Transit Operations Strategies

New York City Noise Code

Local Law 113 of 2005

March, 2010

On the passage of New York City's new noise code in 2005, Mayor Bloomberg stated;

"Noise is New York's number one quality of life complaint and I am proud that my administration proposed, and now the Council has passed, the first comprehensive revision of the noise code in 30 years. The new code will make New York a quieter place to live and work by decreasing excessive and annoying noise. The new code will specifically decrease noise from construction sites, motorcycles, 'boom cars,' air conditioners and nightclubs by strengthening standards and implementing commonsense solutions."

Although not within the direct jurisdiction of the City to regulate, noise from the City's transit systems and airports has long been an additional source of noise complaints from New Yorkers. The City wanted to recognize this continuing issue and included a mandate in the new code which required the Department of Environmental Protection to *"study and propose strategies to control and/or reduce sound levels associated with airports, rapid transit and railroad operations". Local Law 113 of 2005, sec. 3, 24-205.*

This report contains strategies and recommendations for addressing transit noise in New York City and for enhanced public outreach regarding this issue.

Executive Summary:

As required by Local Law 113 of 2005, New York City Department of Environmental Protection (DEP) prepared the following report and recommendations to mitigate noise from the transit system.

Concern about noise has a long history in New York City (NYC). In 1930, the Department of Health appointed the country's first Noise Abatement Commission to highlight the damaging effects of noise on the inhabitants of a dense urban landscape. The Commission's report noted "the serious effects on the nervous system of the riders of subway trains."

This concern continues today. In 2005, the City Council passed and Mayor Bloomberg signed the first comprehensive revamping of the Noise Code since 1975. This legislation clarified the allowable decibel level for a variety of activities making it easier to comply and easier to enforce. In addition, the NYC Transit Authority recently formed a "Noise and Vibration Policy Committee" to address noise in the subway system. In this report, DEP will discuss the health impacts of transit noise, and recommended noise guidelines, attenuation techniques and public outreach.[1]

The effects of noise go beyond hearing impairment and include interference with communications, disturbed sleep, cardiovascular and psycho-physiological effects, reduced performance and changes in social behavior.[2]

There is currently no recognized "correct permissible exposure limits" (PEL), prima facia, for below or above ground rapid transit operations. Surveys of other major domestic and international cities failed to identify specific noise standards for their transit operations. However, New York State does have such a regulation: the Rapid Transit Noise Code (RTNC), that was enacted in 1982. (see **Appendix B**).

Utilizing the RTNC and other science-based data, guidelines or standards that are protective of public health, including those issued by the National Institute for Occupational Safety and Health (NIOSH), U.S. Environmental Protection Administration (EPA), and the World Health Organization (WHO), noise guidelines for train interior noise, entering and leaving stations, curve and brake screech noise and noise from elevated structures were developed:

Summary of Recommendations:

1) Recommended standards for underground transit operations include:

    - Vehicle interior noise : $\leq$75 dBA average for each trip
    - Curve and Brake Screech: All Vehicles – Minimal or No Screech

[1] This report focuses on the impact of transit noise on the public. The impact of noise on employees is regulated by OSHA and NYS Department of Labor.

[2] "Occupational and Community Noise," World Health Organization (WHO) Fact Sheet 258, page 1, rev. February 2001

- Vehicles Entering, Leaving or Passing Through Stations: each noise event should average ≤85 dBA immediately & ≤80 dBA by January 1, 2012

2) Recommended standards for elevated (EL) trains, as they pertain to residents or students affected by EL train operations

   - Interior noise should not exceed a day-night average sound level of 45 decibels[3]
   - Single noise events inside bedrooms should not exceed 45 dB LAmax[4]
   - In the daytime, steady continuous noise in outdoor living areas (e.g. balconies, terraces) should not exceed 55 dB LAeq[5], and in nighttime outdoor noise should not exceed 45 dB LAeq, or an 60 LAmax[6]
   - In schools and preschools noise should not exceed 35 dB LAeq during teaching sessions[7]
   - In hospitals (day & evening) recommended indoor levels should not exceed 30 dB LAeq, and the LAmax of sound events during the night should not exceed 40 dB indoors[8]

3) The TA should provide information about noise levels at stations (e.g. at major transit hubs such as Union Square, Queens Plaza) where a certain noise threshold has been exceeded, so the public can protect themselves, if they chose to.

4) Publicize the ability of 311 to take subway noise related complaints to better track and identify noise "hot spots."

5) The TA should publicize any noise standards or guidelines (including in regard to all entities affected by "EL" train operations) that the TA is presently complying with. Using the RTNC as a model, the TA should set baseline noise attenuation goals over the next 12 years commencing in 2010.

6) The TA should annually submit reports concerning progress made in abating subway noise, funding spent, and noise abatement programs implemented to the governor and legislature as required by the New York State RTNC. A report should be completed annually.

7) It is recommended that the TA develop noise mitigation strategies and incorporate such plans into their capital planning goals.

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[3] HUD "interior noise goal" (see 24 CFR Part 51)
[4] WHO guideline (see "Guidelines for Community Noise," Chapter 4, pages 7-8, 1999)
[5] Ibid (HUD & EPA also recognize Ldn=55 dB as a goal for outdoor residential areas
[6] Ibid, WHO "Guidelines"
[7] Ibid
[8] Ibid

Health Impacts of Noise

The health impacts of noise exposure are a function of frequency-weighted exposure and the exposure duration.[9] Prolonged exposure to noise causes both noise induced hearing loss (NIHL) as well as other health impacts.

In 1971, a WHO working group stated: "Noise must be recognized as a major threat to human well-being."[10] Further, according to Dr. Arline Bronzaft, "it is not only the ear that can be harmed by noise. Noise must be considered a hazard to our overall health and well-being."[11] The WHO documented that "noise can cause hearing impairment, interfere with communication, disturb sleep, cause cardiovascular and psycho-physiological effects, reduce performance, and provoke annoyance responses and changes in social behavior."[12]

A review of the literature by the WHO found that "workers exposed to intense noise daily, for several years, showed noise-induced hearing loss. Considerable hearing loss was rare at lower frequencies but frequent at higher frequencies."[13]

Dr. Arline Bronzaft's research found that noise undermined educational attainment in elementary students:

> *"Elementary school children on the side of a school facing train tracks performed more poorly on a reading achievement test than children in classrooms on the quiet side of the school. (Bronzaft & McCarthy, 1975)"*
>
> *"In 1978 the city of New York reduced the noise of the elevated train and installed acoustical insulation in the affected classrooms, providing a total reduction in the A-weighted noise level of 6 to 8 dB. By 1981, there was essentially no difference in reading achievement between students on the two sides of the school for the classroom studied."*[14]

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[9] "Noise Levels Associated with NYC's Mass Transit Systems," American Journal of Public Health, August 2009, Vol 99, No.8, by Richard Neitzel, Robyn R. M. Gershon, Marina Zeltser, Allison Canton & Muhammad Akram; see **Appendix A1**

[10] Suess, 1973; from "Noise and Its Effects," a report prepared for the consideration of the Administrative Conference of the United States, November 1991, page 1, by Dr. Alice H. Suter

[11] "The increase in noise pollution: what are the health effects? – The Harmful Effects of Noise," Nutritional Health Review, Fall 1996, Dr. Arline L. Bronzaft

[12] "Occupational and Community Noise," WHO, Fact Sheet 258, page 1, Revised February 2001

[13] "Community Noise," published by the WHO and edited by Birgitta Berglund, Institute of Environmental Medicine, Karolinska Institute Department of Psychology, Stockholm University, and Thomas Lindvall, Institute of Environmental Medicine, Karolinska Institute (both also from the Center for Sensory Research, Stockholm), Section 7.1.2.2, S-171 77 Stockholm, Sweden; also available at www.nonnoise.org/library.htm, which has other studies

[14] "Noise and Its Effects;" a report prepared for the consideration of the Administrative Conference of the United States, November 1991, page 20, by Dr. Alice Suter— see the Noise Pollution Clearinghouse Library at www.nonoise.org/library/htm.

Thresholds for Hearing Loss

According to published sources there are variations in noise standards and what constitutes a risk of NIHL. In EPA's "Protective Noise Levels," the agency established a yearly value of 70 decibels (db) (24 hr Equivalent Noise Level (LEQ) average). "To protect against hearing damage, one's 24-hour noise exposure at the ear should not exceed 70 db." However, most numeric levels of concern are focused on the risk of NIHL in the workplace.

The WHO "criteria on noise" identified no risk of "hearing damage" where noise levels were less than 75dBA in the workplace, over an 8 hour LEQ average.[15] However, EPA and NIOSH indicate that NIHL can occur (albeit in small percentages) when workplace levels (over a "40-year working lifetime") equal or exceed 80 dBA. [16] Moreover, the European Community (EC) requires specific "actions" *as soon as* workplace levels exceed 80dBA (hearing protection, information and training and availability of audiometric testing) and when levels exceed 85 dBA additional technical measures must be taken.[17] To avoid irreversible damage to workers' hearing, the EC directive "foresees exposure limit values of 87 dBA and a peak sound pressure of 200 Pa (pascal), above which no worker may be exposed; the noise reaching the ear should, in fact, be kept below these exposure limit values".[18]

At workplace levels over 85dBA, EPA, WHO, and NIOSH indicate that there is a risk of NIHL. OSHA defines the risk of a "hearing handicap from a lifetime's exposure to 90dBA in the range of 20 to 29 percent, from exposure to 85 dBA the risk is estimated at 10 to 15 percent, and only when exposure levels are reduced below 80 dBA would the risk be negligible."[19] Similarly, NIOSH has calculated an "excess risk" for "material hearing impairment" of 8% for "workers exposed to an average daily noise level of 85dBA over a 40-year working lifetime." [20]

In addition to EPA, the WHO and NIOSH, both the National Hearing Conservation Association (NHCA) and data published by the NY Academy of Medicine estimate that hearing damage can occur with extended exposures to noise levels above 85 dBA.[21] It is important to note that the debate continues as to what constitutes "hearing impairment" with some parties arguing for a lower threshold at more frequencies for impairment.

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15 "Proceedings of the Institute of Acoustics", Vol. 22, part 5, page 65, 2000, by B W Lawton)

16 "Criteria For A Recommended Standard," Chapter 3, page 20, June 1998, NIOSH

17 Environmental Policy Centre of Brussels' web site: www.ehstrends.com/2004Forecast_Noise.htm).

18 "European Workplace Legislation on Noise Exposure," European Agency for Safety and Health at Work," page 98, 2005).

19 "Comments of Occupational Noise to the OSHA Standards Planning Committee," page 4, Docket No. C-04, 11-28-94, by Dr. Alice Suter

20 "Criteria For a Recommended Standard-Occupational Noise Exposure," page 24, NIOSH

21 "Crank It Down: Noise…Hearing Loss and Children, NHCA, 2004); "Pilot Survey of Subway and Bus Stop Noise Levels," Jr. of Urban Health: Bulletin of the NY Academy of Medicine, 2006, page 7, by Gershon et alia; also sourced from NIOSH's 1998 "Criteria" (see above) & "Occupational Hearing Loss," American Journal of Industrial Medicine," 2000;37:112-120, by John J. May, M.D.

Subways

Specifically to transit noise, the Center for Hearing and Communication (formerly the "League for the Hard of Hearing"), has stated that "Exposure to a noisy subway, for just 15 minutes a day, over time, can cause damage to hearing."

Published research indicates that regular or chronic exposures to subway noise could be expected to cause hearing loss.[22] "A 30 minute daily exposure to 90dBA of subway noise (equivalent to a daily 8-h exposure of 78 dBA) for 5 days per week over a 40 year period would be expected to produce a 4 dB loss of hearing at 4 kiloHertz (kHz) in the median individual and an 11 dB loss in the 90th percentile individual. Exposure to 100 dBA for 30 minutes per day (equivalent to an 8-h exposure level of 88 dBA) would be expected to produce a 4 kHz hearing loss of 16 dB in the median individual and 24 dB in the 90th percentile individual. A loss of as little as 10 dB averaged across 2 and 4 kHz over both ears may affect speech comprehension."[23] The previous estimates do not assume any other noise exposure during the day. In a NYC Council October 2003 report, research from the National Institute on Deafness and Other Communication Disorders indicated that "noises at 90 decibels and above can cause hearing damage." (see **Appendix D**).[24]

With respect to railroad operations and NIHL, the Journal of the Acoustical Society of America states:

> *"Audiometric testing of nearly 10,000 freight trainmen, engineers, conductors, brakemen, and firemen found that trainmen who used no guns and were free of nosocusis (hearing loss caused by factors other than noise and aging) had a 12-22 db depressed hearing sensitivity at higher frequencies [e.g. 3000-6000 hertz (Hz)] compared to non-exposed men matched by age; by age 50, 60% of the railroad noise-exposed subjects without non-work risk factors had NIHL"*[25]

While this study focused on above-ground railroad workers, some similarities might be projected concerning the type of noise experienced by above-ground railroad workers compared to underground rail workers (or particularly vis a vis above-ground railroad workers and personnel working on EL type lines).

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[22] "Pilot Survey of Subway and Bus Stop Noise Levels," Journal of Urban Health: Bulletin of the New York Academy of Medicine, 2006, by Robyn R. M. Gershon, Richard Neitzel, Marissa A. Barrera, Muhammad Akram & "Noise Levels Associated With New York City's Mass Transit Systems," Neitzel et alia; see **Appendix A & A1**

[23] ibid, "Pilot Survey of Subway and Bus Stop Noise Levels..." page 7

[24] "Subway Noise Rivals Airplane Noise; Residents Suffering Hearing Loss," The Council of the City of New York Office of Communications, October 31, 2003, by Speaker Miller, CM Gioia, & CM Gennaro; see **Appendix D**

[25] "Health and Safety Hazards Associated with Subways*: A Review,"* Journal of Urban Health: Bulletin of the New York Academy of Medicine, Vol. 82, No.1; Feb 28, 2005, page 16, by R.R. M. Gershon, K.A. Qureshi, M.A. Barrera, M.J. Erwin, and F. Goldsmith; as sourced from "*Hearing Loss From Gun and Railroad Noise—Relations with ISO standard 1999,*" The Journal of the Acoustical Society of America 1991;90:180-195, by KD Kryter).

More recently, researchers measured sound levels in the NYC mass transit system, and calculated other action levels of concern. A total of 243 noise measurements were taken from locations in the TA, PATH, LIRR, Staten Island Rail Road (SIRR), Metro-North, Bus, Ferry and Tram systems. According to the researchers "subway cars and platforms had the highest associated equivalent continuous average (Leq) and maximum noise levels." Utilizing a predictive model published by the International Organization for Standardization, the researchers stated: "Based on the WHO and EPA recommendations, chronic exposure to 80.3 dBA for more than 160 minutes per day may be expected to produce hearing loss in some exposed individuals, and a 90.2 dBA level likewise may cause hearing loss with just 18 minutes of exposure per day".[26]

Dr. R. M. Gershon and colleagues are in the process of publishing two more papers which will address noise levels from all sectors in the NYC mass transit system, noise exposure and duration levels affecting customers using the NYC transit system, and any projected noise induced hearing loss (NIHL) risks as a result of these exposures.

