more than 200 ft away.
Jointed Track	+5 dB			Jointed track can cause higher vibration levels than welded track.
Uneven Road Surfaces	+5 dB			Rough roads or expansion joints are sources of increased vibration for rubber-tire transit.
Track Treatments (not additive, apply greatest value only)				
Floating Slab Trackbed	-15 dB			The reduction achieved with a floating slab trackbed is strongly dependent on the frequency characteristics of the vibration.
Ballast Mats	-10 dB			Actual reduction is strongly dependent on frequency of vibration.
High-Resilience Fasteners	-5 dB			Slab track with track fasteners that are very compliant in the vertical direction can reduce vibration at frequencies greater than 40 Hz.

*Mill scale on a new rail is a slightly corrugated condition caused by certain steel mill techniques.

In addition to the comments in Table 6-11, use the following guidelines to select the appropriate adjustment factors. Some adjustments in the same category are not cumulative (additive) and only the greatest applicable adjustment should be applied. The adjustments that are not additive are noted in Table 6-11 and in the descriptions below. Note that some adjustments are not additive across multiple categories and are noted in the comments of Table 6-11. For example, the adjustment for a vehicle with stiff primary suspension is 8 dB, and the adjustment for wheel flats is 10 dB. If the vehicle has a stiff primary suspension and has wheel flats, the projected vibration levels should be increased by 10 dB, not 18 dB.

In addition, some vibration control measures are targeted for specific frequency ranges. The shape of the actual vibration spectra should be considered so that an appropriate vibration control measure may be selected.

- **Speed** – The levels of ground-borne vibration and noise vary, approximately, as 20 times the logarithm of speed. This means that doubling train speed will increase the vibration levels approximately 6 dB, and halving train speed will reduce the levels by 6 dB. The adjustments in Table 6-11 have been tabulated for reference vehicle speeds of 30 mph for rubber-tired vehicles and 50 mph for steel-wheel vehicles. Use the following relationship to calculate the adjustments for other speeds.

  $$Adj_{speed}\ (dB) = 20\log\left(\frac{speed}{speed_{ref}}\right) \qquad \textbf{Eq. 6-4}$$

  Variation with speed has been observed to be as low as $15\log\left(\frac{speed}{speed_{ref}}\right)$, but unless specific speed data for vibration for a vehicle has been obtained, use Eq. 6-4.

- **Vehicle Parameters** – The most important factors for the vehicles are the suspension system, wheel condition, and wheel type. Most new heavy rail and light rail vehicles have relatively soft primary suspensions. However, a stiff primary suspension (vertical resonance frequency greater than 15 Hz) can result in higher levels of ground-borne vibration than soft primary suspensions. Vehicles, for which the primary suspension consists of rubber or neoprene around the axle bearing, usually have a very stiff primary suspension with a vertical resonance frequency greater than 40 Hz or more.

  Deteriorated wheel condition is another factor that increases vibration levels. It can be assumed that a new system has vehicles with wheels in good condition. When older vehicles are used on new track, it is important to consider the condition of the wheels, and it may be appropriate to include an adjustment for the wheel condition.

  Resilient wheels will reduce vibration levels at frequencies greater than the effective resonance frequency of the wheel. When this resonance frequency is relatively high, greater than 80 Hz, resilient wheels may only have a marginal effect on ground-borne vibration.

The adjustments in this category are not additive; apply the greatest applicable value only.

- **Track Conditions** – This category includes the type of rail (welded, jointed, or special trackwork), the track support system, and the condition of the rail. The base curves assume welded rail in good condition. Jointed rail causes higher vibration levels than welded rail and the increase depends on the condition of the joints.

  Wheel impacts at special trackwork, such as frogs at crossovers, create much higher vibration forces than typical track conditions. Because of the higher vibration levels at special trackwork, crossovers are the principal areas of vibration impact on new systems. Methods of mitigating the vibration impact include modifying the track support system, installing low-impact frogs, or relocating the crossover. Special track support systems such as ballast mats, high-resilience track fasteners, resiliently supported ties, and floating slabs have all been shown to be effective in reducing vibration levels.

  The condition of the running surface of the rails can strongly affect vibration levels. Factors such as corrugations, general wear, or mill scale on new track can cause vibration levels 5 to 15 dB higher than normal. Mill scale will typically wear away after some time in service, but the track must be ground to remove corrugations or to reduce the roughness from wear.

  Roadway surfaces in the rubber-tired vehicle base curve are assumed to be smooth. Rough washboard surfaces, bumps, or uneven expansion joints are the types of running surface defects that cause increased vibration levels over the smooth road condition.

  The adjustments in this category are not additive; apply the greatest applicable value only. If there are adjustments for vehicle parameters and the track is worn or corrugated, only include one adjustment.

2b. Apply path adjustments to the base curve using Table 6-12 and the descriptions below to account for the project-specific path characteristics.

Table 6-12 Path Adjustment Factors for Generalized Predictions of GB Vibration and Noise

<table>
<tr><th>Path Factor</th><th colspan="3">Adjustment to Propagation Curve</th><th>Comment</th></tr>
<tr><td>Resiliently Supported Ties (Low-Vibration Track, LVT)</td><td colspan="3">-10 dB</td><td>Resiliently supported tie systems have been found to provide very effective control of low-frequency vibration.</td></tr>
<tr><td colspan="5">Track Structure (not additive, apply greatest value only)</td></tr>
<tr><td rowspan="7">Type of Transit Structure</td><td colspan="3">Relative to at-grade tie & ballast:</td><td rowspan="7">In general, the heavier the structure, the lower the vibration levels. Putting the track in cut may reduce the vibration levels slightly. Rock-based subways generate higher-frequency vibration.</td></tr>
<tr><td colspan="2">Elevated structure</td><td>-10 dB</td></tr>
<tr><td colspan="2">Open cut</td><td>0 dB</td></tr>
<tr><td colspan="3">Relative to bored subway tunnel in soil:</td></tr>
<tr><td colspan="2">Station</td><td>-5 dB</td></tr>
<tr><td colspan="2">Cut and cover</td><td>-3 dB</td></tr>
<tr><td colspan="2">Rock-based</td><td>-15 dB</td></tr>
<tr><td colspan="5">Ground-borne Propagation Effects</td></tr>
<tr><td rowspan="6">Geologic conditions that promote efficient vibration propagation</td><td colspan="2">Efficient propagation in soil</td><td>+10 dB</td><td>Refer to the text for guidance on identifying areas where efficient propagation is possible.</td></tr>
<tr><td rowspan="5">Propagation in rock layer</td><td>Dist.</td><td>Adjust.</td><td rowspan="5">The positive adjustment accounts for the lower attenuation of vibration in rock compared to soil. It is generally more difficult to excite vibrations in rock than in soil at the source.</td></tr>
<tr><td>50 ft</td><td>+2 dB</td></tr>
<tr><td>100 ft</td><td>+4 dB</td></tr>
<tr><td>150 ft</td><td>+6 dB</td></tr>
<tr><td>200 ft</td><td>+9 dB</td></tr>
<tr><td rowspan="6">Coupling to building foundation</td><td colspan="2">Wood-Frame Houses</td><td>-5 dB</td><td rowspan="6">In general, the heavier the building construction, the greater the coupling loss.</td></tr>
<tr><td colspan="2">1-2 Story Masonry</td><td>-7 dB</td></tr>
<tr><td colspan="2">3-4 Story Masonry</td><td>-10 dB</td></tr>
<tr><td colspan="2">Large Masonry on Piles</td><td>-10 dB</td></tr>
<tr><td colspan="2">Large Masonry on Spread Footings</td><td>-13 dB</td></tr>
<tr><td colspan="2">Foundation in Rock</td><td>0 dB</td></tr>
</table>

In addition to the comments in Table 6-12, use the following guidelines to select the appropriate adjustment factors.

- **Track Structure** – The weight and size of a transit structure affects the vibration radiated by that structure. In general, vibration levels are lower for heavier transit structures. Therefore, the vibration levels from a cut-and-cover concrete double-box subway can be assumed to be lower than the vibration from a lightweight concrete-lined bored tunnel.

  The vibration from elevated structures is lower than from at-grade track because of the mass and damping of the structure and the extra distance that the vibration must travel before it reaches the receiver. Elevated structures in AGT applications are sometimes designed to bear on building elements. This is a special case and may require detailed design considerations.

  The adjustments in this category are not additive; apply the greatest applicable value only.

- **Ground-Borne Propagation Effects – Geologic Conditions** – Although it is known that geologic conditions have a considerable effect on the vibration levels, it is rarely possible to develop more than a general understanding of the vibration propagation characteristics for a General Vibration Assessment. One of the challenges with identifying the cause of efficient propagation is the difficulty in determining whether higher than normal vibration levels are due to geologic conditions or due to special source conditions (e.g., rail corrugations or wheel flats).

  Some geologic conditions are repeatedly associated with efficient propagation. Shallow bedrock, less than 30 ft below the surface, is likely to have efficient propagation. Soil type and stiffness are also important factors in determining propagation characteristics. In particular, stiff, clayey soils, consolidated sand, gravel, and glacial till can be associated with efficient vibration propagation. Investigation of soil boring records can be used to estimate depth to bedrock and the presence of problem soil conditions.

  A conservative approach would be to use the 10-dB adjustment for efficient propagation for areas where efficient propagation is likely. However, this adjustment can greatly overstate the potential for vibration impact where efficient propagation is not present and should be applied using good judgment. Review available geological data and any complaint history from existing transit lines and major construction sites near the transit corridor to identify areas where efficient propagation is possible. If there is reason to suspect efficient propagation conditions, conduct a Detailed Vibration Analysis during the engineering phase and include vibration propagation tests at the areas with potential for efficient propagation.

- **Track Structure and Geologic Conditions** – **Examples**
  - **Subway**
    For a subway, determine if the subway will be founded in bedrock. Bedrock is considered to be hard rock. It is usually appropriate to consider soft siltstone and sandstone to be more like soil than hard rock. Whether a subway is founded in soil or rock can make a 15-dB difference in the vibration levels.

    When a subway structure is founded in rock, include the following Track Structure and Ground-borne Propagation Effects adjustments from Table 6-12:
    - Type of Transit Structure adjustment: Rock-based – 15 dB
    - Geologic Conditions adjustment: Propagation in rock layer for the appropriate distance.

    This adjustment increases with distance because vibration attenuates more slowly in rock than in the soil used as a basis for the reference curve.

- **At-grade** – When considering at-grade vibration sources, determine if the vibration propagation characteristics are typical or efficient. Efficient vibration propagation results in vibration levels approximately 10 dB higher than typical levels. This more than doubles the potential impact zone for ground-borne vibration.

- **Ground-Borne Propagation Effects – Coupling to Building Foundation** – Since annoyance from ground-borne vibration and noise is an indoor phenomenon, the effects of the building structure on the vibration must be considered. Wood-frame buildings, such as typical residential structures, are more easily excited by ground vibration than heavier buildings. In contrast, large masonry buildings with spread footings have a low response to ground vibration.

  When a building foundation is directly on the rock layer, there is no coupling loss due to the weight and stiffness of the building. Use the standard coupling factors based on building type if there is at least a 10-foot layer of soil between the building foundation and the rock layer.

2c. Apply receiver adjustments to the base curve using Table 6-13 and the descriptions below to account for the project-specific receiver characteristics. The data in Table 6-13 is applicable when the building structural features are known.

For more generic cases that do not have detailed information on individual buildings, use a conservative approach and apply the following adjustments to predict indoor vibration based on the outdoor vibration, instead of using the adjustments in Table 6-13:(43)(50)

- Light-weight, wood-frame construction 1st floor: +3 dB
- Light-weight, wood-frame construction 2nd and 3rd floors: +6 dB
- Large buildings: 0 dB
- Small masonry buildings: +3 dB

Table 6-13 Receiver Adjustment Factors for Generalized Predictions of GB Vibration and Noise

Receiver Factor	Adjustment to Propagation Curve		Comment
Floor-to-floor attenuation	1 to 5 floors above grade	-2 dB/floor	This factor accounts for dispersion and attenuation of the vibration energy as it propagates through a building starting with the first suspended floor.*
	5 to 10 floors above grade	-1 dB/floor	
Amplification due to resonances of floors, walls, and ceilings	+6 dB		The actual amplification will vary greatly depending on the type of construction. The amplification is lower near the wall/floor and wall/ceiling intersections.

* Floor-to-floor attenuation adjustments for the first floor assume a basement.

In addition to the comments in Table 6-13, use the following guidelines to select the appropriate adjustment factors. Note that receiver adjustments are additive.

- Vibration generally reduces in level as it propagates through a building. As indicated in Table 6-13, a 1- to 2-decibel attenuation per floor is typically appropriate.
- Resonances of the building structure, particularly the floors, will cause some amplification of the vibration. Consequently, for a wood-frame structure, the building-related adjustments nearly cancel out. Example: All adjustments for the first floor assuming a basement are: -5 dB for the coupling loss; -2 dB for the propagation from the basement to the first floor; and +6 dB for the floor amplification. The total adjustment in this case is -1 dB.

2d. Apply adjustments to the final adjusted curve using Table 6-14 and the descriptions below to convert ground-borne vibration levels to ground-borne noise levels.

Table 6-14 Conversion to Ground-borne Noise

Conversion to Ground-borne Noise			
Noise Level in dBA	Peak frequency of ground vibration:		Use these adjustments to estimate the A-weighted sound level given the average vibration velocity level of the room surfaces. See text for guidelines for selecting low-, mid-, or high-frequency characteristics. Use the high-frequency adjustment for subway tunnels in rock or if the dominant frequencies of the vibration spectrum are known to be 60 Hz or greater.
	Low frequency (<30 Hz)	-50 dB	
	Mid Frequency (peak 30 to 60 Hz)	-35 dB	
	High frequency (>60 Hz)	-20 dB	

Estimate the levels of radiated noise using the average vibration amplitude of the room surfaces (floors, walls, and ceiling), and the total acoustical absorption in the room.

The un-weighted sound pressure level is approximately 5 dB[37][43] less than the vibration velocity level when the velocity level is referenced to 1×10^{-6} inches/sec; but for a better estimate, it is necessary to consider general frequency ranges. Since ground-borne noise is A-weighted, the adjustments vary by frequency range, as described below. See Appendix B.1.4.1 for more information on A-weighting.

To select the appropriate adjustment, classify the frequency characteristics according to the guidelines below.

- **Low Frequency (<30 Hz)** – Low-frequency vibration characteristics can be assumed for the following conditions:
  - Subways surrounded by cohesionless sandy soil
  - Vibration isolation track support systems
  - Most surface track

- **Mid Frequency (peak 30 to 60 Hz)** – The mid-frequency vibration characteristic can be assumed for the following conditions:
  - Subways, unless other information indicates that one of the other assumptions is appropriate,
  - Surface track when the soil is very stiff with high clay content

- **High Frequency (>60 Hz)** – High-frequency characteristics can be assumed for the following conditions:
  - Subways with the transit structure founded in rock
  - Subways, when there is very stiff, clayey soil

Step 3: Inventory of Vibration Impact

Take inventory of vibration-sensitive land uses with impact and determine if a Detailed Vibration Analysis is required.

Compare the projected vibration levels, including all appropriate adjustments in Section 6.4, Step 2, to the criteria to determine if impact from ground-borne vibration or noise is likely. Note that for any transit mode, variation in vibration levels under apparently similar conditions is not uncommon. In the General Vibration Assessment, it is preferable to make a conservative assessment of the impact and include buildings that may ultimately not be subject to impact.

The standard curves in Section 6.4, Step 1, represent the upper range of vibration levels from well-maintained systems. Although actual levels fluctuate widely, it is rare that ground-borne vibration will exceed these curves by more than 1 or 2 dB unless there are extenuating circumstances such as wheel- or running-surface defects. However, because actual levels of ground-borne vibration will sometimes differ substantially from the projections, use the following guidelines to interpret vibration impact:

- **Projected vibration is below the impact threshold** – Vibration impact is unlikely, and the environmental document should state this.

- **Projected ground-borne vibration is 0 to 5 dB greater than the impact threshold** – There is a strong chance that actual ground-borne vibration levels will be below the impact threshold. The environmental document should report impact at these locations as exceeding the applicable threshold, present possible mitigation measures and costs, and commit to conducting more detailed studies to refine the vibration impact analysis during the engineering phase. During the Detailed Vibration Analysis, determine appropriate mitigation, if necessary. A site-specific Detailed Vibration Analysis may show that vibration impacts will not occur and control measures are not needed.

- **Projected ground-borne vibration is 5 dB or greater than the impact threshold** – Vibration impact is probable and Detailed Vibration Analysis must be conducted during the engineering phase to determine appropriate vibration control measures. The environmental document should report impact at these locations as exceeding the applicable threshold, present possible mitigation measures and costs, and commit to conducting more detailed studies to refine the vibration impact analysis during the engineering phase. During the Detailed Vibration Analysis, determine appropriate mitigation, if necessary. A site-specific, Detailed Vibration Analysis may show that very costly vibration mitigation must be incorporated into the project to eliminate the impacts.

FTA recommends the reporting of a vibration level as a single value and not as a range, as ranges tend to confuse the interpretation of impact.

Express the results of the General Vibration Assessment in terms of an inventory with the following components:

- Include all vibration-sensitive land uses as identified in the Vibration Screening Procedure.
- Organize the inventory according to the categories described in Table 6-8.
- Include information on potentially feasible mitigation measures to reduce vibration to acceptable levels based on the generalized reduction estimates provided in this section. To be considered feasible, the measure or combination of measures must provide at least a 5-dB reduction of the vibration levels and be reasonable in terms of cost.

These potential mitigation measures are considered preliminary. Final vibration mitigation measures can only be specified after a Detailed Vibration Analysis has been done; see Section 6.5 for more information. Vibration control is frequency-dependent; therefore, specific recommendations of vibration control measures can only be made after evaluating the frequency characteristics of the vibration.

Example 6-1 General Vibration Assessment – LRT

General Vibration Assessment for an LRT project

The hypothetical project is a LRT system that operates at 40 mph on at-grade, ballast and tie track with welded rail. The first floor of houses is at 125 ft from the LRT tracks and there is efficient propagation through the soil. The houses are constructed with wood frames. The houses will be exposed to 260 train passbys per day. Calculate the ground-borne vibration and assess for impact.

Select Base Curve for Ground Surface Vibration

Determine the appropriate base curve and the RMS velocity level (L_v).

According to Table 6-9, the Rapid Transit or Light Rail Vehicles curve is appropriate.

$L_v = 65\ VdB$ at 125 ft for this curve at 50 mph

Apply Adjustments

Apply the appropriate source adjustments using Table 6-11.

$$Source\ Speed\ Adjustment = 20\log\left(\frac{40}{50}\right) = -1.9\ dB$$
$$L_v = 65 - 1.9 = 63.1\ VdB$$

Apply the appropriate path adjustments using Table 6-12.

$$Efficient\ propagation = +10\ dB$$
$$Coupling\ to\ building\ foundation\ (wood\ frame) = -5\ dB$$
$$L_v = 63.1 + 10 - 5 = 68.1\ VdB$$

Apply the appropriate receiver adjustments using Table 6-13.

$$Amplification\ due\ to\ resonance\ of\ floor = +6\ dB$$
$$First\ floor\ attenuation = -2\ dB$$
$$L_v = 68.1 + 6 - 2 = 72.1\ VdB$$

Assess for Impact
Because there are more than 70 events per day, this project is in the Frequent Events category (Table 6-2). For category 2 land uses (residences) with frequent events, the impact criteria is 72 VdB (Table 6-3). Therefore, according to the General Vibration Assessment, there is potential for impact and a Detailed Vibration Analysis should be completed.

6.5 Evaluate Impact: Detailed Vibration Analysis

Evaluate for impact using the Detailed Vibration Analysis procedure, if appropriate (Section 6.1).

The goal of the Detailed Vibration Analysis is to use all available tools to develop accurate projections of potential ground-borne vibration impact and when necessary, to design mitigation measures. A Detailed Vibration Analysis requires developing estimates of the frequency components of the vibration signal, usually in terms of 1/3-octave-band spectra. The analytical techniques for solving vibration problems are complex, and the technology continually advances. Therefore, the approach presented in this section focuses on the key steps for these analyses. The key elements of the Detailed Vibration Analysis procedure and recommended steps are described below.

The methods in this section generally assume a steel-wheel/rail system. The procedures could be adapted to bus systems. However, this is rarely necessary because vibration impact is very infrequent with rubber-tired transit.

In general, when situations arise that are not explicitly covered in the Detailed Vibration Analysis, professional judgment may be used to extend these methods to cover these unique cases, when appropriate. Appendix G provides information on developing and using non-standard modeling procedures.

Step 1: Characterize Existing Vibration Conditions

Conduct measurements to survey and document the existing vibration conditions.

In contrast to noise impact analysis, the existing ambient vibration is not required to assess vibration impact in most cases; but, it is important to document general background vibration in the project corridor. Because the existing environmental vibration is usually below human perception, a limited vibration survey is sufficient even for a Detailed Vibration Analysis.

It is particularly valuable to survey vibration conditions at sensitive locations for the following reasons:

- To obtain valuable information on the true sensitivity of the activity to external vibration and obtain a reference condition under which vibration is not problematic.
- To document that existing vibration levels are above or below the normal threshold of human perception for the existing condition.
- To document levels of vibration created by existing rail lines. If vibration from an existing rail line is higher than the proposed train, there may not be impact even if the standard impact criteria are exceeded.
- To use existing vibration sources to characterize propagation. Existing vibration sources such as freight trains, industrial processes, quarrying operations, or normal traffic can be used to characterize vibration propagation. Carefully designed and performed measurements may eliminate the need for more complex propagation tests. See Appendix G for information on using non-standard modeling procedures.
- To identify the potential for efficient vibration propagation. If a measurement site has existing vibration approaching the range of human perception (e.g., the maximum vibration velocity levels are greater than about 65 VdB), then this site should be carefully evaluated for the possibility of efficient vibration propagation.

Conduct measurements to characterize existing vibration conditions. The goal of most ambient vibration measurements is to characterize the rms vertical vibration velocity level at the ground surface. In almost all cases, it is sufficient to measure only vertical vibration and ignore the transverse components of the vibration. Although transverse components[51] can transmit vibration energy into a building, the vertical component typically dominates.

1a. Choose Measurement Locations – Conduct outdoor and/or indoor measurements to characterize existing vibration conditions, as appropriate, for the project. Although ground-borne vibration is almost exclusively a problem inside buildings, it is generally recommended to perform measurements outdoors because equipment inside the building may cause more vibration than exterior sources. Additionally, the building structure and the resonances of the building can have strong effects on the vibration that are difficult to predict. It can also be important to measure and document those indoor sources of vibration. These indoor sources may cause vibration greater than that due to external sources like street traffic or aircraft overflights. When measuring (indoor) floor vibration, take measurements near the center of a floor span where the vibration amplitudes are the highest.

1b. Measurement Considerations

- **Site selection** – Selecting sites for an ambient vibration survey requires good judgment. Sites selected to characterize a transit corridor should be distributed along the entire project where potential for impacts have been identified and should be representative of the types of vibration environments found in the corridor. This would commonly include:
  - Measurements in quiet, residential areas removed from major traffic arterials to characterize low-ambient vibration areas;
  - Measurements along major traffic arterials and highways or freeways to characterize high-ambient vibration areas;
  - Measurements in any area with vibration-sensitive activities; and
  - Measurements at any major existing source of vibration such as railroad lines.

- **Transducer placement** – Place the transducers near the building setback line. For ambient measurements along railroad lines, it is recommended to include:
  - Multiple sites at several distances from the rail line at each site, and
  - 4 to 10 train passbys for each test.

  Because of the irregular schedule for freight trains and the low number of operations each day, it is often impractical to perform tests at more than two or three sites along the rail line or to measure more than two or three passbys at each site.

  Rail type and condition strongly affect the vibration levels. Consequently, it is important to inspect the track to locate any switches, bad rail joints, corrugations, or other factors that could be responsible for higher than normal vibration levels. Locations with these kinds of irregularities should be represented in addition to locations with rail in better condition.

- **Transducer mounting methods** – The way a transducer is mounted can affect the measured levels of ground-borne vibration.
  - Straightforward methods of mounting transducers on the ground surface or on pavement are adequate for vertical vibration measurements for the frequencies of concern for ground-borne vibration (less than about 200 Hz).
  - Quick-drying epoxy, clay, or beeswax can be used to mount transducers to smooth paved surfaces or metal stakes driven into the ground.
  - Rough concrete or rock surfaces require special mountings. One approach is to use a liberal base of epoxy to attach small aluminum blocks to the surface, and then mount the transducers on the aluminum blocks.
  - When in doubt, review the specific transducer documentation and discuss additional mounting guidance with the transducer manufacturer.

1c. Existing Vibration Characterization – The appropriate methods of characterizing ambient vibration are dependent on the type of information required for the analysis. Consider the following when characterizing the existing vibration:

- **Ambient vibration** – Ambient vibration is usually characterized with a continuous 10- to 30-minute measurement of vibration. The rms velocity level of the vibration velocity level over the measurement period provides an indication of the average vibration energy. The rms velocity level over the measurement period is typically equivalent to a long averaging time rms level.

- **Specific events** – Characterize specific events such as train passbys by the rms level over the time that the train passes by. If the locomotives produce vibration levels more than 5 dB higher than the passenger or freight cars, obtain a separate rms level for the locomotives. The locomotives can usually be characterized by the L_{max} during the train passby. The rms averaging time or time constant should be 1 second when determining L_{max}. In some cases, it may be adequate to characterize the train passby using L_{max}, which is simpler to obtain than the rms averaged over the entire train passby.

- **Spectral analysis** – Perform a spectral analysis of vibration propagation data. For example, if vibration transmission of the ground is suspected of having particular frequency characteristics, use 1/3-octave band charts to describe vibration behavior. Narrowband spectra also can be valuable, particularly for identifying discrete frequency components and designing specific mitigation measures.

  Note that it is preferred to characterize existing vibration in terms of the rms velocity level instead of the peak PPV, which is commonly used to monitor construction vibration. As discussed in Section 5.1, rms velocity is considered more appropriate than PPV for describing human response to building vibration.

Step 2: Estimate Vibration Impact

Estimate ground-borne vibration and noise at sites where significant impact is probable and assess for impact.

Predicting ground-borne vibration associated with a transportation project continues to be a developing field. Because ground-borne vibration is a complex phenomenon that is difficult to model and predict accurately, most projection procedures that have been used for transit projects rely on empirical data.

The procedure described in this section is based on site-specific tests of vibration propagation. This procedure was developed under a FTA-funded research contract(52) and is recommended for detailed evaluations of ground-borne vibration. Other approaches to a prediction procedure, such as finite element methods, can be used. See Appendix G for information on using non-standard modeling procedures.

Overview of Prediction Procedure – This procedure was developed to allow the use of data collected in one location to accurately predict vibration levels in another site where the geologic conditions may be completely different. The procedure is based on transfer mobility. Transfer mobility is the complex velocity response produced by a point force as a function of frequency. It represents the relationship between a vibration source that excites the ground and the resulting vibration of the ground surface. It is a function of both frequency and distance from the source. The analyses in this manual focus on transfer mobility magnitude, which is the magnitude for the velocity relative to the force without reference to phase. The transfer mobility level is the level in decibels relative to 1E-6 in/lb-s.

The transfer mobility measured at an existing transit system is used to normalize ground-borne vibration data and remove the effects of geology. The normalized vibration is referred to as the force density. Force density is the force per root distance along the track in $lb/ft^{1/2}$. The force density can be combined with transfer mobility measurements at vibration-sensitive sites along a new project to develop projections of future ground-borne vibration.

The transfer mobility between two points completely defines the composite vibration propagation characteristics between the two points. In most practical cases, receivers are close enough to the train tracks that the vibration cannot be considered as originating from a single point. Therefore, the vibration source must be modeled as a line-source. Consequently, the point transfer mobility must be modified to account for a line-source. The subsequent line-source transfer mobility is given in units of decibels relative to 1e-6 in/s/lb/sqrt(ft).

The prediction procedure considers ground-borne vibration to be divided into several basic components described below and shown in Figure 6-5.

- **Excitation Force (Force Density)** – The vibration energy is created by oscillatory and impulsive forces. Steel wheels rolling on smooth steel rails create random oscillatory forces. When a wheel encounters a discontinuity such as a rail joint, an impulsive force is created. The force excites the transit structure, such as the subway tunnel or the ballast for at-grade track.

  In the prediction method, the combination of the actual force generated at the wheel/rail interface and the vibration of the transit structure are usually combined into an equivalent force density level. The force density level is the level in decibels of the force density relative to 1 $lb/ft^{1/2}$ and describes the force that excites the soil/rock surrounding the transit structure.

- **Vibration Propagation (Transfer Mobility)** – The vibration of the transit structure causes vibration waves in the soil that propagate away from the transit structure. The vibration energy can propagate through the soil or rock in a variety of wave forms. All ground vibration includes shear and compression waves. Rayleigh waves [(49)] are also created and propagate along the ground surface. These Rayleigh waves can be a major carrier of vibration energy. The mathematical modeling of vibration is complicated when there are soil strata with different elastic properties, which is common. As indicated in Figure 6-5, the propagation through the soil/rock is modeled using the transfer mobility, which is usually determined experimentally.

The combination of the force density level and the transfer mobility is used to predict the ground- surface vibration. This is the major difference from the General Vibration Assessment, which generalizes estimates of the ground-borne vibration.

- **Building Vibration** – When the ground vibration excites a building foundation, it sets the building into vibratory motion and vibration waves propagate throughout the building structure. The interaction between the ground and the foundation causes some reduction in vibration levels. The amount of reduction is dependent on the mass and stiffness of the foundation. The more massive the foundation, the lower the response to ground vibration. As the vibration waves propagate through the building, they can create vibration that can be felt and cause windows and household items to rattle.

- **Audible Noise** – In addition to vibration that can be felt, the vibration of room surfaces radiates low-frequency sound that may be audible. The sound level is affected by the amount of acoustical absorption in the receiver room.

