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Comparison of Light-Rail and Bus Transit Noise Impact Estimates per Federal and Industry Criteria

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----ABSTRACT----

Design work for a Transitway proposed in suburban Maryland near Washington, D.C. for an abandoned railroad right-of-way was begun then halted, then resumed over a period of time. An initial environmental noise evaluation was performed using the APTA Guidelines. When work resumed, the FTA Guidance Manual was available. Consequently, noise impacts were assessed via methods from both documents.

The Transitway was proposed to be serviced by one of three alternative vehicle types: light-rail vehicles, conventional articulated diesel buses, or dual-propulsion (electric motor/diesel engine) articulated buses. Passby noise measurements were performed to quantify or verify the noise emissions of each of the vehicle types and compared to other available data. At 15 m (50 ft) and 56 KPH (35 MPH) , the diesel bus is noisiest with the light-rail vehicle slightly quieter. The electric bus is significantly quieter although its emissions are known with the least confidence.

Line operation sound levels were predicted for each of the vehicle types for the entire length of the proposed project. The predictions were both in terms of maximum passby sound levels for comparison to the APTA criteria and day-night average sound levels for comparison to the FTA criteria. For the local land uses and ambient noise conditions, the distances for the unmitigated passby noise exposures to attenuate to the APTA and FTA criteria limits were estimated and the numbers of included dwellings counted. For the Transitway project with 16% nighttime operations and proposed vehicle alternatives, the FTA impact-onset (i.e., "some impact") criterion curve yielded significantly greater noise exposed areas while the APTA criteria yielded results intermediate to those from the FTA "some" and "severe" impact curves.

INTRODUCTION

The Georgetown Branch Transitway/Trail was proposed as a combined transportation facility and hiker/biker trail using a former railroad right-of-way. The Transitway would link the Bethesda and Silver Spring, Md. central business districts and be developed by the Maryland Mass Transit Administration (MTA) together with the Montgomery Co. Department of Transportation. At the time of this evaluation, three alternatives were considered:

- Railway serviced by light-rail vehicles.
- Busway serviced by diesel buses, or
- Busway serviced by dual-propulsion (electric motor/diesel engine) buses,

The origin of the Transitway proposal dates to 1985 when CSX, which had been using the Georgetown Branch line for freight operations since 1910, announced the cessation of service. Montgomery Co. acquired the right-of-way in 1988. The Montgomery County Council in 1989 approved the combined trolley/trail use of the right-of-way. Work was begun on the project by MTA in 1990 but was halted due to budget constraints. In 1994, the studies were reactivated by MTA with the intent of obtaining federal funding--necessitating the preparation of a Draft Environmental Impact Statement (DEIS). The initial environmental noise evaluation was performed using the American Public Transit Association (APTA) Guidelines. When work resumed, the Federal Transit Administration (FTA) Guidance Manual was available. Consequently, noise impacts were assessed via methods from both documents to maintain continuity with previous work.

TRANSIT SYSTEM NOISE CRITERIA

The industry association, APTA, and an agency of the U.S. Department of Transportation, FTA, both have defined guidelines for the design of transit facilities compatible with adjacent land uses. The APTA Guidelines are intended as a guide for the design of transit systems but are applied in this paper as criteria for defining environmental noise impacts. On the other hand, the FTA Manual is directed explicitly to impact assessment. These guidelines take different approaches to accomplish the same goals. The APTA procedures are based upon the maximum sound level (L_{max}) of a single vehicle passby. The FTA methods are based upon the cumulative effect of the passby maximum sound level, passby duration, number of passbys, and times of day of the passbys--in terms of day-night average sound level (L_{dn}). The single-event L_{max} metric describes the maximum sound level a person experiences as a transit vehicle passes. The L_{dn} metric has been found to most accurately predict public annoyance from noise.

APTA Guidelines. The American Public Transit Association has developed noise and vibration design goals for community exposures as part of its "Guidelines for Design of Rail Transit Facilities." *(1)* The APTA Guidelines include recommendations for noise and vibration exposure to transit property patrons, employees and neighboring community. They provide specifications for vehicle interiors and exteriors, vehicle component equipment, and other auxiliary equipment. Exposures from both line operations and ancillary facilities (in stations, tunnels and shop areas, and in the community adjacent to the transit-system corridor) are addressed.

The APTA document was developed for rapid transit systems and facilities, not bus operations as considered in this paper. While the acoustical signatures of rail cars and buses can be readily distinguished, use of the APTA methods was considered valid for several reasons. Both rail car and bus passbys are brief, transient events which occur on a regular daily schedule. The APTA Guidelines apply to a single-car trolley operating in a public right-of-way--a very bus-like scenario. While rail-bound vehicles with electric-motor propulsion are assumed throughout the APTA Guidelines, the APTA methods could be applied to rubber-tired transit systems or self-propelled diesel-engined rail cars.

The APTA Guidelines consider the effect of noise and vibration on the community because of its importance in public acceptance of transit systems. Sources of wayside intrusion or annoyance created by rail transit facilities are recognized to include airborne noise from: surface and aerial train operations, transit yard operations and maintenance facilities, ventilating fans, trains in subways (transmitted through ventilation shafts), ancillary systems (such as traction-power substations, air-conditioning chiller plants, cooling towers), and emergency-service buildings; and to include groundborne noise and/or vibration from subway, surface, and aerial structure operations.

In defining appropriate community-noise design sound levels, adjacent land uses and existing ambient sound levels are considered. For the purpose of establishing the design goals, general community-area categories are differentiated, as described in Table 1. Noise guidelines for train operations are specified for the land-use categories in terms of train-passby maximum sound levels for single-family and multi-family dwellings, and commercial buildings--as given in Table 2a. In addition to the design goals for general types of buildings, recommendations for noise exposures near specific building types also are provided, as given in Table 2b. (Note that while the APTA design goal maxima are not intended to be applied at distances <15 m (50 ft), in this analysis the distances to the specified sound level limit will be used.)

FTA Guidance Manual. The Federal Transit Administration has developed criteria to be used in evaluating noise impact from mass transit projects. *(2)* These criteria apply to all rail projects--including line operations as well as fixed facilities such as: storage and maintenance yards, passenger stations and terminals, parking facilities, and substations. Also included are certain bus facilities, particularly those using separate roadways built exclusively for buses. The FTA criteria are not recommended for projects involving new highway construction or modification of existing highways to increase carrying capacity. For these projects, the criteria of the Federal Highway Administration (FHWA) are recommended.

The FTA criteria are based upon comparison of the existing outdoor ambient noise to the future outdoor sound levels from the proposed project. They incorporate both absolute criteria, which consider activity interference caused by the transit project alone, and relative criteria, which consider annoyance due to the change in the noise environment caused by the transit project. (An absolute criterion caps the noise exposure from the proposed project regardless of any other considerations; while, the relative criterion limits the extent to which the ambient sound levels may be elevated by a proposed action.) The noise criteria and the sound level descriptors used by the criteria are a function of land use, as defined in Table 3. Depending upon land-use category, the recommended noise metric is either the average sound level for the noisiest hour of transit-related activity during hours of noise sensitivity, L_{Aeq1hr}, or the nighttime-weighted, 24-hr average provided by the day-night average sound level, L_{dn}. For the Transitway assessment, residences and buildings where people sleep were the greatest concern. Thus, L_{dn} was the noise metric evaluated.