The NYS RTNC was enacted by the NYS Legislature in 1982 and established required sound levels for various subway operations. The RTNC required performance deliverables 4, 8 and 12 years from the effective date of the regulation. The RTNC contains other provisions including, but not limited to, a provision that the Transit Authority submit an annual report to the governor and legislature detailing progress made in abating subway noise abatement, funding spent, "contracts let," noise abatement programs implemented and "any and all subway noise measurements made during the previous period."

Noise requirements specified in the RTNC include:

A. Car Interior Noise: 100% of new cars must achieve 80dBA within 12 years of the effective date of the applicable section (i.e. by 1994)

B. Curve and Brake Screech: 100% of new cars (and 100% of old cars) must have "No Screech" within 12 years of the effective date of the applicable section

C. "Trains Entering, Leaving or Passing Through the Station" -- within 12 years of the effective date of the applicable section:

    - 100% of cars must achieve 105 dBA
    - 95% of cars must achieve 90 dBA
    - 80% of cars must achieve 85 dBA
    - 60% of cars much achieve 80 dBA

Attenuation Techniques for Transit Noise

The attached spreadsheet (**Appendix C**) outlines some possible attenuation techniques that transit systems such as the TA could utilize. These were derived from the Federal

[26] "Noise Levels Associated With New York City's Mass Transit Systems," American Journal of Public Health, page 2, August 2009, Neitzel et alia; see **Appendix A1**)

Transit Administration's "Transit Noise and Vibration Impact Assessment" publication of May 2006 (see **Appendix F**). Also included are attenuation suggestions from the study published in October 1973 by the NYC "Environmental Protection Administration." A summary of this study, containing attenuation suggestions based on the original report, was also submitted to the City Council (**Appendix C1**). The FTA and 1973 studies provide estimated decibel reductions for certain techniques.

We would urge the TA to develop noise mitigation strategies in line with these recommended studies and incorporate such plans into their capital planning goals in conjunction with the goals set out in the RTNC. It is also our recommendation that all investments in noise mitigation be evaluated in terms of a reasonable cost benefit analysis.

Beyond Hearing Loss

The WHO's "Guidelines for Community Noise" address sleep disturbance, cardiovascular and psychophysiological effects, mental health effects, effects on performance and other issues. In determining their guidelines, the WHO set the limits at the lowest adverse health effect when multiple adverse health effects are identified for a given environment.[27] For example, in addressing communication the WHO report states: "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."[28] With respect to sleep, "where noise is continuous, the equivalent sound pressure level should not exceed 30 dBA indoors, if negative effects on sleep are to be avoided."[29] Moreover, "fairly consistent evidence shows that noise above 80 dBA is associated with reduced helping behavior and increased aggressive behavior. Particularly, there is concern that high-level continuous noise exposures may contribute to the susceptibility of schoolchildren to feelings of helplessness."[30]

Conversely, the WHO did not find a strong correlation between noise and cardiovascular effects: "Epidemiologial [sic] 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."[31]

In the development of recommendations for EL train operations, DEP relied on EPA, U.S. Housing and Urban Development (HUD) and WHO standards for community noise. For example, in addition to the WHO guidelines indicated above, the HUD has an "interior noise goal" whereby noise levels "shall not" exceed a day-night average sound level of 45 decibels. These are science-based guidelines that address not just hearing loss, but also the other deleterious effects of noise.

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[27] "Guidelines for Community Noise," WHO, Chapter 4, page 9, 1999
[28] Ibid, page 2
[29] Ibid, page 4
[30] Ibid, Chapter 3, page 14; the WHO also references a 1993 study by Evans & Lepore in regard to the exposures to schoolchildren
[31] Ibid, Chapter 4, page 5

See **Appendix G** for "Table 4.1" from the above WHO documents which outlines the above (and other) community noise guidelines, as well as the hourly figures used to derive these values.

For outdoor residential areas, "HUD, DOT and EPA recognize Ldn equal to 55 dB as a goal for protecting the public health and welfare with an adequate margin of safety" (see Suter report, page 29)

It is beyond the scope of this report to evaluate the numerous noise studies that have been completed. The preponderance of evidence in the studies cited here points to a necessity for greater public awareness of the dangers of continuous exposure to transit noise. Organizations such as the WHO, EPA and NIOSH have already analyzed many of these studies and we are confident of their findings and recommendations, which form an integral part of this report. In addition, we recommend reviewing www.nonoise.org/library.htm. **Appendix E** also contains a sampling of noise research. The Federal Interagency Committee on Aviation Noise, while geared toward the issue of aircraft noise, also has a web link that contains an informative discussion on the "Effects of Noise on People."

RECOMMENDATIONS

The recommendations to mitigate transit noise are primarily based on standards and guidelines developed for workers. These workplace exposure guidelines are based on modeling noise exposure over a typical workday (~7-8 hours) over a "lifetime" of work (5, 20, 30 + years). Hence, it could be argued that *these* guidelines (not the community-based ones) should not be utilized or considered for the general population (primarily transit customers) that is exposed to noise for much shorter periods: several minutes/day to usually less that 120 minutes/day. There does exist, however, some reasons for extrapolating guidelines from these primarily workplace standards:

- Various types of city workers not under the TA's direct supervision (without access to any of the TA's health & safety programs) could be exposed for several hours per day such as transit police, contractors etc.
- Infants and very young children ride the subway and there appears to be a dearth of research on how noise affects this sensitive population—hence a prudent approach may be necessary
- The European Community's science-based "action level" of 80dBA appears to be prompted *as soon as* noise exceeds 80dBA (regardless of the duration, or expected duration of employment)
- The typical transit customer has no access to any hearing protection, unlike workers who typically (and should) have access to measures when noise levels meet designated levels, such as training, personal safety protective equipment, etc.

Recommendations for Transit Operations

1) Recommended standards for transit operations include:

- Vehicle interior noise : $\leq$75 dBA average for each trip

- Curve and Brake Screech: All Vehicles – Minimal or No Screech

- Vehicles Entering, Leaving or Passing Through Stations: each noise event should average ≤85 dBA immediately & ≤80 dBA by January 1, 2012 (measured as follows: vehicles entering—from entrance into station of first car until full stop; vehicles leaving—from full stop until last car has exited station; vehicles passing through—from entrance into station of first car until last car has exited station).

Recommendations for EL Train Operations

1) Recommended standards for elevated (EL) trains, as they pertain to residents or students affected by EL train operations:

- Interior noise should not exceed a day-night average sound level of 45 decibels[32]

- Single noise events inside bedrooms should not exceed 45 dB LA max[33]

- In the daytime, steady continuous noise in outdoor living areas (e.g. balconies, terraces) should not exceed 55 dB LAeq,[34] and, at nighttime, outdoor noise should not exceed 45 dB LAeq, or an 60 LAmax[35]

- In schools and preschools noise should not exceed 35 dB LAeq during teaching sessions[36]

- In hospitals (day & evening) recommended indoor levels should not exceed 30 dB LAeq, and the LAmax of sound events during the night should not exceed 40 dB indoors[37]

Recommendations for Public Outreach

Presently the Transit Authority (TA) does not provide information regarding subway noise to the public. For example, there is little or no information about subway noise levels on the TA's web site, nor information about how the public may make a noise complaint. Accordingly, the TA should seek to implement the following to enhance public outreach regarding subway noise.

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[32] HUD "interior noise goal"
[33] WHO guideline (see "Guidelines for Community Noise," Chapter 4, pages 7-8, 1999)
[34] Ibid (HUD & EPA also recognize Ldn=55 dB as a goal for outdoor residential areas)
[35] Ibid, WHO "Guidelines"
[36] Ibid
[37] Ibid

1) Disseminate Noise Data Regarding Noise at Subway Stations That do not Meet Designated Noise Standards

The TA should consider providing information about noise levels at stations (e.g. major transit hubs such as Union Square) where sound levels exceed prescribed thresholds, so the public could protect themselves, if they chose to. This data could be provided on the TA web site, or in/around the station itself. The TA should determine the stations that would require this based on their own data, customer complaints, and applicable standards.

A bill introduced and sponsored by Senator Carl Kruger in January 1999 would require the transit authority to post warning signs at any station where workers found noise levels exceeded 90 dBA. These signs would caution about exposures to sound at or above 90dB, and would recommend hearing protection. A telephone number for the TA would also have to be posted on the sign.

2) Enhanced Complaint Line Response

The TA does not have a designated phone number on their web site to which the public can make noise complaints. Moreover, the search functions under their general search box and the "FAQ" page did not yield any pertinent results (as of early March 2009) as far as making noise complaints.

According to the TA, however, the public can contact 311 regarding noise and this complaint would then be passed on to the TA. However, the option to call 311 for transit-related noise is not well publicized. It is recommended that the ability to call 311 for transit related complaints be better publicized, including on their web site as well as throughout the TA's facilities (subway, bus stops etc.).

Other Recommendations:

1. The TA should publicize any noise standards or guidelines (including in regard to all entities affected by "EL" train operations) that the TA is presently complying with.

2. The TA should annually submit reports concerning progress made in abating subway noise, funding spent, and noise abatement programs implemented to the governor and legislature as required by the New York State RTNC. A report should be completed annually.

3. We also recommend using the RTNC as a model to set baseline noise attenuation goals over the next 12 years commencing in 2010.

4. It is recommended that the TA develop noise mitigation strategies and incorporate such plans into their capital planning goals. It is also our recommendation that all such capital investments in noise mitigation be evaluated in terms of a publicly available cost benefits analysis.

GLOSSARY

"A" – the total sound level of all noise as measured with a sound level meter using the "A" weighting network. The unit of measurement is the [db(A)] dB(A).

"Ambient noise" – the all-encompassing noise associated with a given environment, being usually a composite of sounds from many sources near and far. The sound level at a given location that exists as a result of the combined contribution in that location of all sound sources, excluding the contribution of a source or sources under investigation and excluding the contribution of extraneous sound sources.

"Annoyance" – Any bothersome or irritating occurrence[38]

"Cardiovascular" – Pertaining to the heart and blood vessels[39]

"Day-Night Average Sound Level, DNL" – The Day-Night Average Sound Level (DNL) represents noise as it occurs over a 24-hour period, with the assumption that noise events occurring at night (10 p.m. to 7 a.m.) are 10 dB louder than they really are. This 10 dB penalty is applied to account for greater sensitivity to nighttime noise, and the fact that events at night are often perceived to be more intrusive because nighttime ambient noise is less than daytime ambient noise."[40]

"Decibel" – The decibel is one-tenth of a bel. Thus, the decibel is a unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power. Means the practical unit of measurement for sound pressure level; the number of decibels of a measured sound is equal to 20 times the logarithm to the base 10 of the ratio of the sound pressure to the pressure of a reference sound (20 micropascals); abbreviated "dB".

"Epinephrine" – A hormone secreted by the adrenal medulla (inner or central portion of an organ) in response to stimulation of the sympathetic nervous system.[41]

"Equivalent Noise Level (Leq)" – Leq is the sound level corresponding to a steady-state, A-weighted sound level containing the same total energy as a time-varying signal over a given sample period. Leq is the "energy" average noise level during the time period of the sample. Leq can be measured for any time period, but is typically measured for 15 minutes, 1 hour, or 24 hours.[42]

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[38] "General Health Effects of Transportation Noise," U.S. Department of Transportation, Research and Special Programs Administration, John A. Volpe National Transportation Systems Center, by Cynthia S. Y. Lee and Gregg G. Fleming, June 2002, pages 3-6, "Terminology"
[39] ibid
[40] Federal Interagency Committee on Aviation Noise (see fican.org)
[41] Ibid, "General Health Effects of Transportation Noise," U.S. Dept. of Transportation
[42] Hartsfield-Jackson Atlanta International Airport, FAR Part 150 Study Exposure Report, page B-6, "Cumulative Metrics"

"Hearing Impairment" – A decreased ability to perceive sounds as compared with what the individual or examiner would regard as normal. The result is an increase in the threshold of hearing. [43]

"Hertz" – (abbreviation Hz) Unit of frequency, the number of times a phenomenon repeats itself in a unit of time[44]

"Ischaemic heart disease" – Ischaemic or ischemic heart disease (IHD), or myocardial ischaemia, is a disease characterized by reduced blood supply to the heart muscle, usually due to coronary artery disease (atherosclerosis of the coronary arteries).[45]

"Lmax" – The maximum measured sound level at any instant in time

"Noise" – Any unwanted sound[46]

"Norepinephrine" – A hormone produced by the adrenal medulla similar in chemical and pharmacological properties to epinephrine, but chiefly a vasoconstrictor with little effect on cardiac output. [47]

"Peak Sound Pressure Level" – Level of the peak sound pressure with stated frequency weighting, within a stated time interval. [48]

"Sound Level Meter" -- any instrument including a microphone, an amplifier, an output meter, and frequency weighting networks for the measurement of noise and sound levels in a specified manner and which complies with standards established by the American National Standards Institute specifications for sound level meters S1.4-1971, as amended or S1.4-1983, as amended.

"Sound pressure level" – a sound that is an expression of the acoustic pressure calculated as twenty times the logarithm to the base ten of the ration of the root mean square of the pressure of the sound to the reference pressure, [2 X 10-4 microbars] 20 micropascals.

__Note:__ *Some or all of the above definitions have been quoted verbatim from the referenced sources. In addition, definitions not noted by a footnote have been obtained (in part or in whole) from New York Administration Code, Title 24, Chapter 2 ("NYC Noise Code), section 24-203 "General definitions".*

[43] Ibid, "General Health Effects of Transportation Noise," U.S. Dept. of Transportation
[44] ibid
[45] Wikipedia.org
[46] Ibid, "General Health Effects of Transportation Noise"
[47] ibid
[48] ibid

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Pilot Survey of Subway and Bus Stop Noise Levels

Robyn R. M. Gershon, Richard Neitzel, Marissa A. Barrera, and Muhammad Akram

ABSTRACT *Excessive noise exposure is a serious global urban health problem, adversely affecting millions of people. One often cited source of urban noise is mass transit, particularly subway systems. As a first step in determining risk within this context, we recently conducted an environmental survey of noise levels of the New York City transit system. Over 90 noise measurements were made using a sound level meter. Average and maximum noise levels were measured on subway platforms, and maximum levels were measured inside subway cars and at several bus stops for comparison purposes. The average noise level measured on the subway platforms was 86 ± 4 dBA (decibel-A weighting). Maximum levels of 106, 112, and 89 dBA were measured on subway platforms, inside subway cars, and at bus stops, respectively. These results indicate that noise levels in subway and bus stop environments have the potential to exceed recommended exposure guidelines from the World Health Organization (WHO) and U.S. Environmental Protection Agency (EPA), given sufficient exposure duration. Risk reduction strategies following the standard hierarchy of control measures should be applied, where feasible, to reduce subway noise exposure.*

KEYWORDS *Excessive noise exposure, Hearing protection devices, Mass transit, Noise-induced hearing loss, Sound level meter, Subway noise, Subway riders.*

INTRODUCTION

Increasingly, noise control measures are being considered as part of an overall strategy to help improve the quality of life of urban dwellers. One important source of urban noise is related to mass transit networks, which include buses, subways, light rail, commuter rail and other transportation systems. The U.S. has the largest mass transit infrastructure in the world, and this network provides affordable and efficient transportation for roughly 33 *million riders each weekday*, with over 7 million riders in New York City (NYC) alone.[1] This reliance, coupled with the numerous and varied benefits of mass transit, may have, to some extent, muted our interest and concern regarding the potential health hazards, including excessive noise exposure, associated with mass transit.[2–4] Subways, in particular, are a focus of attention, not only because of their vast ridership, which is far greater than all

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other forms of mass transit combined, but also because of the wide range of potential health and safety hazards associated with them.[5] Even though a number of these hazards, such as excessive vibration, airborne heavy metal particulates, and electromagnetic radiation, have been considered,[5–13] risk assessment data on these and other potential subway-related health hazards remain extremely sparse. Numerous barriers to conducting subway research may explain this information gap, with the lack of interest from the agencies that operate subway systems perhaps the most important barrier. Other research challenges include the inherent complexity of conducting field studies in a fluid, mixed hazard setting, which makes measurement and the determination of exposure dose and exposure rates difficult.