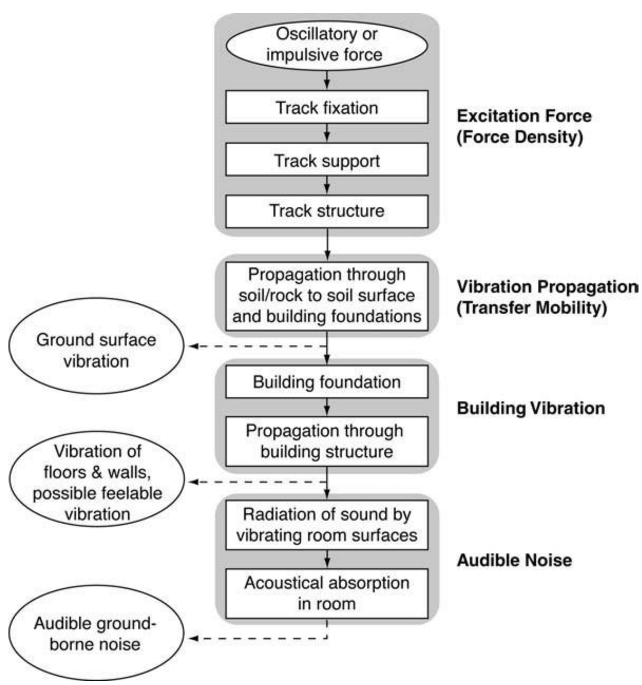


Figure 6-5 Ground-Borne Vibration and Noise Model

A fundamental assumption of the prediction approach outlined in this section is that the force density, transfer mobility, and the building coupling to the ground are all independent factors. The following equations are the basis for the prediction procedure, where all of the quantities are one-third octave band spectral levels in decibels with consistent reference values:

$$L_v = FDL + LSTM + C_{build} \quad \textbf{Eq. 6-5}$$

$$L_A = L_v + K_{rad} + K_{A-wt} \quad \textbf{Eq. 6-6}$$

where:

L_v = rms vibration velocity level in VdB
FDL = force density level in dB for a line vibration source such as a train
$LSTM$ = line-source transfer mobility level in dB from the tracks to the sensitive site
C_{build} = adjustments to account for ground-building foundation interaction and attenuation of vibration amplitudes as vibration propagates through buildings
L_A = A-weighted sound level
K_{rad} = adjustment to account for conversion from vibration to sound pressure level including accounting for the amount of acoustical absorption inside the room. A value of -5 dB can be used for K_{rad} for typical residential rooms when the decibel reference value for L_v is 1 micro in/sec [37][50]
K_{A-wt} = A-weighting adjustment at the 1/3-octave band center frequency

All of the quantities given above are functions of frequency, and the standard approach is to develop projections on a 1/3-octave band basis using the average values for each 1/3-octave band. The end results of the analysis are the 1/3-octave band spectra of the ground-borne vibration and the ground-borne noise.

The spectra are then compared to the vibration criteria for the Detailed Vibration Analysis. The A-weighted ground-borne noise level can be calculated from the vibration spectrum and compared to the criteria. This more detailed approach differs from the General Vibration Assessment, where the overall vibration velocity level and A-weighted sound level are predicted without any consideration of the particular frequency characteristics of the propagation path.

The key steps in obtaining quantities for Eq. 6-5 and Eq. 6-6 are presented in the following steps and include:

Step 2a. Estimate force density
Step 2b. Measure the point-source transfer mobility
Step 2c. Estimate line-source transfer mobility
Step 2d. Project ground-borne vibration and ground-borne noise

2a. Estimate Force Density – The estimate of force density can be based on previous measurements or a special test program can be designed to measure the force density at an existing facility.

If no suitable measurements are available, conduct testing at a transit facility with equipment similar to the planned vehicles. Adjustments for factors such as train speed, track support system, and vehicle suspension may be needed to match the force density to the conditions at a specific site. Review the report

"State-of- the-Art Review: Prediction and Control of Ground-Borne Noise and Vibration from Rail Transit Trains" (41) for examples of appropriate adjustments.

Force density is not a quantity that can be measured directly; it must be inferred from measurements of transfer mobility and train vibration at the same site. To derive force density, the best results are achieved by deriving line-source transfer mobility from a line of impacts. The standard approach is to average the force density from measurements at three or more positions at one site. If feasible, it is recommended to take measurements at more than one site and at multiple speeds.

If no suitable measurements are available, see Steps 2b and 2c for guidelines on obtaining line-source transfer mobility.

The force density for each 1/3-octave band is as follows:

$$FDL = L_v - LSTM \quad \textbf{Eq. 6-7}$$

where:

FDL = force density level in dB
L_v = measured train ground-borne vibration level in VdB
$LSTM$ = line-source transfer mobility level in dB

Figure 6-6 shows example trackbed force densities in decibels relative to 1 $lb/(ft)^{1/2}$. These force densities were developed from measurements of vibration from heavy and LRT vehicles and represent an incoherent line of vibration force equal to the length of transit trains. This figure provides a comparison of the vibration forces from heavy commuter trains and LRT vehicles with different types of primary suspensions, illustrating the range of vibration forces commonly experienced in a transit system. A force density of a vehicle includes the characteristics of its track support system at the measurement site. Adjustments must be applied to the force density to account for differences between the facility where the force density was measured and the new system being analyzed.

Figure 6-7 shows typical force densities for rail transit vehicles at 40 mph on ballast and tie tracks, which are approximately within the tolerances shown in Figure 6-6. The force densities should be applied very carefully for other track types and speeds. The embedded tracks, although considerably stiffer than ballast and tie tracks, are expected to show similar force density levels.(53) The curves in Figure 6-7 should also be applied with caution for newer generations of light rail vehicles as well as vehicles that utilize direct fixation tracks. The preferred approach for vibration predictions would be to perform force density measurements at a system with vehicles and operations that are similar to those of the future project.

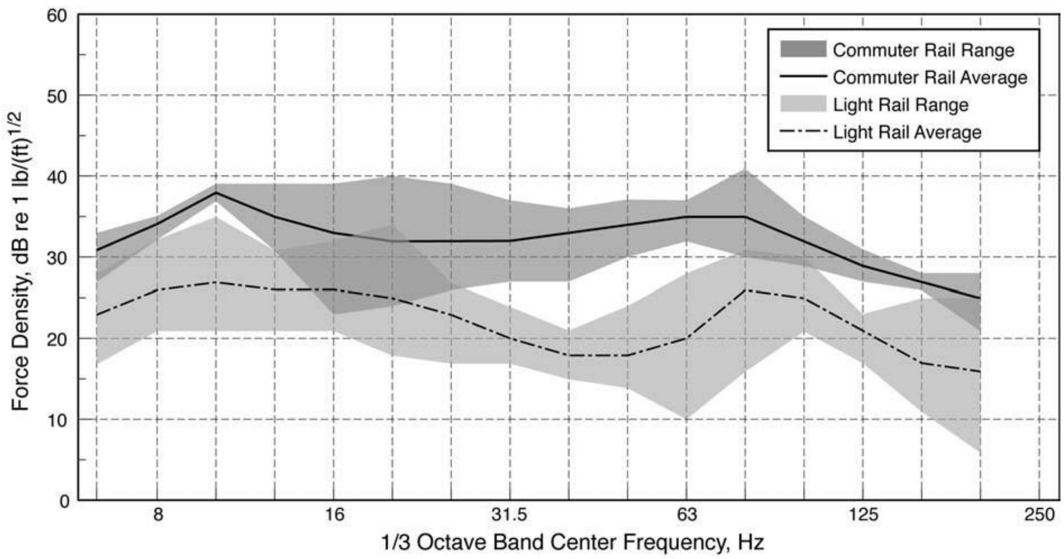


Figure 6-6 Typical Force Densities for Rail Transit Vehicles, 40 mph

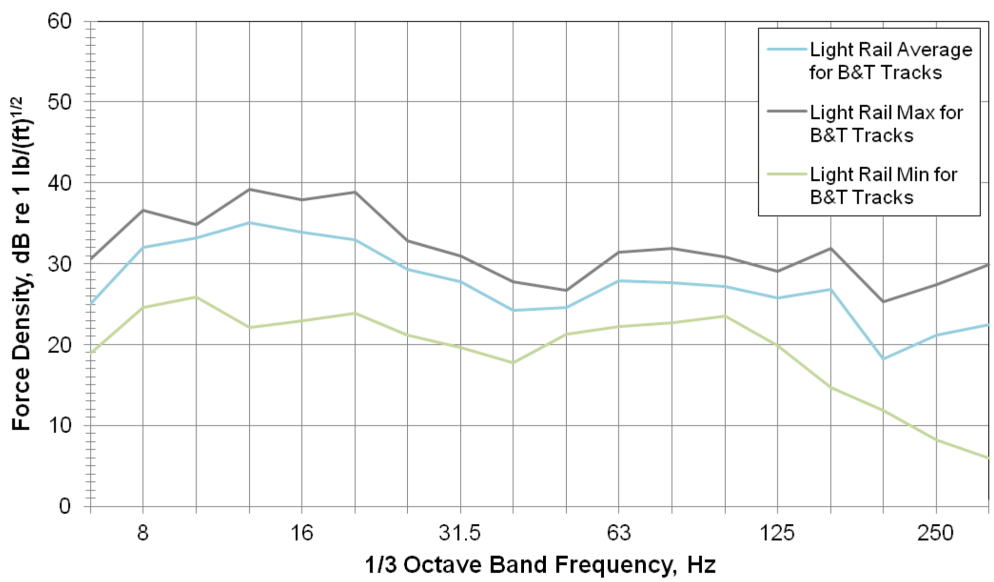


Figure 6-7 Typical Force Densities for LRT Vehicles, 40 mph

2b. Measure Point-Source Transfer Mobility – Using the appropriate instrumentation, measure point-source transfer mobility for sources with short lengths, such as buses or single car vehicles or columns supporting elevated structures. For longer vehicles, see Section 2c for a discussion of measuring line-source transfer mobilities.

The test procedure to measure point-source transfer mobility consists of impacting the ground by dropping a heavy weight and measuring the force into the ground and the response at several distances from the impact. Other excitation sources may include swept sine, sine-dwell, random vibration, and maximum length sequence. The goal of the test is to create vibration pulses that travel from the source to the receiver using the same path that will be taken by the transit system vibration.

Figure 6-8 illustrates the field procedure for measuring both at-grade and subway testing of transfer mobility. A weight is dropped from a height of 3 to 4 ft onto a force transducer. The responses of the force and vibration transducers are recorded on a multichannel recorder for later analysis in the laboratory. An alternative approach is to set up the analysis equipment in the field and capture the signals directly. This complicates the field testing, but eliminates the laboratory analysis of recorded data.

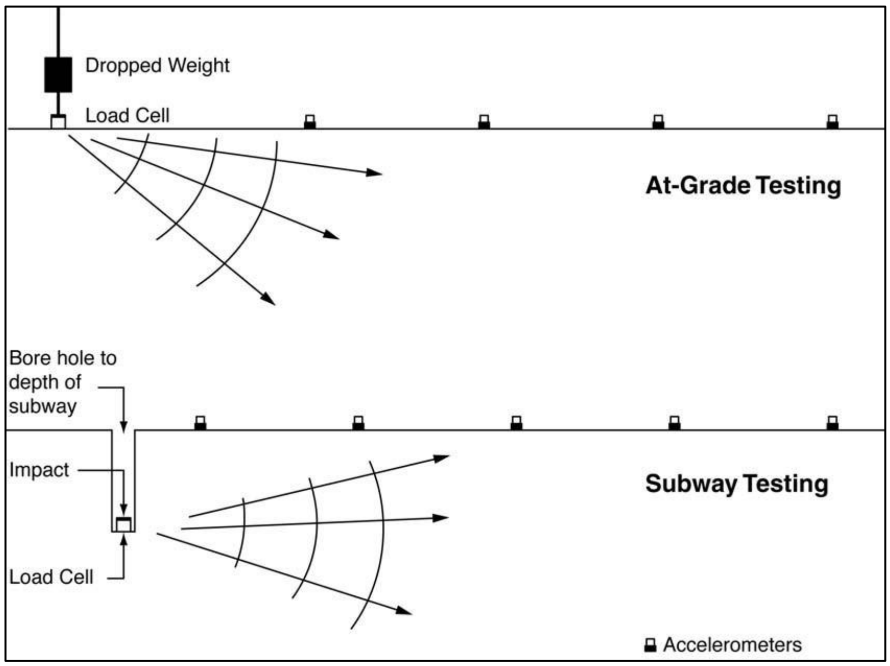


Figure 6-8 Test Configuration for Measuring Transfer Mobility

When the procedure is applied to subways, the force must be located at the approximate depth of the subway. This is done by drilling a bore hole and locating the force transducer at the bottom of the hole. The tests are usually performed while the bore holes are drilled to allow for the use of the soil-sampling equipment on the drill rig for the transfer mobility testing. The force transducer is attached to the bottom of the drill string and lowered to the bottom of the hole. A standard soil sampling hammer is used to excite the ground; typically, a 140-pound weight is dropped 18 inches onto a collar that is attached to the drill string. The force transducer must be capable of operating under water if the water table is near the surface or a slurry drilling process is used.

Standard signal-processing techniques are used to determine the transfer function (frequency response function) between the exciting force and the resultant ground-borne vibration. Numerical regression methods are used to combine a number of two-point transfer functions into a smooth point-source transfer mobility level that represents the average vibration propagation characteristics of a site as a function of both distance from the source and frequency. The transfer mobility level is usually expressed in terms of a group of 1/3-octave band transfer mobility levels. Figure 6-9 is an example of point-source transfer mobility levels from a series of tests at the Transportation Technology Center in Pueblo, Colorado.(50)(54)(55)(56)(57)

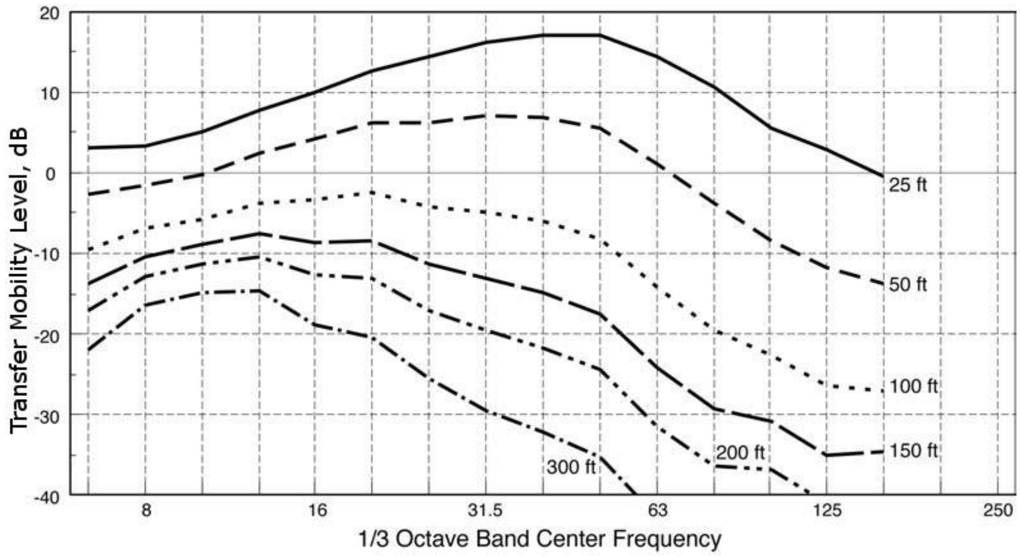


Figure 6-9 Example of Point-Source Transfer Mobility

Instrumentation

Performing a transfer mobility test requires specialized equipment, which is generally available from commercial sources. Typical instrumentation for field-testing and laboratory analysis of transfer mobility is shown in Figure 6-10.

A load cell can be used as the force transducer. The force transducer should be capable of impact loads of 5,000 to 50,000 pounds depending on the hammer used for the impact. For borehole testing, the load cell must be hermetically sealed and capable of being used at the bottom of a 30- to 100-foot-deep hole partially filled with water.

Either accelerometers or geophones can be used as the vibration transducers. Geophones should be carefully mounted so that they are vertical. The requirement is that the transducers with the associated amplifiers be capable of accurately measuring levels of 0.0001 in/sec at 40 Hz and have a flat frequency response from 6 Hz to 400 Hz. Data should be acquired with a digital acquisition system with a flat frequency response over the range of 6 to 400 Hz.

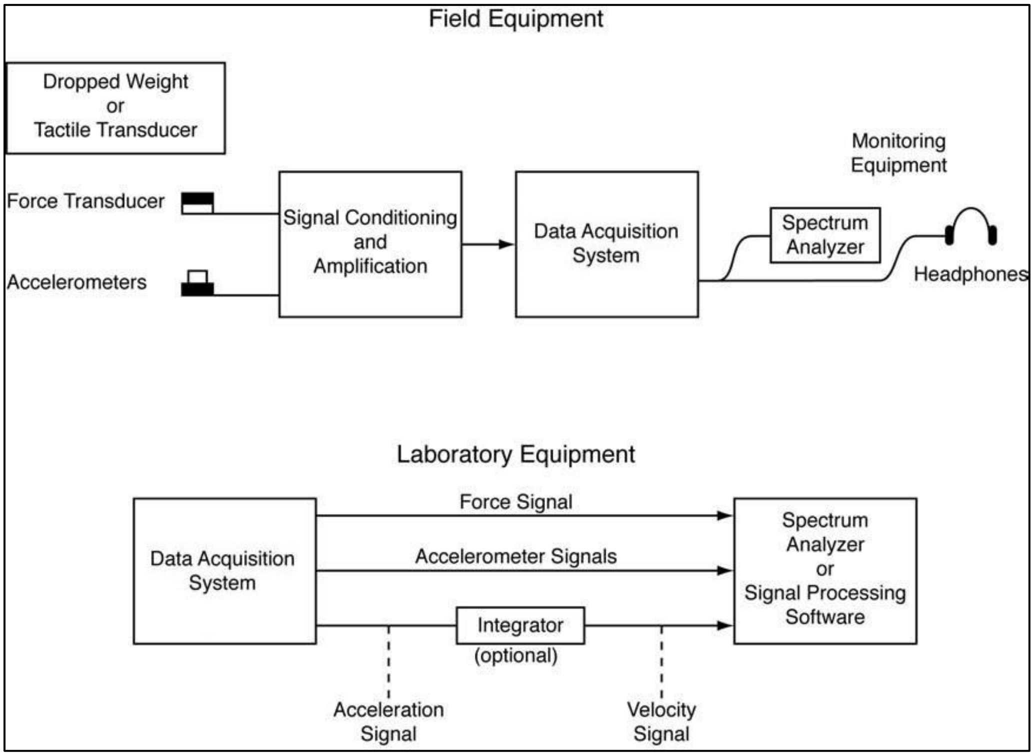


Figure 6-10 Equipment Required for Field Testing and Laboratory Analysis

A narrowband spectrum analyzer or signal-processing software can be used to calculate the transfer function and coherence between the force and vibration data. The analyzer must be capable of capturing impulses from at least two channels to calculate the frequency spectrum of the transfer function between the force and vibration channels. All transfer functions should include the average of at least 20 impulses. Time averaging of the impulses will provide substantial signal enhancement, which is usually required to accurately characterize the transfer function. Signal enhancement is particularly important when the vibration transducer is more than 100 ft from the impact.

Alternative methods of determining transfer mobility may be used, provided that these techniques have been demonstrated to provide the same results as the conventional weight-drop method over the frequency range of 6 Hz to 400 Hz. See Appendix G for information on developing and using non-standard procedures. These methods may include using other impulse-response measurement systems involving the use of shakers or electro-mechanical actuators, stimuli such as sweeps or maximum length sequences (MLS), and various signal processing techniques. A forthcoming ANSI Standard will describe in detail the procedures, methodologies, and reporting requirements for performing ground-borne vibration propagation measurements.

The transfer function can be calculated with either a spectrum analyzer or signal-processing software. Note that transfer functions should include the average of at least 20 impulses. Specialized multi-channel spectrum analyzers have built-in capabilities for computing transfer functions and are computationally efficient. However, signal-processing software can offer more flexibility in analyzing data signals and allows the use of different digital signal processing methods. Typical measurement programs involve acquisition of data in the field and later processing of the information in a laboratory. However, recent advances in instrumentation and signal-processing software allow data to be collected and analyzed while in the field.

2c. Estimate Line-Source Transfer Mobility – Estimate line-source transfer mobility for long sources such as multi-car trains. Line-source transfer mobilities are used to normalize measured vibration velocity levels from train passbys and to obtain force density. Two different approaches can be used to develop estimates of line-source transfer mobility. The first consists of using lines of transducers and the second consists of a line of impact positions.

Option A: Lines of Transducers – Develop line-source transfer mobility curves from tests using one or more lines of transducers as shown in Figure 6-11 and described below.

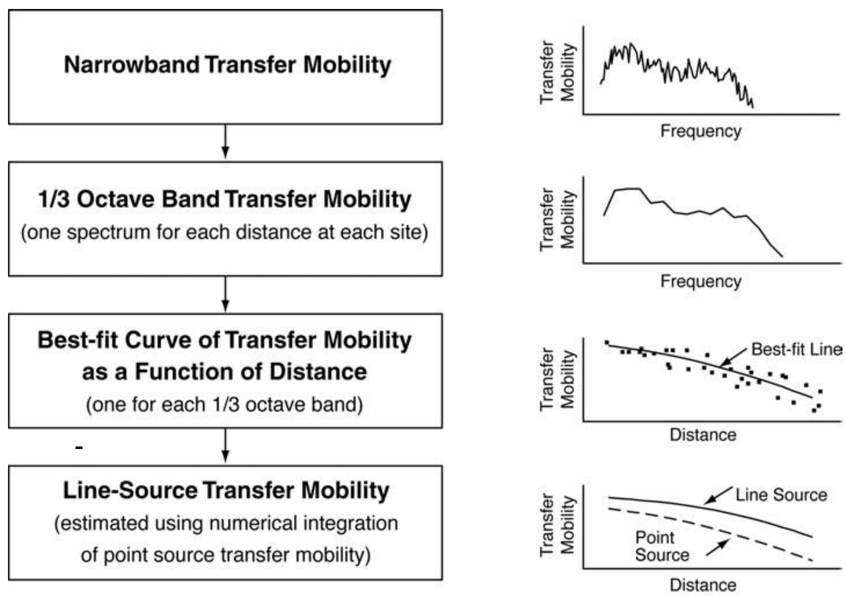


Figure 6-11 Analysis of Transfer Mobility

Ai. Obtain the narrowband transfer function between source and receiver at each measurement position. There should be a minimum of four distances in any test line. Because of the possibility of local variations in propagation characteristics, two or more lines should be used to characterize a site if possible. A total of 10 to 20 transducer positions are often used to characterize a site.

Aii. Calculate the equivalent 1/3-octave band transfer functions, generally between 6 and 400 Hz. This reduces each spectrum to 15 numbers. As shown in Figure 6-11, the 1/3-octave band spectrum is much smoother than the narrowband spectrum.

Aiii. Calculate a best-fit curve of transfer mobility as a function of distance for each 1/3-octave band. When analyzing a specific site, the best-fit curve will be based on 10 to 20 points. Up to several hundred points could be used to determine average best-fit curves for a number of sites.

Aiv. Apply the best-fit curve to the vibration sources. The 1/3-octave band best-fit curves can be directly applied to point vibration sources. Buses can usually be considered point-sources, as can columns supporting elevated structures. However, for a line vibration source such as a train, numerical integration must be used to calculate the equivalent line-source transfer mobility. The numerical integration procedures are detailed in the TRB publication: "A Prediction Procedure for Rail Transportation Ground-Borne Noise and Vibration."[50]

Option B: Line of Impulses – This second procedure for estimating line-source transfer mobility is best for detailed assessment of specific vibration paths or specific buildings and is a more direct approach.

Bi. Measure multiple point-source transfer mobilities according to the procedures in Step 2b above. The vibration transducers are placed at specific points of interest and a line of impacts is used. For example, a 150-foot train might be represented by a line of 11 impact positions along the track centerline at 15-foot intervals (Figure 6-12).

Bii. Sum the point-source results using Simpson's rule[xiii] for numerical integration to calculate the line-source transfer mobility.

Figure 6-13 shows an example of line-source transfer mobilities that were derived from the point-source transfer mobilities shown in Figure 6-9.

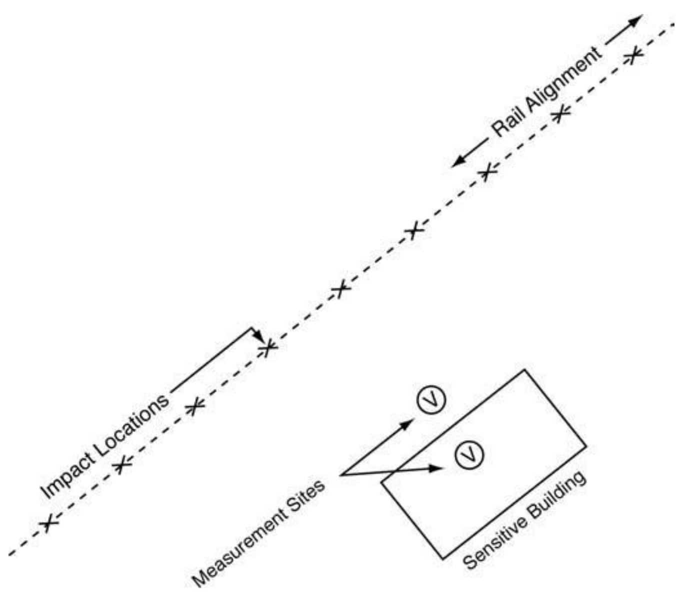


Figure 6-12 Schematic of Transfer Mobility Measurements Using a Line of Impacts

[xiii] Simpson's rule is a method for approximating integrals.

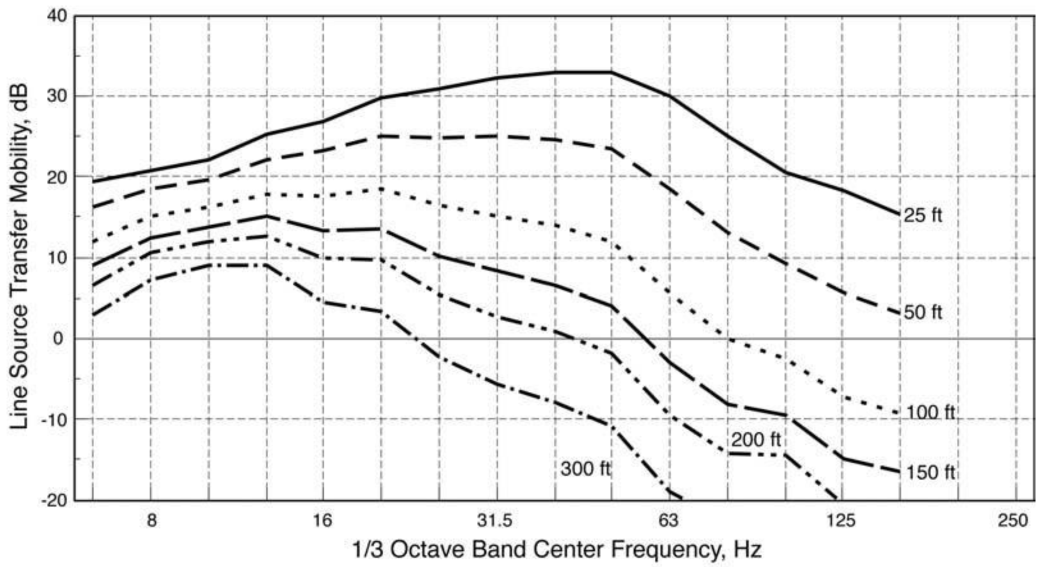


Figure 6-13 Example of Line-source Transfer Mobility

2d. Project Ground-Borne Vibration and Noise – Combine force density and line-source transfer mobility to project ground-borne vibration. Then, apply adjustment factors to estimate the building response to the ground-borne vibration and to estimate the A-weighted sound level inside buildings.

The propagation of vibration from the building foundation to the receiver room is very complex and dependent on the specific design of the building. Detailed evaluation of the vibration propagation would require extensive use of numerical procedures such as the finite element method. Such a detailed evaluation is generally not practical for individual buildings considered in this manual. If the detailed features of the individual buildings are available, the recommended procedure is to estimate the propagation of vibration through a building and the radiation of sound by vibrating building surfaces using simple empirical or theoretical models. The recommended procedures are outlined in the Handbook of Urban Rail Noise and Vibration Control.(44) The approach consists of adding the following adjustments to the 1/3-octave band spectrum of the projected ground-borne vibration:

- **Building response or coupling loss** – This adjustment represents the change in the incident ground-borne vibration due to the presence of the building foundation. The adjustments described in the handbook (44) are shown in Figure 6-14. Note that the correction is zero when estimating basement floor vibration or vibration of at-grade slabs. Measured values may be used in place of these generic adjustments.

- **Transmission through the building** – The vibration amplitude typically decreases as the vibration energy propagates from the foundation through the remainder of the building. The general assumption is that vibration attenuates by 1 to 2 dB for each floor.

- **Floor resonances** – Vibration amplitudes will be amplified because of resonances of the floor/ceiling systems. For a typical wood-frame residential structure, the fundamental resonance is usually in the 15 to 20 Hz range. Reinforced-concrete slab floors in modern buildings will have fundamental resonance frequencies in the 20 to 30 Hz range. An amplification resulting in a gain of approximately 6 dB should be used in the frequency range of the fundamental resonance.

- **Floor vibration and ground-borne noise** – The projected floor vibration is used to estimate the levels of ground-borne noise. The primary factors affecting noise level are the average vibration level of the room surfaces and the amount of acoustical absorption within the room. The radiation adjustment is -5 dB for typical rooms, (37) (50) which gives:

$$L_A \approx L_V + K_{A-wt} - 5 \quad \textbf{Eq. 6-8}$$

where:

L_A = A-weighted sound level in a 1/3-octave band
L_v = rms vibration velocity level in that band
K_{A-wt} = A-weighting adjustment at the 1/3-octave band center frequency

The A-weighted levels in the 1/3-octave bands are combined to produce the overall A-weighted sound level.