The noise impact criteria are defined by two curves which allow increasing project noise with increasing existing ambient noise up to a point, beyond which impact is determined based upon project noise alone. These noise-impact criteria are shown in Figure 1. The lower curve defines the exposure above which *some* impact occurs, i.e., the limit up to which the sound levels for the proposed project are considered to have no impact. The upper curve defines the noise exposure above which *severe* impact occurs. The lower curve, defining the onset of noise impact, increases up to 65 dBA [L_{dn}] for residential land uses--a common limit for acceptable living environment defined by a number of Federal agencies. The upper curve increases to a limit of 75 dBA [L_{dn}] for residential land uses--a level generally associated with an unacceptable living environment. Between the two curves, the proposed project is judged to have an impact, although not severe. At these intermediate exposures, the change in the cumulative noise exposure is described as noticeable to most people but may not be sufficient to cause strong adverse reactions from the community. In this noise exposure zone, FTA recommends: "other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation, such as the predicted level of increase over existing noise levels and the types and numbers of noise-sensitive land uses affected. "The significance of each of the exposure regions is highlighted in Table 4.

A project exposure which is less than the existing community noise exposure can still fall within the "impact" region of Figure 1. E.g., the "some-impact" project noise exposure in a residential area is 55 dBA[L_{dn}] in a 55-dBA[L_{dn}] ambient environment; 60 dBA[L_{dn}] in a 65-dBA[L_{dn}] environment. As the existing level of ambient noise increases, the allowable level of transit noise increases; but, the total amount that the community noise exposure is allowed to increase is reduced. While no increase in noise is allowed in areas with existing ambient noise of 75 dBA[L_{dn}], an exposure increase of 7 dBA is allowed where the ambient noise is currently 45 dBA[L_{dn}]. This is justified by the presumption that people already exposed to high levels of noise will notice and be annoyed by only a small increase in the amount of noise in their community; while, if existing sound levels are low, a greater change in community noise will be required for the equivalent level of annoyance. (The FTA criteria are qualified by a note that they are based upon reported annoyance for community reactions to noise at various levels which have been documented in scientific literature and do not account for any specific community attitudinal factors which may exist.)

The APTA Guidelines, because of their purpose to assist the design and specification of transit systems, are most suitable for the specification of vehicle performance such as may be contractually required of equipment manufacturers. The FTA Guidance Manual is inherently better suited to noise impact assessment since it quantifies noise exposures in terms of a noise metric which includes factors (i.e., number and duration of events) found in noise-effects studies to have important influences on human adverse response to noise.

LINE OPERATION NOISE PREDICTION

Every noise prediction must characterize three elements--the noise source, the sound propagation path, and the affected noise receptor. Vehicle movements along the project right-of-way are the most obvious of the noise concerns of neighboring residents. Noise from line operations was estimated by means of a mathematical procedure which predicts vehicle noise emissions and quantifies the attenuation of sound as it travels from the vehicle to noise-sensitive receptor locations along the corridor.

Noise Receptors. Noise exposures were evaluated at land uses as defined by the APTA and FTA criteria. Residents along the right-of-way are the primary focus. Schools, churches, some parklands, and--per APTA--commercial buildings also are possible concerns but were not an issue for this project. No schools or religious institutions were sufficiently close. Nor were highly noise-sensitive parks or businesses nearby.

Sound Propagation. For this evaluation, the quantification of sound attenuation with distance incorporated simplistic assumptions including sound spreading and the benefit of propagation over "soft" ground (e.g., grass) but no benefits due to shielding of noise by natural topography or rows of houses were considered. To the extent possible, established procedures were used in the calculations--the noise predictions were derived primarily from the FTA guidance manual. *(2)* These propagation assumptions generally are conservative and usually will result in the over-prediction of noise exposures.

Noise Sources. The busway alternatives were to be serviced by 18-m (60-ft)-long, articulated diesel buses or dual-powered buses. The dual-propulsion buses travel under electric power on the Transitway and under diesel power on public streets. The railway alternative was expected to be serviced by 29-m (95-ft) long, single-car, light-rail trains. However, for more conservative noise estimates, 58-m (190-ft)-long, two-car consists were analyzed. Vehicle noise emissions depend upon the type of vehicle and the operating condition.

VEHICLE NOISE EMISSIONS

Fundamental to the prediction of noise impacts due to a source is quantification of the sound emitted from that source. If the sound at a specified distance from a source in an open space is known, the sound at other distances or with more complex propagation conditions--e.g., with barrier shielding--can be calculated. (Operating conditions are characterized by vehicle speed and, for diesel-powered equipment, engine load--e.g. acceleration vs. constant speed or deceleration.)

Noise from an electric railcar is caused by: the interaction of the vehicle wheels and rails, the vehicle propulsion motors, interaction of the current-collecting pantograph and overhead catenary cable, and vehicle auxiliary systems. For a light-rail vehicle, wheel/rail noise is dominant and varies with train speed.

Noise from a diesel-powered bus is caused by: the diesel engine radiation (including--exhaust system, engine block, cooling system and air intake components), the interaction of the vehicle tires with the pavement surface and vehicle auxiliary systems. For a diesel bus, engine noise is dominant at low speeds (i.e., less than about 48 KPH (30 MPH) and tire/pavement noise is dominant at higher speeds. Engine noise is relatively insensitive to bus speed, while tire noise varies strongly with vehicle speed.

The dual-propulsion bus is a hybrid with independent electric motor and diesel engine powerplants. They are unique vehicles--only operated by Seattle METRO in the United States. The dual-propulsion bus was proposed to run under diesel power when on public streets and under electric power (supplied by an overhead catenary) when on the dedicated busway. Thus, when in the Transitway right-of-way, the dual-propulsion bus would effectively function as an electric trolley bus. Noise from an electric-powered bus is caused by: the interaction of the vehicle tires with the pavement surface, the propulsion motor cooling fan, the motor electrical control system, and vehicle auxiliary systems. For an electric bus, tire/pavement noise is expected to be dominant at all but the lowest speeds and varies strongly with vehicle speed.

Light-Rail Vehicles

To quantify light-rail vehicle noise emissions, documented vehicle sound level data were reviewed and compared both in terms of vehicle passby maximum sound level, L_{max}, and sound exposure level, L_{se}. (Sound exposure level is a function of both the passby noise amplitude and duration. It is the basis for computing exposures in terms of L_{Aeq} and L_{dn}.) Although light-rail vehicle sound levels are relatively well documented, additional measurements were performed since the magnitude of the wheel/rail interaction noise is strongly influenced by the quality of wheel and rail maintenance. Measurements were taken on the MTA Baltimore Light Rail Line (LRL) because this operation is likely to be most representative of the vehicle design and system maintenance practices for the proposed Transitway.

The primary data reference for light-rail vehicle sound levels was the FTA Guidance Manual which presents noise emissions for as-new systems. *(2)* This source was complemented by the TSC Urban Rail Noise Handbook *(3)* and acceptance test data for the Baltimore LRL vehicle. *(unpublished data: Booz, Allen & Hamilton)* These data, measured 15 m (50 ft) from the track centerline, are shown in Figures 2 along with sample emission levels used in the earlier Transitway noise evaluation. *(4)* For both the FTA and TSC noise emission relationships, L_{max} increases as 30 log(V). (For any passby event, L_{se} will tend to increase a power-of-ten less rapidly than L_{max} since the increasing speed shortens the event as it tends to increase the passby maximum noise amplitude.) The FTA Guidance Manual data agree well with new-vehicle data but are significantly lower than the TSC Handbook values.

Test Measurements. In-service light-rail vehicle sound levels were measured for revenue-service operations of the MTA Baltimore Light Rail Line. *(5)* The LRL vehicle is manufactured by ABB; and is 29-m (95-ft) long with 84 seats (172-person capacity), fitted with resilient wheels, has a 80-KPH (50-MPH) maximum speed, and uses electrical power supplied from overhead wire. The vehicle normally operates in 2-car trains.