One potential subway-related health hazard for which published data are especially limited is excessive noise. This is important because noise exposure and noise-induced hearing loss (NIHL) is a global problem of significant magnitude, especially in urban settings in industrialized nations.[14–16] In the U.S., over 20–30 million Americans are believed to be exposed to excessively high levels of noise, with about 10 million estimated to have NIHL.[17,18] Worldwide, over 200 million people are believed to be affected.[16,19] While most NIHL is believed to be primarily due to occupational exposure,[17] determining the impact of risk factors for sociocusis (non-work related hearing loss resulting from exposure to high levels of noise associated with recreational activities and transit use) on overall hearing levels is complex.[20–23] The contribution of chronic exposure to short periods of high noise, as might be encountered on subways, especially older subway systems, to hearing loss is not entirely clear.[24] Because NIHL is incremental, involving a gradual and often unnoticeable diminution in hearing acuity, those at risk may not wear hearing protection or limit exposure through avoidance. In addition to hearing loss, excessive exposure to noise may be associated with adverse effects on mental health (believed to be related to the physiological arousal of cortisol and catecholamine) and the cardiovascular system.[25–28] More recent research has focused on the impact of excessive noise on performance, short and long-term memory, and sleep patterns.[29–31] There is also a body of research documenting the negative effect of hearing loss on interpersonal communication and quality of life and work-life issues.[25,29,31] Interesting studies exploring the impact of noise at the community-level are under way; in particular, the concept of "soundscapes"[32] is being used to measure community-wide acoustic environments, and research is focused on the impact of these environments on community level outcomes.

Unfortunately no surgical or medical treatment has been shown to be especially effective for NIHL. Management of mild through moderately severe hearing loss consists primarily of personal amplification in the form of hearing aids. Exposure prevention is therefore the best approach. Not surprisingly given the serious medical and public health implications of NIHL, it is one of the top ten priorities for targeted intervention by the U.S. Public Health Service and one of the Key Healthy People objectives of the U.S.[33]

There are several exposure limits to which subway noise levels can be compared. Limits for occupational exposure to noise have been established by the U.S. Occupational Safety and Health Administration (OSHA) and U.S. National Institute for Occupational Safety and Health (NIOSH). OSHA has established an 8-h average Permissible Exposure Limit (PEL) of 90 A-weighted decibels (dBA),[34] while NIOSH has a more health-protective 8-h average Recommended Exposure Limit (REL) of 85 dBA.[35] These limits are designed to prevent NIHL in most exposed workers. However, approximately one in four workers will suffer a compensable hearing loss after a 40-year working lifetime of daily exposure at the OSHA PEL, and roughly one in 12 workers will suffer a loss after daily exposure even at the lower NIOSH REL.[34,35] This level of risk is considered acceptable in occupational settings, but is unacceptably high for community exposure. To protect nearly all individuals from any hearing loss, the Environmental Protection Agency (EPA)[36] and World Health Organization (WHO)[37] have established guidelines for community noise exposure. Both agencies recommend that individuals not exceed an 8-h daily average level of 75 dBA or a 24-h daily average of 70 dBA over a 40-year exposure period. Table 1 shows the allowable daily exposure duration for several exposure levels according to the above limits. Noise levels below 70 dBA are generally considered to present negligible risk of NIHL, regardless of exposure duration.[35] Material impairment of hearing acuity can occur in 20–30% of workers with consistent exposure to occupational noise levels of 90 dBA or greater over a working lifetime.[35] At 85 dBA, this risk is reduced to 5–15%. It is important to note that very loud single impulse exposures in the range of 125–150 dBA can also result in permanent hearing loss through the mechanical dislocation of cochlea sensory cells.[39] In practical application, approximate levels for familiar sounds are about 30 dBA for a whisper, 45–60 dBA for normal conversation, 100 dBA for a chainsaw, and 140 dBA for a gun blast.[39] The logarithmic nature of decibels means that an increase of 10 dB equals a 10-fold increase in intensity; therefore, a 90 dB sound is ten times as intense as an 80 dB sound, 100 times as intense as a 70 dB sound, and 1,000 times as intense as a 60 dB sound.

To help address some of the knowledge gaps with respect to noise exposure associated with mass transit use, we recently conducted an environmental noise survey of the NYC subway system. This system, which began in 1904, is the largest and one of the oldest in the U.S., with over 450 subway stations, 500 subway trains, and over 2,000 miles of track. Operating 24 h a day throughout the boroughs of NYC, it has the fifth largest ridership in the world.[1]

MATERIALS AND METHODS

A protocol was developed to measure environmental noise on the subway platforms and inside subway cars. Several measurements were also made at bus stops for comparison purposes. A list of potentially high noise sites with ridership access was compiled based upon previous monitoring data[40,41] and accessibility to the research team. Specific subway stations and train lines were then chosen based on the available data and in consultation with long-term subway employees.

Measurements were made on subway platforms located in the four New York boroughs with underground subways (Manhattan, Brooklyn, the Bronx and Queens). To determine if noise levels varied by location on the subway platforms, measure-

TABLE 1. Allowable daily exposure durations for various exposure levels[34–37]

	Exposure duration (min)					
	75 dBA	85 dBA	90 dBA	100 dBA	105 dBA	115 dBA
OSHA PEL	>24 h*	960	480	120	60	15
NIOSH REL	>24 h*	480	151	15	4.5	0.5
EPA/WHO	480	47.5	15	1.5	0.5	0

*Indicates an unlimited allowable exposure duration.

ments were made at three different locations on each platform. These locations were the front end (i.e., the end at which the lead car came to rest when stopped at the platform), the middle section of the platform, and the rear section of the platform (i.e., the end at which the rearmost car came to rest when stopped at the platform). For all samples, other conditions that could affect noise levels were noted (e.g., passing trains, air brake release, police sirens, etc.). The subway stations in which platform measurements were made were classified as major transfer points if three or more subway lines intersected there; stations with fewer or no line intersections were classified as smaller stations (i.e., local stops).

Noise levels were measured using a Quest 2700 (Type II) non-integrating sound level meter (SLM) (Quest Technologies, Inc., Oconomowoc, WI) set to the A-weighting network and SLOW meter response. The SLM was calibrated according to the manufacturer's instructions at the beginning and at the end of each data collection day. A windscreen was used during all measurements. All measurements were made between 10 A.M. and 4 P.M. For convenience, the SLM was placed in a backpack held in front of the researcher's body during measurements, with the microphone protruding from the backpack and pointing towards the subway train or bus stop or, in the case of measurements inside subway cars, towards the centerline of the car. Since the SLM did not have the capability of measuring an average noise level over time, sound pressure levels (SPLs, in dBA) were read off the SLM display at 5-s intervals during the duration of each measurement.

Subway Platform Measurements

For platform noise measurements, the SLM was approximately 3 feet from the ground (the height of the backpack when the researcher was standing) and 1.5 feet from the edge of the platform. Platform measurements began when the operating motor of the first car of an inbound train was flush with the rear edge of the platform. Measurements continued until the train came to a complete stop, usually after 30 to 40 s. An average SPL was computed for each platform measurement by taking the arithmetic mean of the 5-s interval readings within each measurement. SPLs are typically averaged logarithmically to compute an equivalent continuous exposure level (L_{eq}), a measure used to summarize periods of exposure to time-varying noise levels. However, in the current study SPLs were arithmetically averaged because noise levels were not sampled continuously for each measurement, but rather at regular 5-sec intervals. For comparison purposes, calculations were repeated on the data using logarithmic averaging (results not shown); the resulting mean L_{eq} level was 3.4 dBA higher than the arithmetically averaged level. The highest 5-s interval SPL within each measurement was recorded as the maximum level.

Subway Car and Bus Stop Measurements

Subway car noise measurements were made in the middle car of the monitored trains at a height of 2 feet from the floor of the car (the height of the backpack when the researcher was sitting). Measurements began when the train starting pulling out of the station, and stopped when the train came to a complete stop at the next station; only the maximum SPL during each subway car measurement was recorded. As another mass transit comparison, measurements were made at bus stops. For these measurements, the SLM was held 3 feet from the ground and 1 foot away from the curb. Bus stop noise levels were measured as buses pulled into or away from the stop, and, as with the subway car measurements, only the maximum SPL was recorded.

The height of the SLM during all measurements makes the measured SPLs most relevant to children and shorter adults; however, in the highly reverberant environment of subway platforms (all of which were constructed completely of brick, tile, steel, and/or concrete) and subway cars, the difference between levels measured at a height of 2 or 3 feet vs. measurements made at ear height should be minimal.

Statistical Analysis

All statistical analysis was performed using Intercooled Stata 9.0 (Stata Corporation, College Station, TX). Histograms and quantile–quantile plots of the measured average and maximum noise levels were examined for potential outliers. One measured subway car maximum level of 140.3 dBA was identified, which was more than six standard deviations away from the mean maximum level. This level was determined to be an outlier and was removed from the dataset. Descriptive statistics were calculated on the remaining measurements, and mean values were statistically compared using Student *t*-tests. Exceedance fractions (the fraction of measurements over certain threshold levels) were compared using the χ^2 test. Differences were considered statistically significant if $p < 0.05$.

RESULTS

Subway Platform Measurements

Fifty-seven average SPL measurements (encompassing 377 5-s interval SPLs) were made on underground subway platforms in 17 different subway stations. Forty of the 57 measurements had durations of 30 s or less; the longest lasted 90 s. All 57 average levels were over 75 dBA, the threshold level above which there is a duration-dependent risk of NIHL.

Table 2 presents measurement durations and mean and maximum 5-s interval noise levels for all platform measurements and stratified by platform measurement location and station type. The fraction of measurements exceeding 85 and 90 dBA

TABLE 2. Noise levels and exceedance fractions in subway stations

	Measurement duration (s)			Noise level (dBA)				
Location/ station type	*n*	Mean	Standard deviation	Mean	Standard deviation	Highest 5-s interval	Percent (%) >85 dBA	Percent (%) >90 dBA
Overall	57	34.0	10.8	85.7	3.9	106.0	58.0	12.2
Location								
Back of platform	19	38.9	14.2	86.1	4.8	106.0	63.2	21.1
Middle of platform	19	33.2	8.0	85.1	3.9	105.0	63.2	5.3
Front of platform	19	30.0	7.1	86.0	3.0	105.0	47.4	10.5
Station type								
Major transfer point	24	32.3	7.1	87.5	3.1	106.0	79.2	16.7
Local station	33	35.3	12.7	84.5	4.0	105.0	42.4	9.1

is also shown. The mean level across all measurements was 85.7 dBA, and the highest 5-s interval SPL within these measurements was 106 dBA. More than half of all measurements were over 85 dBA, and more than one in ten were over 90 dBA. Measurements made at the back of the platform had the highest mean level and fraction of average exposures over 85 and 90 dBA; however, neither mean noise levels nor exceedance fractions differed significantly by platform location. Stations that are major transfer points had statistically significantly higher mean noise levels (mean difference 3 dBA, $p = 0.002$) than smaller local stations and had a statistically higher fraction of measurements over 85 dBA ($p = 0.006$). Measurement conditions associated with average platform noise levels over 85 and/or 90 dBA included track curvature, presence of two trains at a platform simultaneously, excessive brake squealing, debris on the subway tracks, presence of loud musicians on the platform, and release of compressed air from air brakes on the trains. Major transfer point stations consistently had the highest noise levels.

Maximum Levels for Subway Platforms, Subway Cars, and Bus Stops

Table 3 presents the maximum 5-s interval levels measured on subway platforms, subway cars, and at outdoor bus stops. More than one in ten of the maximum 5-s interval SPLs associated with the 57 subway platform measurements exceeded 100 dBA, and three out of four exceeded 90 dBA. The mean maximum noise level on subway platforms was 93.5 dBA, with a range of 83 to 106 dBA. Maximum SPLs on the platforms were significantly ($p < 0.05$) higher than average in instances when express trains passed the station during measurements.

Twenty-five maximum SPL measurements were collected on subway cars from five different train lines. Inside the subway cars, the mean maximum noise level was 94.9 dBA, with a range of 84 to 112 dBA. Seventeen (68%) of the maximum SPLs exceeded 90 dBA, and 5 (20%) exceeded 100 dBA. The highest maximum subway car levels were associated with passing trains. Maximum SPLs inside the cars were significantly higher ($p < 0.05$) than average when other trains were passing.

Maximum SPLs were measured at ten different outdoor bus stops. At the bus stops, the mean maximum SPL was 84.1 dBA, with a range of 76 to 89 dBA. Maximum bus stop noise levels were significantly increased ($p < 0.05$) when vehicular traffic on the street was heavy, when emergency vehicle sirens were sounding, and when garbage trucks were idling in the vicinity of the sampling.

Mean maximum noise levels on subway platforms were not statistically significantly different than those in the subway cars. However, the mean maximum

TABLE 3. Maximum 5-s interval noise levels for subway platforms, subway cars, and bus stops

		Maximum 5-s interval noise level				
	n	Mean (dBA)	Standard deviation (dBA)	Highest (dBA)	Percentage of maximum levels >90 dBA	Percentage of maximum levels >100 dBA
Subway platform	57	93.5	5.3	106.0	76.0	12.3
Subway car	25	94.9	7.1	112.0	68.0	20.0
Bus stop	10	84.1	4.5	89.0	0.0	0.0

levels on both the subway platforms and the subway cars (9.4 dBA difference, $p < 0.0001$, and 10.8 dBA difference, $p < 0.0001$, respectively) were both statistically significantly higher than those of the bus stops.

DISCUSSION

The findings from this study indicate that subway riders have the potential for exposure to levels that exceed the EPA/WHO community noise limits. The mean noise level (about 85 dBA) from the subway platforms measurements in this study has an allowable exposure duration of about 45 min under the EPA/WHO limits. Nearly 60% of the platform measurements exceeded this level. The maximum level measured on the platforms (106 dBA) has an EPA/WHO allowable exposure duration of less than 30 s, and 12% of platform measurements exceeded the level of 100 dBA, which has a 1.5 min allowable exposure duration. The maximum noise levels inside the subway cars were even higher than those on the platforms, with one in five exceeding 100 dBA (1.5 min allowable EPA/WHO exposure duration) and more than two-thirds exceeding 90 dBA (15 min allowable exposure duration). Bus stop maximum noise levels were significantly lower than those on subway platforms and inside subway cars. The mean maximum bus stop level was about 85 dBA, suggesting that bus stops may present additional, though lower, risk of exposure to excessive noise.