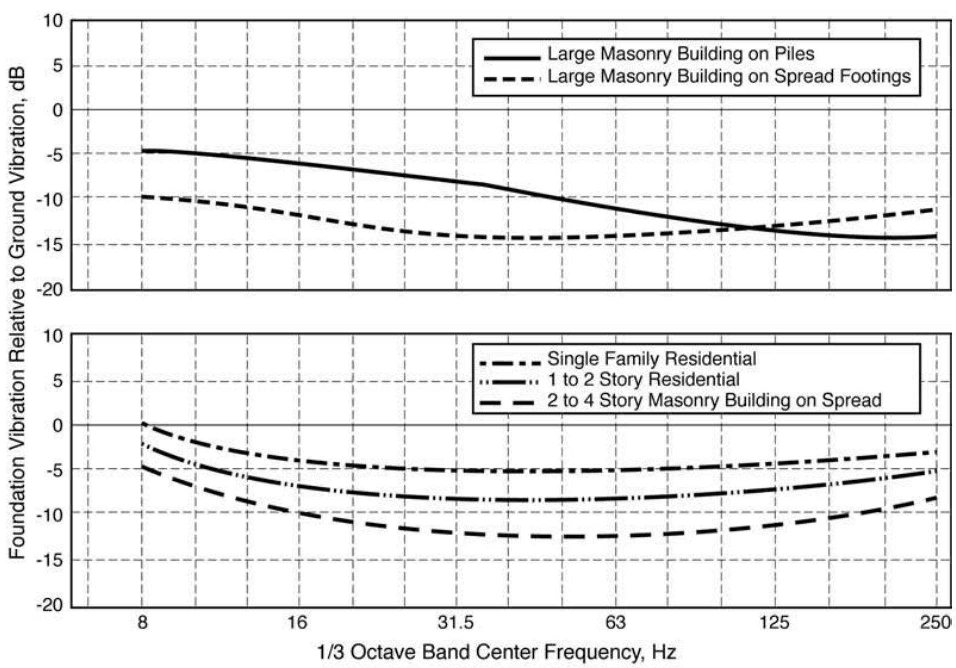


Figure 6-14 Foundation Response for Various Types of Buildings

Where detailed information on the structural features of individual buildings are unavailable and there are no site-specific data on outdoor to indoor propagation characteristics, the preferred approach is to apply a combined factor for the foundation response and the gain from floor resonances. Empirical data based on the TCRP D-12 Project from 34 measurement sites across 5 cities in North

America and other studies suggest that the average change in vibration from outdoor to indoor was 0 dB across all 1/3-octave bands with a standard deviation of approximately 5 to 6 dB in the 31.5 to 63 Hz frequency.(43)(48) Therefore, the recommended approach for predicting indoor vibration based on outdoor data is to use an adjustment of +3 to +6 dB for light-weight, wood-frame construction and use an adjustment of 0 dB for heavier buildings.

However, for buildings with high-vibration sensitivity or where there is concern regarding interference with vibration-sensitive equipment, it is advisable to measure the outdoor-indoor response of the building, using the process described in Section 2b or 2c, to determine the actual response of the foundation and building to vibration.

Step 3: Assess Vibration Impact

Take inventory of vibration-sensitive land uses with impact.

Assess vibration impact at each receiver of interest using the impact criteria in Section 6.3. Note that ground-borne vibration and noise levels that exceeded criteria in the General Vibration Assessment may not cause impact according to the more detailed procedures of the Detailed Vibration Analysis; in which case, mitigation is not required. But if projected levels still exceed the criteria, evaluate vibration mitigation measures using the spectra provided by the Detailed Vibration Analysis.

Step 4: Determine Vibration Mitigation Measures

Select practical vibration control measures that will be effective at the dominant vibration frequencies and compatible with the given transit structure and track support system.

The purpose of vibration mitigation is to minimize the adverse effects that the project ground-borne vibration and ground-borne noise will have on sensitive land uses. Because ground-borne vibration is not as common a problem as environmental noise, the mitigation approaches have not been as well defined. In some cases it may be necessary to develop innovative approaches to control the impact. See Appendix G for information on using non-standard methods.

Standard vibration control measures for rail transit systems are discussed in this step. Note that vibration control measures for rail transit systems are not always effective for freight trains.[xiv] Bus systems rarely cause vibration impact, but if impact occurs, roadway roughness or unevenness caused by bumps, pot holes, expansion joints, or driveway transitions are usually the causes. Smoothing the roadway surface is typically the recommended course of action.[xv]

[xiv] The heavy axle loads associated with freight rail are outside the range of applicable design parameters for vibration reduction on lighter rail transit systems. Plans to relocate existing railroad tracks closer to vibration-sensitive sites in order to accommodate a new rail transit line in the ROW must be carefully considered because it may not be possible to mitigate the increased vibration impact from freight trains.

[xv] In cases where a rubber-tired system runs inside a building, such as an airport people mover, vibration control may involve additional measures. Loading and unloading of guideway support beams may generate dynamic forces that transmit into the building structure. Special guideway support systems may be required, similar to the discussion below regarding floating slabs.

Vibration reduction measures incur additional costs to a system. Some of the same treatments for noise mitigation can be considered for vibration mitigation. Costs for noise control measures are documented in a report from the Transit Cooperative Research Program (TCRP).[31] Where applicable to vibration reduction, costs for noise abatement methods from that report are given in the following sections. These costs reflect the noise mitigation costs as of 1997 (unless otherwise noted), and should only be used as representative estimates when considering noise mitigation options. Current noise mitigation costs should be researched before decisions on noise mitigation options are finalized, and then they should be documented according to Section 8.

Mitigation of vibration impacts may involve treatments at the source, along the source-to-receiver propagation path, or at the receiver.

1a. Evaluate Source Treatments – The most effective vibration mitigation treatments are applied at the vibration source. This is the preferred approach to mitigation when possible. Possible source treatments include:

- **Preventative Maintenance** – Effective maintenance programs are essential for controlling ground-borne vibration. Key vibration points are discussed below; see Section 4.5, Step 7 for more detailed information on the benefits of effective maintenance programs on controlling transit noise and vibration. While these are not mitigation measures in the traditional sense, and should not be included as mitigation in an environmental document, they can help to keep both noise and vibration levels at a "like-new" level or reduce both in systems with deferred maintenance.

    - **Rail grinding** is a particularly important practice for vibration mitigation for rail that develops corrugations. The TCRP report notes that periodic rail grinding results in a net savings per year on wheel and rail wear. Most transit systems contract out rail grinding, although some of the larger systems make the investment and do their own grinding. As mentioned in Section 4.5, Step 7, the typical rail grinding cost would be $1000 to $7000 per grinding pass mile, with an additional investment of approximately $1 million for the equipment for a larger transit system to do its own grinding.

    - **Dramatic vibration reduction** results can be achieved by removing wheel flats through **wheel truing**. As mentioned in Section 4.5, Step 7, a wheel truing machine costs approximately $1 million, including associated maintenance, materials, and labor costs. The TCRP report figures a system with 700 vehicles would incur a yearly cost of $300,000 to $400,000 for a wheel truing program.

    - **Profile grinding of the rail head** in combination with a wheel truing program may be the most practical approach to controlling and reducing vibration and noise where such practices are not normally conducted. Profiles should be defined during the design phase and should be in place when system opens.[32] The cost of wheel and rail profile matching may be incorporated in the new vehicle and new rail costs.

Rough wheels or rails can increase vibration levels by as much as 20 dB in extreme cases, negating the effects of even the most effective vibration control measures. Yet, it is rare that vibration control measures (such as those discussed below) will provide more than 15 to 20 dB attenuation. When there are ground-borne vibration impacts with existing transit equipment, the best vibration control measure often is to implement new or improved maintenance procedures. Grinding rough or corrugated rail and wheel truing to eliminate wheel flats and restore the wheel contour may provide considerable vibration reduction. Regular maintenance may replace the need to modify the existing track system, such as through adding floating slabs.

- **Planning and Design of Special Trackwork** – A large percentage of the vibration impact from a new transit facility is often caused by wheel impacts at special trackwork for turnouts and crossovers. When feasible, the most effective vibration control measure is to relocate the special trackwork to a less vibration-sensitive area. This may require adjusting the location by several hundred feet provided it will not have an adverse impact on the operation plan for the system. Careful review of crossover and turnout locations during the project development phase is an important step to minimizing potential for vibration impact.

  Another approach is to use special devices (frogs) at turnouts and crossovers that incorporate mechanisms to close the gaps between running rails. Frogs with spring-loaded mechanisms and frogs with movable points can substantially reduce vibration levels near crossovers. According to the TCRP report, a spring frog costs about $12,000, twice the cost of a standard frog. A movable point frog involves elaborate signal and control circuitry resulting in higher costs at approximately $200,000.

- **Vehicle Specifications** – The ideal rail vehicle with respect to minimizing ground-borne vibration should have the following characteristics:
  - Low, unsprung weight
  - Soft primary suspension
  - A minimum of metal-to-metal contact between moving parts of the truck
  - Smooth wheels that are perfectly round

  A limit for the vertical resonance frequency of the primary suspension should be included in the specifications for any new vehicle. A vertical resonance frequency of 12 Hz or less is sufficient to control the levels of ground-borne vibration, although some have recommended the vertical resonance frequency be less than 8 Hz.

- **Special Track Support Systems** – When the vibration assessment indicates that vibration levels will be excessive, the track support system is typically modified to reduce the vibration levels.

  Floating slabs, resiliently supported ties, high-resilience fasteners, and ballast mats can be used to reduce the levels of ground-borne vibration. To be effective, all of these measures must be optimized for the frequency spectrum of the vibration. Most of these relatively standard procedures have been successfully used on several subway projects.

  Applications on at-grade and elevated track are less common. This is because vibration impact is less common for at-grade and elevated track. Note that the cost of these types of vibration control measures is a higher percentage of the overall construction costs for at-grade and elevated track, and exposure to the elements can require substantial design modifications.

  Each major vibration control measure for track support is discussed below. Costs for these treatments are not covered by the TCRP report, but are given as estimates based on transit agency experience.

  - **Resilient fasteners** – Resilient fasteners are used to fasten the rail to concrete track slabs. Standard resilient fasteners are very stiff in the vertical direction, usually in the range of 200,000 lb/in, and do provide some vibration reduction compared to the rigid fastening systems used on older systems (e.g., wood half-ties embedded in concrete).

    Special fasteners with vertical stiffness in the range of 30,000 lb/in may reduce vibration by as much as 5 to 10 dB at frequencies above 30 to 40 Hz. These premium fasteners vary in cost and can be priced competitively when purchased in large quantities.

  - **Ballast mats** – A ballast mat consists of a rubber or other type of elastomer pad that is placed under the ballast. In general, the mat must be placed on a concrete pad to be effective. They will not be as effective if placed directly on the soil or the sub-ballast. Consequently, most ballast mat applications are in subway or elevated structures.

    Ballast mats can provide 8 to 12 dB attenuation at frequencies above 25 to 30 Hz.(58) Ballast mats are often a good retrofit measure for existing tie-and-ballast track where there is vibration impact. Installed ballast mats cost approximately $180 per track-foot.

  - **Undertie pads** – Undertie pads (resiliently supported concrete ties) consist of a rubber pad mounted on the bottom of a concrete tie directly on the ballast. The pads provide vibration isolation at frequencies above 25 Hz and are easy to install or retrofit. Installed undertie pads cost approximately $260 per track-foot.

- **Resiliently supported ties** – The resiliently supported tie system consists of concrete ties supported by rubber pads resting on top of a slab track or subway invert. The rails are fastened directly to the concrete ties using standard rail clips. Resiliently supported ties provide vibration reduction in between 15 to 40 Hz, which is particularly appropriate for transit systems with vibration impact in the 20 to 30 Hz range. A resiliently supported tie system costs approximately $400 per track-foot.

- **Floating slabs** – Floating slabs can be very effective at controlling ground-borne vibration and noise and consist of a concrete slab supported on resilient elements such as rubber or a similar elastomer. Floating slabs are effective at frequencies greater than their single-degree-of-freedom vertical resonance frequency.

  Floating slabs are among the most expensive vibration control treatments. A typical double-tie floating slab system costs approximately 4 times the cost of ballast and tie per track foot. Examples of floating slabs include:
  - Floating slabs used in Washington, DC; Atlanta, GA; and Boston, MA, were all designed to have a vertical resonance in the 14 to 17 Hz range.
  - A special system referred to as the double-tie system was first used in Toronto. It consists of 5-foot-long slabs with four or more rubber pads under each slab. This system was designed with a resonance frequency in the 12 to 16 Hz rang3.
  - Another special floating slab was used in San Francisco's Bay Area Rapid Transit (BART) system. It uses a discontinuous precast concrete double-tie system with a resonance frequency in the 5 to 10 Hz frequency range.

- **Tire-derived aggregate (TDA)** – TDA (shredded tires) consists of a layer of tire shreds wrapped in geotech fabric placed underneath the ballast on hard packed ground. This is a new, low-cost option that can provide reduction in vibration levels at frequencies above 25 Hz. This mitigation measure has proven to be effective for the Denver Regional Transportation District (RTD) light rail system as well as the Santa Clara Valley Transportation Authority (VTA) light rail system,[(59)] but the effective life of TDA has not been determined. Installed TDA costs approximately $260 per track-foot.

- **Other treatments** – Changing any feature of the track support system can change the levels of ground-borne vibration. Approaches such as using heavier rail, thicker ballast, or heavier ties can be expected to reduce the vibration levels. There also is some indication that vibration levels are lower with wood ties compared to concrete ties. But there is little confirmation that any of these approaches will make a substantial change in the vibration levels.

- **Operational Changes** – The most effective operational change is to reduce the vehicle speed. Reducing the train speed by a factor of two will reduce vibration levels approximately 6 dB. Other operational changes include:
    - Use of equipment that generates the lowest vibration levels during the nighttime hours when people are most sensitive to vibration and noise.
    - Adjusting nighttime schedules to minimize movements in the most sensitive hours.

While there are tangible mitigation benefits from speed reductions and limits on operations during the most sensitive time periods, FTA does not generally accept speed reduction as a vibration mitigation measure for two important reasons: (1) speed reduction is unenforceable and negated if vehicle operators do not adhere to established policies, and (2) it is contrary to the purpose of the transit investment by FTA, which is to move as many people as possible as efficiently and safely as possible. FTA does not recommend limits on operations as a way to reduce vibration impacts.

1b. Evaluate Path Treatments – When vibration mitigation treatments cannot be applied at the vibration source or additional mitigation is required after treating the source, the next preferred placement of vibration mitigation is along the vibration propagation path between the source and receiver. Possible path treatments include:

- **Trenches** – Use of trenches to control ground-borne vibration is analogous to controlling airborne noise with noise barriers. This approach has not received much attention in the United States, but trenches could be a practical method for controlling transit vibration from at-grade track. A rule-of-thumb given by Richert and Hall[60] is that if the trench is located close to the source, the trench bottom must be at least 0.6 times the Rayleigh wavelength below the vibration source. For most soils, Rayleigh waves travel at around 600 ft/sec, which means that the wavelength at 30 Hz is 20 ft, requiring that a trench be approximately 15 ft deep to be effective at 30 Hz.

  A trench can be effective as a vibration barrier if it is either open or solid. The Toronto Transit Commission tested a trench filled with Styrofoam to keep it open and reported successful performance over a period of at least one year. Solid barriers can be constructed with sheet piling or concrete poured into a trench.

- **Buffer Zones** – Expanding the rail ROW can be the most economical method of reducing the vibration impact by simply increasing the distance between the source and receiver. A similar approach is to negotiate a vibration easement from the affected property owners (e.g., a row of single-family homes adjacent to a proposed commuter rail line). There may be legal limitations, however, on the ability of funding agencies to acquire land strictly for the purpose of mitigating vibration (or noise) impact.

1c. Evaluate Receiver Treatments – When vibration mitigation treatments cannot be applied at the source or along the propagation path, or if combinations of treatments are required, treatments to the receivers can be considered as described below.

- **Building Modifications** – In some circumstances, it is practical to modify the affected building to reduce the vibration level. Vibration isolation of buildings consists of supporting the building foundation on elastomer pads, similar to bridge bearing pads. Vibration isolation of buildings is seldom an option for existing buildings and is typically only possible for new construction. Vibration impacts on sensitive laboratory instruments, such as electron microscopes, may be controlled with vibration isolation tables.

  This approach is particularly important for shared-use facilities such as an office space above a transit station or terminal. When vibration-sensitive equipment such as electron microscopes will be affected by transit vibration, specific modifications to the building structure may be the most cost-effective method of controlling the impact aside from modification of equipment mounting systems. For example, the floor upon which the vibration-sensitive equipment is located could be stiffened and isolated from the remainder of the building to reduce the vibration. Alternatively, the equipment mounting systems could be modified or the equipment could be relocated to a different building at far less cost.

SECTION 7

Noise and Vibration during Construction

Construction noise and vibration often generates complaints from the community, even when construction is for a limited timeframe. Public concerns about construction noise and vibration increase considerably with lengthy periods of heavy construction on major projects as well as prevalence of nighttime construction (often scheduled to avoid disrupting workday road and rail traffic). Noise and vibration complaints typically arise from interference with people's activities, especially when the adjacent community has no clear understanding of the extent or duration of the construction. Misunderstandings can arise when the community thinks a contractor is being insensitive, and the contractor believes it is performing the work in compliance with local ordinances. This situation underscores the need for early identification and assessment of potential problem areas.

This section outlines the procedures for assessing noise and vibration impacts during construction. The type of assessment (qualitative or quantitative) and the level of analysis are determined based on the scale of the project and surrounding land uses. In cases where a full quantitative assessment is not warranted, a qualitative assessment of the construction noise and vibration environment can lead to greater understanding and tolerance in the community. For major projects with extended periods of construction at specific locations, a quantitative assessment can aid contractors in making bids by allowing changes in construction approach and including mitigation costs before the construction plans are finalized.

Generally, local noise ordinances are not very useful for evaluating construction noise impact. They usually relate to nuisance and hours of allowed activity, and sometimes specify limits in terms of maximum levels, but are generally not practical for assessing the impact of a construction project. Project construction noise criteria should take into account the existing noise environment, the absolute noise levels during construction activities, the duration of the construction, and the adjacent land uses. While it is not the purpose of this manual to specify standardized criteria for construction noise impact, the following guidelines can be considered reasonable criteria for assessment. If these criteria are exceeded, there may be adverse community reaction.

Procedures for assessing construction noise are presented in Section 7.1. Procedures for assessing construction vibration are presented in Section 7.2.

7.1 Construction Noise Assessment

Noise impacts from construction may vary greatly depending on the duration and complexity of the project. The key elements of the Construction Noise Assessment procedure and recommended workflow are as follows.

Step 1: Determine Level of Construction Noise Assessment

Step 2: Use a Qualitative Construction Noise Assessment to Estimate Construction Noise

Step 3: Use a Quantitative Construction Noise Assessment to Estimate Construction Noise

Step 4: Assess Construction Noise Impact

Step 5: Determine Construction Noise Mitigation Measures

If there is uncertainty in how to determine the appropriate level of assessment, contact the FTA Regional office.

Step 1: Determine Level of Construction Noise Assessment

Determine the appropriate level of assessment based on the scale and type of the project and depending on the stage of environmental review.

Consider the following factors:
- Scale of the project
- Proximity of noise-sensitive sites to the construction zones
- Number of noise-sensitive receivers in the project area
- Duration of construction activities near noise-sensitive receivers
- Schedule, including the construction days, hours, and time periods
- Method (e.g., cut-and-cover vs. bored tunneling)
- Concern about construction noise expressed in comments by the general public (e.g., through scoping or public meetings)

1a. Determine if an assessment is required – Construction Noise Assessments are not required for many small projects including:
- Installation of safety features like grade-crossing signals;
- Track improvements within the ROW; or
- Erecting small buildings and facilities which are similar in scale to the surrounding development.

For small projects like these, include descriptions in the environmental document of the length of construction, the loudest equipment to be used, the expected truck access routes, the avoidance of nighttime activity, and any other relevant planned construction method.

1b. Determine whether a qualitative or quantitative assessment is required

- **Qualitative Construction Noise Assessment** – Qualitative Construction Noise Assessments may be required for projects with less than a month of construction time in a noise-sensitive area. See Step 2 for more information on Qualitative Construction Noise Assessments.

- **Quantitative Construction Noise Assessments** – Quantitative Construction Noise Assessments may be required for projects with a month or more of construction in noise-sensitive areas or if particularly noisy equipment will be involved. See Step 3 for more information on Quantitative Construction Noise Assessments.

Step 2: Use a Qualitative Construction Noise Assessment to Estimate Construction Noise

Use a qualitative construction noise assessment to estimate construction noise for appropriate projects per Section 7.1, Step 1b.

Provide qualitative descriptions in the environmental document of the following elements:

- Duration of construction (both overall and at specific locations)
- Equipment expected to be used (e.g., noisiest equipment)
- Schedule with limits on times of operation (e.g., daytime use only)
- Monitoring of noise
- Forum for communicating with the public
- Commitments to limit noise levels to certain levels, including any local ordinances that apply
- Consideration of application of noise control treatments used successfully in other projects

Effective community outreach and relations are important for these projects. Disseminate information to the public early regarding the kinds of construction equipment, expected noise levels, and durations to forewarn potentially affected neighbors about the temporary inconvenience. Including a general description of the variation of noise levels during a typical construction day may also be helpful.

Note that the construction criteria in Step 4 do not apply to qualitative assessments.

Step 3: Use a Quantitative Construction Noise Assessment to Estimate Construction Noise

Use a quantitative construction noise assessment to estimate construction noise for appropriate projects per Section 7.1, Step 1b.

For Quantitative Construction Noise Assessments, follow the recommended procedure in this step and include a description of the planned construction methods and any basic measures that have been identified to reduce the potential impact, such as prohibiting the noisiest construction activities during the nighttime, in the environmental document. It may be prudent, however, to defer final decisions on noise control measures until the project and construction plans are defined in greater detail during the engineering phase.

- **Noise Source Levels from Typical Construction Equipment and Operations** – The noise levels generated by construction equipment vary greatly on factors such as the type of equipment, the equipment model, the operation being performed, and the condition of the equipment. Typically, the dominant source of noise from most construction equipment is the engine, often a diesel engine, which usually does not have sufficient muffling. In other cases, such as impact pile-driving or pavement-breaking, noise generated by the process dominates. Construction equipment can be considered to operate in the following two modes for Construction Noise Assessments:

- **Stationary** – Stationary equipment operates in one location for one or more days at a time, with either a fixed power operation (pumps, generators, compressors) or a variable noise operation (pile drivers, pavement breakers).
- **Mobile** – Mobile equipment moves around the construction site with power applied in cyclic fashion (bulldozers, loaders), or to and from the site (trucks). Movement around the site is considered in the construction noise prediction procedure.

Variation in power imposes additional complexity in characterizing the noise source level from mobile equipment. Describe the noise at a reference distance from the equipment operating at full power and adjusting it based on the duty cycle of the activity to determine the $L_{eq(t)}$ of the operation.

Typical noise levels from representative equipment are included in Table 7-1. The levels are based on an EPA Report,(61) measured data from railroad construction equipment taken during the 1976 Northeast Corridor Improvement Project, the FHWA Roadway Construction Noise Model, and other measured data.

For equipment that is not represented in Table 7-1, measure the noise levels according to the standard procedures for measuring the exterior noise levels for the certification of mobile and stationary construction equipment by the Society of Automotive Engineers.(62)(63)

Table 7-1 Construction Equipment Noise Emission Levels

Equipment	Typical Noise Level 50 ft from Source, dBA
Air Compressor	80
Backhoe	80
Ballast Equalizer	82
Ballast Tamper	83
Compactor	82
Concrete Mixer	85
Concrete Pump	82
Concrete Vibrator	76
Crane, Derrick	88
Crane, Mobile	83
Dozer	85
Generator	82
Grader	85
Impact Wrench	85
Jack Hammer	88
Loader	80
Paver	85
Pile-driver (Impact)	101
Pile-driver (Sonic)	95
Pneumatic Tool	85
Pump	77
Rail Saw	90
Rock Drill	95
Roller	85
Saw	76
Scarifier	83
Scraper	85
Shovel	82
Spike Driver	77
Tie Cutter	84
Tie Handler	80
Tie Inserter	85
Truck	84

3a. Use the metric $L_{eq(t)}$ to assess construction noise. This unit is appropriate because $L_{eq(t)}$ can be used to describe:

- Noise level from operation of each piece of equipment separately, and levels can be combined to represent the noise level from all equipment operating during a given period
- Noise level during an entire phase
- Average noise over all phases of the construction

3b. Use Eq. 7-1 to predict construction noise impact for major transit projects, considering the noise generated by the equipment and noise propagation due to distance. Calculate $L_{eq.equip}$ for all equipment individually, then use decibel addition to sum the $L_{Aeq.equip}$ for all equipment operating during the same time period. See Appendix B.1.1 for information on decibel addition.

$$L_{eq.equip} = L_{emission} + 10\log(Adj_{Usage}) - 20\log(\frac{D}{50}) - 10G\log(\frac{D}{50}) \quad \textbf{Eq. 7-1}$$

where:

$L_{eq,equip}$	= $L_{eq(t)}$ at a receiver from the operation of a single piece of equipment over a specified time period, dBA
$L_{emission}$	= noise emission level of the particular piece of equipment at the reference distance of 50 ft, dBA
Adj_{Usage}	= usage factor to account for the fraction of time that the equipment is in use over the specified time period
D	= distance from the receiver to the piece of equipment, ft
G	= a constant that accounts for topography and ground effects

Determine the quantities for Eq. 7-1 based on the level of assessment as described below.

- A general assessment of construction noise is warranted for projects in an early assessment stage when the equipment roster and schedule are undefined and only a rough estimate of construction noise levels is practical.
- A detailed analysis of construction noise is warranted when many noise-sensitive sites are adjacent to a construction project or where contractors are faced with stringent local ordinances or heightened public concerns expressed in early outreach efforts.

Complete the appropriate assessment for each phase of construction. Major construction projects are accomplished in several different phases. Each phase has a specific equipment mix, depending on the work to be accomplished during that phase. As a result of the equipment mix, each phase has its own noise characteristics; some phases have higher continuous noise levels than others, and some have higher impact noise levels than others.

Option A: General Assessment – Determine the quantities for Eq. 7-1 based on the following assumptions for a General Assessment of each phase of construction.

- **Noise emission level ($L_{emission}$)** – Determine the emission level at 50 ft according to noise from typical construction equipment described above and Table 7-1.
- **Usage factor (Adj_{Usage})** – Assume a usage factor of 1. This assumes a time period of one-hour with full power operation. Most construction equipment operates continuously for periods of one-hour or more during the construction period.

  Therefore, $10\log(Adj_{usage}) = 0$ and can be omitted from the equation.
- **Distance (D)** – Assume that all equipment operates at the center of the project, or centerline for guideway or highway construction project.

- **Ground effect (G)** – G = 0 assuming free-field conditions and ignoring ground effects. If ground effects are of specific importance to the assessment, consider using the Detailed Analysis procedure.

  Only determine the $L_{eq.equip}$ for the two noisiest pieces of equipment expected to be used in each phase of construction. Then, sum the levels for each phase of construction using decibel addition.

Option B: Detailed Analysis – Determine the quantities for Eq. 7-1 based on the following assumptions for a Detailed Analysis of each phase of construction. Alternatively, for detailed, long-term, and complex construction projects or projects near a particularly sensitive site, the FHWA's Windows-based screening tool, "Roadway Construction Noise Model (RCNM)," can be used for the prediction of construction noise.(64)

- **Noise emission level ($L_{emission}$)** – Measure or certify the noise emission level for each piece of equipment.

- **Usage factor (Adj_{Usage})** – Long-term construction project noise impact is based on a 30-day average L_{dn}, the times of day of construction activity (nighttime noise is penalized by 10 dB in residential areas), and the percentage of time the equipment is used during a period of time that will affect Adj_{Usage}.

  For example, an 8-hour $L_{eq(t)}$ is determined by making Adj_{Usage} the percentage of time each individual piece of equipment operates under full power in that period. Similarly, the 30-day average L_{dn} is determined from the Adj_{Usage} expressed by the percentage of time the equipment is used during the daytime hours (7 a.m. to 10 p.m.) and nighttime (10 p.m. to 7 a.m.), separately, over a 30-day period. To account for increased sensitivity to nighttime noise, the nighttime noise levels are adjusted by 10 dB in the L_{dn} computation (see Appendix B.1.4.5).

- **Distance (D)** – Determine the location of each piece of equipment during operation and the distance to each receiver.

- **Ground effect (G)** – Use Table 4-26 in Section 4.5, Step 3 to calculate G to account for the site topography, natural and man-made barriers, and ground effects.

  Compute the 8-hour $L_{eq(t)}$ ($L_{eq.equip(8hr)}$) and the 30-day average L_{dn} ($L_{dn.equip(30day)}$) for all equipment expected to be used in each phase of construction separately. Then, sum the levels for each phase of construction using Eq. 4-56 and Eq. 4-57 in Table 4-32.

Step 4: Assess Construction Noise Impact

Compare the predicted noise levels from the Quantitative Construction Noise Assessment with impact criteria to assess impact from construction noise for each phase of construction.

No standardized criteria have been developed for assessing construction noise impact. Consequently, criteria must be developed on a project-specific basis unless local ordinances apply. As stated earlier in this section, local noise ordinances are typically not very useful in evaluating construction noise. They usually relate to nuisance and hours of allowed activity, and sometimes specify limits in terms of maximum levels, but are generally not practical for assessing the impact of a construction project. Project construction noise criteria should account for the existing noise environment, the absolute noise levels during construction activities, the duration of the construction, and the adjacent land use. While it is not the purpose of this manual to specify standardized criteria for construction noise impact, the following guidelines can be considered reasonable criteria for assessment. If these criteria are exceeded, there may be adverse community reaction.

The construction impact guidelines are presented based on the level of quantitative assessment.

Option A: General Assessment – Compare the combined $L_{eq.equip(1hr)}$ for the two noisiest pieces of equipment for each phase of construction determined in Section 7.1, Step 3 to the criteria below. Then, identify locations where the level exceeds the criteria.

Table 7-2 General Assessment Construction Noise Criteria

Land Use	$L_{eq.equip(1hr)}$, dBA	
	Day	Night
Residential	90	80
Commercial	100	100
Industrial	100	100

Option B: Detailed Analysis – Compare the combined $L_{eq.equip(1hr)}$ and the combined $L_{dn.equip(30day)}$ for all equipment for each phase of construction determined in Section 7.1, Step 3 to the criteria below. Then, identify locations where the level exceeds the criteria.