A test location was sought which consisted of straight track with low background noise. The selected test section consisted of single, tangent track with a maximum speed of 56 KPH (35 MPH). The wayside elevation at 15 m (50 ft) from the track centerline was approximately the same as that of the rail head. Sound levels were measured at nominally 56 and 29 KPH (35 and

18 MPH) for several northbound and southbound trains. Train speed data were obtained from read-outs by the train operator. For each passby, two spectra were recorded: third-octave band sound levels at the time of the overall maximum A-weighted sound level and third-octave band sound exposure levels.

Expected Emissions. The LRL measurements were adjusted to correspond to single-car passbys and plotted with the other available light-rail vehicle data, in Figure 2. The results indicate that the FTA Guidance Manual values tend to be slightly low and the TSC Handbook values generally high. Consequently, a new expression was assumed for the Transitway impact analysis which yielded 1-dBA higher sound levels than FTA and is representative of the measured MTA vehicle in-service emissions for all but the noisiest passby with wheel flats.

Diesel Buses

To quantify diesel bus noise emissions, documented vehicle sound level data were reviewed and compared both in terms of vehicle passby maximum sound level and sound exposure level. The vehicle sound level data were available from a number of sources. *(2, 6, unpublished data: VNTSC)* Additional measurements were performed primarily to obtain high-speed data for diesel and dual-mode bus operations (discussed below).

The bus sound levels, measured or corrected to 15 m (50 ft) from the travel lane centerline, are shown in Figures 3 as a function of passby speed. For operation above 48 KPH (30 MPH) , L_{max} increases at between 22 log(V) and 34 log(V). Below about 48 KPH, engine loading is most important. This is represented by the 10 log(V) relationship for V < 48 KPH in the Harris Co., Houston METRO fleet-average emission levels.

Test Measurements. Sound levels were measured for a 18-m (60-ft), articulated diesel bus operated by MTA in controlled tests. The purpose of these tests was to complement the documented noise emission data (and provide measurements representative of dual-propulsion buses). The test vehicle was of the type serving the Baltimore Metropolitan area, an American Ikarus, Inc. Model 436 seating 65 persons. Maximum speed is approximately 97 KPH (60 MPH). The bus is powered by a diesel engine rated at 246 KW (330 HP) at 2000 RPM.

The test location consisted of a nearly level, straight road with low background noise and existing traffic; and with approach and runout sufficient to permit 97-KPH (60-MPH) operation. The selected site was a rural two-lane undivided highway, 12-m (38-ft) wide, including shoulders, with a recently laid asphalt surface in excellent condition. Measurements were made on both the curb- and street-side of the bus with microphones placed on both sides of the road at 15 m (50 ft) from the pavement centerline.

The tests were performed at nominal constant speeds of 48 and 97 KPH (30 and 60 MPH) with normal engine operation and with the engine off--for unpowered bus coast-bys. (The bus air conditioning was off during all measurements.) At about 30 m (100 ft) before the microphone, the bus moved to the center of the road and remained there until about 30 m past the microphone. High-speed tests were performed with only eastbound travel to avoid the slight upgrade with the westerly approach. The low-speed tests were performed in both directions: The powered runs were eastbound; the unpowered runs were westbound. Bus speed in the test area was measured with radar. For each passby, the third-octave band sound levels corresponding to the maximum A-weighted sound level and the third-octave band sound exposure levels were recorded.

Three passby measurements for each speed, engine condition and bus side were obtained with the exception of the 97-KPH (60-MPH), unpowered, curbside condition. Prior to running this test condition, the bus driver experienced bus instability during a high-speed unpowered run; consequently all subsequent high-speed unpowered runs were aborted.

Overall sound levels were computed from the sum of the band sound levels. A linear regression analysis of the overall sound levels was performed for both the powered and unpowered events. For the powered passbys, L_{max} increased as 18 log(V), a flatter slope than the other documented emission data. (This outcome may be the result of conducting most of the 48-KPH (30-MPH) runs against the 1% grade versus the 97-KPH (60-MPH) runs on level road; however, the one 48-KPH powered run on level road is not consistent with this explanation. Thus, the observed variation may in fact be characteristic of the bus.)

Expected Emissions. The MTA articulated bus results were plotted in Figure 3 with the other diesel bus data. The MTA bus is relatively quieter than most of the other reported vehicles. However, since the Houston METRO Study represented a much more extensive database, it was chosen as the basis for the Transitway noise impact analysis, although it may overstate impacts somewhat.

Dual-Propulsion Buses

To quantify dual-propulsion bus noise emissions, documented electric trolley bus sound level data also were reviewed and compared. Electric trolley buses are operated by a limited number of transit properties in North America. Vehicles in service include 12-m (40-ft) buses and some 18-m (60-ft), articulated buses. Their powerplants are mostly older-style DC motors. Only San Francisco and Seattle operate buses with AC motors--both articulated vehicles of unusual configuration. The San Francisco vehicle has dual motors and drive axles to negotiate the San Francisco hills. The Seattle vehicle is a dual-propulsion type--like that proposed for the Transitway--in which either the diesel engine or the electric motor operates (each driving through its own drive axle). Sound level data for various electric bus types were available from several sources. *(unpublished data: MVRTA, MUNI, New Flyer Industries, Seattle METRO, HMMH)* Additional measurements were performed, as described above.

The bus sound levels measured or corrected to 15 m (50 ft) from the travel lane centerline are shown in Figures 4 as a function of passby speed. (Some of the MVRTA, MUNI and Seattle METRO data are from acceleration tests. These have been plotted in Figure 4 at their estimated/measured speeds at the measurement location.) The data indicate that L_{max} increases at between about 35 log(V) and 40 log(V).

Test Measurements. Sound levels of a 18-m (60-ft), articulated diesel bus were obtained in controlled *power-off* tests. The primary purpose of these tests was to provide sound levels representative of dual-propulsion buses operating under electric power. A linear regression analysis of the overall sound levels was performed for the unpowered events as for the powered events. For the unpowered passbys, L_{max} increased as 42 log(V), a steeper slope than that of the other documented emission data. (This outcome may be due to the absence of the propulsion system noise sources since only tire and aerodynamic noise are present during a coast-by.)

Expected Emissions. The MTA articulated bus coast-by results were plotted in Figure 4 with the other electric bus data. The coasting MTA bus is significantly quieter than the other reported vehicles, including the dual-propulsion bus built by Breda Transportation, Inc. For the Transitway noise impact analysis, a relationship--with 35 log(V) slope--was *assumed* as conservatively achievable with contemporary technology.

EXPECTED EXPOSURES

The noise-emission relationships as a function of speed for each of the three vehicle types are shown in Figure 5. The resultant sound levels as a function of distance are illustrated in Figure 6 for vehicles traveling at 80 KPH (50 MPH) . The diesel bus is noisiest with the light-rail vehicle roughly comparable at high speed. The bus under electric propulsion creates the least noise exposure for all conditions.

Transitway operations were expected between 5 AM and midnight. Headways were taken as: 6 min, peak period, and 12 min, mid-day, for rail cars; and 3 min, peak period, and 12 min, mid-day, for buses. About 16% of the operations were at night. Day-night average sound levels were calculated based upon 301 daytime and 58 nighttime bus passbys, or 191 daytime and 38 nighttime light-rail vehicle passbys. Vehicle speeds along the transitway route will vary between 56-89 KPH (35-55 MPH) depending upon guideway curvature and distance from passenger stations. Right-of-way features influencing noise generation (primarily for the light-rail alternative) also were considered: at-grade versus elevated structure or tunnel, and tie-and-ballast versus direct-fixation (embedded) track.