The implications of these findings are clear. NIHL generally results from chronic exposure to noise levels in excess of 85 dBA.[35,42] OSHA and NIOSH workplace noise exposure limits restrict 8-h work shift exposure to 90 and 85 dBA, respectively, in order to protect most workers from compensable hearing loss after a 40-year working lifetime.[34,35] EPA and WHO recommend lower daily exposures (75 dBA for 8 h, or 70 dBA for 24 h) to prevent any hearing loss among exposed individuals.[36,37] Loss of hearing is determined by audiometric measurements of hearing threshold levels, which represent hearing sensitivity at various frequencies. A 30 min daily exposure to 90 dBA of subway noise (equivalent to a daily 8-h exposure of 78 dBA) for 5 days per week over a 40 year period would be expected to produce a 4 dB loss of hearing at 4 kiloHertz (kHz) in the median individual and an 11 dB loss in the 90th percentile individual.[36] Exposure to 100 dBA for 30 min per day (equivalent to an 8-h exposure level of 88 dBA) would be expected to produce a 4 kHz hearing loss of 16 dB in the median individual and 24 dB in the 90th percentile individual. A loss of as little as 10 dB averaged across 2 and 4 kHz over both ears may affect speech comprehension.[37,43] Note that these estimates assume no other exposure to noise during the day, which is clearly not the case for many subway riders exposed to other sources of occupational and non-occupational noise. Individuals living in urban areas have been demonstrated to have greater hearing loss than those with similar occupational exposures to noise but living in rural areas.[44]

With respect to subway operators (who were not monitored for this study but are presumably exposed to levels similar to those measured here), these data indicate a potential for 8-h average exposure levels that exceed the OSHA and NIOSH limits. Additional monitoring is needed to quantify the risk of overexposure among this occupational group.

The noise levels measured in this study generally agree with the limited data available in the literature. A 1975 EPA study[45] noted that interior noise levels from various measurements in commuter railroad and subway cars in New York, Boston, and other major U.S. cities ranged from 69 to 91 dBA and concluded that riders exposed to subway and commuter railroad car noise for 1 h per day, five days per week, would exceed the EPA's recommended 24-h exposure limit of 70 dBA even in the absence of any occupational noise exposure. Cohen et al.[46] noted in 1970 that subway platform and car levels were in the range of 90 to 97 dBA (though data collection protocols were not described) and that some segment of subway riders is therefore likely at risk of NIHL from riding subways daily. Johanning et al.[47] cited New York City Transit Authority subway operator exposure levels of 80 to 85 dBA in 1991 and found that more than two-thirds of 600 operators surveyed by questionnaire complained of excessive noise exposure. As with Cohen, Johanning et al. did not describe how they derived their noise subway exposure estimates. Finally, Chang and Hermann[48] conducted an extensive assessment of noise in Chicago Transit Authority subways in 1974 and concluded that there was some risk of development of NIHL among subway operators and regular subway riders, though they stated that the risk was low. The methods and results of the Chang et al. study are somewhat difficult to compare to current exposure limits, given the changes in noise standards and measurement methodology in subsequent years and alterations over time in subway structures and maintenance. Also, the authors' assumptions regarding recovery from temporary hearing loss resulting from subway ridership are not completely consistent with current theories in noise exposure assessment.

While transportation-related noise exposure over time can be estimated, as can occupational exposure, all other sources and durations of noise exposure must be accounted for in order to assess the contribution of transit-related noise to total NIHL risk. The next step in evaluating exposure to subway-related noise among riders would be personal dosimetry measurements, which would provide time-integrated estimates of exposure to noise on subway platforms and aboard subway cars. This dosimetry would be followed by extensive assessments of noise exposure histories among subway riders and audiometric testing or self-reported hearing status. Statistical models are available to estimate the contributions of past noise exposure history, including occupational exposure, other sources of noise (e.g., recreational sources of noise such as gun use, loud music, power-tool use, etc.) and the relative contributions of aging and other risk factors for hearing loss. Estimates of transportation-related NIHL would involve some degree of imprecision and exposure misclassification but would nevertheless provide a useful indication of the risk of NIHL presented by transit use.

In the absence of definitive risk assessment data and given our findings, it would seem prudent to apply risk reduction strategies where feasible. A number of engineering controls may be implemented by subway system agencies to reduce noise levels in the subway environment.[49–52] These include sound dampening acoustical materials placed in particularly noisy sections of a subway line and repair and improved maintenance of tracks, braking mechanisms, and equipment in general. Newer subway systems can be and are designed and engineered to reduce noise through the use of rubberized rails, acoustical tiles, and other effective techniques.

At the individual level, another risk management approach is the use of personal hearing protection devices (HPDs), such as earplugs and earmuffs, which serve to attenuate the intensity of the sound that reaches the eardrum. Properly fitted ear plugs and ear muffs can reduce noise exposure by up to 33 dB; simultaneous use of both devices can add an additional 5 dB of attenuation.[53] Blocking the ear canal with cotton or other materials not specifically designed to protect hearing only reduces noise levels slightly. The use of personal listening devices by subway riders, which may be perceived as protective against noise exposure, is not protective and will, in fact, contribute to noise exposure and risk of NIHL if music is played at high volumes.[53] Public education is needed to increase awareness of the risk of NIHL from noise and appropriate use of HPDs. Persons concerned about hearing loss can complete a simple risk assessment questionnaire, available at: http://www.nidcd.nigh.gov/health/hearing/10ways.asp. Finally, avoidance may be an option for some riders, but for most urban dwellers and commuters, this is probably not practical.

CONCLUSION

With approximately 30 million mass transit subway riders in the U.S., the population at potential risk of exposure to subway-related noise is large, and the seriousness of the outcomes is well documented. Additional study of this potential public health problem is warranted in order to fully characterize the risk and to guide the development of effective risk management strategies.

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APPENDIX A1

Noise Levels Associated With New York City's Mass Transit Systems

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Objectives. We measured noise levels associated with various forms of mass transit and compared them to exposure guidelines designed to protect against noise-induced hearing loss.

Methods. We used noise dosimetry to measure time-integrated noise levels in a representative sample of New York City mass transit systems (subways, buses, ferries, tramway, and commuter railways) aboard transit vehicles and at vehicle boarding platforms or terminals during June and July 2007.

Results. Of the transit types evaluated, subway cars and platforms had the highest associated equivalent continuous average (L_{eq}) and maximum noise levels. All transit types had L_{eq} levels appreciably above 70 A-weighted decibels, the threshold at which noise-induced hearing loss is considered possible.

Conclusions. Mass transit noise exposure has the potential to exceed limits recommended by the World Health Organization and the US Environmental Protection Agency and thus cause noise-induced hearing loss among riders of all forms of mass transit given sufficient exposure durations. Environmental noise–control efforts in mass transit and, in cases in which controls are infeasible, the use of personal hearing protection would benefit the ridership's hearing health. (*Am J Public Health.* 2009;99:XXX–XXX. doi:10.2105/AJPH.2008.138297)

For the first time in history, more than half of the world's population lives in cities, and it is projected that more than two thirds of the population will live in cities by 2030.[1] An important factor supporting the growth and viability of urban centers is mass transportation, which is rapidly expanding to keep pace with increasing demand. For example, in 2004 there were 95 subway systems worldwide; today there are 167, a 76% increase in only 5 years.[2] Although there are well-documented environmental and public health benefits associated with mass transit, interest in the health and safety effects of mass transit on urban communities is increasing.[3–5] A particular concern is the potential for mass transit to result in excessive exposure to noise.

Noise exposure is a function of 2 main factors: (1) the frequency-weighted exposure level, measured in A-weighted decibels (dBA), and (2) the exposure duration. The causal association between chronic exposure to excessive noise and permanent, irreversible, noise-induced hearing loss (NIHL) is well known, as are the adverse social, psychological, and occupational effects associated with the condition. Nonauditory adverse health effects have also been reported,[6–8] and recent research suggests that excessive noise exposure may be linked to hypertension and ischemic heart disease, disruptions in stress hormones, and sleep disorders.[9–12]

There are no comprehensive national or international surveillance programs for hearing loss. Worldwide, more than 250 million people are estimated to suffer from hearing loss, of which at least 30 million *cases* represent NIHL.[15] In the United States alone, between 3 to 10 million people are estimated to have NIHL.[13] Hearing loss from all causes ranks among the top 10 most common serious health problems worldwide, and NIHL is the leading occupational disease in industrialized nations.[14,15] The limited data available suggest not only that NIHL prevalence and incidence rates are extraordinarily high but also that the associated costs are enormous.[16,17] Importantly, even though US occupational exposure regulations have been in place for decades, rates of NIHL-related workers' compensation cases remain high. Therefore, nonoccupational sources of exposure are coming under scrutiny, including mass transit.

The size of the population exposed to mass transit noise is of considerable magnitude. The US mass transit network, with an infrastructure encompassing subways, buses, commuter and light rail, ferry boats, trolleys, and tramways, is the largest in the world, with 9.7 billion passenger rides in 2006.[18] There are 14 subway systems in the United States, with a combined daily ridership in excess of 10 million people.[19–21] Five of the US systems are more than 75 years old, and the largest, the New York City subway system, with over 4 million riders per weekday,[22] is more than 100 years old. These older systems were designed before noise-control technologies were available. Worldwide, there are 2 subway systems with even greater ridership rates: Tokyo's is the largest at 2.6 billion passenger rides per year, and Moscow's is the second largest with 2.5 billion.[23,24]

In a recent sound-level pilot survey on subways,[3] we noted levels that potentially exceeded the community exposure limits initially recommended by the US Environmental Protection Agency (EPA) in 1974 and confirmed by the World Health Organization (WHO) in 1998. WHO and EPA recommended daily allowable exposure times are 24 hours at 70 dBA, 8 hours at 75 dBA, 2.7 hours at 80 dBA, 0.9 hours at 85 dBA, and 0.3 hours at 90 dBA. Chronic exposures that exceed these allowable combinations of duration and noise level are expected to produce NIHL in some members of the exposed population.[25,26]

The amount of NIHL anticipated to result from specific noise-exposure levels can be predicted with a model published by the International Organization for Standardization.[27] This model allows users to estimate the amount of NIHL expected to result from chronic 8-hour equivalent continuous average (L_{eq}) noise exposures between 75 and 100 dBA or 24-hour L_{eq} exposures between 70 and 95 dBA. The model permits the estimation of median values of expected NIHL as well as values for the 0.05 to 0.95 fractiles among an exposed population for given exposure levels and durations. Based on the WHO and EPA recommendations, chronic exposure to 80.3 dBA for more than 160 minutes per day may be expected to produce hearing loss in some exposed individuals, and a 90.2-dBA level likewise may cause hearing loss with just 18 minutes of exposure per day.

Few data involving dosimetry measurements of noise exposures associated with mass transit have been reported previously. In a study of the daily noise exposures experienced by 32 people in Madrid, Spain, Diaz et al.[28] measured noise levels associated with a variety of self-reported transportation exposures with noise dosimeters. Zheng et al.[29] conducted 24-hour noise dosimetry on 221 residents of Beijing, China, and assessed the noise levels associated with self-reported activities, including commuting. Nearly all other studies that have evaluated noise levels associated with subway equipment are decades old and based on sound level measurements rather than dosimetry. In 1931, Stanton conducted an unpublished noise-level survey of the New York City subways,[30] and in 1971, Harris and Aitken[31] reported levels measured on specific New York City train line platforms and cars. A small sound level survey on a subway system in India was also recently reported.[33]

Our current study expanded on our pilot study of subway noise and assessed average noise levels on a variety of types of mass transit to further evaluate noise exposure among transit riders.

METHODS

Noise levels were measured in the New York City area during June and July 2007 on various types of mass transit, including subways, buses, ferries, commuter railways, and the tramway. We measured equivalent continuous average (L_{eq}) and maximum (L_{max}) noise levels with type II noise dosimeters (Q-300; Quest Technologies, Oconomowoc, WI). L_{eq} levels represent the average exposure level over a measured period of time, and L_{max} levels represent the highest level reached during a measurement. Although point-in-time area measurements made with sound level meters—such as those collected in our pilot study[3]—can provide useful screening information for noise exposure potential, time-integrated L_{eq} measurements made via personal dosimetry are preferable for assessment of long-term average noise exposure levels, especially where noise levels vary widely over time and space, as is the case for transit noise exposures. L_{max} levels provide useful information about the maximum possible noise level in a given exposure scenario.

The dosimeters were configured according to the exposure standard recommended by the US National Institute for Occupational Safety and Health.[32] Research staff carried the dosimeters in backpacks during measurements, and microphones were located within 4 inches of the researcher's ear[27] to provide the most representative estimate of personal exposure.

Data Collection

We made measurements aboard transit vehicles and at vehicle boarding platforms or terminals from 7:00 AM to 7:00 PM. Platform measurements had a target length of 2 minutes and captured noise levels of vehicles passing by a station (e.g., express trains at local stops) or arriving and departing from a station. Measurements aboard vehicles had a target length of 10 minutes while vehicles were in motion. To ensure measurement consistency and to mimic typical commuter noise exposures, the researchers sat approximately in the middle of the transit vehicle and stood at the center of the platform or terminal.

To account for variations in acoustics, passenger loads, and ambient noise levels, we made multiple in-vehicle and platform measurements for each mode of transit. We collected subway data on each of the 26 Metropolitan Transit Authority (MTA) subway lines and all 4 Port Authority Trans-Hudson subway lines. We made 6 measurements for each subway line: 2 in subway cars (1 on an aboveground and 1 on an underground track section) and 4 on station platforms (2 aboveground and 2 underground). We made platform measurements at a mixture of local stops and major high-traffic hubs.

We took measurements of commuter railway noise levels on the Metro-North Railroad (2 lines), Long Island Railroad (3 lines), and the Staten Island Railroad (1 line). We made 6 measurements for each commuter railway line: 2 in train cars (1 on an aboveground and 1 on an underground track section), and 4 on station platforms (2 aboveground and 2 underground). We made bus measurements aboard public New York (MTA) buses (13 lines) and while waiting at street-level bus stops at a variety of locations, including in residential neighborhoods, in commercial areas, and near airports. We also made measurements aboard the Staten Island ferry and at the ferry terminal, as well as aboard the Roosevelt Island Tramway to Manhattan and at the tramway terminal.

During measurements, researchers recorded on a paper time-location log the type of transit vehicle or boarding area being measured, their location on the transit route, the surrounding environment (aboveground or underground), the time and duration of the measurement, and any unusual circumstances during the measurement (e.g., musicians on platform or inside cars). At the conclusion of each measurement day, we entered time-location log data into an Excel file (Microsoft Corp, Redmond, WA). Dosimetry data was then downloaded using QuestSuite software (Quest Technologies, Oconomowoc, WI), exported into Intercooled Stata version 9.0 (Stata Corporation, College Station, TX) and combined with the time-location log data for analysis.