Table 7-3 Detailed Analysis Construction Noise Criteria

Land Use	$L_{eq.equip(8hr)}$, dBA		$L_{dn.equip(30day)}$, dBA
	Day	Night	30-day Average
Residential	80	70	75
Commercial	85	85	80*
Industrial	90	90	85*

*Use a 24-hour $L_{eq(24hr)}$ instead of $L_{dn.equip(30day)}$.

Step 5: Determine Construction Noise Mitigation Measures

Evaluate the need for mitigation and select appropriate mitigation measures.

Where potential impacts have been identified according to Section 7.1, Step 4, evaluate appropriate control measures. Include descriptions of how each affected location will be treated with one or more mitigation measures in the environmental document.

5a. Determine the appropriate approach for construction noise control. Categories of approaches include:

- **Design considerations and project layout**
    - Construct noise barriers, such as temporary walls or piles of excavated material, between noisy activities and noise-sensitive receivers.
    - Re-route truck traffic away from residential streets. Select streets with the fewest homes if no alternatives are available.
    - Site equipment on the construction lot as far away from noise-sensitive sites as possible.
    - Construct walled enclosures around especially noisy activities or clusters of noisy equipment. For example, shields can be used around pavement breakers, and loaded vinyl curtains can be draped under elevated structures.

- **Sequence of operations**
    - Combine noisy operations to occur in the same time period. The total noise level produced will not be substantially greater than the level produced if the operations were performed separately.
    - Avoid nighttime activities. Sensitivity to noise increases during the nighttime hours in residential neighborhoods.

- **Alternative construction methods**
    - Avoid impact pile-driving where possible in noise-sensitive areas. Drilled piles or the use of a sonic/vibratory pile driver or push pile driver are quieter alternatives where the geological conditions permit their use.
    - Use specially-quieted equipment, such as quieted and enclosed air compressors and properly-working mufflers on all engines.
    - Select quieter demolition methods. For example, sawing bridge decks into sections that can be loaded onto trucks results in lower cumulative noise levels than impact demolition by pavement breakers.

Include descriptions of how each impacted location will be treated with one or more mitigation measures in the environmental impact assessment when possible.

5b. Describe and commit to a mitigation plan that will be developed later when the information is available to make final decisions (not often available during the project development phase) on all specific mitigation measures. This may be the case for large, complex projects. The objective of the plan should be to minimize construction noise using all reasonable (e.g., cost vs. benefit) and feasible (e.g., possible to construct) means available.

Components of a mitigation plan may include some or all of the following provisions, which should also be specified in construction contracts:

- **Equipment noise emission limits** – Equipment noise limits are absolute noise limits applied to generic classes of equipment at a reference distance (typically 50 ft). The limits should be set no higher than what is reasonably achievable for well-maintained equipment with effective mufflers. Lower limits that require source noise control may be appropriate for certain equipment when needed to minimize community noise impact, if reasonable and feasible. Provisions could also be included to require equipment noise certification testing prior to use on-site.

- **Lot-line construction noise limits** – Lot-line construction noise limits are noise limits that apply at the lot-line of specific noise-sensitive properties. The limits are typically specified in terms of both noise exposure (usually $L_{eq(t)}$ over a 20-30-minute period) and maximum noise level. They should be based on local noise ordinances if applicable, as well as pre-construction baseline noise levels (usually 3 to 5 dB above the baseline).

- **Operational and/or equipment restrictions** – It may be necessary to prohibit or restrict certain construction equipment and activities near residential areas during nighttime hours. This is particularly true for activities that generate tonal, impulsive, or repetitive sounds, such as back-up alarms, hoe ram demolition, and pile-driving.

- **Noise abatement requirements** – In some cases, specifications may be provided for particular noise control treatments based on the results of the design analysis and/or prior commitments made to the public by civic authorities. An example would be the requirement for a temporary noise barrier to shield a particular community area from noisy construction activities.

- **Noise monitoring plan requirements** – Plans can be developed for pre-project noise monitoring to establish baseline noise levels at sensitive locations, as well as for periodic equipment and lot-line noise monitoring during the construction period. The plan should outline the measurement and reporting methods that will be used to demonstrate compliance with the project noise limits.

- **Noise control plan requirements** – For major construction projects, preparation and submission of noise control plans on a periodic basis (e.g., every six months) are generally required. These plans should predict the construction noise at noise-sensitive receiver locations based on the proposed construction equipment and methods. If the analysis predicts that the specified noise limits will be exceeded, the plan should specify the mitigation measures that will be applied and should demonstrate the expected noise reductions these measures will achieve. The objective of this proactive approach is to minimize the likelihood of community noise complaints by ensuring that any necessary mitigation measures are included in the construction plans.

- **Compliance enforcement program** – If construction noise is an issue in the community, it is important that a program be implemented to monitor contractor compliance with the noise control specifications and mitigation plan. It is recommended that this function be performed by a construction management team on behalf of the public agency.

- **Public information and complaint response procedures** – To maintain positive community relations, it is recommended to keep the public informed about the construction plans and efforts to minimize noise, and procedures should be established for prompt response and corrective action to noise complaints during construction.

Most of these provisions are appropriate for large-scale projects, where construction activity will continue for many months, if not years. The linked references contain more information on construction noise for major transportation projects.[60][65]

7.2 Construction Vibration Assessment

Construction activity can result in varying degrees of ground vibration, depending on the equipment and methods employed. Operation of construction equipment causes ground vibrations that spread through the ground and diminish in strength with distance. Buildings founded on the soil near the construction site respond to these vibrations with varying results, ranging from no perceptible effects at the lowest levels, low rumbling sounds and perceptible vibrations at moderate levels, and slight damage at the highest levels.

While ground vibrations from construction activities do not often reach the levels that can damage structures, fragile buildings must receive special consideration. The construction vibration criteria include consideration of the building condition.

The key elements of the Construction Vibration Assessment procedures and recommended workflow are as follows:

Step 1: Determine level of construction vibration assessment

Step 2: Use a qualitative construction vibration assessment

Step 3: Use a quantitative construction vibration assessment

Step 4: Assess construction vibration impact

Step 5: Determine construction vibration mitigation measures

Step 1: Determine Level of Construction Vibration Assessment

Determine the appropriate level of assessment based on the scale and type of the project and the stage of environmental review.

1a. Determine if an assessment is required.
Construction Vibration Assessments are not required for many small projects including:

- Installation of safety features like grade-crossing signals
- Track improvements within the ROW
- Erecting small buildings and facilities, which are similar in scale to the surrounding development

1b. Determine whether a qualitative or quantitative assessment is required.

- **Qualitative Construction Vibration Assessment** – A qualitative construction vibration assessment is appropriate for projects where prolonged annoyance or damage from construction vibration is not expected. For example, equipment that generates little or no ground vibration—such as air compressors, light trucks, and hydraulic loaders—only require qualitative descriptions. See Section 7.2, Step 2 for more information on qualitative construction vibration assessments.

- **Quantitative Construction Vibration Assessment** – A quantitative construction vibration analysis is appropriate for projects where construction vibration may result in building damage or prolonged annoyance. For example, activities such as blasting, pile-driving, vibratory compaction, demolition, and drilling or excavation near sensitive structures require a quantitative analysis. See Section 7.2, Step 3 for more information on quantitative construction vibration assessments.

If there is uncertainty in how to determine the appropriate level of assessment, contact the FTA Regional office.

Step 2: Use a Qualitative Construction Vibration Assessment

Use a qualitative construction vibration assessment to estimate vibration for appropriate projects per Section 7.2, Step 1b.

Provide qualitative descriptions in the environmental document of the following elements:

- Duration of construction (both overall and at specific locations)
- Equipment expected to be used
- Description of how ground-borne vibration will be maintained at an acceptable level

Note that the criteria in Section 7.2, Step 4 do not apply to qualitative assessments.

Step 3: Use a Quantitative Construction Vibration Assessment

Use a quantitative construction vibration assessment to estimate vibration for appropriate projects per Section 7.2, Step 1b.

For quantitative construction vibration assessments, follow the recommended procedure in this step. Vibration source levels from typical construction equipment and operations are provided below, and procedures on how to estimate construction vibration for damage and annoyance are provided in Steps 3a and 3b, respectively.

- **Vibration Source Levels from Construction Equipment** – Table 7-4 presents average source levels in terms of velocity for various types of construction equipment measured under a wide variety of construction activities. The approximate rms vibration velocity levels were calculated from the PPV limits using a crest factor of 4, representing a PPV-rms difference of 12 dB. Note that although the table gives one level for each piece of equipment, there is considerable variation in reported ground vibration levels from construction activities. The data in Table 7-4 provide a reasonable estimate for a wide range of soil conditions.(66)(67)(68)(69)

Table 7-4 Vibration Source Levels for Construction Equipment

Equipment		PPV at 25 ft, in/sec	Approximate Lv* at 25 ft
Pile Driver (impact)	upper range	1.518	112
	typical	0.644	104
Pile Driver (sonic)	upper range	0.734	105
	typical	0.17	93
Clam shovel drop (slurry wall)		0.202	94
Hydromill (slurry wall)	in soil	0.008	66
	in rock	0.017	75
Vibratory Roller		0.21	94
Hoe Ram		0.089	87
Large bulldozer		0.089	87
Caisson drilling		0.089	87
Loaded trucks		0.076	86
Jackhammer		0.035	79
Small bulldozer		0.003	58

* RMS velocity in decibels, VdB re 1 micro-in/sec

3a. Damage Assessment

Assess for building damage for each piece of equipment individually. Construction vibration is generally assessed in terms of peak particle velocity (PPV), as described in Section 5.1.

- Determine the vibration source level (PPV_{ref}) for each piece of equipment at a reference distance of 25 ft as described above and in Table 7-4.
- Use Eq. 7-2 to apply the propagation adjustment to the source reference level to account for the distance from the equipment to the receiver. Note that the equation is based on point sources with normal propagation conditions.

$$PPV_{equip} = PPV_{ref} \times (\frac{25}{D})^{1.5} \quad \textbf{Eq. 7-2}$$

where:

PPV_{equip}	= the peak particle velocity of the equipment adjusted for distance, in/sec
PPV_{ref}	= the source reference vibration level at 25 ft, in/sec
D	= distance from the equipment to the receiver, ft

3b. Annoyance Assessment
Assess for annoyance for each piece of equipment individually. Ground-borne vibration related to human annoyance is related to rms velocity levels, expressed in VdB as described in Section 5.1.

Estimate the vibration level (L_v) using Eq. 7-3.

$$L_{v.distance} = L_{vref} - 30log(\frac{D}{25}) \quad \textbf{Eq. 7-3}$$

where:

$L_{v.distance}$	= the rms velocity level adjusted for distance, VdB
L_{vref}	= the source reference vibration level at 25 ft, VdB
D	= distance from the equipment to the receiver, ft

Step 4: Assess Construction Vibration Impact

Compare the predicted vibration levels from the Quantitative Construction Vibration Assessment with impact criteria to assess impact from construction vibration.

Assess potential damage effects from construction vibration for each piece of equipment individually. Note that equipment operating at the same time could increase vibration levels substantially, but predicting any increase could be difficult. The criteria presented in this section should be used during the environmental impact assessment phase to identify problem locations that must be addressed during the engineering phase.

Compare the PPV and approximate L_v for each piece of equipment determined in Section 7.2, Step 3 to the vibration damage criteria in Table 7-5, which is presented by building/structural category, to assess impact.(70)(71) The approximate rms vibration velocity levels were calculated from the PPV limits using a crest factor of 4.

Table 7-5 Construction Vibration Damage Criteria

Building/ Structural Category	PPV, in/sec	Approximate L_v*
I. Reinforced-concrete, steel or timber (no plaster)	0.5	102
II. Engineered concrete and masonry (no plaster)	0.3	98
III. Non-engineered timber and masonry buildings	0.2	94
IV. Buildings extremely susceptible to vibration damage	0.12	90

*RMS velocity in decibels, VdB re 1 micro-in/sec

Compare the L_v determined in Section 7.2, Step 3 to the criteria for the General Vibration Assessment in Section 6.2 to assess annoyance or interference with vibration-sensitive activities due to construction vibration.

Step 5: Determine Construction Vibration Mitigation Measures

Evaluate the need for mitigation and select appropriate mitigation measures where potential human impacts or building damage from construction vibration have been identified according to Section 7.2, Step 4.

5a. Determine the appropriate approach for construction vibration mitigation considering equipment location and processes.

- **Design considerations and project layout**
  - Route heavily-loaded trucks away from residential streets. Select streets with the fewest homes if no alternatives are available.
  - Operate earth-moving equipment on the construction lot as far away from vibration-sensitive sites as possible.

- **Sequence of operations**
  - Phase demolition, earth-moving, and ground-impacting operations so as not to occur in the same time period. Unlike noise, the total vibration level produced could be substantially less when each vibration source operates separately.
  - Avoid nighttime activities. Sensitivity to vibration increases during the nighttime hours in residential neighborhoods.

- **Alternative construction methods**
  - Carefully consider the use of impact pile-driving versus drilled piles or the use of a sonic/vibratory pile driver or push pile driver where those processes might create lower vibration levels if geological conditions permit their use.
    - Pile-driving is one of the greatest sources of vibration associated with equipment used during construction of a project. The source levels in Table 7-4 indicate that sonic pile drivers may provide substantial reduction of vibration levels compared to impact pile drivers. But, there are some additional vibration effects of sonic pile drivers that may limit their use in sensitive locations.
    - A sonic pile driver operates by continuously shaking the pile at a fixed frequency, literally vibrating it into the ground. Continuous operation at a fixed frequency may, however, be more

noticeable to nearby residents, even at lower vibration levels. Furthermore, the steady-state excitation of the ground may induce a growth in the resonant response of building components. Resonant response may be unacceptable in cases of fragile buildings or vibration-sensitive manufacturing processes. Impact pile drivers, however, produce a high vibration level for a short time (0.2 seconds) with sufficient time between impacts to allow any resonant response to decay.

- Select demolition methods involving little to no impact, where possible. For example, sawing bridge decks into sections that can be loaded onto trucks results in lower vibration levels than impact demolition by pavement breakers. Milling generates lower vibration levels than excavation using clam shell or chisel drops.
- Avoid vibratory rollers and packers near sensitive areas.

5b. Describe and commit to a mitigation plan that will be developed and implemented during the engineering and construction phase when the information available during the project development phase will not be sufficient to define specific construction vibration mitigation measures. The objective of the plan should be to minimize construction vibration damage using all reasonable and feasible means available. The plan should include the following components:

- A procedure for establishing threshold and limiting vibration values for potentially affected structures, based on an assessment of each structure's ability to withstand the loads and displacements due to construction vibrations
- A commitment to develop a vibration monitoring plan during the engineering phase and to implement a compliance monitoring program during construction

SECTION

8

Documentation of Noise and Vibration Assessment

The level of required documentation is determined according to the project class of action. Section 2.1 covers the appropriate class of action (EIS, EA, or CE) for different projects. If there is uncertainty in the appropriate level of documentation, contact the FTA Regional office.

The noise and vibration analysis must be articulated to the public in a clear, comprehensive manner for all levels of documentation. The technical data and information necessary to withstand scrutiny in the environmental review process must be documented in a way that remains intelligible to the public. Justification for all assumptions used in the analysis, such as selection of representative measurement sites and all baseline conditions, must be presented for review.

A separate technical report or memorandum is often prepared as a supplement to the environmental document. A technical report is appropriate in cases when including the data from the assessment would create an unreasonably long environmental document. The details of the analysis are important for establishing the basis for the assessment. Therefore, all details in the technical report should be contained in a well-organized format for easy access to the information.

For large-scale projects, the environmental document should contain a summary of the essential analysis information to provide subject matter context and the analysis findings. For these projects, separate technical reports are usually prepared as supplements to the EIS or EA and referred to in the environmental document. For smaller projects, or projects with minimal noise or vibration impact, all of the technical information may be presented in the environmental document itself or in a technical memorandum. Other projects might have no potential for noise or vibration impacts. For those projects, that environmental documentation should explain that no noise or vibration impacts are expected.

This section provides guidance on presenting the necessary noise and vibration information in the environmental document (Section 8.1) and the associated technical report (Section 8.2).

8.1 Environmental Document

In the environmental document, provide a summary of the comprehensive noise and vibration information from the technical report and emphasize the salient points of the analysis in a format and style that the public can understand. Smaller projects may have all of the technical information contained within the environmental document, so take special care in summarizing the technical details to convey the information adequately.

Step 1: Choose the Information to Include

Choose the appropriate noise and vibration analysis information to include based on the level of environmental review and the associated documentation.

1a. Provide full disclosure of noise and vibration impacts in the environmental document, including identification of locations where impacts cannot be mitigated below the severe impact level. In general, an EIS describes significant impacts and plans to mitigate the impacts. For EAs, completion of the environmental review with a finding of no significant impact (FONSI) may depend on mitigation being considered for incorporation in the proposed project. The way mitigation is presented in the environmental document depends on the type of impact (noise or vibration) and the stage of project development and environmental review. Projects that meet the criteria of a CE may also require the completion of a noise and/or vibration analysis, and the results of such an analysis should be documented in a noise memo or the CE documentation.

1b. Document noise impacts – Typically, airborne noise impacts can be accurately predicted during the environmental review. For projects that focus on a single alternative, noise impacts can be accurately identified in the draft environmental document. If mitigation is anticipated, then mitigation options should be explored in the EA or draft EIS; firm decisions on mitigation can be deferred to the final document. But for all projects, decisions on noise mitigation should be made before the final document is approved.

1c. Document vibration impacts – Predicting vibration impacts accurately is more complex because ground-borne vibration may be strongly influenced by subsurface conditions. The geotechnical studies that reveal these conditions are normally undertaken during the engineering phase, after the environmental review process is complete. Therefore, the final environmental document will usually not be able to state with certainty whether mitigation is needed for ground-borne vibration and noise.

If the engineering phase is conducted at the same time as the final environmental document, report the results of the Detailed Vibration Analysis in the final environmental document. If the engineering phase is conducted after the final environmental document, report the results of the General Vibration Assessment in the final environmental document. If impact is determined, include a commitment in the final document to conduct a Detailed Vibration Analysis during the engineering phase to complete the impact assessment. Also, include a discussion on various control measures that could be used and the likelihood that the criteria could be met through the use of one or more of the measures. It may be possible to state a commitment in the final environmental document to adhere to the impact criteria for the Detailed Vibration Analysis, while deferring the selection of specific vibration control measures until the completion of detailed studies in the engineering phase. When work is conducted after FTA signs its final decision document (i.e., ROD, combined FEIS/ROD, or FONSI), additional documentation, such as a reevaluation of the previous decision, may be necessary. FTA recommends contacting the FTA Regional office directly in these situations.

1d. Describe mitigation measures in the decision document – After the decision document is approved, incorporate the mitigation measures by reference in the actual grant agreements signed by FTA and the project sponsor. The mitigation measures then become contractual conditions that must be adhered to by the project sponsor.

It is typically appropriate to include the following noise and vibration information in the environmental document, as described in Section 8.1:

- The existing conditions (affected environment)
- The direct impacts from operation (environmental consequences)
- The construction impacts (environmental consequences)

Step 2: Organize information in the Environmental Document

Include information in the following sections of the environmental document separating out the noise and vibration information.

2a. Existing Conditions (Affected Environment) – Describe the existing conditions (conditions without the project) in terms of the existing noise and vibration conditions in this section of the document. The primary function of this section is to establish the focus and baseline conditions for the discussion of environmental impacts. Include the following basic information and separate the noise and vibration sections.

- **Description of noise/vibration metrics, effects and typical levels** – Include a targeted summary of relevant information from Section 3 of this manual. This will serve as background for the discussions of noise/vibration levels and characteristics that will follow in later sections. Provide illustrative material to convey typical levels to the public.

- **Inventory of noise/vibration-sensitive sites** – Describe the approach for identifying noise- and vibration-sensitive sites as well as the identified sites and site descriptions. Use sufficient detail to demonstrate completeness. Document these results on a map.

- **Noise/vibration measurements** – Document the basis for selecting measurement sites, including tables of sites coordinated with maps showing locations of sites. Summarize the measurement approach and include the justification for the measurement procedures used.

  Present measurement data in well-organized tables and figures with a summary and interpretation of measured data. Measurements are often included in the table of measurement sites described in the previous paragraph. In some cases, measurements may be supplemented or replaced by collected data relevant to the noise and vibration characteristics of the area. For example, soil information for estimating ground-borne vibration propagation characteristics may be available from other projects in the area.

A summary and interpretation of how the collected data define the project setting is fundamental to this section.

2b. Direct Impacts – Include the following in the discussion on direct impacts due to project operation:

- **Overview of approach** – Provide a targeted summary of relevant information on the assessment procedure for determining noise/vibration impacts as a framework for the following sections.

- **Estimated noise/vibration levels** – Provide a general description of prediction models used to estimate project noise/vibration levels. Describe any distinguishing features unique to the project, such as source levels associated with various technologies.

  Describe the results of the predictions in general terms first, followed by a detailed accounting of predicted noise levels. Supplement this information with tables and illustrate by contours, cross-sections, or shaded mapping. If contours are included in a technical report, it is not necessary to repeat them in this section.

- **Criteria for noise/vibration impact** – Describe the impact criteria for the project in detail and reference the appropriate section in this manual. Include tables listing the criteria levels or the figures included in this manual.

- **Noise/vibration impact assessment** – Present the impact assessment in its own section or combined with the section above.

  Describe the locations, as identified in the screening procedure, where noise/vibration impact is expected to occur without implementation of mitigation measures, based on the screening results, predicted future levels, existing levels, and application of the impact criteria.

  Include inventory tables of impacted noise- and vibration-sensitive sites to quantify the impacts for all noise/vibration-sensitive sites included in the Affected Environment (Existing Conditions) as described in the Existing Conditions section above.

- **Noise/vibration mitigation measures** – Perhaps the greatest difference between the technical report and the environmental document is with mitigation. The technical report discusses mitigation options and recommendations, while the environmental document provides the vehicle for reaching decisions on appropriate mitigation measures.

  Begin this section with a summary of the noise/vibration mitigation measures considered for the impacted locations. Describe the specific measures selected for implementation in detail. Also, include any applicable, specific noise or vibration policies the project sponsor may have in place.

In cases where it is not possible to commit to a specific mitigation measure in the final environmental document, it may be possible to commit to a certain noise/vibration level. For example, the environmental document could include a commitment to meet or exceed the impact criteria specified in Sections 4.1 and 6.2.

- **Unavoidable adverse environmental effects** – If it is projected that adverse noise/vibration impacts will result after all reasonable abatement measures have been incorporated, identify these impacts in this section.

2c. Construction Impacts – Discuss construction impacts in the environmental document's section on construction impacts, if present. If, because of the scale of the project, the environmental document does not have a separate construction impacts section, then the construction impacts should be discussed with the rest of the resource impacts.

When a special section on construction noise/vibration impacts is included in the document, it should be organized according to the comprehensive outline on long-term impacts described above. For projects with relatively minor effects, include a brief summary of impact.

8.2 Technical Report on Noise and Vibration

The technical report is intended to present complete technical data and descriptions in a manner that can be understood by the general public, but is more technical than the information found in the environmental document. All necessary background information should be present in the technical report, including tables, maps, charts, drawings, and references that may be too detailed for the environmental document, but which are important in helping to draw conclusions about the project's noise and vibration impacts and mitigation options.

Include the following major subject headings and key information described below. If both noise and vibration have been assessed, include separate sections for noise and vibration with subsections for key information as described below. Additional details on documentation requirements for the technical report of non-standard procedures and methodologies are included in Appendix G.

- **Overview** – Include a brief description of the project and an overview of the noise/vibration concerns to highlight initial considerations in framing the scope of the study.

- **Inventory of Noise/Vibration-Sensitive Sites** – Describe the approach for identifying noise- and vibration-sensitive sites as well as the identified sites and site descriptions. Use sufficient detail to demonstrate completeness. Document results on a map.

- **Measurements of Existing Noise/Vibration Conditions**
  - Document the basis for selecting measurement sites, including tables of sites coordinated with maps showing locations of sites. Summarize the measurement approach with justification for the measurement procedures used.
  - If the measurement data are used to estimate existing conditions at other locations, include the rationale and the method of estimation. Describe measurement procedures in detail.
  - Include tables of measurement instruments documenting manufacturer, type, serial number, and date of most recent calibration by authorized testing laboratory. Document measurement periods, including the time of day and length of time at each site to demonstrate adequate representation of ambient conditions.
  - Present measurement data in well-organized tables and figures with a summary and interpretation of measured data.

- **Additional Measurements Related to the Project** – Include detailed description of measurements and results for projects that require specialized measurements at noise- and vibration-sensitive sites. Examples include:
  - Outdoor-to-indoor noise level reduction of homes
  - Transmission of vibration into concert halls and recording studios
  - Special source-level characterization

- **Predictions of Noise/Vibration from the Project**
  - Describe the prediction model used to estimate future project conditions and specific data used as input to the models. Reference the appropriate section in this manual. Document any change or extension to the models recommended in this manual, so that the validity of the adjustments can be confirmed. See Appendix G for more information.
  - Describe in detail the modeled scenarios and why the scenarios were chosen.
  - Tabulate computed levels and illustrate by contours, cross-sections, or shaded mapping. Illustrate noise/vibration impacts with base maps at a scale with enough detail to provide reference for the location.

- **Noise/Vibration Criteria**
  - Describe the impact criteria for the project in detail and reference the appropriate section in this manual. Include tables specifying the criteria levels or the figures included in this manual.
  - If construction noise and/or vibration assessments were conducted, include the construction criteria in a separate section with the construction assessment details. See below for more information.

- **Noise/Vibration Impact Assessment**
  - Describe the impact assessment according to the appropriate noise and/or vibration impact assessment sections in this manual.
  - If an alternatives analysis was conducted, present a resulting impact inventory for each alternative mode or alignment in a format that allows comparison among alternatives.
  - Tabulate the inventory according to the different types of affected noise- and vibration-sensitive sites. Present the results of the assessment both before and after mitigation.

- **Noise/Vibration Mitigation**
  - Begin this section with a summary of all treatments considered, including those not carried to final consideration.
  - Consider final candidate mitigation treatments separately and provide a description of the features of the treatment, including costs, expected benefit in reducing impacts, locations where the benefit would be realized, and a discussion of the practicality of alternative treatments.
  - Include enough noise and vibration impact information to allow the project sponsor and FTA to reach decisions on mitigation prior to issuance of an environmental decision document.

- **Construction Noise/Vibration Impacts**
  - Describe criteria adopted for construction noise or vibration if construction noise and/or vibration assessments were conducted.
  - Describe the method used for predicting construction noise or vibration and include inputs to the models such as equipment roster by construction phase, equipment source levels, assumed usage factors, and other assumed site characteristics.
  - Present predicted levels for noise- and vibration-sensitive sites and identify short-term impacts.
  - In cases where construction impacts are identified, discuss feasible abatement methods using enough detail to allow construction contract documents to include mitigation measures.

- **References** – Provide references for all criteria, approaches, and data used in the analyses, as well as other reports related to the project that may be relied on for information, e.g., geotechnical reports.

Appendix A: Glossary of Terms

Terminology used through the manual is defined in this appendix.(49)(72)

A-weighting	A standardized filter used to alter the sensitivity of a sound level meter with respect to frequency so that the instrument is less sensitive at low and high frequencies where the human ear is less sensitive. Abbreviated as dBA.
Absolute Noise Impact	Noise that interferes with activities independent of existing noise levels and is expressed as a fixed level threshold.
Accelerometer	A transducer that converts vibratory motion to an electrical signal proportional to the acceleration of that motion.
Ambient	The pre-project background noise or vibration level, which is often used interchangeably with "existing noise" in this manual.
Amplitude	Difference between the extremes of an oscillating signal.
Alignment	The horizontal location of a railroad or transit system as described by curved and tangent track.
At-grade	Tracks on the ground surface.
Automated Guideway Transit (AGT)	Guided steel-wheel or rubber-tired transit passenger vehicles operating singly or in multi-car trains with a fully automated system on fixed-guideways along an exclusive ROW. AGT includes personal rapid transit, group rapid transit, and automated people mover systems.
Auxiliaries	The term applied to a number of separately driven machines, operated by power from the main engine or electric generation. They include the air compressor, radiator fan, traction motor blower, and air conditioning equipment.
Ballast mat	A 2- to 3-inch-thick elastomer mat placed under the normal track ballast on top of a rigid slab or packed sub-grade.
Ballast	Granular material placed on the trackbed for the purpose of holding the track in line and at surface.
Bus Rapid Transit (BRT)	A type of limited-stop bus operation that relies on technology to help speed up the service. Buses can operate on exclusive transitways, high-occupancy-vehicle lanes, expressways, or ordinary streets.
Catenary	On electric railroad and LRT systems, the term describing the overhead conductor that is contacted by the pantograph or trolley, and its support structure.
Commuter rail	Conventional passenger railroad serving areas surrounding an urban center. Most commuter railroads utilize locomotive-hauled coaches, often in push-pull configuration.
Consist	The total number and type of cars, locomotives, or transit vehicles in a trainset.
Continuous welded rail	A number of rails welded together to form unbroken lengths of track without gaps or joints.
Corrugated rail	A rough condition of alternating ridges and grooves which develops on the rail head in service.
Crest factor	The ratio of peak particle velocity to maximum RMS amplitude in an oscillating signal.
Criteria	Plural form of "criterion," the relationship between a measure of exposure (e.g., sound or vibration level) and its corresponding effect.
Cross tie	The transverse member of the track structure to which the rails are spiked or otherwise fastened to provide proper gage and to cushion, distribute, and transmit the stresses of traffic through the ballast to the trackbed.
Crossover	Two turnouts with the track between the frogs arranged to form a continuous passage between two nearby and generally parallel tracks.
Cumulative	The summation of individual sounds into a single total value related to the effect over time.
Cut	A terrain feature typically created to allow for a trackbed to be at a lower level than the surrounding ground.

dB	See Decibel.
dBA	See A-weighting.
Decibel	The standard unit of measurement for sound pressure level and vibration level. Technically, a decibel is the unit of level which denotes the ratio between two quantities that are proportional to power; the number of decibels is 10 times the logarithm of this ratio. Abbreviated as dB.
DMU	Diesel-powered multiple unit. See Multiple Unit.
DNL	See L_{dn}.
Electrification	A term used to describe the installation of overhead wire or third rail power distribution facilities to enable operation of trains.
Embankment	A bank of earth, rock, or other material constructed above the natural ground surface.
Equivalent level	The level of a steady sound, which, in a stated time period and at a stated location, has the same sound energy as the time-varying sound. Also, written as L_{eq}.
Event	A passby of a vehicle (e.g., train, bus, or car) of any size consist.
Ferry boat	A transit mode comprised of vessels to carry passengers and/or vehicles over a body of water.
Fixed-guideway	A public transportation facility with a separate ROW for the exclusive use of public transportation and other high-occupancy vehicles.
Flange	The vertical projection along the inner rim of a wheel that serves, together with the corresponding projection of the mating wheel of a wheel set, to keep the wheel set on the track.
Floating slab	A special track support system for vibration isolation, consisting of concrete slabs supported on resilient elements, usually rubber or similar elastomer.
Force density	Force density is the force per root distance along the track in $lb/ft^{1/2}$. The force density level is the level in decibels of the force density relative to 1 $lb/ft^{1/2}$ and describes the vehicle force that excites the soil/rock surrounding the transit structure.
Frequency	The number of times that a periodically occurring quantity repeats itself in a specified period. With reference to noise and vibration signals, the number of cycles per second.
Frequency spectrum	Distribution of frequency components of a noise or vibration signal.
Frog	A track structure used at the intersection of two running rails to provide support for wheels and passageways for their flanges, thus permitting wheels on either rail to cross the other.
Gage (of track)	The distance between the rails on a track.
Grade crossing	The point where a rail line and a motor vehicle road intersect at the same vertical elevation.
Guideway	Supporting structure to form a track for rolling or magnetically-levitated vehicles.
Head-End Power (HEP)	A system of furnishing electric power for a complete railway train from a single generating plant in the locomotive.
Heavy rail	See Rail Rapid Transit.
Hertz (Hz)	The unit of acoustic or vibration frequency representing cycles per second.
Hourly average sound level	The time-averaged A-weighted sound level, over a 1-hour period, usually calculated between integral hours. Abbreviated as $L_{(1h)}$.
Hybrid Bus	A rubber-tired vehicle that features a hybrid diesel-electric propulsion system. A diesel engine runs an electric generator that powers the entire vehicle including electric drive motors that deliver power to the wheels.
Idle	The speed at which an engine runs when it is not under load.
Intermediate Capacity Transit (ICT)	A transit system with less capacity than rail rapid transit (RRT), but more capacity than typical bus operations. Examples of ICT include bus rapid transit (BRT), automated guideway transit (AGT), monorails, and trolleys.
Intermodal facility	Junction of two or more modes of transportation where transfers may occur.
Jointed rail	A system of joining rails with steel members designed to unite the abutting ends of contiguous rails.