The resultant noise exposures at 15 m (50 ft) from the guideway centerline for operations at the varying route speeds for individual vehicle passbys and cumulative noise exposures were calculated for the evaluated noise metrics (both L_{max} and L_{dn}) at 15 m from the guideway centerline by longitudinal station number. These predictions are conservative since: Attenuation due to existing topography or buildings was not considered; and noise mitigation was not incorporated into the computations. The results are valid for comparing the relative performance of the alternatives and for identifying areas requiring further engineering analysis for the selected alternative.

The appropriate APTA or FTA criteria sound level for the Transitway station-number vicinity was identified and the distance from the guideway for the vehicle noise to attenuate to the criterion value was computed. For the study area corridor, the criteria sound levels were: L_{max} = 70-85 dBA per APTA and L_{dn} = 55-65 dBA per FTA "some impact."

Comparative Impacts

The line-operation sound levels along the alignment varied with vehicle speed and track features. The predicted magnitudes at 15 m (50 ft) from the right-of-way centerline were:

- *Light-Rail Vehicles*--L_{max}, 61-87 dBA, and L_{dn}, 51-69 dBA;
- *Diesel Buses*--L_{max}, 77-85 dBA, and L_{dn}, 62-68 dBA; and
- *Dual-Propulsion Buses*--L_{max}, 69-78 dBA, and L_{dn}, 55-62 dBA.

The sound levels predicted for unmitigated line operations indicate significant noise exposures above the criteria at some locations. This finding holds for all vehicle types, but the impacts are least for electric-bus operations. The distances from the guideway centerline required to reach the criteria values are:

- *Light-Rail Vehicles*--APTA, 3-67 m (average, 19 m) [10-220 ft (average, 63 ft)]; FTA "some impact," 9-143 m (average, 51 m) [30-470 ft (average, 167 ft)]; and FTA "severe impact," 3-58 m (average, 21 m) [10-190 ft (average, 68 ft)].

- *Diesel Buses*--APTA, 6-61 m (average, 25 m) [20-200 ft (average, 83 ft)]; FTA "some impact," 24-119 m (average, 63 m) [80-390 ft (average, 208 ft)]; and FTA "severe impact," 6-49 m (average, 27 m) [20-160 ft (average, 87 ft)].

- *Dual-Propulsion Buses*--APTA, 3-34 m (average, 13 m) [10-110 ft (average, 44 ft)]; FTA "some impact," 9-43 m (average, 23 m) [30-140 ft (average, 74 ft)]; and FTA "severe impact," 3-18 m (average, 9 m) [10-60 ft (average, 30 ft)].

These distances can be considered impact-zone contours and may fall within the right-of-way. The width of the zone will be twice the setback distance to the criterion value if the land uses are the same on both sides of the right-of-way.

A rough pattern was suggested by the light-rail and diesel bus results. (The electric bus contour widths were too narrow to confidently draw inferences.) The average width of the impact zone defined by the APTA criteria was only about 95% of that defined by the FTA/"severe" criteria. (However, APTA includes more land uses, i.e., commercial, extending the affected area but narrowing the average width.) The width of the FTA/"some" zone was about 2.5 times that of the FTA/"severe" or that of APTA.

When the evaluation focused upon the actual numbers of structures defined by the criteria as adversely affected, a slightly different pattern appeared. The comparative noise impacts in terms of affected structures are tabulated in Table 5. These results apply only to the land uses in the Transitway study area, although they *may* be generally representative. Based upon impacted structures, the APTA criteria showed 10-50% *more* impacts than FTA/"severe." The FTA/"some" criteria gave about two to three times as many impacts as FTA/"severe" and about twice as many impacts as APTA. The FTA procedure would yield greater impacts with decreased headways and/or more nighttime activity.

Thus, the FTA "some impact" (impact-onset) criterion was most restrictive, i.e., extended further from the guideway. For the Transitway project with about 16% night operations and proposed vehicle alternatives, the FTA "some impact" criterion curve yielded significantly greater noise exposed areas and impacts while the APTA criteria produced results intermediate to those from the FTA "some" and "severe" impact curves.

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TABLE 1 General Categories of Communities along Rail System Corridors per APTA Guidelines

COMMUNITY AREA		TYPICAL AMBIENT NOISE (dBA)
Category	Description	L_{50}*
I	*Low-Density* urban residential, open space park, suburban residential or recreational area; no nearby highways or boulevards	40-50 – day 35-45 – night
II	*Average* urban residential, quiet apartments and hotels, open space, suburban residential, or occupied outdoor areas near busy streets	45-55 – day 40-50 – night
III	*High-Density* urban residential, average semi-residential/commercial areas, urban parks, museum, and non-commercial public building areas	50-60 – day 45-55 - night
IV	*Commercial* areas with office buildings, retail stores, etc., primarily daytime occupancy; central business districts	60-70
V	*Industrial* areas or *Freeway* and *Highway Corridors*	>60

* The 50th percentile sound level (L_{50}) is the sound level exceed 50% of the time.

TABLE 2 APTA Guidelines for Maximum Airborne Noise from Train Operations

a. Near General Types of Buildings

The design-goal sound levels are generally applicable at the near side of the nearest dwelling or occupied building or in residential areas at 50 ft from the track centerline, whichever is *farther*.

COMMUNITY AREA		MAXIMUM PASSBY SOUND LEVEL (dBA)		
Category	Description	Single-Family Dwellings	Multi-Family Dwellings	Commercial Buildings
I	Low-Density Residential	70	75	80
II	Average Residential	75	75	80
III	High-Density Residential	75	80	85
IV	Commercial	80	80	85
V	Industrial/Highway	80	85	85

b. Near Specific Types of Buildings

The design-goal sound levels are generally applicable at the near side of the nearest building under consideration.

BUILDING or OCCUPANCY TYPE	MAXIMUM PASSBY SOUND LEVEL (dBA)
Amphitheaters	60
“Quiet” Outdoor Recreation Areas	65
Concert Halls, Radio and TV Studios	70
Churches, Theaters, Schools, Hospitals, Museums, Libraries	75

TABLE 3 FTA Land-Use Categories and Metrics for Transit Noise Impact Criteria

LAND-USE CATEGORY	NOISE METRIC (dBA)	DESCRIPTION OF LAND-USE CATEGORY
1	Outdoor $L_{eq}(1)^*$	*Tracts of land where quiet is an essential element in their intended purpose*--This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use.
2	Outdoor L_{dn}	*Residences and building where people normally sleep*--This category includes homes, hospitals and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.
3	Outdoor $L_{eq}(1)^*$	*Institutional land uses with primarily daytime and evening use*--This category includes schools, libraries and churches where it is important to avoid interference with such activities as speech, mediation and concentration on reading material. Buildings with interior spaces where quiet is important (such as: medical offices, conference rooms, recording studios and concert halls) fall into this category. Places for meditation or study associated with cemeteries, monuments, museums. Certain historical sites, parks and recreational facilities are also included.