Analyses

We conducted analyses by individual transit system (e.g., MTA subway, Port Authority Trans-Hudson subway) as well as by transit type (e.g., subway, commuter rail).

We computed descriptive statistics for each system and type of transit by station and line and by measurement location (i.e., vehicle or station) and surrounding conditions (i.e., aboveground or underground). We also computed the percentage of measurements exceeding various exposure thresholds by transit system and type and by measurement location. We used 1-way repeated-measures analysis of variance (ANOVA) to compare statistical differences in L_{eq} levels by transit system and type between measurement locations, surrounding conditions, and borough or region within transit system and type as well as between individual stations and lines within transit

TABLE 1—Average (L_{eq}) Noise Levels in dBA, by Transit Type and Measurement Location: New York City, June and July 2007

	Combined[a] L_{eq} Levels		L_{eq} Levels Inside Vehicle		L_{eq} Levels at Platforms or Terminals		
Transit Type or System	No.[b]	Mean dBA (SD)	No.[b]	Mean dBA (SD)	No.[b]	Mean dBA (SD)	P[c]
Subway							
MTA	156	80.4 (4.3)	60	79.3 (3.1)	96	81.1 (4.7)	.01
PATH	12	79.4 (3.3)	4	79.2 (4.2)	8	79.5 (3.1)	.89
Commuter rail							
LIRR	18	74.9 (5.8)	6	71.4 (3.8)	12	76.6 (6.0)	.07
SIRR	3	76.7 (0.6)	2	76.5 (0.5)	1	77.2[d]	.43
Metro-North	11	75.1 (5.1)	4	71.9 (1.6)	7	77.0 (5.5)	.10
Bus	30	75.7 (3.7)	14	75.3 (2.6)	16	76.0 (4.4)	.62
Ferry	4	75.3 (3.1)	2	77.7 (2.1)	2	72.9 (1.1)	.09
Tram	4	77.0 (3.1)	2	77.5 (2.3)	2	76.6 (4.7)	.83

Note. L_{eq} = Equivalent continuous noise level; dBA = A-weighted decibel; MTA = Metropolitan Transportation Authority; PATH = Port Authority Trans-Hudson; LIRR = Long Island Rail Road; SIRR = Staten Island Rail Road; Metro-North = Metro-North Railroad.
[a]All L_{eq} levels across all measurement locations.
[b]The number of noise measurements taken.
[c]Calculated with 1-way analysis of variance by measurement location.
[d]Single measurement.

systems. We considered statistical test results significant at the .05 level.

RESULTS

There were 243 valid dosimetry measurements. Table 1 provides the type and number of noise measurements collected and the L_{eq} noise levels associated with each transit type and system and by measurement location. Combined mean L_{eq} levels for the transit systems ranged from 75.1 dBA (Metro-North) to 80.4 dBA (MTA subway). The highest mean L_{eq} noise level inside a vehicle (79.3 dBA) was associated with MTA subway cars. MTA subway platforms also had the highest mean platform noise levels (81.1 dBA). The highest individual in-vehicle L_{eq} measurement (data not shown) was associated with an underground MTA subway car (87.9 dBA), and the highest individual platform L_{eq} measurement (90.2 dBA) was associated with an underground MTA subway station.

In general, noise levels were 1 to 5 dBA higher at platforms and terminals than in vehicles for all types of transit except ferries and the tram. Vehicle and platform levels were significantly different only for the MTA subways. Subway L_{eq} levels differed significantly (data not shown; 1-way ANOVA, $P<.001$) between local stations (mean=79.0 dBA) and major hubs (mean=82.2 dBA) and across all subway stations ($P<.001$) and lines ($P=.02$). Overall, L_{eq} noise levels differed significantly across all transit types (1-way ANOVA, $P<.001$) but were not significantly different among the 3 commuter rail systems or the 2 subway systems.

We determined the percentage of L_{eq} measurements exceeding 2 threshold levels (the 24-hour 70-dBA WHO and EPA suggested exposure limit and the National Institute for Occupational Safety and Health 8-hour 85-dBA Recommended Exposure Limit) to evaluate the fraction of measurements with the potential to produce overexposure situations given sufficient exposure durations. Nearly all bus measurements, 3 out of 4 commuter rail measurements, and 100% of subway, ferry, and tram L_{eq} measurements exceeded the 70 dBA threshold. Almost 20% of the subway measures exceeded the 85 dBA threshold. Two subway lines (7%) had mean vehicle L_{eq} levels greater than 85 dBA, and 7 subway lines (23%) had mean L_{eq} platform levels greater than 85 dBA.

Table 2 shows the L_{max} levels associated with each transit type and system and by measurement location. In Table 1, underground and aboveground measurements are combined. MTA subways had the highest maximum noise levels on average (90.4 dBA). The highest L_{max} level among all platform measurements was at an MTA subway station (102.1 dBA), followed closely by a bus stop measurement (101.6 dBA). The 2 highest L_{max} levels among all vehicle measurements were on an MTA subway car (97.8 dBA) and a bus (96.8 dBA). L_{max} noise levels were on average about 2 dBA higher at platforms and terminals than in vehicles for 2 transit types (commuter rail and buses) and 1 to 5 dBA lower for the other transit types. Roughly half the 30 measured subway lines had average vehicle and platform L_{max} levels that exceeded 90 dBA. Vehicle and platform levels were significantly different only for the ferry.

Table 3 shows L_{eq} noise levels for subway and commuter rail measurements stratified by location (i.e., inside vehicle vs platform) and surroundings (i.e., aboveground vs underground). Mean vehicle and platform L_{eq} levels were equal for aboveground subway measurements. Mean aboveground vehicle L_{eq} levels were 1 to 5 dBA than were aboveground platform levels. Mean vehicle L_{eq} levels for underground measurements were always lower than those for underground platforms—in the case of commuter rail, vehicle levels were as much as 11 dBA lower. Aboveground vehicle

TABLE 2—Maximum (L_{max}) Noise Levels in dBA, by Transit Type and Measurement Location: New York City, June and July 2007

	Combined[a] L_{max} Levels			L_{max} Levels Inside Vehicle			L_{max} Levels on Platforms or Terminals			
Transit Type or System	No.[b]	Mean dBA (SD)	Highest dBA Level	No.[b]	Mean dBA (SD)	Highest dBA Level	No.[b]	Mean dBA (SD)	Highest dBA Level	P[c]
Subway										
MTA	156	90.4 (4.6)	102.1	60	90.5 (3.6)	97.8	96	90.3 (5.2)	102.1	.75
PATH	12	88.1 (3.8)	94.9	4	88.3 (4.5)	94.9	8	88.0 (3.7)	92.6	.91
Commuter rail										
LIRR	18	84.9 (6.0)	97.3	6	83.8 (5.2)	92.4	12	85.5 (6.5)	97.3	.59
SIRR	3	90.4 (3.2)	93.0	2	92.2 (1.2)	93.0	1	86.8[d]	86.8	.17
Metro-North	11	86.5 (6.1)	99.5	4	82.2 (1.1)	83.4	7	89.0 (6.5)	99.5	.07
Bus	30	86.8 (6.1)	101.6	14	85.6 (4.7)	96.8	16	87.8 (7.1)	101.6	.34
Ferry	4	89.9 (3.0)	92.5	2	92.5 (0.0)	92.5	2	87.4 (0.1)	87.4	<.001
Tram	4	88.7 (6.5)	93.9	2	90.9 (1.1)	91.7	2	86.6 (10.4)	93.9	.62

Note. L_{max} = maximum noise level; dBA = A-weighted decibel; MTA = Metropolitan Transportation Authority; PATH = Port Authority Trans-Hudson; LIRR = Long Island Rail Road; SIRR = Staten Island Rail Road; Metro-North = Metro-North Railroad.
[a]All L_{eq} levels measured inside vehicles and at platforms or terminals.
[b]The number of noise measurements taken.
[c]Calculated with 1-way analysis of variance by measurement location.
[d]Single measurement.

and platform levels were not significantly different for any transit system; however, underground vehicle and platform levels differed significantly for the MTA subways, Long Island Railroad, and Metro-North systems.

Table 4 shows mean L_{eq} noise levels for all transit systems and types by borough or region and environment. The effect of borough or region on L_{eq} noise levels was significant for MTA subways, the Long Island Railroad, buses, and Metro-North. For each of these transit types and systems, the highest measurements were associated with the borough of Manhattan, which had a mean L_{eq} level 3 to 9 dBA higher than other boroughs. Surrounding environment (aboveground or underground) had a statistically significant effect for only 1 transit system: MTA subways.

DISCUSSION

The results of this mass transit noise survey confirm our pilot study finding that transit noise levels can present a risk of NIHL given sufficient exposure duration. We found that subways have the highest mean L_{eq} noise levels (80.3 dBA) and the highest individual measured L_{eq} (90.2 dBA on a subway platform) among the types of transit assessed. On average, subways also had the highest individual L_{max} level (90.2 dBA) and the highest measured L_{max} (102.1 dBA on a subway platform) among the transit modes assessed. In comparison, 30 dBA is the noise level of a whisper, 60 to 70 dBA is normal conversation, 100 dBA is a chainsaw, and 140 dBA is gunfire. It is important to note that decibels are logarithms and that the risk of NIHL from noise rises quickly with small increases in exposure level. For example, a 95-dBA exposure is 10 times more intense than an 85-dBA exposure and 100 times more intense than a 75-dBA exposure.

Nearly 1 in 5 subway L_{eq} measures exceeded 85 dBA, and roughly half of subway L_{max} measurements exceeded 90 dBA. L_{eq} levels associated with the other transit types evaluated—commuter rail, buses, ferries, and a tramway—were 3 to 5 dBA lower than subway noise levels but still potentially presented a risk of NIHL. The transit noise levels reported by Diaz et al.[28] (average L_{eq} noise levels from the study were 75.6 dBA for buses, 78.8 dBA for subways, and 76.0 dBA for commuter trains) are remarkably consistent with those we measured. Diaz et al. found that transportation noise accounted for about 13% of participants' total noise exposure, and for participants older than 60 years, transportation noise was the primary source of noise exposure.

Zheng et al.[29] found that the average amount of time spent commuting was 40 minutes and the mean L_{eq} noise level was 76.1 ±7.8 dBA—consistent with the measures for several of the transit types examined here. Commuting noise contributed approximately 8% of the total noise exposure among this group of participants. Zheng et al. did not report the types of transit assessed in the study, but presumably, in a large urban setting such as Beijing, a variety of transit types, including some of those assessed here, were utilized.

A relatively recent (1996) study of stations and cars in the underground subway system in Calcutta, India, by Bhattacharya et al.[33] found point-in-time sound pressure levels of 84 to 87 dBA in the 3 stations assessed, with the highest level measured in the only aboveground station. These levels were 7 to 10 dBA higher than the time-integrated L_{eq} levels we measured. The maximum sound pressure level in a station was 95 dBA, similar to the L_{max} levels in our current study. L_{eq} noise levels of 92 to 99 dBA (much higher than the levels we measured) were found aboard the subway cars during operation, with vehicle levels dropping to 72 to 75 dBA during stops. The generally higher levels measured in the Calcutta subway system may be at least partly explained by differences in system

TABLE 3—Average (L_{eq}) Noise Levels in dBA for Subway and Commuter Rail Systems, by Measurement Location and Surroundings: New York City, June and July 2007

	L_{eq} Level Inside Vehicle		L_{eq} Level at Platforms or Terminals		
Transit Type or System	No.[a]	Mean dBA (SD)	No.[a]	Mean dBA (SD)	P^b
Aboveground					
Subway					
MTA	24	77.9 (3.1)	42	77.9 (3.3)	0.98
PATH	...	...	...	...	...
Commuter rail					
LIRR	3	69.6 (3.9)	9	74.8 (5.8)	0.18
SIRR	2	76.5 (0.5)	1	77.2[c]	0.43
Metro-North	2	71.2 (1.3)	5	74.3 (3.5)	0.29
Underground					
Subway					
MTA	36	80.2 (2.8)	54	83.5 (4.3)	<.001
PATH	4	79.2 (4.2)	8	79.5 (3.1)	.88
Commuter rail					
LIRR	3	73.1 (3.4)	3	82.0 (2.3)	.02
SIRR	...	...	...	...	...
Metro-North	2	72.5 (2.0)	2	83.9 (0.4)	.02

Note. L_{eq} = Equivalent continuous noise level; dBA = A-weighted decibel; MTA = Metropolitan Transportation Authority; PATH = Port Authority Trans-Hudson; LIRR = Long Island Rail Road; SIRR = Staten Island Rail Road; Metro-North = Metro-North Railroad.
[a]The number of noise measurements taken.
[b]Calculated with 1-way analysis of variance by measurement location.
[c]Single measurement.

construction, public-address system configuration, and subway car design.

When compared with our current results, the 1931[30] and 1971[31] New York City subway studies suggest that subway noise levels have declined over time, although such a comparison must consider possible differences in measurement equipment and protocols. Sound pressure levels in the 1931 study by Stanton[30] ranged from 87 to 97 dBA, with measurements taken on subway platforms and on the tracks themselves. The 1971 study by Harris and Aitken[31] found sound pressure levels that ranged from 87 to 110 dBA, with the highest levels on Queens and Broadway lines, both at the platform level and inside cars. Harris and Aitken found that certain subway cars, especially those manufactured before 1970, had higher levels than newer cars.[31]

A number of studies have assessed noise exposures associated with commuting in automobiles, the primary alternative to mass transit in an urban setting. In a study of nonoccupational noise exposures among 112 construction workers, Neitzel et al.[34] found that commuting by car or bus had mean L_{eq} levels of 76 to 78 dBA. In another study of nonoccupational noise, Schori and McGatha[35] found that many of the highest L_{eq} sound levels measured on 50 participants were associated with riding in cars. Automobile noise levels in that study ranged from 76.9 to 78.3 dBA.

In an early report,[36] the EPA estimated that passenger cars have mean interior noise levels of 67 dBA at 30 miles per hour and 77 dBA at 60 miles per hour. More recently, Diaz et al. found a mean L_{eq} noise level for passenger cars of 79.7 dBA.[28] Although limited, these data suggest that noise levels associated with automobile commuting are comparable to the L_{eq} levels we measured for buses, ferries, trams, and commuter rails and are lower than those measured for subways.

Comparison of Current Results To Pilot Study

To assess the validity of the L_{eq} noise levels estimated in our pilot study,[3] we compared them to the levels we measured for the current study. The mean L_{eq} measured on underground subway platforms in the current study (83.5±4.3 dBA) was significantly different (Student t test, P=.006) from the mean in the pilot study (85.7±3.9 dBA), though the absolute difference was only about 2 dBA. The mean L_{max} measured on underground subway cars in the current study (91.0±3.2 dBA) was also significantly different (P=.01) from the mean in the pilot study (94.9±7.1 dBA). Measured L_{max} levels at aboveground bus stops did not differ significantly between the current study (87.8±7.1) and the pilot study (84.1±4.5 dBA).