$L_{(1h)}$	See Hourly Average Sound Level.
L_{dn}	Day-Night Sound Level. The sound exposure level for a 24-hour day calculated by adding the sound exposure level obtained during the daytime (7 a.m. to 10 p.m.) to 10 times the sound exposure level obtained during the nighttime (10 p.m. to 7 a.m.). This unit is used throughout the United States for environmental impact assessment. Also, written as DNL.
$L_{eq(1hr)}$	Equivalent Sound Level. The metric for cumulative noise exposure over a specific time interval is the equivalent sound level
Light Rail Transit (LRT)	A mode of public transit with tracked vehicles in multiple units operating in mixed traffic conditions on streets as well as sections of exclusive ROW. Vehicles are generally powered by electricity from overhead lines.
Locomotive	A self-propelled, non-revenue rail vehicle designed to convert electrical or mechanical energy into tractive effort to haul railway cars. See also Power Unit.
Main line	The principal line or lines of a railway.
Maglev	Magnetically-levitated vehicle; a vehicle or train of vehicles with guidance and propulsion provided by magnetic forces. Support can be provided by either an electrodynamic system wherein a moving vehicle is lifted by magnetic forces induced in the guideway or an electromagnetic system wherein the magnetic lifting forces are actively energized in the guideway.
Maximum sound level	The highest exponential-time-average sound level, in decibels, that occurs during a stated time period. Abbreviated as L_{max}. The standardized time periods are 1 second for L_{max}, slow, and 0.125 second for L_{max}, fast.
Metric	Measurement value or a quantitative descriptor used to identify a specific measure of sound level.
Monorail	Guided transit vehicles operating on or suspended from a single rail, beam, or tube.
Multimodal Project	In this manual, the term multimodal project is used to describe a project that includes changes to both transit and highway components in segments of the project.
Multiple Unit (MU)	A term referring to the practice of coupling two or more diesel-powered or electric-powered passenger cars together with provision for controlling the traction motors on all units from a single controller.
Noise	Any disagreeable or undesired sound or other audible disturbance.
Octave band	A standardized division of a frequency spectrum in which the interval between two divisions is a frequency ratio of 2.
One-third octave band	A standardized division of a frequency spectrum in which the octave bands are divided into thirds for more detailed information. The interval between center frequencies is a ratio of 1.25.
Pantograph	A device for collecting current from an overhead conductor (catenary), consisting of a jointed frame held up by springs or compressed air and having a current collector at the top.
Park-and-ride facility	A parking garage and/or lot used for parking passengers' automobiles while they use transit agency facilities and vehicles.
Peak factor	See Crest factor.
Plan-and-profile	Mapping used by transportation planners that shows two-dimensional plan views (x- and y- axes) on the same page as two-dimensional profiles (x- and z-axes) of a road or track.
Peak Particle Velocity (PPV)	The peak signal value of an oscillating vibration velocity waveform. Usually expressed in inches/second in the United States.
Peak-to-Peak (P-P) Value	Of an oscillating quantity, the algebraic difference between the extreme values of the quantity.
Power unit	A self-propelled vehicle, running on rails and having one or more electric motors that drive the wheels and thereby propel the locomotive and train. The motors obtain electrical energy either from a rail laid near, but insulated from, the track rails, or from a wire suspended above the track. Contact with the overhead wire is made by a pantograph mounted on top of the unit.
Project segment	Portions of a project with similar characteristics.

Pure tone	Sound of a single frequency.
Radius of curvature	A measure of the severity of a curve in a track structure based on the length of the radius of a circle that would be formed if the curve were continued.
Rail	A rolled steel shape, commonly a T-section, designed to be laid end to end in two parallel lines on cross ties or other suitable supports to form a track for railway rolling stock.
Rail Rapid Transit (RRT)	Often called "Heavy Rail Transit." A mode of public transit with tracked vehicles in multiple units operating in exclusive rights-of-way. Trains are generally powered by electricity from a third rail alongside the track.
Receiver	A stationary far-field position at which noise or vibration levels are specified.
Relative Noise Impact	Noise increase above existing levels.
Resonance frequency	The phenomenon that occurs in a structure under conditions of forced vibration such that any change in frequency of excitation results in a decrease in response.
Right-of-Way	Abbreviated as ROW. Lands or rights used or held for railroad or transit operation.
Root Mean Square (rms)	The square root of the mean-square value of an oscillating waveform, where the mean-square value is obtained by squaring the value of amplitudes at each instant of time and then averaging these values over the sample time.
RMS Velocity Level (LV)	See Vibration Velocity Level.
SEL	See Sound Exposure Level.
Sound Exposure Level	The level of sound accumulated over a given time interval or event. Technically, the sound exposure level is the level of the time-integrated mean square A-weighted sound for a stated time interval or event, with a reference time of one second. Abbreviated as SEL.
Sound	A physical disturbance in a medium that is capable of being detected by the human ear.
Spectrum	See Frequency Spectrum.
Sub-ballast	Any material of a superior character, which is spread on the finished subgrade of the roadbed and below the top-ballast, to provide better drainage, prevent upheaval by frost, and better distribute the load over the roadbed.
Subgrade	The finished surface of the roadbed below the ballast and track.
Suburban bus	A bus similar to an intercity bus with high-backed seats but no luggage compartment, often used in express mode to city centers from suburban locations.
Switch	A track structure used to divert rolling stock from one track to another.
Tangent track	Track without curvature.
Track	An assembly of rail, ties, and fastenings over which cars, locomotives, and trains are moved.
Traction motor	A specially designed direct current series-wound motor mounted on the trucks of locomotives and self-propelled cars to drive the axles.
Trainset	A group of coupled cars including at least one power unit.
Transducer	Device designed to receive an input signal of a given kind (motion, pressure, heat, etc.) and to provide an output signal of a different kind (electrical voltage, amperage, etc.) in such a manner that desired characteristics of the input signal appear in the output signal for measurement purposes.
Transfer mobility	Transfer mobility is the complex velocity response produced by a point force as a function of frequency and represents the relationship between a vibration source that excites the ground and the resulting vibration of the ground surface.
Transit center	A fixed location where passengers interchange from one route or vehicle to another.
Trolley bus	A rubber-tired, electrically-powered bus operating on city streets drawing power from overhead lines.
Truck	The complete assembly of parts including wheels, axles, bearings, side frames, bolster, brake rigging, springs, and all associated connecting components, the function of which is to provide support, mobility, and guidance to a railroad car or locomotive.
Trunk line	See Mainline. The mainline of a commuter railroad where the branch line traffic is combined.

Turnout	An arrangement of a switch and a frog with closure rails, by means of which rolling stock may be diverted from one track to another.
VdB	See Vibration Velocity Level.
Vibration Velocity Level (LV)	Ten times the common logarithm of the ratio of the square of the amplitude of the RMS vibration velocity to the square of the amplitude of the reference RMS vibration velocity. The reference velocity in the United States is one micro-inch per second. Abbreviated as VdB.
Vibration	An oscillation wherein the quantity is a parameter that defines the motion of a mechanical system.
Wheel flat	A localized flat area on a steel wheel of a rail vehicle, usually caused by skidding on steel rails, causing a discontinuity in the wheel radius.
Wheel squeal	The noise produced by wheel-rail interaction, particularly on curves where the radius of curvature is smaller than allowed by the separation of the axles in a wheel set.

Additional, relevant acoustic terminology and formulas are defined in ANSI S1.1-1994 (49).

Appendix B: Fundamentals of Noise

Noise is generally considered to be unwanted sound. Sound is what we hear when our ears are exposed to small pressure fluctuations in the air. There are many ways in which pressure fluctuations are generated, but typically they are caused by vibrating movement of a solid object. This manual uses the terms noise and sound interchangeably because there is no physical difference between them. Noise can be described in terms of three variables: amplitude (loud or soft); frequency (pitch); and time pattern (variability).

B.1 Amplitude

The loudness of a sound is described by the sound wave's amplitude of pressure fluctuations above and below atmospheric pressure. Pressure is measured in Pascals. The mean value of the positive and negative pressure fluctuations is the static atmospheric pressure and is not a useful metric of sound. However, the effective magnitude of the sound pressure in a sound wave can be expressed by the rms of the oscillating pressure. See Figure B-1 for an illustration of the rms pressure.

The rms pressure is calculated according to Eq. B-1. The values of sound pressure are squared and time-averaged to smooth out variations. The rms pressure is the square root of this time-averaged value.

$$P_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} P_i^2} \qquad \textbf{Eq. B-1}$$

where:

P_{rms} = sound pressure
P_i = individual sound pressure
N = number of samples
$i = 1$ = index of summation

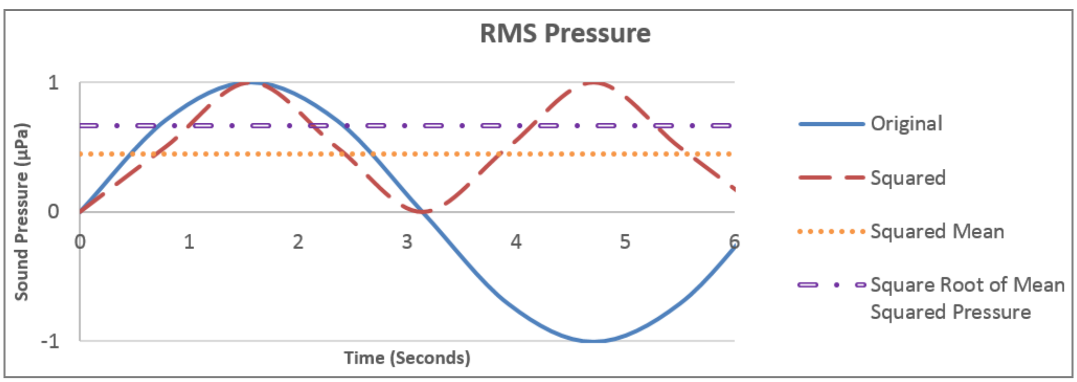


Figure B-1 RMS Pressure Illustration

Most humans with typical or average hearing can perceive sounds ranging from approximately 20 microPascals to 20 million microPascals or more. Because of the difficulty in dealing with such an extreme range of numbers, acousticians use a logarithmic scale to describe sound levels. Acousticians use a compressed scale based on logarithms of the ratios of the sound energy contained in the wave related to the square of sound pressures instead of the sound pressures themselves, resulting in the "sound pressure level" in decibels (dB). The 'B' in dB is always capitalized because the unit is named after Alexander Graham Bell, a leading 19th century innovator in communication.

Sound pressure level (L_p) is defined as:

$$L_p = 10log_{10}(\frac{p_{rms}^2}{p_{ref}^2}); or$$

$$L_p = 20log_{10}(\frac{P_{rms}}{P_{ref}})\ dB \qquad \textbf{Eq. B-2}$$

where

L_P = sound pressure level, dB
P_{rms} = RMS sound pressure
P_{ref} = 20 microPascals

Inserting the range of sound pressure values mentioned above into Eq. B-2 results in a typical quietest sound at 20 microPascals at 0 dB. A typical loudest sound of 20 million microPascals is 120 dB.

B.1.1 Decibel Addition

The combination of two or more sound pressure levels at a single location requires decibel addition, which is the addition of logarithmic quantities of sound energy (P^2_{rms}).

To add sound energy from multiple, unique sources, add the sound energy as shown Eq. B-3.

$$L_p = 10log_{10}(\frac{{P_1}^2 + {P_2}^2 + \cdots + {P_n}^2}{P_{ref}^2}) \qquad \textbf{Eq. B-3}$$

where

L_P = sound pressure level, dB
$P_1, P_{2,} P_n$ = individual source RMS sound pressures to add
P_{ref} = 20 microPascals

A doubling of identical sound sources results in a 3-dB increase, as shown mathematically below.

$$L_p = 10log_{10}(2\frac{p_{rms}^2}{p_{ref}^2})$$

$$= 10log_{10}(\frac{p_{rms}^2}{p_{ref}^2}) + 10log_{10}(2)$$

$$= 10log_{10}(\frac{p_{rms}^2}{p_{ref}^2}) + 3$$

To add decibel levels (instead of sound energy) use the following equation:

$$L_p = 10log_{10}(\sum_{i=1}^{N} 10^{(L_i/10)})$$

where

L_p = sound pressure level, dB
N = number of samples
i = index of summation
L_i = individual sound pressure levels, dB
L_P = sound pressure level, dB
$L_1, L_{2,} L_n$ = individual source sound pressure levels to add

The equation above can be rewritten as follows:

$$L_p = 10log_{10}(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} + \cdots + 10^{\frac{L_n}{10}})$$ **Eq. B-4**

where

$L_1, L_{2,} L_n$ = individual source sound pressure levels to add

Decibel addition can be quickly approximated using Figure B-2.

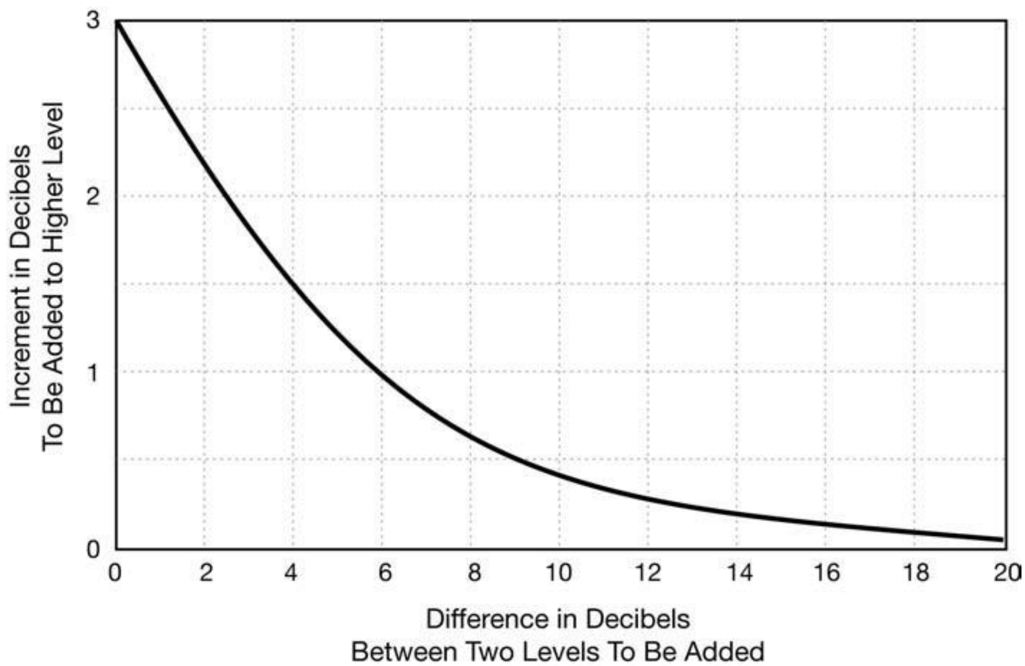


Figure B-2 Graph for Approximate Decibel Addition

Example B-1 Decibel Addition – Identical Buses

Decibel Addition

What is the combined sound pressure level of two identical buses if the noise from one bus resulted in a sound pressure level of 70 dB?

Since a doubling of identical sound sources results in a 3-dB increase:

$$\begin{aligned} L_p &= 70 + 3 \\ &= 73\ dB \end{aligned}$$

Example B-2 Decibel Addition – Two Sources

Decibel Addition

What is the combined sound pressure level of 64 dB and 60 dB?

Using Eq. B-4:

$$\begin{aligned} L_p &= 10log_{10}(10^{64/10} + 10^{60/10}) \\ &= 65.5\ dB \end{aligned}$$

Using Figure B-2:
The x-axis values represent the difference between the two sound levels, 64 and 60 dB. The difference between the sound levels in this example is 4. The point on the curve corresponding to 4 on the x-axis is 1.5. The y-axis values represent the increment that is added to the higher level.

$$\begin{aligned} L_p &= 64 + 1.5 \\ &= 65.5\ dB \end{aligned}$$

B.1.2 Frequency

Sound is a fluctuation of air pressure. The number of times the fluctuation occurs in one second is called its frequency. In acoustics, frequency is quantified in cycles per second, or Hertz (Hz). The hearing for a typical human covers the frequency range from 20 Hz to 20,000 Hz.

Some sounds, like whistles, are associated with a single frequency; this type of sound is called a pure tone. However, most often, noise is made up of many frequencies, called a spectrum. Analyzing a noise spectrum allows for identification of dominant frequency ranges and can assist in identifying noise sources. Often a frequency spectrum is divided into standardized frequency bands for analysis. Most commonly, the frequency bands for transit analyses are octave bands (where the interval between two divisions is a frequency ratio of 2) and one-third octave bands (where the interval between center frequencies is a ratio of 1.25).[73]

If the spectrum associated with a transit noise source is dominated by many low-frequency components, the noise will have a characteristic like the rumble of thunder; this is often associated with noise from a subway. Mid-range frequencies are often associated with wheel/rail noise, and high frequencies may be associated with wheel squeal due to sharp curves on a track.

The spectrum in Figure B-3 illustrates the full range of acoustical frequencies that can occur near a transit system. In this example, the noise spectrum was measured near a train on an elevated steel structure with a sharp curve.

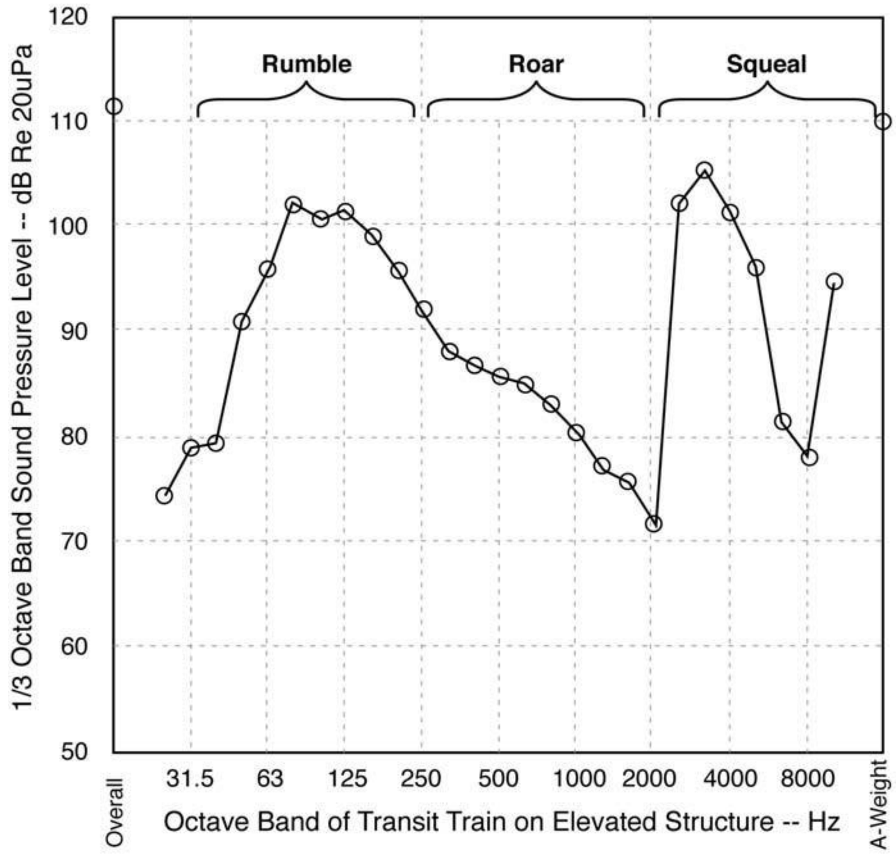


Figure B-3 Noise Spectrum of Transit Train on Curve and Elevated Structure

The human auditory system does not respond equally to all frequencies of sound. For sounds normally heard in our environment, low frequencies below 250 Hz and frequencies above 10,000 Hz are generally considered less audible than the frequencies in between. This is because our ears are less sensitive in those areas. To better represent human hearing, frequency response functions were developed to characterize the way people respond to different frequencies. These are referred to as A-, B-, and C-weighted curves and represent human auditory response to normal, very loud, and extremely loud sound levels, respectively. Environmental noise is generally considered to be in the normal sound level range; and, therefore, the A-weighted sound level is considered best to represent the human response.

The A-weighting curve is shown in Figure B-4. This curve illustrates that sounds at 50 Hz would have to be amplified by 30 dB to be perceived as loud as a sound at 1000 Hz at normal sound levels.

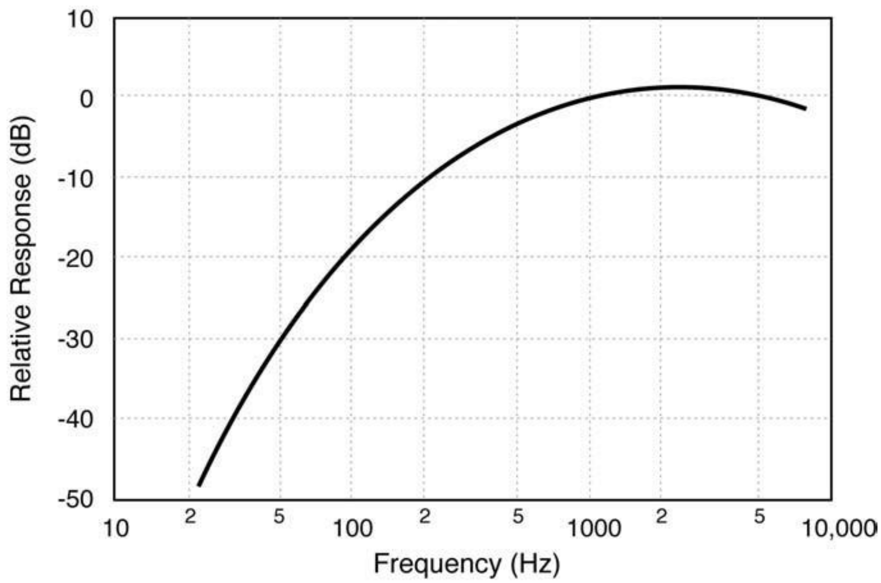


Figure B-4 A-Weighting Curve

Low frequencies have longer wavelengths of sound (cycles are less frequent) and, conversely, high frequencies have shorter wavelengths (cycles are more frequent). The size of the wavelength in feet is dependent on frequency and speed of sound as follows:

$$f\lambda = c \qquad \textbf{Eq. B-5}$$

where

f = frequency in cycles per second, Hz
λ = wavelength, ft
c = speed of sound, ft/sec

The speed of sound in air varies with temperature; but at standard conditions, it is approximately 1000 ft per second. Therefore, at standard conditions, a frequency of 1000 Hz has a wavelength of 1 foot and a frequency of 50 Hz has a wavelength of 20 ft. The scale of these waves explains, in part, the reason humans perceive sounds of 1000 Hz better than those of 50 Hz. A wavelength of 1 foot is similar to the size of a person's head; whereas, a wavelength of 20 ft is similar to dimensions associated with a house, which is why low-frequency sounds (such as those from an idling locomotive) are sometimes not attenuated by walls and windows of a home. These sounds transmit indoors with relatively little reduction in strength.

B.1.3 Time Pattern

The third important characteristic of noise is its variation in time. Environmental noise is considered to be a combination of all outdoor noise sources. When combined, sources such as distant traffic, wind in trees, and distant industrial or farming activities often create a low-level background noise in which no particular individual source is identifiable. Background noise is often relatively constant from moment to moment, but varies slowly over time as natural forces change or as human activity follows its daily cycle. In addition to this low-level, slowly varying background noise, a succession of identifiable noisy events of relatively brief duration may be added. These events may include single-vehicle passbys, aircraft flyovers, screeching of brakes, and other short-term events, which all cause the noise level to substantially fluctuate from moment to moment.

It is possible to describe these fluctuating noises in the environment using single-number metrics to allow for manageable measurements, computations, and impact assessment. The search for adequate single-number noise metrics has encompassed hundreds of attitudinal surveys and laboratory experiments in addition to decades of practical experience with many alternative metrics.

B.1.4 Noise Metrics

The noise metrics referred to in this manual are described in the sections below.

B.1.4.1 A-weighted Sound Level: The Basic Noise Unit

The basic noise unit for transit noise is the A-weighted sound level and is described in ANSI S1.1-1994 (49). It describes the noise level at the receiver at any moment in time and can be read directly from noise-monitoring equipment when frequency weighting is set to A-weighting. Figure B-5 shows examples of typical A-weighted sound levels for both transit and non-transit sources, ranging from approximately 30 dBA (very quiet) to 90 dBA (very loud).

The unit dBA denotes the decibel level is A-weighted. The letter "A" indicates that the sound has been filtered to reduce the strength of very low and very high-frequency sounds to emulate the human response to sound levels as described in Appendix B.1.2. This allows for events that are out of the range of human hearing, such as high-frequency dog whistles and low-frequency seismic disturbances, to be filtered out. On average, each A-weighted sound level increase of 10 dB corresponds to an approximate doubling of subjective loudness.

A-weighted sound levels are adopted as the basic noise unit for transit noise impact assessments because they:

- Can be measured easily,
- Approximate the human ear's sensitivity to sounds of different frequencies,
- Match attitudinal-survey tests of annoyance better than other basic units,
- Have been in use since the early 1930s, and
- Are endorsed as the proper basic unit for environmental noise by most agencies concerned with community noise throughout the world.

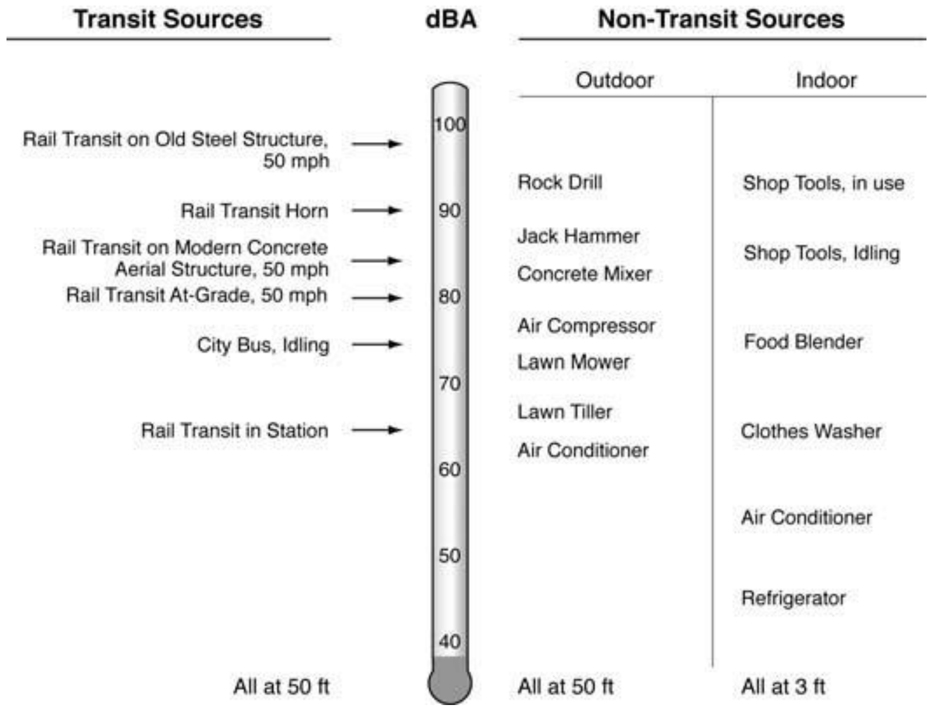


Figure B-5 Typical A-weighted Sound Levels

B.1.4.2 Maximum Sound Level (L_{max}) During a Single Noise Event

As a transit vehicle approaches, passes by, and then recedes into the distance, the A-weighted sound level rises, reaches a maximum, and then fades into the background noise. The maximum A-weighted sound level reached during this passby is called the maximum sound level, (49) abbreviated here as L_{max}. L_{max} is illustrated in Figure B-6 where time is plotted horizontally, and A-weighted sound level is plotted vertically.