$^*L_{eq}(1)$ for the noisiest hour of transit-related activity *during hours of noise sensitivity*

TABLE 4 FTA Noise Exposure Ranges

noise exposure ranges for regions defined by upper and lower curves in Figure 1

- *Exposures Up to Impact-Onset Curve*
    - Insignificant increase in numbers of persons highly annoyed
    - Generally considered an acceptable environment

- *Exposures Above Severe Impact Curve*
    - Significant increase in numbers of persons highly annoyed
    - Generally considered an unacceptable environment
    - Project proceeds only in absence of more desirable alternative
    - Mitigation measures for substantial noise reduction desired

- *Exposures in Region Between Curves*
    - Some increase in numbers of persons highly annoyed
    - Change may be noticeable but not sufficient for severe adverse reaction
    - Degree of impact depends upon magnitude of noise increase and types and extent of affected noise-sensitive land uses
    - Need for mitigation depends upon local values and project-specific factors

TABLE 5 Comparative Noise Impacts

estimated noise exposures versus FTA and APTA criteria

BUILDING TYPE	IMPACTED BUIDLINGS		
	APTA	FTA	
		Severe	Some*
RAILWAY			
SFD	96	59	197
MF	22	22	45
Total Residential	118	81	242
BUSWAY--DIESEL			
SFD	93	78	188
MF	13	23	45
Total Residential	106	101	233
BUSWAY--ELECTRIC			
SFD	14	1	44
MF	8	1	16
Total Residential	22	2	60

* includes "severe" impacts

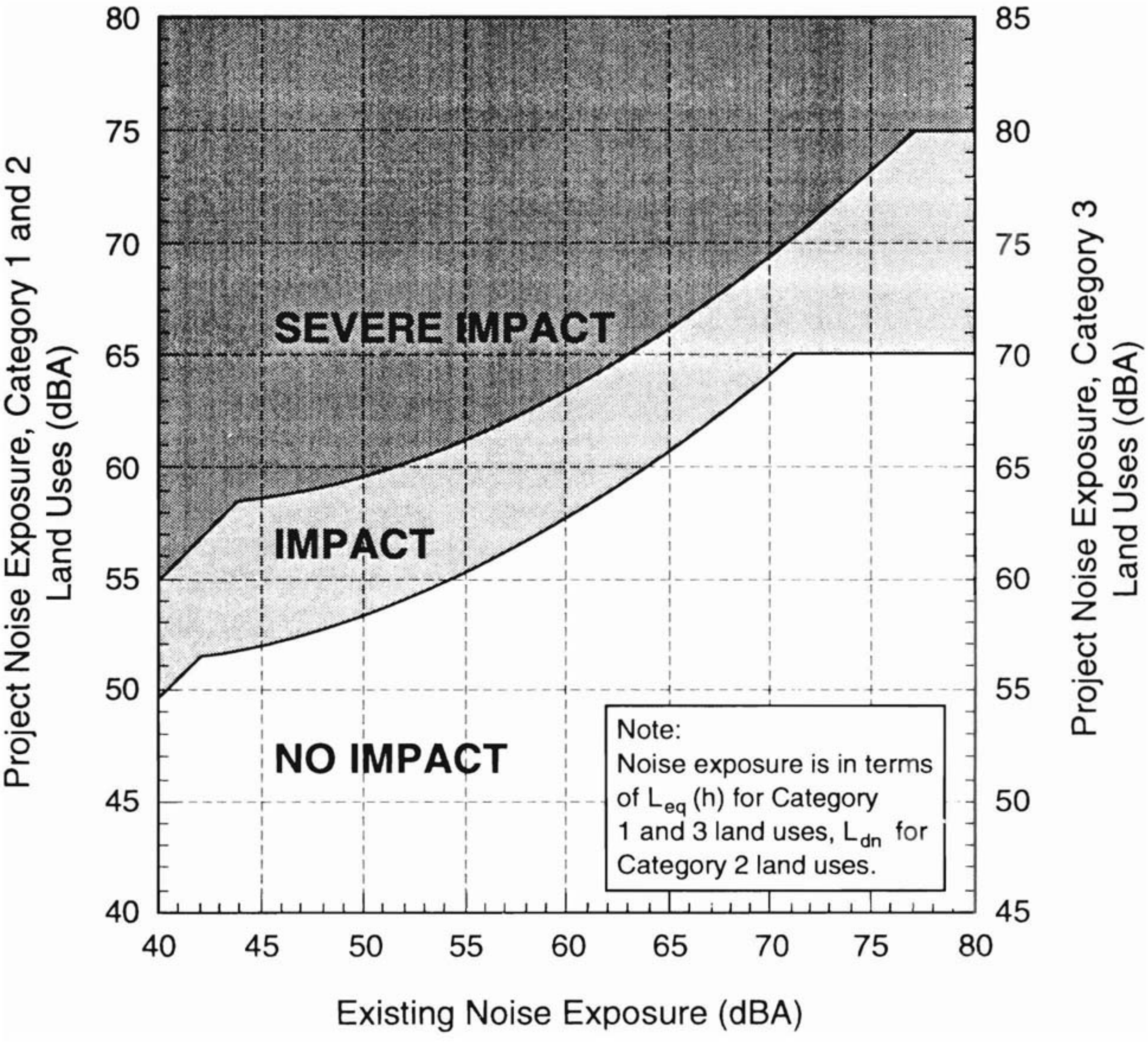
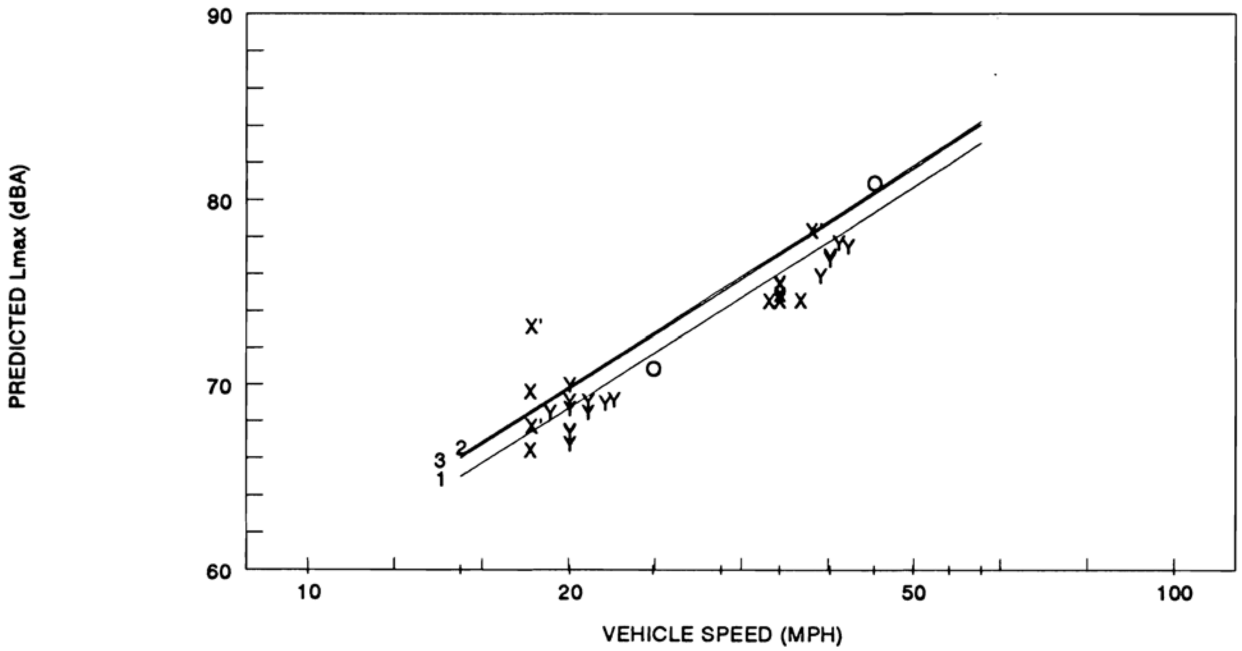
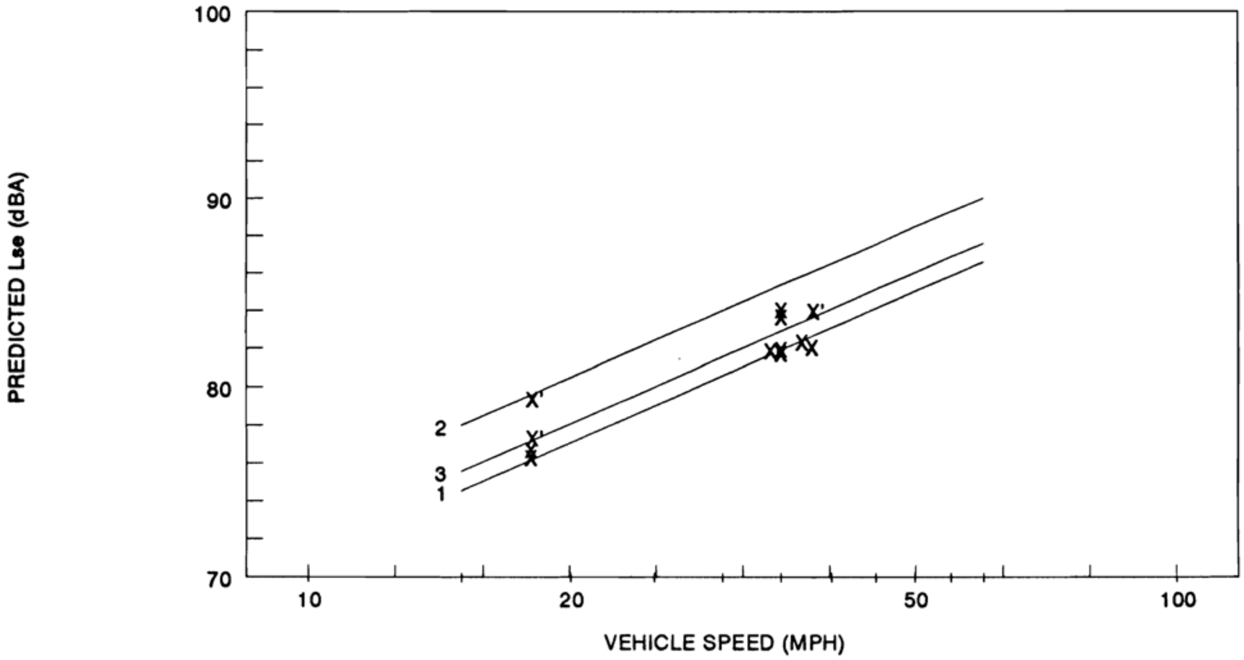


