

THE EFFECT OF INSTALLATION LOCATION ON RAILROAD HORN SOUND LEVELS

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ABSTRACT

Many comments have been received as a result of the Federal Railroad Administration's (FRA) issuance of a Proposed Rule for the Use of Locomotive Horns at Highway-Rail Grade Crossings. A large group of comments were received on a particular provision within the rule, stating that the sound level generated by the horn, when measured at the side of the locomotive, shall not exceed the sound level measured in front of the locomotive. In the late 1980's it became the de facto standard to install horns on the top/center portion of the locomotive. This was done in an attempt to reduce the noise exposure for the locomotive cab occupants. However, the result was that measured sound levels off to the side of the locomotive were often higher than levels in front of the locomotive. Consequently, this provision in the FRA's Proposed Rule may force railroad operators to relocate many installed horns. While supporting comments were made by many municipalities and individuals, negative comments were also received on this provision.

In order to document precisely the effect of horn placement on the locomotive, a series of tests were conducted. These tests measured the sound level around the locomotive for five types of locomotive horns, mounted in four locations on two locomotives. By measuring and documenting the variation in sound level around the horn and locomotive in a consistent manner, the differences in sound level output as a function of distance and the differences in noise exposure levels can be assessed.

1.0 INTRODUCTION

Many comments have been received as a result of the Federal Railroad Administration's (FRA) issuance of a Proposed Rule for the "Use of Locomotive Horns at Highway-Rail Grade Crossings"¹. One particular provision states that the sound level generated by the horn, when measured at the side of the locomotive, shall not exceed the sound level measured in front of the locomotive. In the late 1980's it became the de facto standard to install horns on the top/center portion of the locomotive. This was done in an attempt to reduce the noise exposure for the locomotive cab occupants. However, the result was that measured sound levels off to the side of the locomotive were often higher than levels in front of the locomotive. Consequently, this provision in the FRA's Proposed Rule may force railroad operators to relocate many installed horns. A number of negative comments were also received on this provision.

In response to these comments and concerns the FRA, in conjunction with the Volpe National Transportation Systems Center, Environmental Measurement and Modeling Division, has undertaken a measurement study with the primary objective of documenting precisely the effect of installation location on the railroad horn sound level output at distances around the locomotive and inside the locomotive cab. The sound level around the locomotive was expected to vary by installation location due to two factors: (1.) the sound level distribution around the locomotive will be affected by the presence of the locomotive body (as is the case with center-installed horns), and (2.) the sound level projection in all directions will be affected due to attenuation by the ground (as a function of height). The sound levels inside the locomotive cab due to the railroad horn were expected to be affected by: (1.) the distance between the horn and cab, (2.) the acoustic insulation of the cab, and (3.) whether the windows are open or closed. This study examined, through a controlled set of measurements, the sound around and inside the locomotive for five types of horns, installed in four locations on two models of locomotive

This paper documents and assesses the sound level inside and around the locomotive produced by each horn / installation location / locomotive combination and makes observations on the most effective horn installations.

2.1 HORNS, LOCOMOTIVES, AND INSTALLATION LOCATIONS

Five horns, provided by the manufacturers, were utilized for measurements. These horns represent the majority of horns that are currently in use.

- (1.) Airchime K-5-LA: A five-chime horn, operating at frequencies of 311, 370, 415, 494, and 622 Hz. The horn is rated by the manufacturer to have a sound level output of 114 dB(A) at 100 ft with a 100 psi air supply.
- (2.) Airchime K-5-LAR24: Same as the above horn with 3 chimes facing forward and 2 chimes (370 and 494 Hz) facing rearward.

- (3.)Leslie RS-3L: A three-chime horn, operating at frequencies of 255, 311, and 440 Hz. The horn is rated by the manufacturer to have a sound level output of 114 dB(A) at 100 ft with a 100 psi air supply.
- (4.)Leslie RS-3L-RF: Same as the above horn with one chime (440 Hz) facing rearward.
- (5.)Airchime P-3: A three-chime horn, operating at frequencies of 277, 330, and 440 Hz. The horn is rated by the manufacturer to have a sound level output of 114 dB(A) at 100 ft with a 100 psi air supply.