Although L_{max} is commonly used in vehicle-noise specifications,[xvi] it is not used for transit environmental noise impact assessment. L_{max} does not include the number and duration of transit events, which are important for assessing people's reactions to noise. It also cannot be normalized to a one-hour or 24-hour cumulative measure of impact, and therefore, is not conducive to comparison among different transportation modes. For example, cumulative noise metrics commonly used in highway noise assessments are $L_{eq(1hr)}$ and L_{10}, the noise level exceeded for 10 percent of the peak hour.

[xvi] For noise compliance tests of transient sources, such as moving transit vehicles under controlled conditions with smooth wheel and rail conditions, L_{max} is typically measured with the sound level meter's time weighting set to "fast." However, for tests of continuous or stationary transit sources, it is usually more appropriate to use the "slow" setting. When set to "slow," sound level meters ignore some of the very-transient fluctuations, which are negligible when assessing the overall noise level.

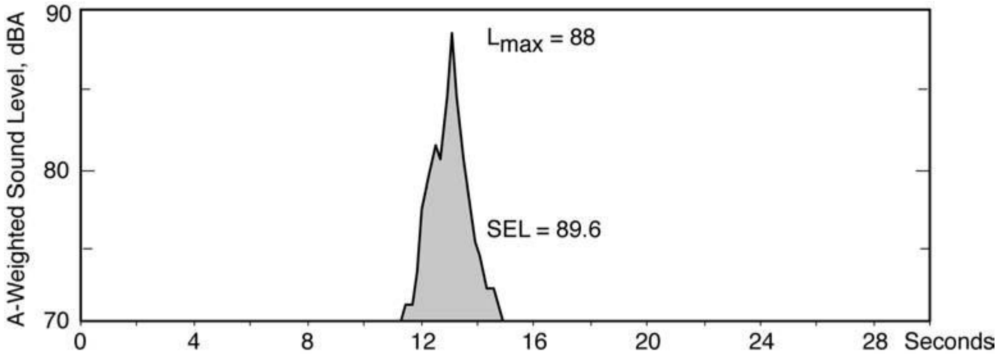


Figure B-6 Typical Transit-Vehicle Passby

B.1.4.3 Sound Exposure Level (SEL): Exposure from a Single Noise Event

Sound exposure level, abbreviated here as SEL, is the cumulative noise exposure from a single noise event, normalized to one second (49). SEL contains the same overall sound energy as the actual varying sound energy during the event. It is the primary metric for the measurement of transit vehicle noise emissions and an intermediate metric in the measurement and calculation of both $L_{eq(1hr)}$ and L_{dn}. The SEL metric is A-weighted and is expressed in the unit dBA.

This concept is illustrated in Figure B-6 and Figure B-7 where the shaded regions are the sound exposure during and event. The example in Figure B-6 is a transit-vehicle passby and Figure B-7 is an example of a fixed-transit facility as a transit bus is started, warmed up, and then driven away. For this event, the noise exposure is large due to duration of the event.

SEL is an A-weighted cumulative measure that is referenced to one second. Louder events have greater SELs than quieter events, and events of longer duration have greater SELs than shorter events. This is generally consistent with community response to noise. Noise events of longer duration are considered more disruptive than events of shorter duration with equal maximum A-weighted sound levels.

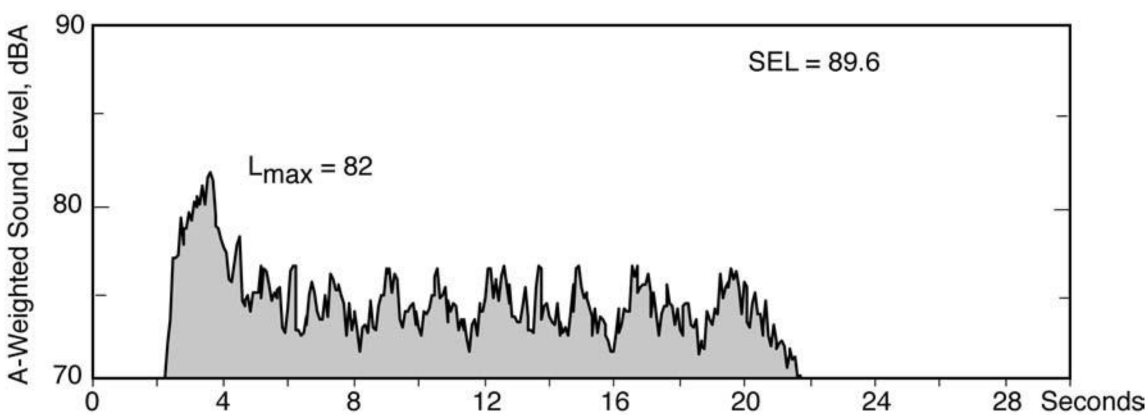


Figure B-7 Typical Fixed-Facility Noise Event

Conceptually, the sound exposure level can be expressed as:

$$SEL = 10log_{10}(\frac{Total\ sound\ energy}{during\ the\ event})$$

Mathematically, the sound exposure level is computed as follows:

$$SEL = 10log_{10}(\sum_{i=1}^{N} 10^{(L_i/10)})$$ **Eq. B-6**

where

SEL = Sound exposure level, dBA
N = number of samples
i = index of summation
L_i = individual A-weighted sound level, dBA

The events shown in Figure B-6 and Figure B-7 are compared graphically in Figure B-8 using a logarithmic vertical scale. The shaded zones in these figures indicate noise exposure over time. The actual event shows the noise exposure over the time of the event, and the equivalent SEL shows the total noise exposure normalized to one second. Note that events 1 and 2 in Figure B-8 have different time periods and noise levels throughout the event, but the same resulting SEL.

SEL is used in transit noise analyses because it:

1. Accounts for both the duration and amplitude of an event,
2. Allows a uniform assessment method for both transit-vehicle passbys and fixed-facility noise events, and
3. Can be used to calculate the one-hour and 24-hour cumulative metrics for comparison across different transportation modes.

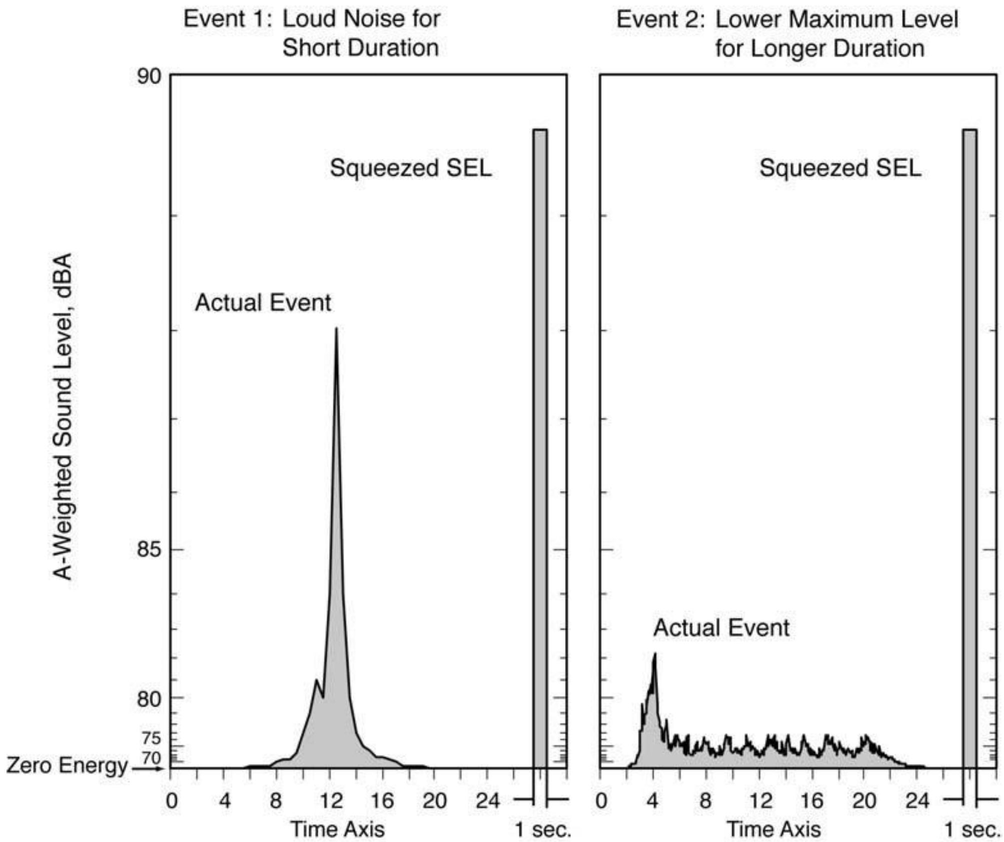


Figure B-8 An Energy View of Noise Events

B.1.4.4 Equivalent Sound Level ($L_{eq(t)}$)

The metric for cumulative noise exposure over a specific time interval is the equivalent sound level (49). It is a single decibel value that accounts for total sound energy from all sound levels over a specified time interval (or time period). The time period associated with the equivalent sound level metric can vary for different types of analyses. This metric is abbreviated as $L_{eq(t)}$, where "t" is the duration of the time period. $L_{eq(t)}$ represents a hypothetical constant sound level and contains the same overall sound energy as the actual varying sound energy during the time period "t". For most transit noise analyses, an A-weighted, hourly equivalent sound level is used, abbreviated here as $L_{eq(1hr)}$. $L_{eq(1hr)}$ is expressed in the unit, dBA.

Figure B-9 shows examples of typical unmitigated hourly $L_{eq(1hr)}$'s, both for transit and non-transit sources ranging from 40 (quiet) to 80 dB (loud). Note that these $L_{eq(1hr)}$'s depend upon both the number of events during the hour as well as each event's duration, which is affected by vehicle speed. For example, doubling the number of events during the hour will increase the $L_{eq(1hr)}$ by 3 decibels, as will doubling the duration of each individual event.

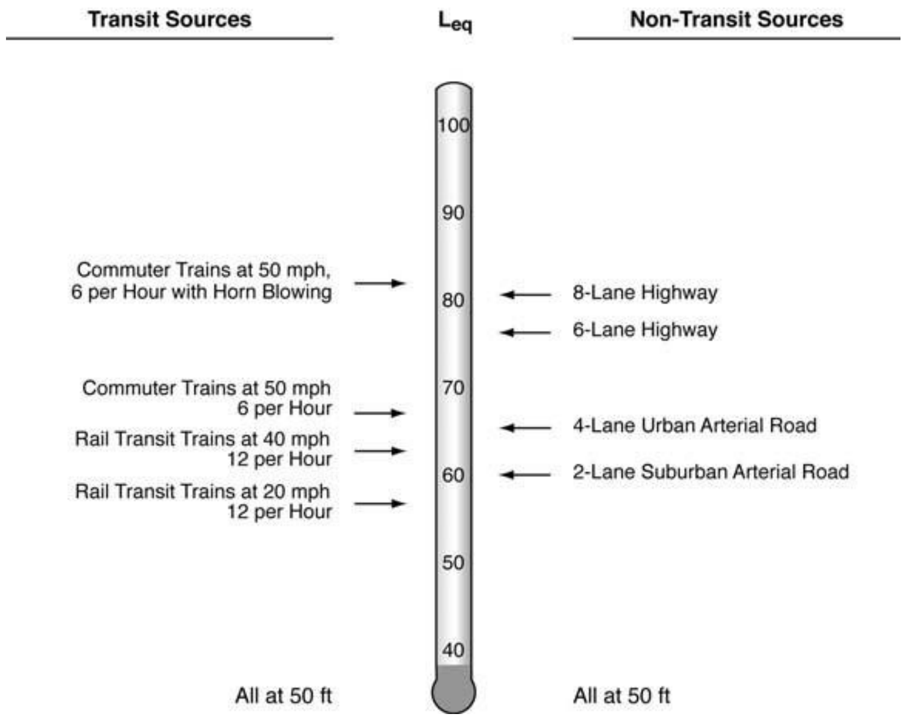
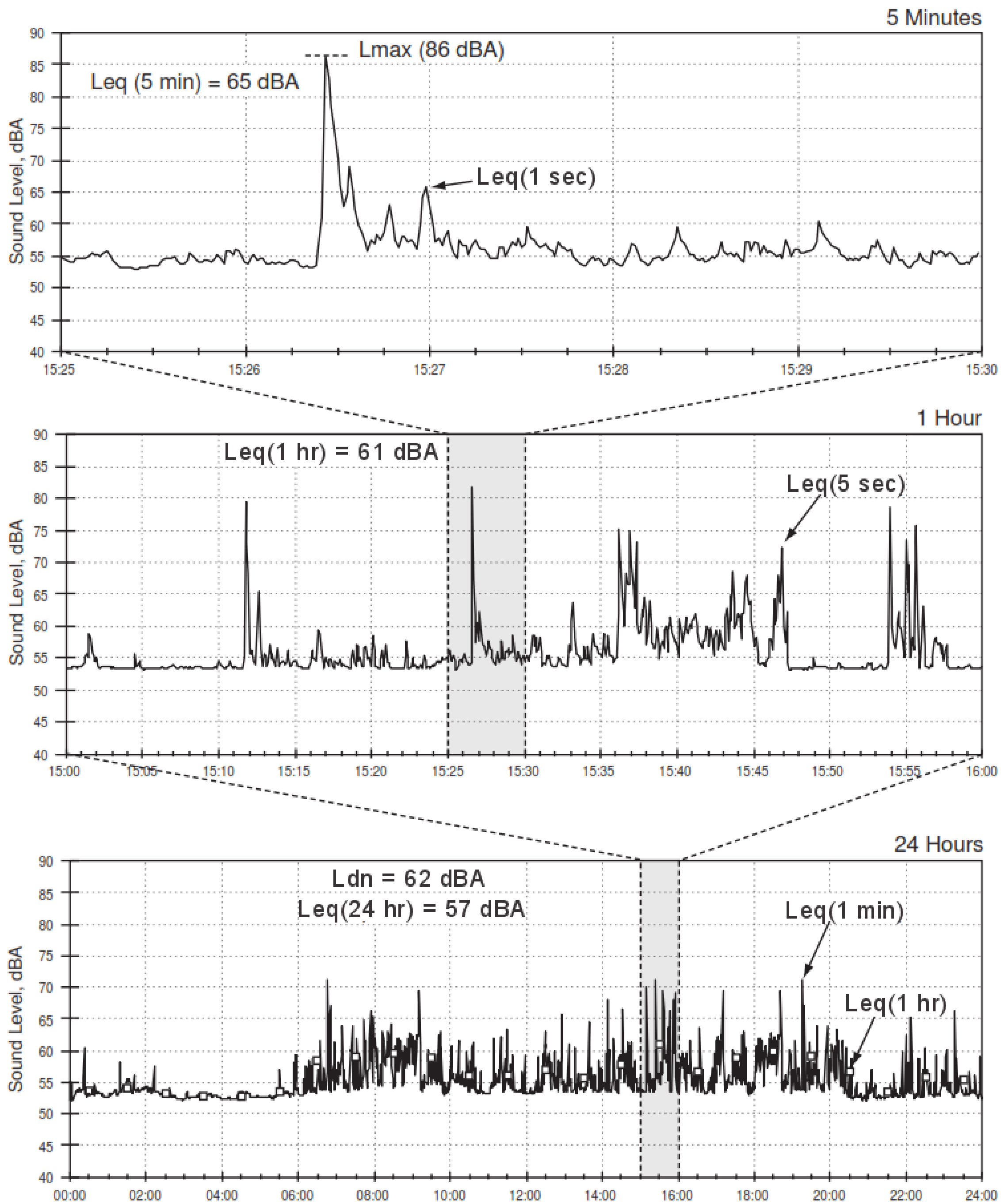


Figure B-9 Typical Hourly $L_{eq(1hr)}$'s

An example of sound levels over time for a single noise event such as a train passing on nearby tracks is illustrated in the top frame of Figure B-10. As the train approaches, passes by, and then recedes into the distance, the A-weighted sound level rises, reaches a maximum, and then fades into the background noise. The equivalent sound level is shown for three different time periods Figure B-10. The area under the curve in this top frame is the noise that reaches the receiver (noise exposure) over this five-minute period. The center frame of the figure shows sound levels over the one-hour period, including the five-minute period from the top frame. The area under the curve represents the noise exposure for one hour. The bottom frame shows sound levels over a full 24-hour period and is discussed in Appendix B.1.4.5.



Typical A-weighted Sound Level Variation over a 24-Hour Period

Figure B-10 Example A-weighted Sound Level Time Histories

Conceptually, the equivalent sound level can be expressed as:

$$L_{eq}(t) = 10log_{10}(\frac{Total\ Sound\ Energy}{Time\ Period})$$

Mathematically, the equation is as follows:

$$L_{eq}(t) = 10log_{10}(\frac{1}{T}\sum_{i=1}^{N} 10^{(L_i/10)})$$

where

$L_{eq(t)}$ = equivalent sound level of time period "t", dBA
T = time period, sec (3600 for an hourly $L_{eq(1hr)}$)
N = number of samples, sec (3600 for an hourly $L_{eq(1hr)}$)
i = index of summation
L_i = individual A-weighted sound level, dBA

The equation above can be rewritten as follows for a one-hour time period:

$$L_{eq}(1h) = 10log_{10}[Total\ Sound\ Energy\ in\ 1\ hr] - 35.6$$ **Eq. B-7**

where

35.6 = numerical adjustment for a time period of 1 hour ($10log_{10}(t)$)

The sound energy is totaled over a full hour (3600 seconds) and is accumulated for all noise events during that hour. When computing the equivalent sound level for a time period other than one hour, T is modified in the equation to the duration of the time period in seconds. The numerical adjustment (35.6) accounts for time period of interest, in this case, one hour.

An alternate way for computing $L_{eq(1hr)}$ for a series of transit-noise events using sound exposure levels can be expressed conceptually as follows:

$$L_{eq}(1h) = 10log_{10}(\begin{matrix} Energy\ Sum\ of \\ all\ SELs \end{matrix}) - 35.6$$

Mathematically, the equation is as follows:

$$L_{eq}(t) = 10log_{10}(\frac{1}{T}\sum_{i=1}^{N} 10^{(SEL_i/10)})$$ **Eq. B-8**

where

$L_{eq(t)}$ = equivalent sound level of time period "t", dBA
T = time period, sec (3600 for an hourly $L_{eq(1hr)}$)
N = number of sample, sec (3600 for an hourly $L_{eq(1hr)}$)
i = index of summation
SEL = individual sound exposure level, dBA

Hourly $L_{eq(1hr)}$ is adopted as the measure of cumulative noise impact for non-residential land uses (those not involving sleep) because $L_{eq(1hr)}$:

- Correlates well with speech interference in conversation and on the telephone – as well as interruption of TV, radio, and music enjoyment;
- Increases with the duration of transit events;
- Accounts for the number of transit events over the hour, which is also important to people's reactions; and

- Is used by the Federal Highway Administration in assessing highway-traffic noise impact.(Thus, this noise metric can be used for directly comparing and contrasting highway, transit, and multimodal alternatives).

B.1.4.5 Day-Night Sound Level (L_{dn}): 24-Hour Exposure from All Events

The metric for cumulative 24-hour exposure is the Day-Night Sound Level, [49] abbreviated here as L_{dn}. It is a single, A-weighted decibel value that accounts for total sound energy from all sound sources over 24 hours and is expressed in the unit, dBA. Events between 10 p.m. and 7 a.m. are increased by 10 dB to account for people's greater nighttime sensitivity to noise.

Figure B-11 shows examples of typical L_{dn}'s, both for transit and non-transit sources, ranging from 50 to 80 dB, where 50 is considered a quiet 24-hour period and 80 a loud 24-hour period. Note that these L_{dn}'s depend upon the number of events during day and night separately, including each event's duration, which is affected by vehicle speed.

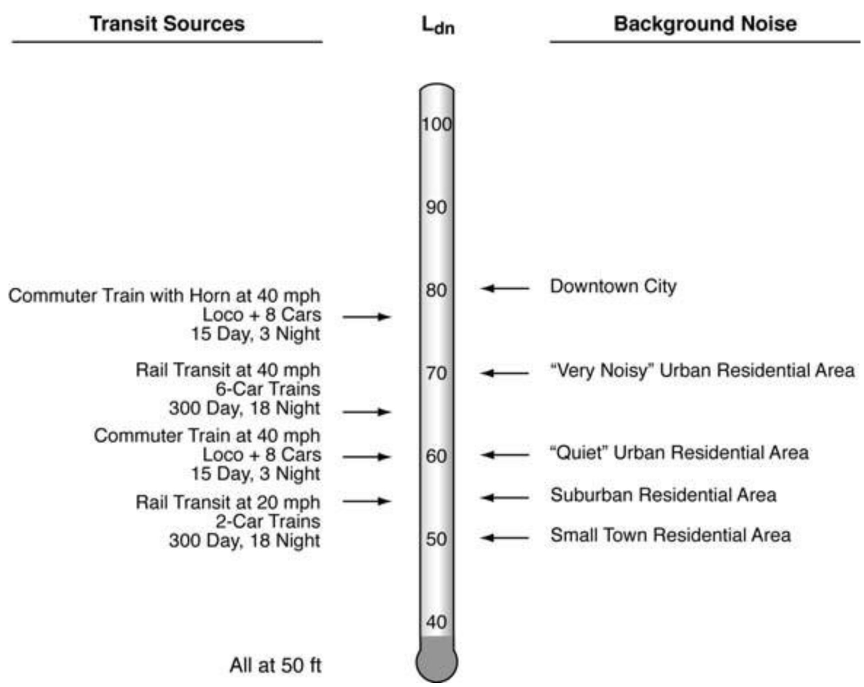


Figure B- 11 Typical L_{dn}'s

An example of sound level variation over 24 hours is visualized in the bottom frame of Figure B-10. The area under the curve represents the receiver's noise exposure over the 24 hours. Note that some vehicle passbys occur at night, when the background noise is typically lower and the 10 dB adjustment is applied.

Conceptually, the day-night level can be expressed as:

$$L_{dn} = 10log_{10}\left(\frac{Total\ Sound\ Energy_{Day}}{Time\ Period_{Day}\ (seconds)} + \frac{n_{adj,n} \times Total\ Sound\ Energy_{Night}}{Time\ Period_{Night}\ (seconds)}\right)$$

Mathematically, the equation is as follows:

$$L_{dn} = 10log_{10}(\frac{1}{T_d}\sum_{i=1}^{N} t_i \times 10^{(L_{d,i}/10)} + \frac{1}{T_n}\sum_{j=1}^{M} t_j \times 10^{((L_{n,j}+n_{adj,n})/10)}) \quad \textbf{Eq. B-9}$$

where

L_{dn} = cumulative 24-hour exposure (day-night sound level), dBA
T_d = time period during the daytime, between 7 a.m. and 10 p.m. sec (54,000)
N = number of samples during the daytime (54,000)
i = index of summation
t_i = time interval of measurements in seconds (1)
$L_{d,i}$ = individual A-weighted sound level during the daytime, dBA
T_n = time period during the nighttime, between 10 p.m. and 7 p.m. sec (32,400)
M = number of samples during the nighttime (32,400)
j = index of summation
t_j = time interval of measurements, sec (1)
$L_{n,j}$ = individual A-weighted sound level during the nighttime, dBA
$n_{adj,n}$ = nighttime noise adjustment (10 dB)

The equation above can be rewritten as follows:

$$L_{dn} = 10log_{10}[\,(15 * Total\ Sound\ Energy_{Day}) + (9 * n_{adj,n} *\ Total\ Sound\ Energy_{Night})] - 49.4$$

The sound energy is totaled over a full 24 hours, and the sound energy is accumulated from all noise events during that time period. The numerical adjustment (49.4) accounts for time period of interest, in this case, 24 hours.

An alternative way of computing L_{dn} from twenty-four hourly $L_{eq(1hr)}$'s can be expressed conceptually as follows:

$$L_{dn} = 10log_{10}(\frac{\begin{matrix}Energy\ sum\ of\\ daytime, hourly\ Leqs\end{matrix} + (n_{adj,n} * \begin{matrix}Energy\ sum\ of\\ nighttime, hourly\ Leqs\end{matrix})}{Time\ period\ (seconds)})$$

The equation above can be rewritten as:

$$L_{dn} = 10log_{10}(\frac{\begin{matrix}Energy\ sum\ of\\ daytime, hourly\ Leqs\end{matrix} + (n_{adj,n} * \begin{matrix}Energy\ sum\ of\\ nighttime, hourly\ Leqs\end{matrix})}{(\frac{86400}{3600})})$$

The equation above can be reduced further and rewritten as:

$$L_{dn} = 10log_{10}(\begin{matrix}Energy\ sum\ of\\ daytime, hourly\ Leqs\end{matrix} +\ (n_{adj,n} * \begin{matrix}Energy\ sum\ of\\ nighttime, hourly\ Leqs\end{matrix})) - 13.8 \quad \textbf{Eq. B-10}$$

L_{dn} due to a series of transit-noise events can also be computed in terms of SEL. The equation below assumes that transit noise dominates the 24-hour noise environment, where nighttime SELs are increased by 10 dB before totaling:

$$L_{dn} = 10log_{10}(\begin{matrix}Energy\ sum\ of \\ all\ daytime\ SELs\end{matrix} + (n_{adj,n} * \begin{matrix}Energy\ sum\ of \\ all\ nighttime\ SELs\end{matrix})) - 49.4 \quad \textbf{Eq. B-11}$$

L_{dn} is adopted as the measure of cumulative noise impact for residential land uses (those involving sleep), because it:

- Correlates well with the results of attitudinal surveys of residential noise impact
- Increases with the duration of transit events
- Accounts for the number of transit events over the full twenty-four hours
- Accounts for the increased sensitivity to noise at night, when most people are asleep
- Allows composite measurements to capture all sources of community noise combined
- Allow quantitative comparison of transit noise with other community noises
- Is the designated metric of choice of other Federal agencies (e.g., HUD, FAA, and EPA) and has wide international acceptance

Appendix C: Background for Transit Noise Impact Criteria

The noise criteria presented in Section 4.1 of this manual have been developed based on well-documented criteria and research on human response to community noise. The primary goals in developing the noise criteria were to ensure that the impact limits are firmly founded in scientific studies, realistically based on noise levels associated with new transit projects, and represent a reasonable balance between community benefit and project costs. This appendix provides background information on the development of these criteria.

C.1 Relevant Literature

The following is an annotated list of the documents that are particularly relevant to the noise impact criteria:

1. **U.S. EPA's "Levels Document"**(74)
   This report identifies noise levels consistent with the protection of public health and welfare against hearing loss, annoyance, and activity interference. It has been used as the basis of numerous community noise standards and ordinances.

2. **Committee on Hearing, Bioacoustics and Biomechanics (CHABA) Working Group 69, "Guidelines for Preparing Environmental Impact Statements on Noise"**(75)
   This report was the result of deliberations by a group of leading acoustical scientists with the goal of developing a uniform national method for noise impact assessment. Although the CHABA's proposed approach has not been adopted, the report serves as an excellent resource documenting research in noise effects. It provides a strong scientific basis for quantifying impacts in terms of L_{dn}.

3. **American Public Transportation Association (APTA) Guidelines for Design of Rapid Transit Facilities**(76)
   The noise and vibration sections of the APTA Guidelines have been used successfully in the past for the design of rail transit facilities. The APTA Guidelines include criteria for acceptable community noise and vibration. Experience has shown that meeting the APTA Guidelines will usually result in acceptable noise levels; but the metric used in the APTA Guidelines is not appropriate for environmental assessment purposes.

   The APTA Guidelines criteria are in terms of L_{max} for conventional RRT vehicles, and they cannot be used to compare among different modes of transit. Since the APTA Guidelines are expressed in terms of maximum passby noise, they are not sensitive to the frequency or duration of noise events for transit modes other than conventional RRT operations with 5 to 10 minute headways. Therefore, the APTA criteria are questionable for assessing the noise impact of other transit modes that differ from conventional rapid transit with respect to source emission levels and operating characteristics (e.g., commuter rail, AGT, and a variety of bus projects).

4. **Synthesis of Social Surveys on Noise Annoyance**(77)
   In 1978, Theodore J. Schultz, an internationally known acoustical scientist, synthesized the results of a large number of social surveys concerning annoyance due to transportation noise. A group of these surveys were remarkably consistent, and the author proposed that their average

results be taken as the best available prediction of transportation noise annoyance. This synthesis has received essentially unanimous acceptance by acoustical scientists and engineers. The "universal" transportation response curve developed by Schultz (Figure 3-7) shows that the percent of the population highly annoyed by transportation noise increases from zero at an L_{dn} of approximately 50 dBA to 100% when L_{dn} is approximately 90 dBA. Most importantly, this curve indicates that for the same increase in L_{dn}, there is a greater increase in the number of people highly annoyed at high noise levels than at low noise levels. For example, a 5 dB increase at low ambient levels (40 - 50 dB) has less impact than at higher ambient levels (65 - 75 dB). A recent update of the original research containing several railroad, transit, and street traffic noise surveys, confirming the shape of the original Schultz curve [12].

5. **HUD's Standards**[19]
   HUD has developed noise standards, criteria, and guidelines to ensure that housing projects supported by HUD achieve the goal of a suitable living environment. The HUD acceptability standards define 65 dB (L_{dn}) as the threshold for a normally unacceptable living environment (moderate impact for FTA) and 75 dB (L_{dn}) as the threshold for an unacceptable living environment (severe impact for FTA).

C.2 Basis for Noise Impact Criteria Curves

The lower curve in Figure 4-2 represents the onset of moderate impact and is based on the following considerations:

- The EPA finding that a community noise level of L_{dn} less than or equal to 55 dBA is "requisite to protect public health and welfare with an adequate margin of safety."[72]
- The conclusion by EPA and others that a 5 dB increase in L_{dn} or $L_{eq(1hr)}$ is the minimum required for a change in community reaction.
- The research concludes that there are very few people highly annoyed when the L_{dn} is 50 dBA, and that an increase in L_{dn} from 50 dBA to 55 dBA results in an average of 2% more people highly annoyed (Figure 3-7).