FIGURE 1 FTA noise impact criteria for transit projects.



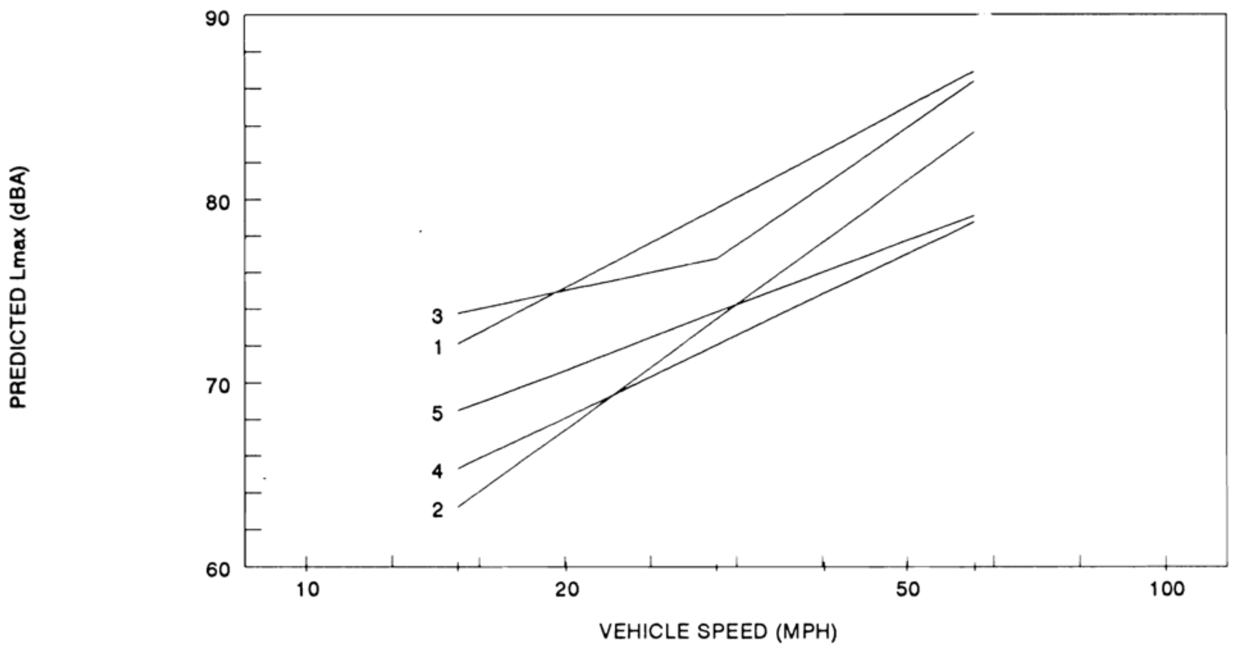
a. maximum sound level



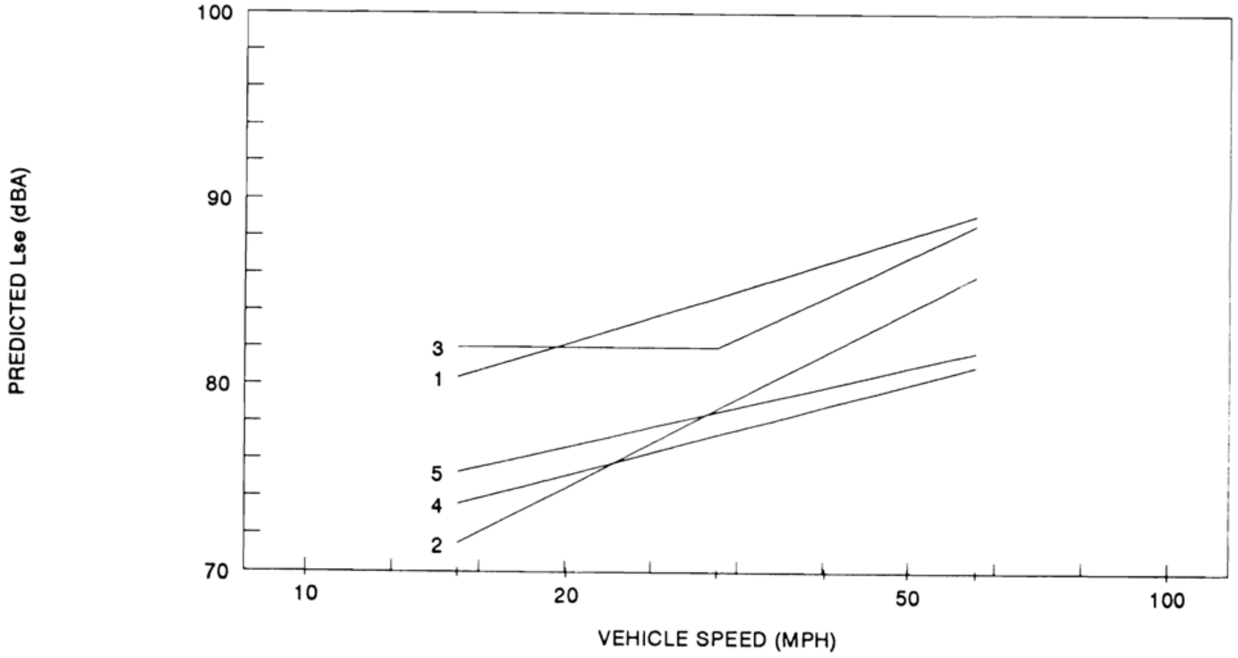
b. sound exposure level

FIGURE 2 Light-rail vehicle noise emissions.