Differences in the subway car and platform levels measured in the 2 studies are likely caused by measurement protocol and equipment differences. In our pilot study, measurements were made with a sound level meter held approximately 3 feet off the ground and in front of the researcher's body, whereas researchers in our current study used noise dosimeters with microphones mounted next to their ears. Having the microphone of the sound level meter in front of the researcher's body and relatively close to the ground may have produced acoustic reflections that increased the noise levels measured by the sound level meter, whereas the dosimetry protocol in the current study collected levels that were more representative of the true exposure at the researcher's ear. We made measurements in the pilot study during nonpeak commuting hours (10:00 AM to 4:00 PM), whereas measurements in the current study included rush hour (7:00 AM to 7:00 PM). The more-densely packed rush hour cars may have lower ambient noise levels because of sound absorption by clothing and human bodies.

Our pilot study focused on high-noise events (i.e., measurements were made only when subway cars were entering or leaving a station, and only maximum levels were recorded in subway cars), whereas measurements in our current study focused instead on obtaining average exposure levels and included times of relative quiet. The sound level meters used in the pilot study could not make time-integrated L_{eq} measurements; instead, the researcher read and recorded the noise level on the sound level meter display at 5-second intervals. We then arithmetically averaged these interval readings to determine an average

TABLE 4—Mean (L_{eq}) Noise Levels in dBA, by Transit Type, Borough, and Surroundings: New York City, June and July 2007

	Borough						Surroundings		
Transit Type or System	Bronx, Mean dBA	Brooklyn, Mean dBA	Manhattan, Mean dBA	Queens, Mean dBA	Staten Island, Mean dBA	P^a	Aboveground, Mean dBA	Underground, Mean dBA	P^a
Subway									
MTA	79.0	77.8	82.5	79.3	...	<.001	77.9	82.2	<.001
PATH	...	...	79.4	...	...	...	...	79.4	...
Commuter rail									
LIRR	...	...	82.0	73.4	...	.01	73.5	77.6	.17
SIRR	...	...	...	...	76.7	...	76.7	...	...
Metro-North	71.0	...	77.5	...	...	.03	73.4	78.2	.14
Bus	...	...	77.1	72.9	...	<.001	75.7	...	...
Ferry	...	...	...	...	75.3	...	75.3	...	...
Tram	...	...	77.0	...	...	...	77.0	...	...

Note. L_{eq} = Equivalent continuous noise level; dBA = A-weighted decibel; MTA = Metropolitan Transportation Authority; PATH = Port Authority Trans-Hudson; LIRR = Long Island Rail Road; SIRR = Staten Island Rail Road; Metro-North = Metro-North Railroad.
[a]Calculated with 1-way analysis of variance by measurement location.

level for each measurement, which may have introduced error into the results. The dosimeters in the current study made time-integrated L_{eq} measurements, and no additional averaging or manipulation was required. Overall, the time-integrated personal noise levels measured in the current study must be considered a more robust representation of commuter exposures than the area noise levels measured in our pilot study, because the current study involved a much larger number of measurements made at a more representative measurement location (i.e., the ear).

Conclusions

Our results confirm that, given sufficiently long exposure durations, noise levels associated with mass transit are high enough to produce NIHL in riders. We noted significant differences between the mean levels of various transit types evaluated and between subway lines, stations, and station types. One borough (Manhattan) consistently had the highest associated L_{eq} levels. Subways (including cars and platforms) had the highest associated mean L_{eq} and L_{max} noise levels (80.4 and 90.4 dBA, respectively) of all transit types evaluated. At the noise levels measured in the subway, exposures of a few hours to as little as 2 minutes a day (in the case of the highest L_{max} level measured, 102.1 dBA) would be expected to cause hearing loss for some people given chronic exposure. Other types of transit had mean L_{eq} noise levels 3 to 5 dBA lower than the subway system but still above the NIHL risk threshold of 70 dBA averaged over a 24-hour period.[37]

L_{eq} noise levels were higher at platforms than on vehicles for subways, commuter rail, and buses, whereas ferries and the tram had higher L_{eq} noise levels on vehicles than at stations. L_{eq} levels in underground subway and commuter rail cars and stations were higher—in some cases by 10 dBA or more—than those in aboveground cars and stations. L_{max} noise levels were higher aboard vehicles than at stations for the subway, ferry, and tram systems. The effect of surroundings (i.e., aboveground vs underground), borough or region, and measurement location (i.e., platform vs in vehicle) are important considerations for subway and commuter rail transit noise-exposure assessments.

Additional data are needed on average commute duration by transit type for transit riders. By combining exposure durations with the noise levels measured in our current study, estimates of annual rider noise exposures can be developed. These estimates can then be incorporated into the available International Organization for Standardization model for the prediction of hearing impairment from noise.[27] This model will allow us to infer the percentage of transit riders with probable NIHL resulting from transit noise. These inferences can then be used to assess the need for transit noise-control efforts or the use of hearing protection, which have the potential to reduce both the risk of NIHL and other adverse effects of excessive noise.

In accordance with the "hierarchy of controls" for public health hazards,[38] engineering noise-control efforts, including increased transit infrastructure maintenance and the use of quieter equipment, should be given priority over use of hearing protection, which requires rider motivation and knowledge of how and when to wear it. Given the various nonauditory health effects associated with noise exposure and the large percentage of US residents—both riders and nonriders—exposed to transit noise, noise-abatement efforts have the potential to benefit the public's health. ■

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Contributors

R.L. Neitzel conceptualized the study, conducted the quantitative analysis, and led the writing. R.R.M. Gershon conceptualized and directly supervised all aspects of the study and helped write the article. M. Zeltser coordinated data collection and data entry efforts and contributed significantly to all aspects of the study. A. Canton collected data, assisted in article preparation, and contributed significantly to all aspects of the study. M. Akram helped design the data collection strategy and supervised data collection efforts.

Human Participant Protection

Approval for this research was obtained from the Columbia University institutional review board before collection of noise-level data. All data were collected by researchers, and no human participants were enrolled in the study.

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§ 1204–a. Rapid transit noise code

[As added by L.1982, c. 736, § 3. Another section of this number was added by another act.]

1. As used in this section, unless another meaning is indicated by the context:

a. "Authority" means the New York City Transit Authority.

b. "Subways" means all rail rapid transit systems operated by the authority including but not limited to rolling stock, track and track beds, passenger stations, tunnels, elevated structures, yards, depots, and shops.

c. "New cars" means all those cars the purchase and/or construction of which is contracted for subsequent to the enactment of this section.

d. "Screech" means any noise generated by wheel-track interactions on curves or by brake application and which is a prominent discreet [1] tone above 1000 Hertz as defined by the American National Standards Institute specifications (ANSIS1.13—1971).

e. "Sound pressure level" means twenty times the logarithm to the base ten of the ratio of the root mean squared pressure of a sound to a reference pressure of twenty micropascals. The unit applied to this measure shall be the decibel (dB).

f. "A-weighted sound level or (dBA)" means the sound pressure level measured by the use of an instrument with the metering characteristics and A-weighting frequency response prescribed for sound level meters. The sound level measurement system must meet or exceed the requirements of the American National Standard Institute Specification for Sound Level Meters ANSI S1.4—1971, approved April twenty-seventh, nineteen hundred seventy-one, throughout the applicable frequency range for either:

(a) A Type 1 sound level meter; or

(b) A Type 2 sound level meter; or

(c) A Type S sound level meter which has:

(1) an A-weighting frequency response; and

(2) a fast dynamic characteristic which complies with section 5.3 of ANSI S1.4—1971; and

(3) a relative response level tolerance consistent with that of either a Type 1 or Type 2 sound level meter, as specified in section 3.2 of ANSI S1.4—1971.

g. "Equivalent sound level" means the energy-average of the integrated A-weighted sound level over a specified observation time T and is identified by the symbol Leg.

2. The authority shall undertake a rail rapid transit noise abatement study, incorporating a comprehensive review of the results of noise abatement studies and projects done for or by the Urban Mass Transportation Administration of the United States Department of Transportation and other mass transit systems. Such study shall

evaluate the range of strategies available for meeting the sound levels set forth in the following sound level table, propose strategies and indicate the approximate time and necessary cost for meeting such sound levels, and indicate the expected dBA reduction of each proposed strategy. Such study shall be submitted to the governor and the legislature, and made available to the public, within one year of enactment of this section.

SOUND LEVEL TABLE

a.

	EQUIVALENT SOUND LEVEL		PERCENT COMPLIANCE		
			within 4 years of the effective date of this section	within 8 years of the effective date of this section	within 12 years of the effective date of this section
I.	CAR INTERIOR				
	A. new cars	80dBA	100%	100%	100%
	B. old cars	85dBA	20%	40%	70%
II.	CURVE AND BRAKE SCREECH				
	A. new cars	No Screech	100%	100%	100%
	B. old cars	No Screech	20%	60%	100%
III.	STATION TRAINS ENTERING, LEAVING OR PASSING THROUGH				
		105dBA	85%	90%	100%
		90dBA	70%	80%	95%
		85dBA	50%	60%	80%
		80dBA	5%	15%	60%
IV.	ELEVATED STRUCTURES				
		Sound level to be established	10%	30%	60%

b. In all cases noise levels shall be measured so as to reflect accurately the worst case of noise exposure at a specific location where a noise abatement strategy has been implemented, to which a subway passenger, employee, or any person who is within range of subway noise could reasonably be exposed under normal operating conditions. Noise measurements shall be made under the following conditions:

Car interior: when the car is in motion at a speed of forty miles per hour during normal operation with measurements in the center of the car and the microphone five feet above the floor.

Station: (express) when the train is in motion and passing in front of the on-platform measuring point.

(local) when the train is in motion and any part of it is within the station.

Car exterior (elevated tracks) when the train is in motion and is passing in front of the point from which noise measurements are being made.

c. All measurements shall be taken with fast dynamic characteristic of the sound level measurement system. Energy equivalent measurements shall normally be used; provided, however, alternative measures may be proposed to incorporate new instrumentation or analyses that may become available.

3. Within six months of the completion of the study conducted pursuant to subdivision two of this section, the authority shall report to the governor and the legislature which strategies or portions of strategies proposed by such study it has chosen to implement, and the schedule for such implementation.

To the extent, if any, that the authority's plan fails to meet the standards specified in the sound table, the authority shall so state and provide the reasons for its inability to meet such standards.

4. Within twelve months of the completion of the study conducted pursuant to subdivision two of this section, and at twelve month intervals thereafter, the authority shall submit to the governor and the legislature comprehensive reports detailing the authority's progress to date in abating subway noise. The report shall include, but not be limited to an itemized summary of all monies spent, bids requested and received, contracts let, and actual work done on noise abatement programs during the previous period. Any and all subway noise measurements made during the previous period shall be included, with, whenever possible, analyses of such measurements.

Such report shall also include a detailed analysis of all noise abatement activities planned for the next twelve months. Following the first twelve month interval these reports shall also include comprehensive statements of progress made on all planned noise abatement activities included in the previous annual report.

Nothing herein shall preclude such report from being incorporated in the authority's annual capital report submitted pursuant to the "capital financing and services system act of nineteen hundred eighty-one," so long as it is maintained as a separate, distinct and identifiable component in such report.

(Added L.1982, c. 736, § 3.)

1 So in original. Probably should read "discrete".

Historical and Statutory Notes

L.1982, c. 736 legislation

L.1982, c. 736, §§ 1, 2, eff. July 27, 1982, provide:

"§ 1. Legislative findings. The legislature hereby finds that excessive noise may present a substantial threat to the health, safety, and welfare of the people of this state.

"One major source of excessive noise in New York city is the rail rapid transit system. Subway noise daily affects millions of riders, thousands of transit workers, and hundreds of thousands of people who live or work in the vicinity of elevated subway lines. Excessive noise may subject people to possible hearing impairments, physiological damage, psychological stresses, adverse cardiovascular system responses, and everyday emotional strain and physical discomfort.

"The legislature further finds that excessive noise has been a contributing factor in the loss of subway ridership decline and thus has contributed to the Metropolitan Transportation Authority's operating deficit.

"The legislature further finds that there are reasonable, economic and technologically feasible strategies which can be implemented to abate subway noise, such as wheel-trueing, track grinding, rail butt welding, acoustical retrofitting of subway facilities, and the installation of resilient track pads. If implemented, these strategies would promote the health and safety of New Yorkers, encourage subway ridership, thereby helping to reduce the operating deficit, and improve the overall condition of the system.

"Therefore, the legislature hereby enacts a rapid transit noise code as a prudent and necessary action to promote the health and welfare of a substantial number of the state's residents and directs that a rail rapid transit noise abatement study be undertaken for the purpose of planning capital improvements in conformance with the Rapid Transit Noise Code.

"§ 2. Short title. This act shall be known and may be cited as the 'Rapid Transit Noise Code Act'."

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C.J.S. Health and Environment § 168.

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Research References

Encyclopedias

NY Jur. 2d, Rail Transportation § 36, New York City Transit Authority.