The increase in noise level from an existing ambient level of 50 dBA to a cumulative level of 55 dBA because of a project is found to cause minimal impact, with 2% of people highly annoyed, as described in the bullets above. This is considered the lowest threshold where impact starts to occur. Therefore, for an existing ambient noise level of 50 dBA, the curve representing the onset of moderate impact is at 53 dBA, the combination of which yields a cumulative level of 55 dBA by decibel addition. The remainder of the lower curve in Figure 4-2 was determined from the annoyance curve (Figure 3-7) by allowing a fixed 2% increase in annoyance at other levels of existing ambient noise. As cumulative noise increases, the increment to attain the same 2% increase in highly annoyed people is smaller. While it takes a 5-dB noise increase to cause a 2% increase in highly annoyed people at an existing ambient noise level of 50 dB, an increase of only 1 dB causes a 2% increase of highly annoyed people at an existing ambient noise level of 70 dBA.

The upper curve in Figure 4-2 represents the onset of severe impact based on a total noise level, corresponding to a higher degree of impact. The severe noise impact curve is based on the following considerations:

- HUD defines an L_{dn} of 65 as the onset of a normally unacceptable noise zone (moderate impact for FTA) in its environmental noise standards [19]. FAA considers that residential land uses are not compatible with noise environments where L_{dn} is greater than 65 dBA (20).

- An increase of 5 dB in L_{dn} or $L_{eq(t)}$ is commonly assumed as the minimum required increase for a change in community reaction.
- The research concludes that an increase of 5 dB in L_{dn} or $L_{eq(t)}$ represents a 6.5% increase in the number of people highly annoyed (Figure 3-7).

The increase in noise level from an existing ambient level of 60 dBA to a cumulative level of 65 dBA caused by a project represents a change from an acceptable noise environment to the threshold of an unacceptable noise environment. This is considered the level at which severe impact starts to occur with a 6.5% increase in the number of people highly annoyed as described in the bullets above. Therefore, for an existing ambient noise level of 60 dBA, the curve representing the onset of severe impact is at 63 dBA, the combination of which yields a cumulative level of 65 dBA by decibel addition. The remainder of the upper curve in Figure 4-2 was determined from the annoyance curve (Figure 3-7) by allowing a fixed increase of the 6.5% increase in annoyance at all existing ambient noise levels.

Both curves incorporate a maximum limit for the transit project noise in noise-sensitive areas. Independent of existing noise levels, moderate impact for land use categories 1 and 2 is considered to occur whenever the transit L_{dn} equals or exceeds 65 dBA, and severe impact occurs whenever the transit L_{dn} equals or exceeds 75 dBA. These absolute limits are intended to restrict activity interference caused by the transit project alone.

Both curves also incorporate a maximum limit for cumulative noise increase at low existing noise levels (below approximately 45 dBA). This is a conservative limit that reflects the lack of social survey data on people's reactions to noise at such low ambient levels. Like the FHWA approach in assessing the relative impact of a highway project, the transit noise criteria include limits on noise increase of 10 dB and 15 dB for moderate impact and severe impact, respectively, relative to the existing noise level.

Note that due to the types of land use included in category 3, the criteria allow the project noise for category 3 sites to be 5 dB greater than for category 1 and category 2 sites. This difference is reflected by the offset in the vertical scale on the right side of Figure 4-2. Aside from active parks, which are clearly less sensitive to noise than category 1 and 2 sites, category 3 sites include primarily indoor activities. Therefore, the criteria account for some noise reduction from the building structure.

C.3 Equations for Noise Impact Criteria Curves

The equations for the noise impact criteria curves shown in Figure 4-2 are included in this section. These equations may be useful when performing the noise assessment methodology using spreadsheets, computer programs, or other analysis tools. Otherwise, such mathematical detail is generally not necessary to implement the criteria, and direct use of Figure 4-2 is adequate and less time-consuming.

A total of four continuous curves are included in the criteria, creating two threshold curves for moderate and severe impact for category 1 and 2, and two curves for category 3 (See Table C-1). Note that for each level of impact, the overall curves for categories 1 and 2 are offset by 5 dB from category 3. While each curve is graphically continuous, each one is defined by a set of three discrete equations. These equations are approximately continuous at the transition points. The following is a description of the three equations:

- The first equation in each set is a linear relationship, representing the portion of the curve in which the existing noise exposure is low, and the allowable increase is limited to 10 dB and 15 dB for moderate impact and severe impact, respectively.

- The second equation in each set represents the impact threshold over the range of existing noise exposure for which a fixed percentage of increase in annoyance is allowed, as described in Appendix C.2. This curve is a third-order, polynomial approximation derived from the Schultz curve[(75)] and covers the range of noise exposure encountered in most populated areas. This curve is used for determining noise impact in most cases for transit projects.
- The third equation represents the absolute limit of project noise imposed by the criteria for areas with high existing noise exposure. For land use category 1 and 2, the absolute limit is 65 dBA for moderate impact and 70 dBA for severe impact. For land use category 3, the absolute limit is 75 dBA for moderate impact and 80 dBA for severe impact.

Table C-1 Threshold of Moderate and Severe Impacts

Threshold of Moderate Impact

Category 1 and 2

$$L_p = \begin{cases} 11.450 + 0.953L_E, & L_E < 42 \\ 71.662 - 1.164L_E + 0.018{L_E}^2 - 4.088 \times 10^{-5}{L_E}^3, & 42 \le L_E \le 71 \\ 65, & L_E > 71 \end{cases} \quad \text{Eq. C- 12}$$

Category 3

$$L_p = \begin{cases} 16.450 + 0.953L_E, & L_E < 42 \\ 76.662 - 1.164L_E + 0.018{L_E}^2 - 4.088 \times 10^{-5}{L_E}^3, & 42 \le L_E \le 71 \\ 70, & L_E > 71 \end{cases} \quad \text{Eq. C- 13}$$

Threshold of Severe Impact

Category 1 and 2

$$L_p = \begin{cases} 17.322 + 0.940L_E, & L_E < 44 \\ 96.725 - 1.992L_E + 3.02 \times 10^{-2}{L_E}^2 - 1.043 \times 10^{-4}{L_E}^3, & 44 \le L_E \le 77 \\ 75, & L_E > 77 \end{cases} \quad \text{Eq. C- 14}$$

Category 3

$$L_p = \begin{cases} 22.322 + 0.940L_E, & L_E < 44 \\ 101.725 - 1.992L_E + 3.02 \times 10^{-2}{L_E}^2 - 1.043 \times 10^{-4}{L_E}^3, & 44 \le L_E \le 77 \\ 80, & L_E > 77 \end{cases} \quad \text{Eq. C- 15}$$

L_E = the existing noise exposure in terms of L_{dn} or $L_{eq(1hr)}$
L_p = the project noise exposure which determines impact in terms of L_{dn} or $L_{eq(1hr)}$)

Appendix D: Clustering Receivers of Interest

This appendix supplements the information in Section 4.5 on clustering receivers of interest.

The general approach to selecting noise-sensitive receivers in the study area is included in Section 4.5, Step 1. General guidelines are as follows:

- Select the following types of receivers to evaluate individually:
  - Every major noise-sensitive public building
  - Every isolated residence
  - Every relatively small outdoor noise-sensitive area
- Residential neighborhoods and relatively large outdoor noise-sensitive areas can often be clustered and represented by a single receiver.

Clustering similar receivers reduces the number of computations needed later, especially for large-scale projects where a greater number of noise-sensitive sites may be affected. For this approach to be effective, it is essential that the representative receiver accurately represents the noise environment of the cluster.

The major steps in clustering receivers include:

1. First, cluster receivers according to approximately equal exposure to the primary project noise source. These areas typically run parallel to a linear project or circle major stationary sources relative to the proposed project.
2. Next, cluster receivers according to major sources of ambient noise. These areas typically run parallel to or encircle major sources of ambient noise.
3. Then, cluster receivers according to changes in the project layout or operations along the corridor.
4. Finally, select a representative receiver for each cluster.

The major steps are expanded below and include instructions on how to draw cluster boundaries on a map.

1. **Boundaries along the proposed project** – Draw cluster boundaries along the proposed project as described below to separate clusters based on distance from the project. Draw these cluster boundaries for the project sources listed as major in Table 4-19.

   Within both residential and noise-sensitive outdoor areas:

   - **Primary project source**
     Draw cluster boundaries at the following distances from the near edge of the primary project source: 0 ft, 50 ft, 100 ft, 200 ft, 400 ft, and 800 ft. For linear sources, such as a rail line, draw these boundaries as lines parallel to the proposed ROW line. For stationary sources, draw these boundaries as approximate circles around the source, starting at the property line.

     Do not extend boundaries beyond the noise study area, identified in the Noise Screening Procedure in Section 4.3 or the General Noise Assessment of Section 4.4.

- **Remaining project sources** – Repeat the process for the primary project source for all other project listed as major in Table 4-19, such as substations and crossing signals. If several project sources are located approximately together, only consider one source, since the others would produce approximately the same boundary.

  It is good practice to optimize the number of clusters for a project to simplify the procedure.

Where rows of buildings parallel the transit corridor:

- Ensure that cluster boundaries fall between the following rows of buildings, counting back away from the proposed project:
  - Between rows 1 and 2
  - Between rows 2 and 3
  - Between rows 3 and 4
- Add cluster boundaries between these rows if not already included.

2. **Boundaries along sources of ambient noise** – Draw cluster boundaries along all major sources of ambient noise based upon distance from these sources, as described below.
   - Draw cluster boundaries along all interstates and major roadway arterials at the following distances from the near edge of the roadway: 0 ft, 100 ft, 200 ft, and 500 ft.
   - Draw cluster boundaries along all other roadways that have state or county numbering at 0 ft and 100 ft from the near edge of the roadway.
   - For all major industrial sources of noise, draw cluster boundaries that encircle the source at the following distances from the near property line of the source: 0 ft, 100 ft, 200 ft, and 400 ft.

3. **Boundaries based on changes in project layout or operations** – Further subdivision is needed to account for changes in project noise where proposed project layout or operating conditions change considerably along the corridor. Draw a cluster boundary perpendicular to the corridor extending straight outward to both sides at the following locations:
   - Where parallel tracks previously separated by more than approximately 100 ft are moved closer together
   - Approximately where speed and/or throttle are reduced when approaching stations and where steady service speed is reached after departing stations
   - Approximately 200 ft up and down the line from grade crossing bells
   - At transitions from jointed to welded rail
   - At transitions from one type of cross section to another including on structure, on fill, at-grade and in cut
   - At transitions from open terrain to heavily wooded terrain
   - At transitions between areas free of locomotive horn noise and areas subject to this noise source
   - Any other positions along the line where project noise is expected to change considerably, such as up and down the line from tight curves where wheels may squeal

4. **Selection of a representative receiver from each cluster** – Determine a representative receiver for each cluster boundary drawn in the steps above.
   - **Residential clusters**
     Select a representative receiver within the cluster at the house closest to the proposed project. If this receiver is not the clear choice, select the receiver furthest from major sources of ambient noise.
   - **Outdoor noise-sensitive clusters (e.g., urban park or amphitheater)**

Select a representative receiver within the cluster at the closest point of active noise-sensitive use. If this receiver is not the clear choice, select the receiver farther from major sources of ambient noise.

Note that some clusters may fall between areas with receivers of interest. This could occur when operational changes or track layouts change in an open, undeveloped area. Retain these clusters. Do not merge them with adjacent clusters. Do not select a representative receiver of interest from them.

Example D-1 Clustering Receivers

Receivers of Interest and Clustering Receivers

In this hypothetical situation, a new rail transit line, labeled "new rail line" in Figure D-1, is proposed along a major urban street with commercial land use. A residential area is located adjacent to the commercial strip, located approximately one-half block from the proposed transit alignment. A major arterial, labeled "highway," crosses the alignment.

Cluster Receivers Along the Primary Project Source

Primary Project Source

The primary project source in this example is the new rail line. Boundaries are first drawn at distances of 0 ft from the right-of- way line (edge of the street in this example), 50 ft, 100 ft, 200 ft, 400 ft, and 800 ft, (Figure D-1). Distances are labeled at the top of the figure.

This is proposed to be a constant speed section of track, so there are no changes in boundaries due to changes in operations along the corridor. Moreover, no other project sources are shown here, but if there had been a station with a parking lot, lines would have been drawn enveloping the station site at the specified distances from the property line.

Rows of Buildings Parallel to the Transit Corridor

This example includes rows of buildings parallel to the transit corridor. The first set of boundary lines satisfies the requirement that cluster boundaries fall between rows 1 and 2, and between rows 2 and 3, but there is no line between rows 4 and 5. Consequently, a cluster boundary labeled "R" at the top of the figure has been drawn between the 4th and 5th row of buildings.

Cluster Receivers Along the Primary Project Source

The roadway arterial (labeled "highway") is the only major source of ambient noise shown.

Cluster boundaries are drawn at 0 ft, 100 ft, 200 ft and 500 ft from the near edge of the roadway on both sides. These lines are shown with distances labeled at the side of the figure.

Select a Representative Receiver from Each Cluster

Representative receivers are shown as filled circles in Figure D-1. Note that the receivers labeled with “REC” are primarily for use in Appendix E.

Locate receiver, "REC 3". Note that this cluster is located at the outer edge of influence from the major source ("highway") where local street traffic is the dominant source for ambient noise (in practice, this would be verified by a measurement).

"REC 3" is chosen to represent this cluster because it is among the houses closest to the proposed project source in this cluster and it is in the middle of the block affected by the dominant local street. Ambient noise levels at one end of the cluster may be influenced more by the highway and the other end may be affected more by the cross street, but the majority of the cluster would be represented by receiver site "REC 3."

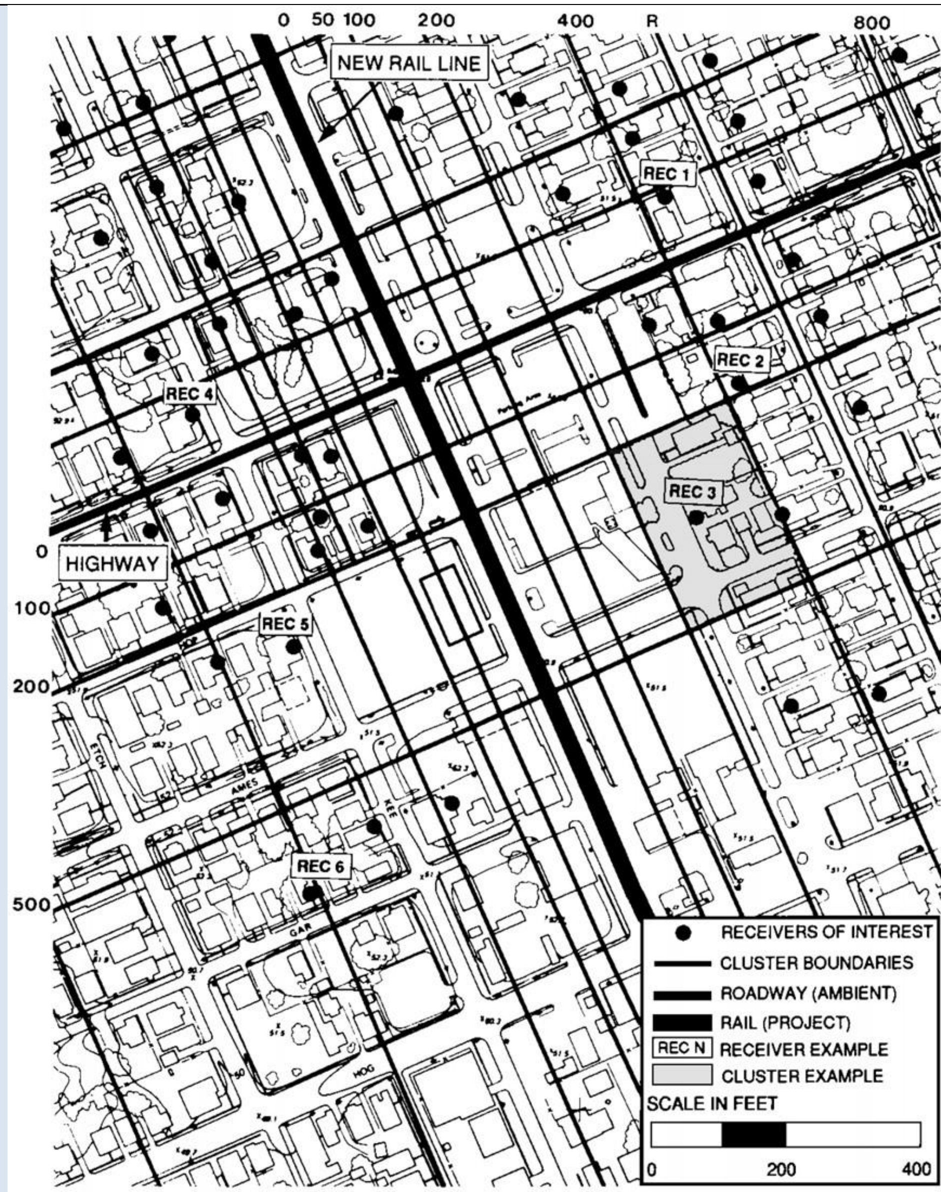


Figure D-1 Example of Receiver Map Showing Cluster Boundaries

Appendix E: Determining Existing Noise

Different options of determining existing noise, including full measurement, computation from partial measurements, and tabular look-up, are described in Section 4.5, Step 5. This appendix provides additional details associated with each method and examples of when each method could be used.

Additional details on the methods for estimating existing noise are provided below:

Option 1: $L_{eq(1hr)}$ measurement (non-residential) – Full one-hour measurements are recommended to determine existing noise for non-residential receivers of interest. These measurements are preferred over all other options and will accurately represent the $L_{eq(1hr)}$. The following procedures apply to these full-duration measurements:

- Measure $L_{eq(1hr)}$ at the receiver of interest during a typical hour of use on two non-successive days. Choose the hour in which maximum project activity will occur. The $L_{eq(1hr)}$ will be accurately represented using this method. Typically, measuring between noon Monday and noon Friday is recommended, but weekend days may be more appropriate for places of worship.
- Position the measurement microphone for all sites as shown in Figure 4-19, considering relative orientation of project and ambient sources. Position the microphone in a location that is somewhat shielded from the ambient source to measure the ambient noise at these locations at the quietest area on the property.
- Conduct all measurements in accordance with good engineering practice.

Option 2: L_{dn} measurement (residential) – Full 24-hour measurements are recommended to determine ambient noise for residential receivers of interest. These measurements are preferred over all other options and will accurately represent the L_{dn}. The following procedures apply to these full-duration measurements:

- Measure a full 24-hour L_{dn} at the receiver of interest for a single weekday (generally between noon Monday and noon Friday).
- Position the measurement microphone for all sites as shown in Figure 4-19 considering relative orientation of project and ambient sources. Position the microphone in a location that is somewhat shielded from the ambient source to measure the ambient noise at these locations at the quietest area on the property.
- Conduct all measurements in accordance with good engineering practice.

Option 3: L_{dn} computation of L_{dn} from 3 partial $L_{eq(1hr)}$ measurements (residential) – An alternative way to determine L_{dn} is to measure $L_{eq(1hr)}$ for three typical hours of the day, then compute the L_{dn} from these three $L_{eq(1hr)}$ measurements. This method is less precise than its full-duration measurement. The following procedures apply to this partial-duration measurement method for L_{dn}:

- Measure the $L_{eq(1hr)}$ during each of the following time periods:
  - During peak-hour roadway traffic
  - Midday, between the morning and afternoon roadway-traffic peak hours
  - During late night between midnight and 5 a.m.
- Position the measurement microphone for all sites as shown in Figure 4-19 considering relative orientation of project and ambient sources. Position the microphone in a location that is somewhat shielded from the ambient source to measure the ambient noise at these locations at the quietest area on the property.
- Conduct all measurements in accordance with good engineering practice.
- Compute the L_{dn} using the equation below

$$L_{dn} \approx 10\log(3 \times 10^{\frac{L_{eq.peakhour\cdot}-2}{10}} + 12 \times 10^{\frac{L_{eq.midday}-2}{10}} + 9 \times 10^{\frac{L_{eq.latenight}+8}{10}}) - 13.8 \qquad \textbf{Eq. E-1}$$

The resulting L_{dn} will be slightly underestimated due to the adjustment to the measured levels in these equations. This underestimation is intended to compensate for the reduced precision of the computed L_{dn}. If using this method, a minimum time duration of one hour should be used for each measurement period in computing an Ldn.

Option 4: Computation of L_{dn} from 1 partial $L_{eq(1hr)}$ measurement (residential) – L_{dn} can also be determined by measuring $L_{eq(1hr)}$ for one hour of the day, and then computing L_{dn} from the $L_{eq(1hr)}$. This method is less precise than computing L_{dn} from 3 $L_{eq(1hr)}$ measurements. This method may be useful for projects with are many sites assessed by the General Noise Assessment. This method may also be appropriate when determining if a particular receiver of interest represents a cluster in a Detailed Noise Analysis. The following procedures apply to this partial-duration measurement option for L_{dn}:

- Measure the $L_{eq(1hr)}$ for the loudest hour of project-related activity during hours of noise sensitivity. If this hour is not selected, other hours may be used with the understanding that the estimate is less precise.
- Position the measurement microphone for all sites as shown in Figure 4-19, considering relative orientation of project and ambient sources. Position the microphone in a location that is somewhat shielded from the ambient source to measure the ambient noise at these locations at the quietest area on the property.
- Conduct all measurements in accordance with good engineering practice.
- Convert the measured hourly $L_{eq(1hr)}$ to L_{dn} with the appropriate equation below.

For measurements between 7 a.m. and 7 p.m.:

$$L_{dn} \approx L_{eq} - 2 \qquad \textbf{Eq. E-2}$$

For measurements between 7 p.m. and 10 p.m.:

$$L_{dn} \approx L_{eq} + 3 \qquad \textbf{Eq. E-3}$$

For measurements between 10 p.m. and 7 a.m.:

$$L_{dn} \approx L_{eq} + 8 \qquad \textbf{Eq. E-4}$$

The resulting L_{dn} will be moderately underestimated due to the use of the adjustment constants in these equations. This underestimation is intended to compensate for the reduced precision of the computed L_{dn}. If using this method, a minimum time duration of one hour should be used for each measurement period in computing an Ldn.

Option 5: Computation of $L_{eq(1hr)}$ or L_{dn} from $L_{eq(1hr)}$ or L_{dn} of a comparable site (all land uses) – Computing $L_{eq(1hr)}$ or L_{dn} from the $L_{eq(1hr)}$ or L_{dn} of a comparable site where the ambient noise is dominated by the same source that is comparable in precision to Option 4. This method can be used to characterize noise in several neighborhoods by using a single representative receiver. It is critical that the measurement site has a similar noise environment to all areas represented. If measurements made by others are available and the sites are equivalent, the existing measurements can be used to reduce the amount of project noise monitoring. The following procedures apply to this method of determining of ambient noise:

- Choose another receiver that is comparable to the receiver (CompRec) of interest with the following:
  - The same source of dominant ambient noise

    - The ambient level of the comparable receiver was measured according to Option 1 or Option 2 above
    - The ambient measurement at the comparable receiver was made in direct view of the major source of ambient noise, unshielded by noise barriers, terrain, rows of buildings, or dense tree zones
- Determine the following from a plan or aerial photograph:
    - The distance ($D_{CompRec}$) from the comparable receiver to the near edge of the ambient source
    - The distance (D_{Rec}) from this receiver of interest to the near edge of the ambient source
- Determine the number of rows of buildings (N) that intervene between the receiver of interest and the ambient source.
- Compute the ambient level at the receiver of interest (Rec) with the appropriate equation below

If roadway sources dominate:

$$L_{Rec} \approx L_{CompRec} - 15\log(\frac{D_{Rec}}{D_{CompRec}}) - 3N$$ **Eq. E-5**

If other sources dominate:

$$L_{Rec} \approx L_{CompRec} - 25\log(\frac{D_{Rec}}{D_{CompRec}}) - 3N$$ **Eq. E-6**

The resulting L_{Rec} will be moderately underestimated. This underestimation is intended to compensate for the reduced precision of the computed L_{dn}.

Option 6: Estimation of L_{dn} by table look-up (all land uses) – The least precise way to determine the ambient noise is to estimate the level using a table. A tabular look-up can be used to establish baseline conditions for a General Noise Assessment if a noise measurement cannot be made. This method should not be used for a Detailed Noise Analysis. The following instruction applies to this method of determining of ambient noise:

Estimate either the $L_{eq(1hr)}$ or the L_{dn} using Table 4-17 based on distance from major roadways, rail lines, or upon population densities. In general, these tabulated values are substantially underestimated.

The underestimation is intended to compensate for the reduced precision of the estimated ambients.

Examples – Examples of when each method of determining existing noise may be appropriate are provided below using the example from Appendix D. Existing noise at the receivers labeled "REC" in Figure D-1 could be estimated as follows:

- **Option 1: $L_{eq(1hr)}$ measurement** – Existing noise at REC 1 is due to the highway at the side of this church. $L_{eq(1hr)}$ can be measured during a typical church hour.
- **Option 2: L_{dn} measurement –** Existing noise at the residence REC 2 is due to a combination of the highway and local streets. L_{dn} can be measured for a full 24-hours.
- **Option 3: L_{dn} computation of L_{dn} from 3 partial $L_{eq(1hr)}$ measurements** – Existing noise at the residence REC 3 is due to the street in front of this residence. L_{dn} can be computed from three $L_{eq(1hr)}$ measurements.

- **Option 4: Computation of L_{dn} from 1 partial $L_{eq(1hr)}$ measurement** – Existing noise at the residence REC 4 is due to the highway. Because the highway has a predictable diurnal pattern, L_{dn} can be computed from one $L_{eq(1hr)}$ measurement.
- **Option 5: Computation of L_{dn} from L_{dn} of a comparable site** – Existing noise at the residence REC 5 is due to Kee Street. REC 3 is also affected by local street traffic and is a comparable distance from the highway. L_{dn} for REC 5 can be computed based on the L_{dn} at REC-3.
- **Option 6: Estimation of L_{dn} by table look-up** – Existing noise at the residence REC 6 is due to local traffic. L_{dn} can be estimated by tables based on population density along this corridor.

Appendix F: Computing Source Levels from Measurements

This appendix contains the procedures for computing source reference levels (SEL_{ref}) from source measurements in cases where the source reference tables in Section 4.5, Step 2 indicate measurements are preferred, data are not available for the source of interest, or more precise data are required than available in the table.

Close-by source measurements for vehicle passbys may capture either the vehicle's sound exposure level (SEL) or maximum noise level (L_{max}). Both metrics can be measured directly by commonly available sound level meters. While the L_{max} metric is not used for transit noise impact assessments, it can be used to compute SEL source reference levels. L_{max} measurements are often available from transit-equipment manufacturers and some transit system equipment specifications may limit close-by L_{max} levels.

Close-by source measurements for stationary sources capture the source's SEL over one source event, where the event duration may be chosen based on measurement convenience. The duration will factor out of the computation when the measured value is converted to reference operating conditions.

This manual does not specify elaborate methods for undertaking the close-by source measurements, but rather, provides general processes. It is required that all measurements conform to good engineering practice, guided by the standards of the American National Standards Institute and other such organizations (27, 28, 29).

This appendix presents information according to noise source as follows:

- Appendix F.1: Highway and rail vehicle passbys for vehicles of the same type
- Appendix F.2: Stationary sources
- Appendix F.3: L_{max} for single train passbys (for trains of mixed consists)

F. 1 Highway and Rail Vehicle Passbys

This section provides information on appropriate conditions for vehicle passby measurements, instructions on converting measurements made under non-reference conditions to source reference levels, and examples of these computations.

The following conditions are required for vehicle passbys, in addition to good engineering practice:

- Measured vehicles must be representative of project vehicles in all aspects, including representative acceleration and speed conditions for buses.
- Track must be relatively free of corrugations and train wheels relatively free of flats, unless these conditions are typical of the proposed project.
- Road surfaces must be smooth and dry, unless these conditions are typical of the proposed project.
- Perpendicular distance between the measurement position and the source's centerline must be 100 ft or less.
- Vehicle speed must be 30 mph or greater, unless typical project speeds are less than that.
- No noise barriers, terrain, buildings, or dense tree zones may break the lines-of-sight between the source and the measurement position.

When close-by source measurements are made under non-reference conditions, use the instructions below and the equations in Table F-1 to convert the measured values to source reference levels. For rail vehicles, measure/convert a group of locomotives or a group of cars separately. This computation requires that all measured vehicles be of the same type. For trains of mixed consists, see Appendix F.3.

SEL measured for a highway-vehicle passby, or a passby of a group of identical rail vehicles

- Collect the following input information:
  - SEL_{meas}, the measured SEL for the vehicle passby
  - N, the consist of the measured group of rail cars or group of locomotives
  - T, the average throttle setting of the measured diesel-powered locomotive(s)
  - S_{meas}, the measured passby speed, in miles per hour
  - D_{meas}, the closest distance between the measurement position and the source, in feet
- Compute the Source Reference Level SEL_{ref}, using Eq. F-1.

L_{max} measured for a passby of a group of identical rail vehicles

- Collect the following input information:
  - L_{max}, measured for the group passby
  - N, the consist of the measured group of rail cars or group of locomotives
  - T, the average throttle setting of the measured diesel-powered locomotive(s)
  - S_{meas}, the measured passby speed, in miles per hour
  - D_{meas}, the closest distance between the measurement position and the source, in feet
  - L_{meas}, the total length of the measured group of locomotives or group of rail cars, in feet
- Compute the Source Reference Level SEL_{ref}, using either Eq. F-2 or Eq. F-3, as appropriate, for locomotives or rail cars.

L_{max} measured for a highway-vehicle passby

- Collect the following input information:
  - L_{max}, measured for the highway-vehicle passby
  - S_{meas}, the vehicle speed, in miles per hour
  - D_{meas}, the closest distance between the measurement position and the source, in feet
- Compute the Source Reference Level, SELref, using Eq. F-4.