Study and Baltimore Key: 1--FTA Guidance Manual, 2--TSC Handbook, 3--expected Transitway vehicle, O--1990 Baltimore LRL vehicles, Y--acceptance test and X--in-service test (X'--with wheel flats)



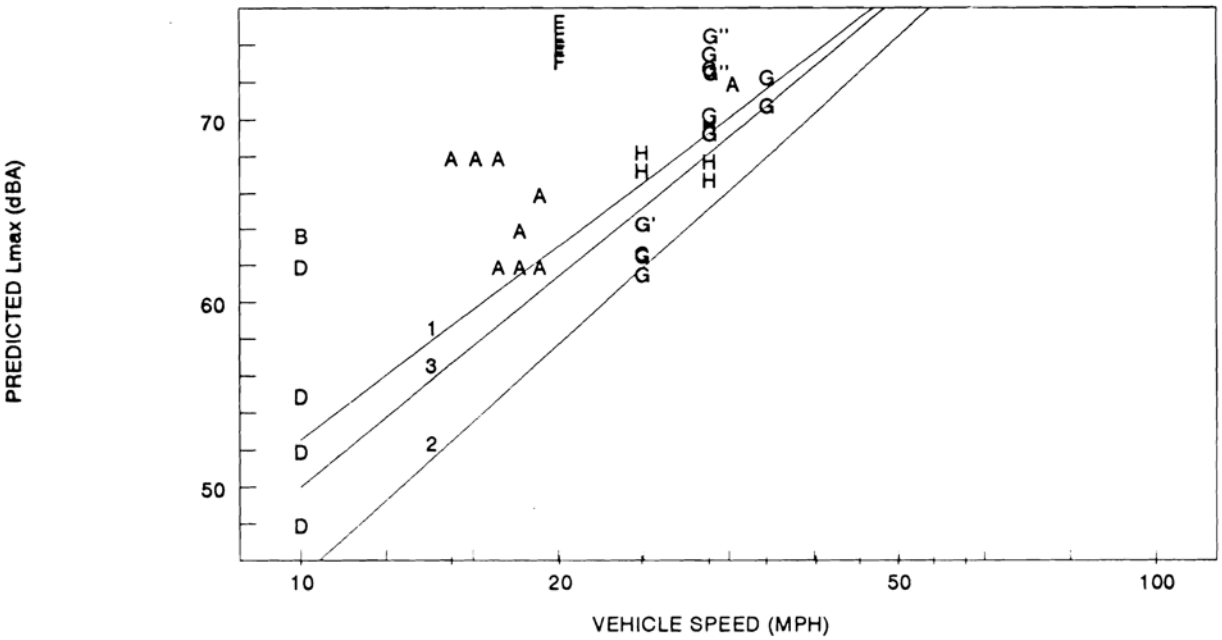
a. maximum sound level



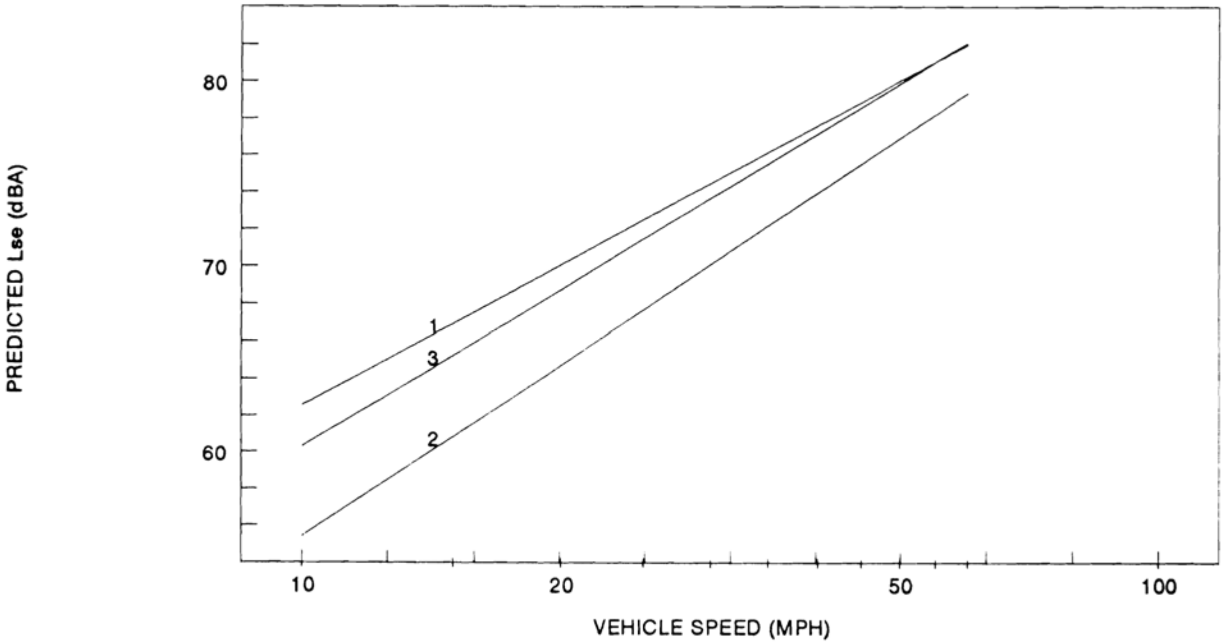
b. sound exposure level

FIGURE 3 Diesel bus noise emissions.

Key: 1--FTA Guidance Manual, commuter buses(no acceleration); 2--FTA Guidance Manual, city buses; 3--Houston METRO Study; 4--VNTSC 2-axle buses; and 5--MTA articulated bus



a. maximum sound level



b. sound exposure level

FIGURE 4 Electric bus noise emissions.

Key: 1--expected Transitway vehicle, 2--MTA articulated bus coast-bys, 3--Seattle METRO Survey, A--MVRTA maximum acceleration tests, B and C--MUNI maximum acceleration and passby tests (respectively), D--MUNI maximum acceleration test, F--Seattle METRO Breda dual-power bus acceleration test, and G and H--Seattle METRO MAN and AM General buses (respectively) passby tests (G', climbing; G", stopping)