APPENDIX C -- SAMPLE MITIGATION MEASURES

			Potential Effectiveness		
Control Type	**Mitigation Measure (with estimated dB reductions)**	**Source***	*FTA*	*NYCEPA ("EPA")*	
Equipment	Resiliant or Damped Wheels--for wheel squeal on curved track	FTA	10-20 dB	"eliminates curve squeal" (see Table IV-1)	
	Resiliant or Damped Wheels--for rolling noise on tangent track	FTA/EPA	2 dB	2-3 dBA less "run noise," (p. 54)	
	Vehicle Skirts	FTA	6-10 dB		
	Undercar Absorption	FTA	5 dB		
	Modified Rail Fasteners	EPA		3-5dBA (p. 39)	
	Spin-slide control (prevents flats)	FTA	5 dB		
	Wheel Truing (eliminates wheel flats)	FTA/EPA/JUH	5 dB	10 dBA wayside; 7 dbA in car (Table IV-1) (1)	
	Rail Grinding (eliminates corrugations)	FTA/JUH/EPA	5 dB	4-5 dBA (inside car) & 5-10 dBA (wayside) (2)	
	Rail Lubrication on Sharp Curves	FTA/EPA	"reduces squeal"	7dBA (in car; see Table IV-1)	
	Seamless (not jointed) welded rails	JUH/EPA		4dBA in station & 5-10dBA inside car (see Table IV-1)	
	Improved Maintenance of Braking Mechanisms	JUH			
	Replace track type	EPA		3dBA in car (see Table IV-1)	
Pathway:	Sound Barriers close to Vehicles	FTA/EPA	6-15 dB	10-12 dBA at "EL" train (p.46)	
	Sound Barriers at ROW Line	FTA	3-10 dB		
	Ballast on At-Grade Guideway or on Aerial Guideway	FTA	3/5 dB		

APPENDIX C -- SAMPLE MITIGATION MEASURES

	Absorption/acoustical materials & systems--in station	EPA/JUH		in station: ceiling (6-7dBA), welded rail (4dBA), barrier (11-12 dBA), under platform (3 dBA), from Tbl IV-1	
	Absorption/acoustical materials & systems--in tunnel	EPA/JUH		5-9dBA (p.44 & Tbl IV-1)	
Receiver:	Acquisition of Property Rights for Construction of Snd Barriers	FTA	5-10 dB		
	Building Noise Insulation	FTA	5-20 dB		
(1) "most cost effective for NYCTA" (p. 52)					
(2) inside cars: 4-5dBA for above/below ground (& 9-12dBA in "parts" of frequency); wayside: 6-9dBA above & 5-10dBA below ground;					
"greatest effect of any single noise abatement method at BART" (see page 32)					
	Other Mitigation Measures (without dBA savings):	***Source***	***Note***		
	Stringent Vehicle & Equipment Specifications	FTA	"Varied"		
	Operational Restrictions	FTA	"Varied"		
	Turn Radii greater than 1000 ft	FTA	"avoids squeal"		
	Movable-Point Frogs (reduce rail gaps at crossovers)	FTA	"reduces impact noise"		
	Braking mechanisms including anti-lock	JUH	see also EPA p. 55		
	Acoustic insulation in cars	EPA	see p. 56-62		
	Lighter weights & spring mounted motor	EPA	see p. 56		
	Acoustical Tiles	JUH	see JUH reports		
	Resiliant Track Support on Aerial Guideway	FTA	"Varied"		
	Alteration of Horiz. & Vert. Alignments	FTA	"Varied"		
	Acquisition of Buffer Zones	FTA	"Varied"		
*** Sources:**					
FTA: "Transit Noise and Vibration Impact Assessment," U.S. Federal Transit Administration, May 2006					
JUH:"Pilot Survey of Subway and Bus Stop Noise Levels," J. of Urban Health: Bulletin of the NY Academy of Medicine, p. 8 (Gershon et alia, 2006)					
& "Health and Safety Hazards Associated with Subways: A Review," ibid, page 16 (Gershon et alia)					
EPA = "Subway Noise in NYC," NYC Environmental Protection Administration, October 1973					

Bureau of Noise Abatement -- Department of Air Resources
Environmental Protection Administration - City of New York

RAPID TRANSIT RAILROAD NOISE

Summary of Report Submitted to the City Council
Pursuant to Section 5.07 of the New York City Noise Control Code

October, 1973

Introduction

When the New York City noise control code was enacted in October, 1972, it mandated that the Environmental Protection Administrator define and submit to the City Council allowable sound levels and acoustical performance standards for the design and operation of new and existing rapid transit railroads, within one year.

In the course of our studies, we have determined that the noise levels in the system are so great, so far from what we would consider acceptable acoustical performance standards, that we find it to be unproductive to establish these standards just for their own sake. Instead, we have examined all feasible technologies for noise reduction, and have developed a comprehensive program to deal with the problems of subway noise.

The key elements in the program are presented in the remainder of this summary.

SUMMARY OF RECOMMENDED PROGRAM

The recommendations listed below are shown, with cost information, in Table (IV - 1) at the end of the summary.

<u>For the existing system</u>

1. The noise abatement program that we are recommending for the New York City Transit Authority (NYCTA) begins with the alleviation of the major noise source; the interaction of the wheels with the rails. The rail grinding and wheel truing program should be intensified to ensure "round" wheels and smooth track. Wheel truing should be done on a 6 month schedule (requiring additional wheel truing machines) and the normal rail grinding should be supplemented by one or two Chicago-type full speed rail grinders.

2. Our second recommendation is to install air conditioning on all of the newer cars (bought after 1960) in the system. This has the effect of reducing the noise levels inside cars since they may be operated with all windows and doors closed.

3. Curve squeal is one of the most annoying sounds in the subway system. The installation of track greasers on curves provides some relief, and expansion of their use is warranted, as current plans of the TA indicate.

4. We recommend that continuous welded rail be installed in all stations to protect passengers waiting on platforms, and on all concrete trackbed, in the near future. Additionally,

as ballast trackbed is replaced by concrete trackbed, welded rail should be installed.

Wherever welded rail is installed, the necessary insulated points should be glued joints. All insulated joints in the system should be replaced by glued joints on a retrofit basis.

5. The (60) noisiest stations should receive acoustic treatment. This should include an acoustic ceiling, welded rail, acoustic barriers and under-the-platform cavity treatment.

6. The tunnel system should be treated with sound absorbent material to a 12 foot height. This would reduce the high noise levels in the tunnels.

7. Resilient rail fasteners should be used when ballast trackbed is replaced by concrete trackbed.

8. Resilient wheels should be installed on new cars (bought after 1960) on a retrofit basis. This recommendation should be deferred until a number of test cars have undergone thorough testing by the NYCTA.

9. Acoustic barriers should eventually be installed on steel elevated structures. A closed deck should also be considered. This recommendation should be deferred pending the results of a NYCTA study to determine the effects of additional weight on elevated structures.

10. The Transit Authority and the Bureau of Noise Abatement should continue its investigation of the causes of brake screech from the cars already in operation.

For new construction and purchases

All new construction plans, and all new car purchases must include comprehensive noise control specifications. The Environmental Protection Administrator should be given final approval authority for the specifications before the projects or purchases can be undertaken.

The costs shown in the following table in most cases do not provide for associated maintenance benefits. This would reduce the "noise abatement costs." When several noise abatement techniques are used, the expected noise reduction benefits* can not be added directly. Rather, the methods are complimentary. None of the methods can achieve its full potential by itself.

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* Noise is measured on a logarithmic scale (decibels, i.e. dB) to correspond to the ear's non-linear response. A sound 10 dB louder than another, sounds 2 or 3 times as loud. A change of 1 or 2 dB is hardly detectable. A change of 5 or 6 dB makes a noticeable difference. Also, in this report the A weighting scale is used, which de-emphasizes very high pitched and very low pitched noises so that the resulting sound levels represent what people actually hear (dB(A)).

TABLE IV - 1 NOISE ABATEMENT RECOMMENDATIONS
(In order of Priority)

Priority	Noise Abatement Technique	Expected Benefits	Cost	Urgency
(1)	Increased rail grinding	6-9 dB(A) Wayside 4-5 dB(A) In Car	Capital Cost $25,000 Expense Cost 100,000/yr.	Immediate
(1)	Wheel Truing (6 new wheel truing machines)	10 dB(A) Wayside 7 dB(A) In Car	Capital Cost $400,000/Machine $ 2.4 Million total Expense Cost 40,000/yr. for one shift on one machine 720,000/yr. for 3 shifts on 6 machines	Immediate
(2)	Air Conditioning existing mewer Cars (3,000 Cars)	8 dB(A) in Car	$30,000/Car $90 Million Total No actual noise cost; primarily for passenger comfort	Present TA schedule is Acceptable 250 1974 500 Each succeeding yr
(3)	Track Greasers	7 dB(A) in Car on Curve	$50,000/curve $9.4 Million/188 curves scheduled for treatment 50 of these are in yards (No actual noise cost; Entirely for Maintenance Reasons)	Present TA Schedule is Acceptable 50 curves/yr.
(4)	Welded Rail All Stations	4 dB(A) in station 5-10 dB(A) in Car	$4 Million	Near Future
	Concrete Roadbed Existing Type II and Type III		$3 Million	Near Future
	As Type I. Ballast roadbed (575 track miles approx.) is changed to concrete roadbed		$20,000/track mile 16,000/track mile more than bolted joints	Retrofit basis

TABLE IV - 1 (Cont.) NOISE ABATEMENT RECOMMENDATIONS
(In order of Priority)

Priorit	Noise Abatement Technique	Expected Benefits	Cost	Urgency
(4)	Glued Insulated Joints	minimizes noise of car passing over insulated joint	$25/Joint $10/Joint More than Bolted Joint	Retrofit Basis and wherever welded rail is installed
	20,000 insulated joints in system		$500,000/total number insulated	
(5)	Station Acoustic Treatment			
	Ceiling	6-7 dB(A)	$300,000/Station	Near Future
	Welded Rail	4 dB(A)	10,000/Station	
	Barrier	11-12 dB(A)	40,000/Barrier	
	Under Platform	3 dB(A)	12,500/Platform Side	
	Total	15-20 dB(A)	$450,000/Station	
	For top 60 Noisy Stations		$ 27 Million/60 stations	
(6)	Tunnel Treatment for 41 Type II Route Miles			
	6-foot Height	5-7 dB(A)	$4.5 Million	Near Future
	12-foot Height	7-9 dB(A)	$ 9 Million	
	Total Tunnel Treatment 6-foot Height	5-7 dB(A)	$15 Million $30 Million	

TABLE IV - 1 (Cont.) NOISE ABATEMENT RECOMMENDATIONS
(In Order of Priority)

Priority	Noise Abatement Technique	Expected Benefits	Cost	Urgency
(7)	Replace Type I track with Type VIII or equivalent rather than Type II (a less expensive equivalent should be found)	3 dB(A) in Car	$250,000/Mile More than Type II (resulting incremental cost 575 Type I track miles - $145 million)	Retrofit Basis
(8)	Resilient Wheels Retrofit newer cars (3000)	Effectively eliminates Curve Squeal	$550/Wheel $430/Wheel More Than Steel Wheels (resulting incremental cost 3000 cars $10 Million)	Future
(9)	Barriers - Steel Elevated Structure	10-12 dB(A) Wayside Noise of Train	$100,000/Route Mile 7.5 Million Total	Future

Total cost of recommended program $337 Million

Subtracting Type VIII incremental cost (145 Million)
and air conditioning ($90 Million)
Total cost $102 Million

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SUBWAY NOISE RIVALS AIRPLANE NOISE; RESIDENTS SUFFERING HEARING LOSS

Speaker, CM Gioia, CM Gennaro Call for Measures to Reduce Health Risks and Improve Reporting System

City Hall – City Council Speaker Gifford Miller was joined by Council Member Eric Gioia, Chair of the Committee on Oversights and Investigations and Council Member James Gennaro, Chair of the Committee on Environmental Protection, in releasing a Council Investigation Division (CID) report that found that New York City residents are exposed to no ise that registers at dangerously high decibel levels, potentially causing both physical and emotional health damage.

The Council's Investigation Division report found that at subway stations surveyed, New Yorkers are exposed to noise that peaks at dangerous levels. Out of the sites investigated, two-thirds of the subway stations were the survey's loudest areas. The highest decibel level recorded at a single location, 98.6 dB occurred at the Union Square 4, 5, 6 platform. Out of six subway stations visited, four had peak decibel levels that were recorded to be above 92. This finding comes close to the noise levels previously recorded near the city airports, were noise has been measured at 105 decibels.

"Noise in New York City is a health issue that both the City and the state need to start dealing with", said Speaker Miller. "As this report shows, New Yorkers are affected by extreme and potentially debilitating noise every day. It affects our schools, our jobs and our daily lives. For the sake of our resident's physical and mental health, we must begin to manage this issue."

Normal Conversation is recorded at 60 decibels, and heavy traffic at 85-decibel levels. According to the National Institute on Deafness and Other Communication Disorders, noises at 90 decibels and above can cause hearing damage. Every 10-decibel increase is a doubling of noise.

"The people of Queens are subjected to a seemingly endless barrage of train noise, the equivalent of a jet

(over)

plane landing over one's head every two minutes, every day of the week, every day of the year," said Council Member Gioia. "This noise has an adverse impact on health, on business for the commercial strip under elevated trains on Roosevelt Avenue and the dozens of schools within earshot of trains. The State must take immediate steps to alleviate this wrong. The federal government has spent hundreds of millions of dollars around the country to alleviate noise at our nations airports, we must make the same efforts to deal with the excessive noise from our subways."

A League for the Hard of Hearing report indicates that between 1981 and 2000 the rate of hearing failure increase 15% in men aged 60 to 69 and 25% in women in the same age category. Additionally, a 1997 study by a Cornell University psychologist found that children exposed to frequent aircraft noise in school did not learn to read as well as children in quieter environments.

The New York State Legislature passed the Rapid Transit Noise Code in 1982, which required that New York City Transit (NYCT) reduce noise on the subway and elevated train system. However, in 1994, NYCT determined that the law had expired and there has since been no noise abatement program.

"The City and State need to pro-actively deal with the public health crisis of noise. As our study points out, excessive noise is potentially affecting the physical and mental health of our citizens," said Council Member Gennaro. "This study points out that the city's transportation system is one of the biggest contributors to noise pollution. People shouldn't dread going into the subway and fear that every ride to work might affect their health. We must immediately begin to address this issue."

The investigation also found that enforcement of noise violations and the Noise Control Code is ineffective in dealing with the kind of noise that is noted in the report. In 1972, New York City adopted the Noise Control Code. In an effort to enhance the deterrent effect of the law, the Council substantially increased the fines in 1997. Beyond that increase, however, the Code has never had substantial revision.

The Council submitted recommendations that would work to reduce noise levels and the subsequent health damage. The Council is calling on the DEP to revise the Noise Control Code, Pass a resolution calling on New York State to require NYCT to establish a new noise abatement program, and call on NYCT to ensure continued efforts in its noise abatement program and to take steps to reduce noise such as installing noise-dampening materials, utilizing new track technology, and requiring Requests for Proposals to include plans for quieter wheel systems. Additionally, the Council is calling on the DEP to create a noise impact map of New York City.

The Council seeks to instill proactive measures to protect people from excessive noise, slow the increasing rates of hearing loss in the City and address area where enforcement is not feasible or fails to be effective.

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APPENDIX E

In the aforementioned report by Dr. Alice H. Suter ("Noise and Its Effects") this researcher also stated (see page 14) that "according to the U.S. Public Health Service (PHS, 1991), some 10 million of the estimated 21 million Americans with hearing impairments owe their losses to noise exposure (as cited in Carney, 1991)." Moreover, from the Suter (page 15) report:

> *"Noise damages the delicate sensory cells of the inner ear, the cochlea. This process can be studied in the laboratory by inducing temporary shifts in hearing threshold level in humans. Over recent years the preferred method of investigation is to produce temporary and permanent threshold shifts in animals, and to study the resulting physiological and anatomical changes in the cochlea, as well as shifts in hearing threshold level. The laboratory allows for strict control of noise level and duration, but the durations are usually relatively short because of the time and expense involved. Also there is some controversy over the extent to which the results can be generalized to humans".*

The Suter report (page 25) also referred to the following:

> *"EPA sponsored one of the most notable animal studies of noise exposure, in which Peterson and his colleagues performed five sets of experiments on the cardiovascular effects of noise on monkeys (Peterson et al., 1978, 1981, and 1983). The stimulus consisted of A-weighted levels of workplace noise at 85 to 90 dB, and the exposures there as long as 9 months. The results showed significant elevations of both systolic and diastolic blood pressure the fact that these changes persisted long after exposure cessation argues for a chronic effect, at least in this case. Unfortunately, an attempt to replicate this experiment with another primate model was discontinued for lack of funding after only two subjects had been exposed (Turkkan, et al., 1983). Relatively few animal experiments have been conducted in this area over recent years.*
>
> *With respect to laboratory investigations involving human subjects, Rehm (1983) cites six studies showing increases in blood pressure, but questions whether these effects would be permanent. In an attempt to identify more susceptible populations, Michalak et al. (1990) investigated the effects of low-flying aircraft on elderly subjects. Using recorded aircraft sounds, they found significant increases in both systolic and diastolic blood pressure after exposure to the two types of noise, with significantly greater response to the rapid-onset flyover noise. Whether or not these increases would become permanent with protracted exposure is not known".*

Other selected summaries of noise-related research:

a) “Community Noise Exposure and Stress in Children,” Journal of the Acoustical Society of America, Volume 109, Issue 3, pp. 1023-1027 (March 2001), by Gary W. Evans, Peter Lercher, Markus Meis, Harmut Ising, Walter W. Kofler

This study measured “indices of stress among children living under 50 dB or above 60 dB (A-weighted, day-night average sound levels) in small towns and villages in Austria”. Further, the primary noise sources were local road and rail traffic. After accounting for variables such as parental education, family size, body fat indices etc. the author found that “children in the noisier areas had elevated resting systolic blood pressure and 8-h, overnight urinary cortisol. The children from noisier neighborhoods also evidenced elevated heart rate reactivity to a discrete stressor (reading test) in the laboratory and rated themselves higher in perceived stress symptoms on a standardized index. Furthermore, girls, but not boys, evidenced diminished motivation in a standardized behavioral protocol”. (Note: the abstract of this study that we were able to obtain did not attribute individual values to the road or rail noise that may have caused the observed abnormalities).

b) “Effects of Noise,” TNO Prevention & Health, Sept. 2000, by Willy Passchier-Vermeer

The study by Ms. Passchier relates primarily to “the adverse effects of noise exposure on the health of children” (it also discusses effects on the foetus [sic] and teens to a lesser degree). This study also contains a very detailed compilation and analysis of studies regarding the effects of noise (aircraft and road) on preschool children and schoolchildren, with respect to blood pressure and neuroendocrine indices (some of the studies have contradictory findings).