Table F-1 Conversion to Source Reference Levels at 50 ft – Highway and Rail Sources

Measured	Source	Equation	
SEL	Vehicle passby	$SEL_{ref} = SEL_{meas} + 10\log(\frac{S_{meas}}{50}) + 10log(\frac{D_{meas}}{50}) + C_{consist} + C_{emissions}$	**Eq. F-1**
L_{max}	Rail-vehicle passby, locomotives only	$SEL_{ref} = L_{Amax} + 10\log(\frac{L_{meas}}{50}) + 10\log(\frac{D_{meas}}{50}) - 10\log(2 \propto) + C_{consist}$ $+C_{emissions} + 3.3$	**Eq. F-2**
	Rail-vehicle passby, cars only	$SEL_{ref} = L_{Amax} + 10\log(\frac{L_{meas}}{50}) + 10\log(\frac{D_{meas}}{50}) - 10\log\ [2 \propto + \sin(2 \propto)]$ $+C_{consist} + C_{emissions} + 3.3$	**Eq. F-3**
	Highway-vehicle passby	$SEL_{ref} = L_{Amax} + 20\log(\frac{D_{meas}}{50}) + C_{emissions} + 3.3$	**Eq. F-4**

S_{meas} = speed of measured vehicle(s), mph

D_{meas} = closest distance between measurement position and source, ft

$C_{consist}$ = 0 for buses and automobiles
$-10\log(N_{Cars})$ for locomotives and rail cars
where N is the number of locomotives or rail cars in the measured group

$C_{emissions}$ = 0 for T < 6 for locomotives
-2 (T-5) for T ≥ 6
where T is average throttle setting of measured diesel – electric locomotive(s)

$-30\log(\frac{S_{meas}}{50})$ for rail cars

$-25\log(\frac{S_{meas}}{50})$ for buses

$-38.1\log(\frac{S_{meas}}{50})$ for automobiles

E_{meas} = event duration of measurement, sec

L_{meas} = total length of measured group of locomotives *or* rail cars, ft

$\propto$ = arctan($\frac{L_{meas}}{2D_{meas}}$), rad

Example F-1 Calculate SEL_{ref} – Locomotives

Computation of SEL_{ref} from SEL Measurement of Fixed-guideway Source

SEL was measured for a passby of two diesel-powered locomotives with the following conditions:

SEL_{meas} = 90 dBA
N_{Cars} = 2
T = 6
S_{meas} = 55 mph
D_{meas} = 65 ft

Compute the source reference level using Eq. F-1.

$$SEL_{ref} = SEL_{meas} + 10\log(\frac{S_{meas}}{50}) + 10log(\frac{D_{meas}}{50}) + C_{consist} + C_{emissions}$$

$$= 90 + 10\log\left(\frac{55}{50}\right) + 10\log\left(\frac{65}{50}\right) - 10\log(2) + (-2(6-5))$$

= 86.5 dBA

Example F-2 Calculate SEL_{ref} – Rail Cars

Computation of SEL_{ref} from L_{max} Measurement of Fixed-Guideway Source

L_{max} was measured for a passby of a 4-car consist of 70-ft long rail cars with the following conditions:

L_{max} = 90 dBA
N_{Cars} = 4
S_{meas} = 70 mph
D_{meas} = 65 ft
L_{meas} = 280 ft
$\propto$ = 1.14

Compute the source reference level using Eq. F-3.

$$SEL_{ref} = L_{Amax} + 10\log(\frac{L_{meas}}{50}) + 10\log(\frac{D_{meas}}{50}) - 10\log\,[2\propto + \sin(2\propto)] + C_{consist} + C_{emissions} + 3.3$$

$$= 90 + 10\log(\frac{280}{50}) + 10\log(\frac{65}{50}) - 10\log\,[2(1.14) + \sin(2(1.14))] - 10\log(4) - 30\log(\frac{70}{50}) + 3.3$$

= 86.7 dBA

Example F-3 Calculate SEL_{ref} – Bus

Computation of SEL_{ref} from L_{max} Measurement of Highway Vehicle Source

L_{max} was measured for a bus with the following conditions:

L_{max} = 78 dBA
D_{meas} = 80 ft
S_{meas} = 40 mph

Compute the source reference level using Eq. F-4

$$SEL_{ref} = L_{max} + 20\log(\frac{D_{meas}}{50}) + C_{emissions} + 3.3$$
$$= 78 + 20\log(\frac{80}{50}) - 25\log(\frac{40}{50}) + 3.3$$
= 87.8 dBA

F.2 Stationary Sources

This section provides information on appropriate conditions for stationary source measurements, instructions on converting measurements made under non-reference conditions to source reference levels, and an example of this type of computation.

The following conditions are required for stationary sources, in addition to good engineering practice:

- Measured source operations must be representative of project operations in all aspects.
- The following ratio must be 2 or less, and the distance to the closest source component must be 200 ft or less.

$$\frac{Distance\ to\ the\ farthest\ source\ component}{Distance\ to\ the\ closest\ source\ component}$$

  If both conditions cannot simultaneously be met, separate close-by measurements of individual components of this source must be made, for which these distance conditions can be met.

- The following ratio must be 2 or less:

$$\frac{Lateral\ length\ of\ the\ source\ area}{Distance\ to\ the\ closest\ source\ component}$$

  The lateral length of the source area is measured perpendicular to the general line-of-sight between source and measurement positions.

  If this condition cannot be met, then make separate close-by measurements of individual components of this source, for which this condition can be met.

- No noise barriers, terrain, buildings, or dense tree zones may break the lines-of-sight between the source and the measurement position.

When close-by source measurements are made under non-reference conditions, use the instructions below and the equation in Table F- 2 to convert the measured values to source reference levels.

SEL was measured for a stationary noise source

- Collect the following input information:
  - SEL_{meas}, the measured SEL for the noise source, for whatever source "event" is convenient to measure
  - E_{meas}, the event duration, in seconds
  - D_{meas}, the closest distance between the measurement position and the source, in feet
- Compute the source reference level, SELref using Eq. F- 5.

Table F-2 Conversion to Source Reference Levels at 50 ft - Stationary Sources

Measured	Source	Equation	
SEL	Stationary noise source	$SEL_{ref} = SEL_{meas} - 10\log(\frac{E_{meas}}{3600}) + 20\log(\frac{D_{meas}}{50})$	**Eq. F- 5**

S_{meas} = speed of measured vehicle(s), in miles per hour
E_{meas} = event duration of measurement, in seconds
D_{meas} = closest distance between measurement position and source, in feet

Example F-4 Calculate SEL_{ref} – Signal Crossing

Computation of SEL_{ref} from SEL Measurement of Stationary Source

SEL was measured for a signal crossing with the following conditions:

SEL_{meas} = 70 dBA
E_{meas} = 10 sec
D_{meas} = 65 ft

Compute the source reference level using Eq. F-5.

$$SEL_{ref} = SEL_{meas} - 10\log(\frac{E_{meas}}{3600}) + 20\log(\frac{D_{meas}}{50})$$

$$= 70 - 10\log(\frac{10}{3600}) + 20\log(\frac{65}{50})$$

= 97.8 dBA

F.3 L_{max} for Single Train Passby

This section provides procedures for the computation of L_{max} for a single train passby. This procedure can be used to characterize trains of mixed consists using L_{max}. Follow the instructions below.

- Collect the following input information:
  - SEL_{ref}, from Section 4.5, specific to both the locomotive type and car type of the train
  - N_{loco}, the number of locomotives in the train
  - N_{cars}, the number of cars in the train
  - L_{loco}, the total length of the train's locomotive(s), in feet (or N_{loco} unit length)
  - L_{cars}, the total length of the train's set of rail car(s), in feet (or N_{cars} unit length)
  - S, the train speed, in miles per hour
  - D, the closest distance between the receiver of interest and the train, in feet

- Use the equations in Table F-3 to compute the following:
  - $L_{max.loco}$ for the locomotive(s) using Eq. F-6

- $L_{max.cars}$ for the rail car(s) using the Eq. F-7
- $L_{max.total}$, the larger L_{max} from the locomotives(s) and rail car(s) is the L_{max} for the total train passby, see Eq. F- 8.

Table F-3 Conversion to Lmax at the Receiver, for a Single Train Passby

Source	Equation	
Locomotives	$L_{max.Loco} = SEL_{locos} + 10log\left(\frac{S}{50}\right) - 10log\left(\frac{L}{50}\right) + 10\log(2\propto) - 3.3$	**Eq. F-6**
Rail Cars	$L_{max.Rcars} = SEL_{Rcars} + 10log\left(\frac{S}{50}\right) - 10log\left(\frac{L}{50}\right) + 10\log(2\propto + \sin(2\propto)) - 3.3$	**Eq. F-7**
Total Train	$L_{max.total} = max(L_{max.Loco}\ or\ L_{max.RCars})$	**Eq. F-8**

L = total length of measured group of locomotive(s) or rail car(s), ft

S = vehicle speed, mph

$\propto$ = arctan $\left(\frac{L}{2D}\right)$, rad

D = closest distance between receiver and source, ft

Example F-5 Calculate L_{max} – Train Passby

Computation of L_{max} for Train Passby

Calculate the L_{max} of commuter train at receiver of interest according to the following conditions:

SEL_{ref} = 92 dBA for locomotives
= 82 dBA for rail cars
N_{Loco} = 1
N_{Cars} = 6
S = 43 miles per hour
D = 125 ft
$\propto_{locos}$ = 0.27
$\propto_{cars}$ = 1.03

The locomotive and rail cars each have a unit length (L) of 70 ft.

Determine the total length of the locomotive and rail cars.

L_{Loco} = 70 ft
L_{cars} = 420 ft

Compute L_{max} for the locomotive using Eq. F-6:

$$L_{max.Loco} = SEL_{loco} + 10log\left(\frac{S}{50}\right) - 10log\left(\frac{L}{50}\right) + 10\log(2\propto) - 3.3$$

$$= 92 + 10log\left(\frac{43}{50}\right) - 10log\left(\frac{70}{50}\right) + 10\log(2 \times 0.27) - 3.3$$

= 84.0 dBA

Compute L_{max} for the rail cars using Eq. F-7:

$$L_{max.Rcars} = SEL_{Rcars} + 10log\left(\frac{S}{50}\right) - 10log\left(\frac{L}{50}\right) + 10\log(2\propto + \sin(2\propto)) - 3.3$$

$$= 82 + 10log\left(\frac{43}{50}\right) - 10log\left(\frac{420}{50}\right) + 10\log((2 \times 1.03) + \sin(2 \times 1.03)) - 3.3$$

= 73.5 dBA

Find the total L_{max} for the train passby using Eq. F-8.

$$L_{max.total} = max(L_{max.Loco}\ or\ L_{max.Rcars})$$

=84.0 dBA

Appendix G: Non-Standard Modeling Procedures and Methodology

This manual provides guidance for preparing and reviewing the noise and vibration sections of environmental documents, as well as FTA-approved methods and procedures to determine the level of noise and vibration impact resulting from most federally-funded transit projects. Situations may arise, however, that are not explicitly covered in this manual. Professional judgment may be used to extend the basic methods to cover these cases, when appropriate. It is important to note that each project is unique and must be evaluated on a case-by-case basis. This appendix provides procedures for the use of non-standard noise and vibration modeling procedures and methodologies on public transportation projects.

Submittal Procedure – The procedure for using non-standard modeling procedures and methodology is as follows:

1. The transit project manager should contact the FTA Regional office to discuss the proposed methods and/or data not described in this manual prior to use of the non-standard approach.
2. The non-standard methodology should be documented according to the guidelines below as part of the technical report described in Section 8.2.

Examples of Methods that Require Communication and Documentation – The following noise and vibration analysis methods and data require communication with the FTA Regional office and documentation:

- Non-standard transit noise and vibration modeling and analysis methods not described in this manual (including non-standard adjustments, computations, and assumptions). This includes modifications to standard FTA noise and vibration methods.
- Non-standard transit noise and vibration reference data not described in this manual (including measured data, substitution data, data at non-standard reference distances and/or speeds, new transit noise sources, and transit noise sources operating in non-standard conditions).
- Non-standard transit noise and vibration impact criteria not described in this manual, including the maximum sound pressure level metric.
- Non-standard methods of evaluating construction noise, including non-standard construction noise impact criteria.
- Other noise modeling tools besides the FTA Noise Impact Assessment Spreadsheet or Traffic Noise Model (TNM®) for highway noise modeling, such as the development of a finite element method model.
- Any transit noise and vibration analysis that involves an impact area or noise source that is controversial.

Documentation Guidelines – The use of non-standard noise and vibration analysis methods or data requires the following documentation components in a technical memorandum attached to the environmental document:

- **Background**
  Briefly describe the transit project for which non-default methods or data are needed. State the dominant noise sources, type of analysis, and the impact criteria. Include any additional relevant information.

- **Statement of Benefit**
  Briefly describe the benefit of the non-default noise and vibration methods or data to the transit project. Describe the appropriateness of the non-default methods or data, as well as why the standard method or data are insufficient or problematic.

- **Non-standard Data Description**
  Describe the non-standard noise or vibration data in detail. Include source type, manufacturer, reference conditions (speed, distance, and operational conditions), name of data supplier, and a date associated with data development/measurement. For measured noise or vibration data, provide corresponding data documentation (such as a data measurement or a development report). For substitution data, a comparison between the non-standard data and corresponding standard data should be provided. Furthermore, if outside sources recommend the use of the non-standard data (such as a technical society, a standards organization, or a vehicle manufacturer), references for those recommendations should be included.

- **Non-standard Methods Description**
  Describe the non-standard noise or vibration analysis method in detail. This should include a detailed description and derivation of the method (including data used in the development of the method), a description of the usage of the method, and a comparison between the non-standard method and the corresponding standard method in the context of the transit analysis. If the method has been validated against measurement data, a description of that validation analysis should be provided. If the method is derived from another source (such as a different transportation noise or vibration method), provide corresponding documentation for that source. A description of how the method is conservative (for example, estimating the worst-case scenario) or some discussion on the probability of exceeding the predicted level should be provided. Furthermore, if outside sources recommend the use of the non-standard method (such as a technical society or standards organization), references for those recommendations should be included.

- **Non-standard Tools Description**
  Describe in detail any non-standard noise or vibration models that have not been explicitly recommended in this manual. This should include a detailed description of the tool (including data used, the computations implemented in the tool, any modifications or adjustments to the tool or the corresponding data, and the usage of the tool), a description of the validation of the tool (including reference documentation and validation analyses), and a comparison between the non-standard tool and the equivalent standard tool in the context of the transit analysis. Quantitative comparisons, such as the standard deviation of the non-standard tool and an estimate of the least mean square of differences between the standard and non-standard tools, should be provided and explained. A description of how the method is conservative (for example, estimating the worst-case scenario) or some discussion on the probability of exceeding the predicted level should be provided. If outside sources recommend the use of the non-standard tool (such as a technical society or standards organization), references for those recommendations should be included.

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Federal Transit Administration

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Via Email

August 10, 2023

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City of Los Angeles
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Rey.Fukuda@lacity.org

Re: Comment on Draft Environmental Impact Report, Violet Street Creative Office Campus Project (ENV-2021-2232-EIR)

Dear Mr. Fukuda:

This comment is submitted on behalf of Supporters Alliance for Environmental Responsibility ("SAFER") regarding the Draft Environmental Impact Report ("DEIR") prepared for the Violet Street Creative Office Campus Project (ENV-2021-2232-EIR), which proposes the construction of a 13-story, approximately 450,599 square-foot building, and a seven-story parking garage, located at 2030, 2034, 2038, 2042, 2046, 2054, and 2060 East 7th Street; 715, 721,725, 729, 733, 777, 801, 805, 809, 813, 817, 821, 825, 827, and 829 East Santa Fe Avenue; 2016, 2020, 2023, 2026, 2027, 2030, 2031, 2034, 2035, 2037,2038, 2040; and 2043 East 7th Place and 2017, 2023, 2027, 2031, 2035, 2039, 2045, and 2051 Violet Street, in the City of Los Angeles ("Project").

SAFER is concerned that the DEIR fails as an informational document and fails to impose all feasible mitigation measures to reduce the Project's impacts. The DEIR fails to select the environmentally superior reduced density Alternative 3 despite admitting that it achieves all project objectives. The DEIR fails to have adequate evidence to support a statement of overriding considerations to support a finding that the Project's economic benefits outweigh its admittedly significant unmitigated environmental impacts. SAFER requests that the Community Development Department address these shortcomings in a revised draft environmental impact report ("RDEIR") and recirculate the RDEIR prior to considering approvals for the Project.

SAFER reserves the right to supplement these comments during the administrative process. *Galante Vineyards v. Monterey Peninsula Water Management Dist*., 60 Cal. App. 4th 1109, 1121 (1997).

Sincerely,

Richard Drury
Lozeau Drury LLP

FORM GEN. 160 (Rev. 8-12)

CITY OF LOS ANGELES
INTER-DEPARTMENTAL CORRESPONDENCE

DATE: August 29, 2023

TO: Vincent P. Bertoni, AICP, Director of Planning
Department of City Planning

Attn: Rey Fukuda, City Planner
Department of City Planning

FROM: Rowena Lau, Division Manager
Wastewater Engineering Services Division
LA Sanitation and Environment

SUBJECT: VIOLET STREET CREATIVE OFFICE CAMPUS PROJECT - NOTICE OF COMPLETION AND AVAILABILITY OF DRAFT ENVIRONMENTAL IMPACT REPORT

This is in response to your June 29, 2023 letter requesting a review of the proposed mixed-use project located at 2030, 2034, 2038, 2042, 2046, 2054, 2060 East 7TH Street; 715, 721, 725, 729, 733, 777, 801, 805, 809, 813, 817, 821, 825, 827, 829 East Santa Fe Avenue; 2016, 2020, 2023, 2026, 2027, 2030, 2031, 2034, 2035, 2037, 2038, 2040, 2043 East 7th Place; and 2017 2023, 2027, 2031, 2035, 2039, 2045, 2051 Violet Street, Los Angeles, CA 90021. The project will consist of office space and retail/restaurant. Sanitation has conducted a preliminary evaluation of the potential impacts to the wastewater and stormwater systems for the proposed project.

WASTEWATER REQUIREMENT

LA Sanitation, Wastewater Engineering Services Division (WESD) is charged with the task of evaluating the local sewer conditions and to determine if available wastewater capacity exists for future developments. The evaluation will determine cumulative capacity impacts and guide the planning process for any future sewer improvement projects needed to provide future capacity as the City grows and develops.

Projected Wastewater Discharges for the Proposed Project:

Type Description	Average Daily Flow per Type Description (GPD/UNIT)	Proposed No. of Units	Average Daily Flow (GPD)
Existing			
Warehouse	30 GPD/KGSF	25,798 SF	(774)
Office	120 GPD/KGSF	9,940 SF	(1,193)
Proposed			
Office	120 GPD/KGSF	435,100 SF	52,212
Retail/Restaurant	25 GPD/KGSF	15,499 SF	387
Outdoors	50 GPD/KGSF	74,018 SF	3,701
Total			**54,333 GPD**

SEWER AVAILABILITY

The sewer infrastructure in the vicinity of the proposed project includes an existing 8-inch line on Santa Fe Avenue. The sewage from the existing 8-inch line feeds into a 10-inch line on Santa Fe Avenue before discharging into a 60-inch sewer line on Enterprise Street. Figure 1 shows the details of the sewer system within the vicinity of the project. The current flow level (d/D) in the 8-inch line cannot be determined at this time without additional gauging.

The current approximate flow level (d/D) and the design capacities at d/D of 50% in the sewer system are as follows:

Pipe Diameter (in)	Pipe Location	Current Gauging d/D (%)	50% Design Capacity
8	Santa Fe Ave.	*	324,000 GPD
10	Santa Fe Ave.	*	416,000 GPD
60	Enterprise St.	18	31.26 MGD

* No gauging available

Based on estimated flows, it appears the sewer system might be able to accommodate the total flow for your proposed project. Further detailed gauging and evaluation will be needed as part of the permit process to identify a specific sewer connection point. If the public sewer lacks sufficient capacity, then the developer will be required to build sewer lines to a point in the sewer system with sufficient capacity. A final approval for sewer capacity and connection permit will be made at the time. Ultimately, this sewage flow will be conveyed to the Hyperion Water Reclamation Plant, which has sufficient capacity for the project.

All sanitary wastewater ejectors and fire tank overflow ejectors shall be designed, operated, and maintained as separate systems. All sanitary wastewater ejectors with ejection rates greater than 25 GPM shall be reviewed and must be approved by LASAN WESD staff prior to other City plan check approvals. Lateral connection of development shall adhere to Bureau of Engineering Sewer Design Manual Section F 480.

This response letter is not intended to address any potential utility conflicts associated with the wastewater or stormwater conveyance systems. Construction of any type near any wastewater or stormwater conveyance infrastructure in the public right of way, or in/near any conveyance easement must be evaluated separately.

If you have any questions, please call Than Win at (323) 342-6268 or email at than.win@lacity.org.

STORMWATER REQUIREMENTS

LA Sanitation, Stormwater Program is charged with the task of ensuring the implementation of the Municipal Stormwater Permit requirements within the City of Los Angeles. We anticipate the following requirements would apply for this project.

POST-CONSTRUCTION MITIGATION REQUIREMENTS

In accordance with the Municipal Separate Storm Sewer (MS4) National Pollutant Discharge Elimination System (NPDES) Permit (Order No. R4-2012-0175, NPDES No. CAS004001) and the City of Los Angeles Stormwater and Urban Runoff Pollution Control requirements (Chapter VI, Article 4.4, of the Los Angeles Municipal Code), the Project shall comply with all mandatory provisions to the Stormwater Pollution Control Measures for Development Planning (also known as Low Impact Development [LID] Ordinance). Prior to issuance of grading or building permits, the applicant shall submit a LID Plan to the City of Los Angeles, Public Works, LA Sanitation, Stormwater Program for review and approval. The LID Plan shall be prepared consistent with the requirements of the Planning and Land Development Handbook for Low Impact Development.

Current regulations prioritize infiltration, capture/use, and then biofiltration as the preferred stormwater control measures. The relevant documents can be found at: www.lacitysan.org. It is advised that input regarding LID requirements be received in the preliminary design phases of the project from plan-checking staff. Additional information regarding LID requirements can be found at: www.lacitysan.org or by visiting the stormwater public counter at 201 N. Figueroa, 2nd Fl, Suite 280.

GREEN STREETS

The City is developing a Green Street Initiative that will require projects to implement Green Street elements in the parkway areas between the roadway and sidewalk of the public right-of-way to capture and retain stormwater and urban runoff to mitigate the impact of stormwater runoff and other environmental concerns. The goals of the Green Street elements are to improve the water quality of stormwater runoff, recharge local groundwater basins, improve air quality, reduce the heat island effect of street pavement, enhance pedestrian use of sidewalks, and encourage alternate means of transportation. The Green Street elements may include infiltration systems, biofiltration swales, and permeable pavements where stormwater can be easily directed from the streets into the parkways and can be implemented in conjunction with the LID requirements. Green Street standard plans can be found at: https://eng2.lacity.org/techdocs/stdplans/index.htm

CONSTRUCTION REQUIREMENTS

All construction sites are required to implement a minimum set of BMPs for erosion control, sediment control, non-stormwater management, and waste management. In addition, construction sites with active grading permits are required to prepare and implement a Wet Weather Erosion Control Plan during the rainy season between October 1 and April 15. Construction sites that disturb more than one-acre of land are subject to the NPDES Construction General Permit issued by the State of California, and are required to prepare, submit, and implement the Storm Water Pollution Prevention Plan (SWPPP).

If there are questions regarding the stormwater requirements, please call WPP's plan-checking counter at (213) 482-7066. WPD's plan-checking counter can also be visited at 201 N. Figueroa, 2nd Fl, Suite 280.

GROUNDWATER DEWATERING REUSE OPTIONS

The Los Angeles Department of Water and Power (LADWP) is charged with the task of supplying water and power to the residents and businesses in the City of Los Angeles. One of the sources of water includes groundwater. The majority of groundwater in the City of Los Angeles is adjudicated, and the rights of which are owned and managed by various parties. Extraction of groundwater within the City from any depth by law requires metering and regular reporting to the appropriate Court-appointed Watermaster. LADWP facilitates this reporting process, and may assess and collect associated fees for the usage of the City's water rights. The party performing the dewatering should inform the property owners about the reporting requirement and associated usage fees.

On April 22, 2016 the City of Los Angeles Council passed Ordinance 184248 amending the City of Los Angeles Building Code, requiring developers to consider beneficial reuse of groundwater as a conservation measure and alternative to the common practice of discharging groundwater to the storm drain (SEC. 99.04.305.4). It reads as follows: "Where groundwater is being extracted and discharged, a system for onsite reuse of the groundwater, shall be developed and constructed. Alternatively, the groundwater may be discharged to the sewer."

Groundwater may be beneficially used as landscape irrigation, cooling tower make-up, and construction (dust control, concrete mixing, soil compaction, etc.). Different applications may require various levels of treatment ranging from chemical additives to filtration systems. When onsite reuse is not available the groundwater may be discharged to the sewer system. This allows the water to be potentially reused as recycled water once it has been treated at a water reclamation plant. If groundwater is discharged into the storm drain it offers no potential for reuse. The onsite beneficial reuse of groundwater can reduce or eliminate costs associated with sewer and storm drain permitting and monitoring. Opting for onsite reuse or discharge to the sewer system are the preferred methods for disposing of groundwater.

To help offset costs of water conservation and reuse systems, LADWP offers a Technical Assistance Program (TAP), which provides engineering and technical assistance for qualified projects. Financial incentives are also available. Currently, LADWP provides an incentive of $1.75 for every 1,000 gallons of water saved during the first two years of a five-year conservation project. Conservation projects that last 10 years are eligible to receive the incentive during the first four years. Other water conservation assistance programs may be available from the Metropolitan Water District of Southern California. To learn more about available water conservation assistance programs, please contact LADWP Rebate Programs 1-888-376-3314 and LADWP TAP 1-800-544-4498, selection "3".

For more information, related to beneficial reuse of groundwater, please contact Greg Reed, Manager of Water Rights and Groundwater Management, at (213)367-2117 or greg.reed@ladwp.com.

SOLID RESOURCE REQUIREMENTS

The City has a standard requirement that applies to all proposed residential developments of four or more units or where the addition of floor areas is 25 percent or more, and all other development projects where the addition of floor area is 30 percent or more. Such developments must set aside a recycling area or room for onsite recycling activities. For more details of this requirement, please contact LA Sanitation Solid Resources Recycling hotline 213-922-8300.

RL/TW: ra

Attachment: Figure 1 - Sewer Map

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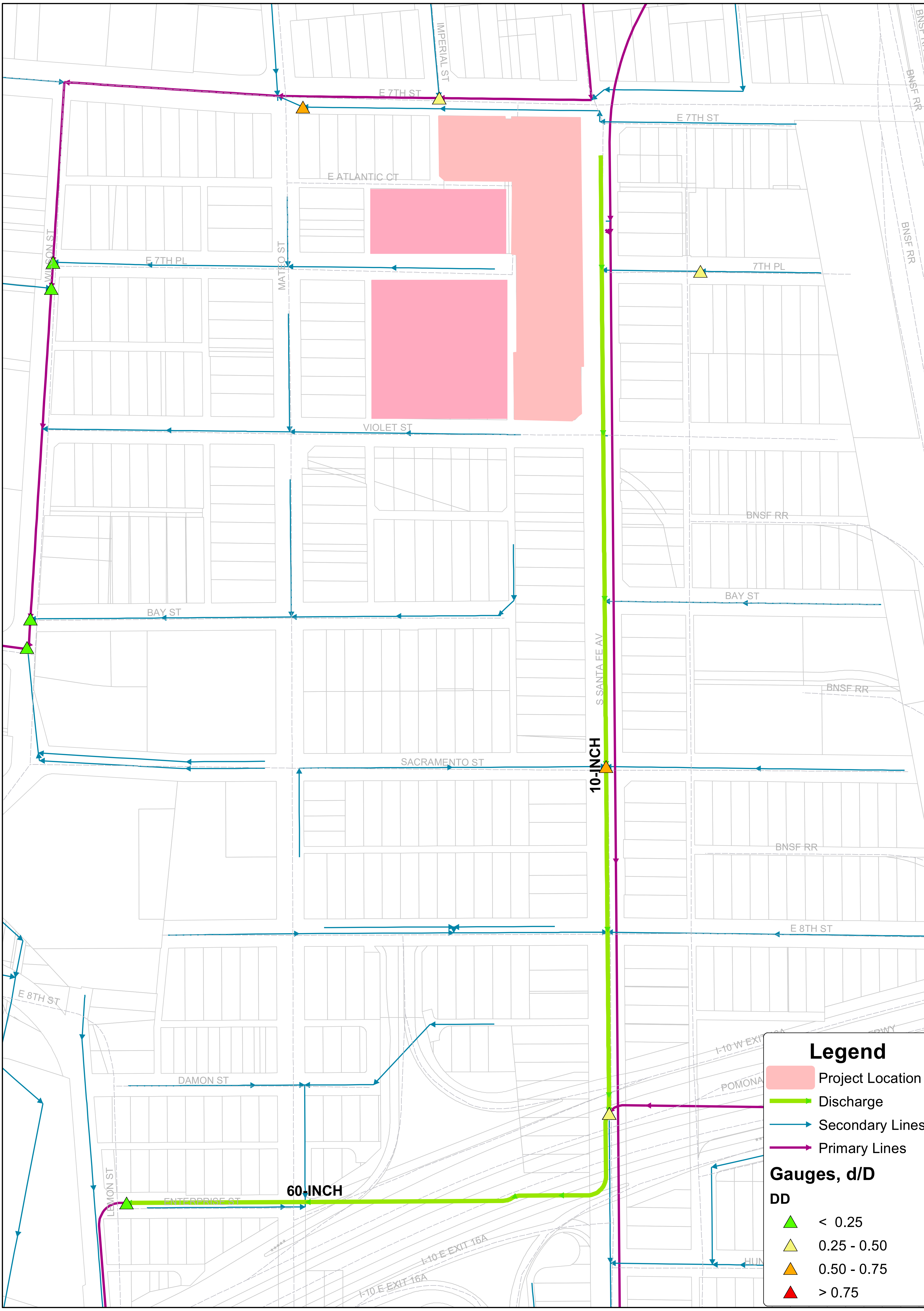

Wastewater Engineering Services Division
Bureau of Sanitation
City of Los Angeles

Figure 1
VIOLET STREET CREATIVE OFFICE CAMPUS PROJECT
Sewer Map

0 62.5 125 250 375 500 Feet

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