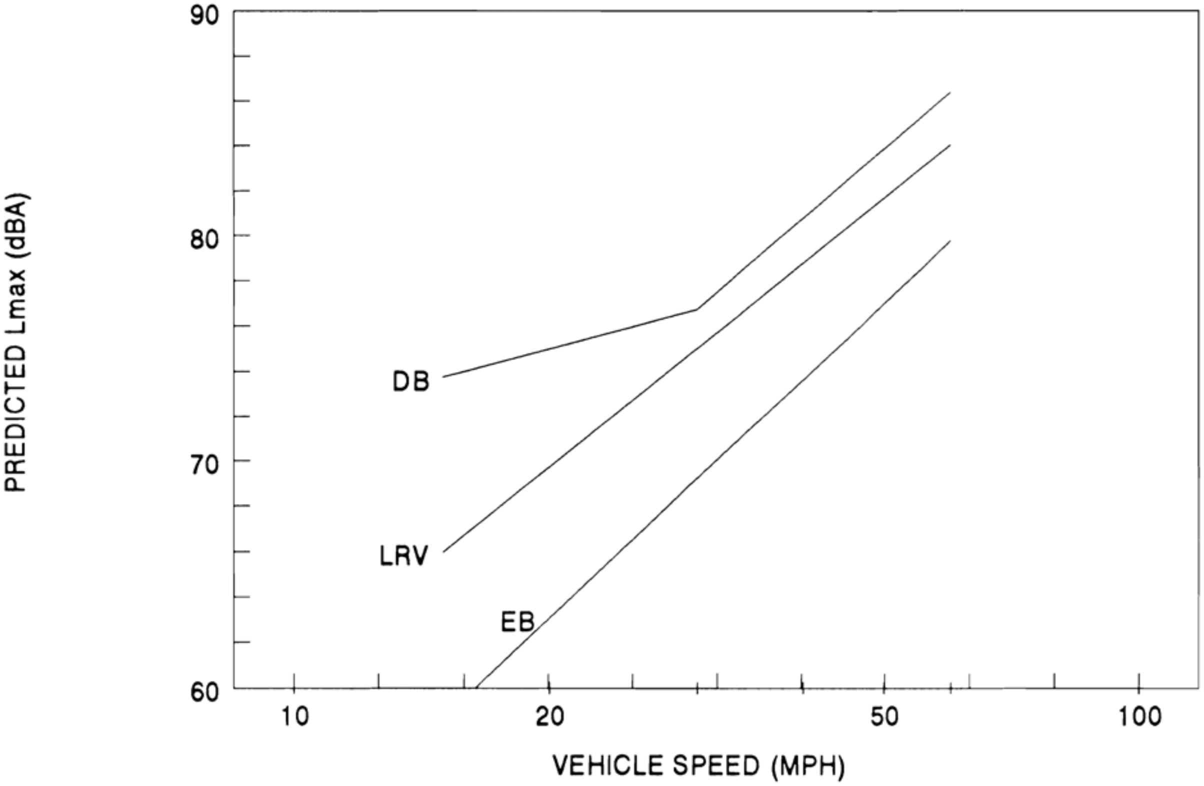
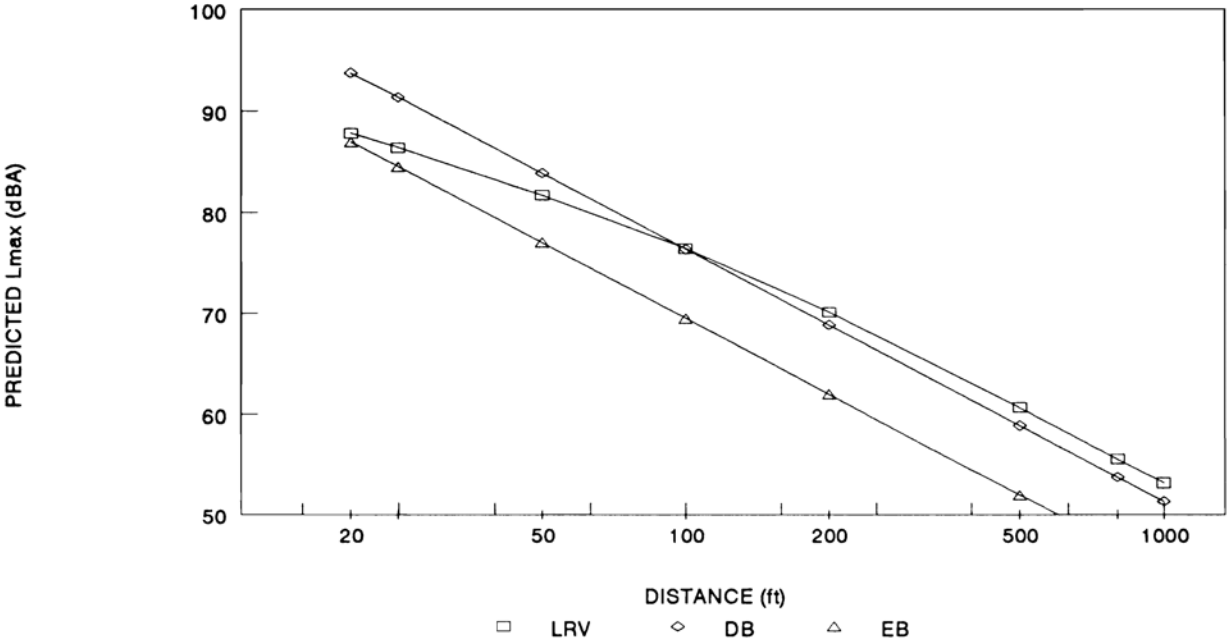
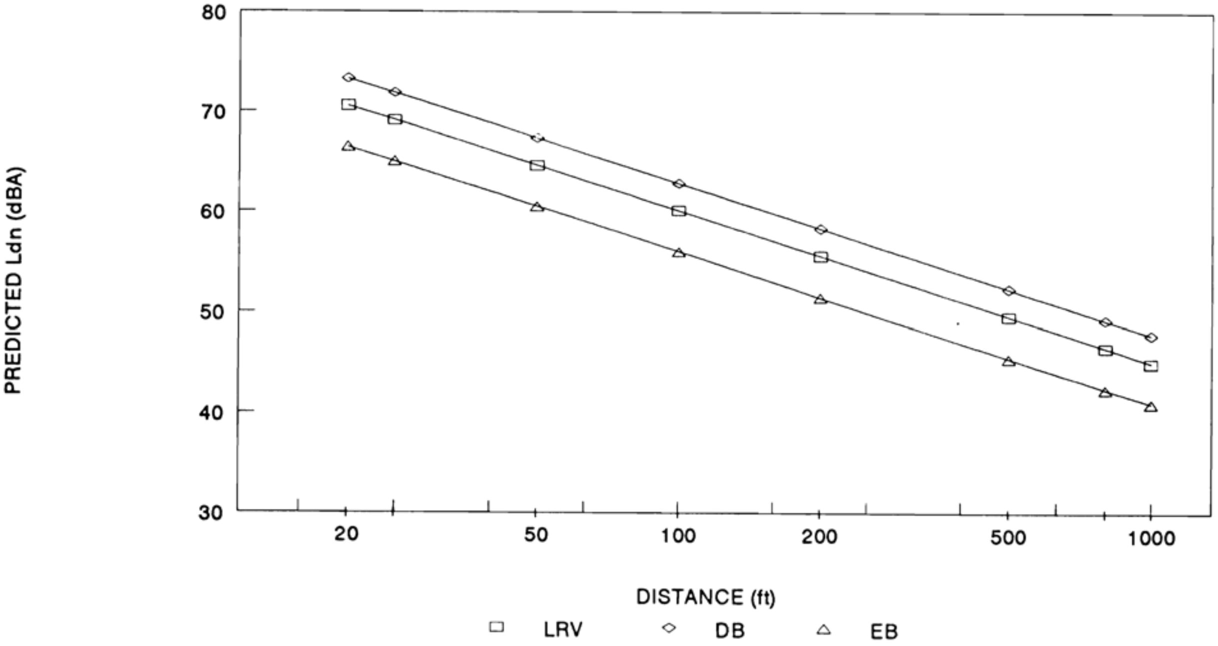


FIGURE 5 Transitway vehicle noise emissions.

Passby maximum sound levels (L_{max}) at 50 ft from centerline of at-grade guideway for--light rail vehicle (LRV) on tie-and-ballast track, diesel bus (DB) and electric bus (EB)



a. maximum sound level



b. day-night average sound level

FIGURE 6 Line operation noise exposures versus distance.

for vehicles traveling at 50 MPH at-grade (LRV on tie and ballast); no shielding due to topography or buildings