Ms. Passchier also makes the claim that “ongoing research indicates that growth retardation of the child is associated with extensive occupational noise exposure of the pregnant mother” (see page 48, as cited from HRUBA D, KUKLA L, TYRLIK M., “Occupational risks for human reproduction: ELSPAC study,” Central European Journal of Public Health 1999:7(4):210-215). She also states that “sleep disturbance caused by night-time noise can impair memory reprocessing during sleep” (see page 54). She also indicates that with respect to older teens who are employed, the “hearing impairment at the most affected frequency (4000 Hz)” that occurs in the first 10 years of exposure is only somewhat less than the impairment that would occur over a lifetime of exposure (as sourced from “Acoustics – determination of occupational noise exposure and estimation of noise-induced hearing impairment,” International Standard ISO 1999. Geneva: International Organization for Standardization, 1990). This latter claim would seem to possibly contradict the 30 and 40 year exposure models used by various agencies.

c) "The 75 dB(A) Threshold Level of the Physical Agents Directive: A Flawed Evolution," Proceedings of the Institute of Acoustics, Vol. 22, Part 5, 2000, pages 61-68, by BW Lawton, Institute of Sound and Vibration Research, University of Southhampton

d) "Noise…Hearing Loss and Children," National Hearing Conservation Association Task Force on Hearing Conservation Education for Children and Adolescents, 2004

e) "EPA Identifies Noise Levels Affecting Health and Welfare," (see epa.gov/history/topics/noise/01.htm)

f) "Effect of infrasound on cochlear damage from exposure to a 4-k-Hz octave band of noise," Hearing Research, March 2007, by Gary W. Harding, Barbara A. Bohne, Steve C. Lee, and Alec N. Salt

g) "Histopathological differences between temporary and permanent threshold shift," Hearing Research, January 2000, by AS Nordmann, BA Bohne and GW Harding

h) "Degeneration in the Cochlea after noise damage: primary versus secondary events," American Journal of Otolaryngology, July 2000, by Barbara A. Bohne and Gary W. Harding

i) "General Health Effects of Transportation Noise," U.S. Department of Transportation, Federal Railroad Administration, Research and Special Programs Administration, John A. Volpe National Transportation Systems Center, June 2002, by Cynthia S. Y. Lee and Gregg G. Fleming

The above is only a sampling of current noise research. By listing the above examples, the NYCDEP does not intend to only recommend these sources, as there are many other worthy organizations and individuals that can be contacted who are performing valuable research in the area of noise. For more information see also the publications cited in this report.

- 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.

The program 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.

6.8 MITIGATION OF NOISE IMPACT

6.8.1 Noise Mitigation Measures

Where the noise impact assessment shows either Severe Impact or Moderate Impact, this section provides guidance on considering and implementing noise reduction measures. In general, mitigation options are chosen from those below, and then portions of the project noise are recomputed and reassessed to account for this mitigation. This allows an accurate prediction of the level of noise reduction. It is important to emphasize that the source levels used in this manual are typical of systems designed according to current engineering practice, but they do not include special noise control features that could be incorporated in the specifications at extra cost. This approach provides a reasonable analysis of conditions without mitigation measures. If special features that result in noise reductions are included in any of the predictions, then the Federal environmental document must include a commitment by the project sponsor to adopt such treatments before the project is approved for construction. Since cost considerations often play into decisions before committing to mitigation, this manual provides general cost information based on data presented in a Transit Cooperative Research Program (TCRP) report.[8] A detailed discussion of mitigation costs is presented in Chapter 5 of the TCRP report, especially the tables included in Chapter 5.

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

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

6.8.2 Source Treatments

Vehicle Noise Specifications (Rail and Bus)

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

Effective enforcement includes significant penalties for non-compliance with the specifications. The noise mitigation achieved by source treatment depends on the quality of installation and maintenance. In the past, transit vehicles have been delivered that did not meet a noise specification, causing complaints from the public and requiring additional noise mitigation measures applied to the wayside.

<table>
<tr><th colspan="4">Table 6-12. Transit Noise Mitigation Measures</th></tr>
<tr><th>Application</th><th colspan="2">Mitigation Measure</th><th>Effectiveness</th></tr>
<tr><td rowspan="13">SOURCE</td><td colspan="2">Stringent Vehicle & Equipment Noise Specifications</td><td>Varied</td></tr>
<tr><td colspan="2">Operational Restrictions</td><td>Varied</td></tr>
<tr><td rowspan="2">Resilient or Damped Wheels*</td><td>For Rolling Noise on Tangent Track:</td><td>2 dB</td></tr>
<tr><td>For Wheel Squeal on Curved Track:</td><td>10-20 dB</td></tr>
<tr><td colspan="2">Vehicle Skirts*</td><td>6-10 dB</td></tr>
<tr><td colspan="2">Undercar Absorption*</td><td>5 dB</td></tr>
<tr><td colspan="2">Spin-slide control (prevents flats)*</td><td>**</td></tr>
<tr><td colspan="2">Wheel Truing (eliminates wheel flats)*</td><td>**</td></tr>
<tr><td colspan="2">Rail Grinding (eliminates corrugations)*</td><td>**</td></tr>
<tr><td colspan="2">Turn Radii greater than 1000 ft*</td><td>(Avoids Squeal)</td></tr>
<tr><td colspan="2">Rail Lubrication on Sharp Curves*</td><td>(Reduces Squeal)</td></tr>
<tr><td colspan="2">Movable-Point Frogs (reduce rail gaps at crossovers)*</td><td>(Reduces Impact Noise)</td></tr>
<tr><td colspan="2">Engine Compartment Treatments (Buses)</td><td>6-10 dB</td></tr>
<tr><td rowspan="7">PATH</td><td colspan="2">Sound Barriers close to Vehicles</td><td>6-15 dB</td></tr>
<tr><td colspan="2">Sound Barriers at ROW Line</td><td>3-10 dB</td></tr>
<tr><td colspan="2">Alteration of Horiz. & Vert. Alignments</td><td>Varied</td></tr>
<tr><td colspan="2">Acquisition of Buffer Zones</td><td>Varied</td></tr>
<tr><td colspan="2">Ballast on At-Grade Guideway*</td><td>3 dB</td></tr>
<tr><td colspan="2">Ballast on Aerial Guideway*</td><td>5 dB</td></tr>
<tr><td colspan="2">Resilient Track Support on Aerial Guideway</td><td>Varied</td></tr>
<tr><td rowspan="2">RECEIVER</td><td colspan="2">Acquisition of Property Rights for Construction of Sound Barriers</td><td>5-10 dB</td></tr>
<tr><td colspan="2">Building Noise Insulation</td><td>5-20 dB</td></tr>
<tr><td colspan="4">* Applies to rail projects only
** These mitigation measures work to maintain a rail system in its as-new condition. Without incorporating them into the system, noise levels could increase up to 10 dB.</td></tr>
</table>

Stationary Source Noise Specifications

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

Wheel Treatments (Rail)

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

- **Resilient wheels** serve to reduce rolling noise, but only slightly. A typical reduction is 2 decibels on tangent track. This treatment is more effective in eliminating wheel squeal on tight turns; reductions of 10 to 20 decibels for high-frequency squeal noise are typical. The costs for resilient wheels are approximately $3000 per wheel, in comparison to about $700 for standard steel wheels.

- **Damped wheels,** like resilient wheels, serve to reduce rolling noise, but only slightly. A typical reduction is 2 decibels on tangent track. This treatment involves attaching vibration absorbers to standard steel wheels. Damping is effective in eliminating wheel squeal on tight turns; reductions of 5 to 15 decibels for high-frequency squeal noise are typical. The costs for damped wheels add approximately $500 to $1000 to the normal $700 for each steel wheel.

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

- **Maintenance** of wheels by truing eliminates wheel flats from the treads and restores the wheel profile. As discussed above, wheel flats are a major source of impact noise. A good maintenance program includes the installation of equipment to detect and correct wheel flats on a continuing basis. Costs vary according to transit property practices, but the TCRP report identifies a cost for truing wheels at $60 per wheelset.

Vehicle Treatments (Rail and Bus)

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

- **Propulsion systems** of transit vehicles include diesel engines, electric motors and diesel-electric combinations. Noise from the propulsion system depends on the type of unit and how much noise mitigation is built into the design. Mufflers on diesel engines are generally required to meet noise specifications; however, mufflers are generally practical only on buses, not on locomotives. Control of noise from engine casings may require shielding the engine by body panels without louvers, dictating other means of cooling and ventilation.
- **Ventilation** requirements for vehicle systems are related to the noise generated by a vehicle. Fan noise often remains a major noise source after other mitigation measures have been instituted because of the need to have direct access to cooling air. This applies to heat exchangers for electric traction motors, diesel engines and air-conditioning systems. Fan-quieting can be accomplished by installation of one of several new designs of quiet, efficient fans. Forced-air cooling on electric traction motors can be quieter than self-cooled motors at operating speeds. Placement of fans on the vehicle can make a significant difference in the noise radiated to the wayside or to patrons on the station platforms.
- The **vehicle body** design can provide shielding and absorption of the noise generated by the vehicle components. Acoustical absorption under the car has been demonstrated to provide up to 5 decibels of mitigation for wheel/rail noise and propulsion-system noise on rapid transit trains. Similarly, vehicle skirts over the wheels can provide more than 5 decibels of mitigation. By carrying their own noise barriers, vehicles with these features can provide cost-effective noise reduction.

Use of Locomotive Horns at Grade Crossings

In cases where commuter rail operations share tracks or rights-of-way with freight or intercity passenger trains that are part of the "general railroad system," the safety rules of the Federal Railroad Administration (FRA) apply. In particular, the rule for the use of locomotive horns at highway-rail grade crossings is in effect.[9] This rule requires generally that horns be sounded at public road crossings, although some exceptions are allowed in carefully defined circumstances. One exception enables the establishment of a "quiet zone" in which certain supplemental safety measures (SSM's) are used in place of the locomotive horn to provide an equivalent level of safety at grade crossings. 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 SSM's which 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 one period for each 24 hours, and must be closed 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 SSM's, the FRA rule also identifies a range of other measures that may be used in establishing a quiet zone. These could be modified SSM's 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 the horn.

Locomotive horns are quite loud, and horn noise is often the major contributor in projections of adverse noise impact in the community from proposed commuter rail projects. Since sound barriers are not feasible at highway-rail grade crossings, the establishment of quiet zones may be an attractive option. The lead agency in designating a quiet zone is the local public authority responsible for traffic control and law enforcement on the roads crossing the tracks. In order 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 right-of-way. Depending on the circumstances, establishment of a quiet zone would probably not be completed in the time frame of the environmental review process. However, as with other types of mitigation, the final environmental document should discuss the main considerations in adopting the quiet zone, for example, engineering feasibility, receptiveness of the local public authority, consultation with the railroad, preliminary cost estimates, etc., and show 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 assurance that any remaining issues can and will be resolved.

The cost of establishing a quiet zone varies considerably, depending on the number of intersections that must be treated and the specific SSM's, ASM's, 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. 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 has been a sore point in the community. In cases where a quiet zone would mitigate a Severe Impact situation brought about by the proposed transit project, the costs would be borne by the local transit agency and FTA in the same proportion as the overall cost-sharing for the project.

Guideway Support (Bus and Rail)

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

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

Operational Restrictions (Rail and Bus)

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

Other operational restrictions that can reduce noise impact for light rail and commuter rail systems include minimizing or eliminating horn blowing and other types of warning signals at grade crossings. While these mitigation options are limited by safety considerations, they can be effective in the right circumstances and they are discussed elsewhere in this section (e.g., wayside horns).

6.8.3 Path Treatments

Sound Barriers

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

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

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

Costs for noise barriers, based on highway installations, range from $25 to $35 per square foot of installed noise barrier at-grade, not counting design and inspection costs(10). Installation on aerial structure may be a factor of two greater, especially if the structure has to be strengthened to accommodate the added weight and wind load.

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

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 the intersection instead of the locomotive horn has been shown to 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, but the real advantage is the focusing of the warning sound 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. Field tests have shown that noise levels in nearby residential and business areas can be reduced significantly 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 right-of-way, 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.

Noise Buffers

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

Ground Absorption

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

6.8.4 Receiver Treatments

Sound Barriers

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

Building Insulation

In cases where sound barriers are not feasible, such as multi-story buildings, buildings very close to the rights-of-way, or grade crossings, the only practical noise mitigation measure may be to provide sound insulation for the buildings. 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 usually 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 special windows. A minimum STC rating of 39 should be used on any window exposed to the noise source. These treatments are beneficial for heat insulation as well as for sound insulation. As an added consideration for costs, however, acoustical windows are usually non-operable so that central ventilation or air conditioning is needed.

Additional building sound insulation, if needed, can be provided by sealing vents and ventilation openings and relocating them to a side of the building away from the noise source. In cases where low frequency noise from diesel locomotives is the problem, it may be necessary to increase the mass of the building façade of wood frame houses by adding a layer of sheathing to the exterior walls.

Criteria for Interior Noise Levels. 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 dBA. In order to be considered cost-effective, a treatment should provide a minimum of 5 dBA reduction in the interior of the building and provide an interior noise level of 65 dBA or less from transit sources. In homes where noise impact from train horns is identified, the sound insulation should provide sufficient noise reduction such that horn noise inside the building is 70 dBA or less.

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 the Federal Aviation Administration (FAA). Based on FAA experience, a typical single-family home can be fitted for sound insulation for costs ranging from $25,000 to $50,000.

Appendix G

World Health Organization

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