The two locomotives used were chosen to be representative of both older (1970's) and newer (1990's) technologies. They are: (1.) an older General Motors EMD GP-40-2, Serial #786143-1. Overall dimensions: 15.2 feet in height, 10.2 feet in width, 59.2 feet in length; and (2.) a newer General Motors EMD SD60MAC, BNSF #9501. Overall dimensions: 15.9 feet in height, 10.5 feet in width, 71.6 feet in length.

Four installation locations, described below and depicted in Figure 1, were chosen as representative of those either currently in service or being considered for service. Note that all horns were centered over the width of the locomotive.



Figure 1. Horn Installation Locations

- (1.)Center Installation
 - a. GP-40. Installed on the top of the locomotive, 16 feet above ground level, 30 feet from the front of the locomotive.
 - b. SD60MAC. Installed on the top of the locomotive, 16 feet above ground level, 40 feet from the front of the locomotive.
- (2.)Cab Roof Installation
 - a. GP-40. Installed on the top of the cab roof, 16 feet above ground level, 10 feet from the front of the locomotive.
 - b. SD60MAC. Installed on the top of the cab roof, 16 feet above ground level, 7 feet from the front of the locomotive.
- (3.)Front Hood Installation
 - a. GP-40. Installed on the top of the front hood, 12 feet above ground level, 5 feet from the front of the locomotive.

- b. SD60MAC. Installed on the top of the front hood, 12 feet above ground level, 3 feet from the front of the locomotive.
- (4.) Knuckle (Coupler) Installation
- a. GP-40. Installed above the coupler, 3 feet above ground level, 0 feet from the front of the locomotive.
 - b. SD60MAC. Installed above the coupler, 3 feet above ground level, 0 feet from the front of the locomotive.

To facilitate installation changes, each horn was mounted on the locomotive using a magnetic base, and connected to the main air reservoir (pressurized to between 130 and 140 psi) via the main reservoir hose located on the front of the locomotive, next to the coupler. A control valve and pressure gauge were placed in the air line to monitor and regulate the air pressure delivered to the horn.

2.2 SOUND MEASUREMENT LOCATIONS

Sound level measurement instrumentation was positioned inside and around the locomotive in locations that would satisfy three types of measurement requirements: (1.) sound level as a function of location around the locomotive (directivity), at a constant distance from the horn, (2.) sound level per FRA certification regulations, at a constant distance from the front of the locomotive, and (3.) sound level inside the locomotive cab. Figure 2 is a plan view showing the measurement locations.

For directivity measurements, fourteen microphones were positioned as follows: four microphones, located 200 and 400 ft from the front of the horn and 200 and 400 ft to the side of the horn (90 degrees relative to the front of the horn), were connected to Larson-Davis Model 824 Sound Level Meter / Analyzers which were set up to measure and record both the overall A-weighted sound level and the sound level in one-third octave bands from 25 Hz to 10 kHz, at one-second intervals. The remaining ten microphones were positioned in a circular array at 45-degree increments, 100 and 200 feet from the horn, and connected to Larson-Davis Model 820 Sound Level Meters which were set up to measure and record the overall A-weighted sound level at one-second intervals. All distances were measured from the horn, allowing direct comparisons to be made between horn / locomotive / installation location configurations.

For FRA certification measurements, two microphones were positioned at a distances of 100 and 200 ft from the front of the locomotive, and connected to Larson-Davis Model 820 Sound Level Meters, which were set up to measure and record the overall A-weighted sound level at one-second intervals.

To measure sound levels in the locomotive cab, a microphone was connected to a Larson-Davis Model 820 Sound Level Meter which was set up to measure and record the overall A-weighted sound level at one-second intervals. The microphone was placed inside the locomotive cab, ear-

level at the engineer's typical position. Locomotive cab interior sound levels were measured both with the windows open (on both sides of the cab) and closed.

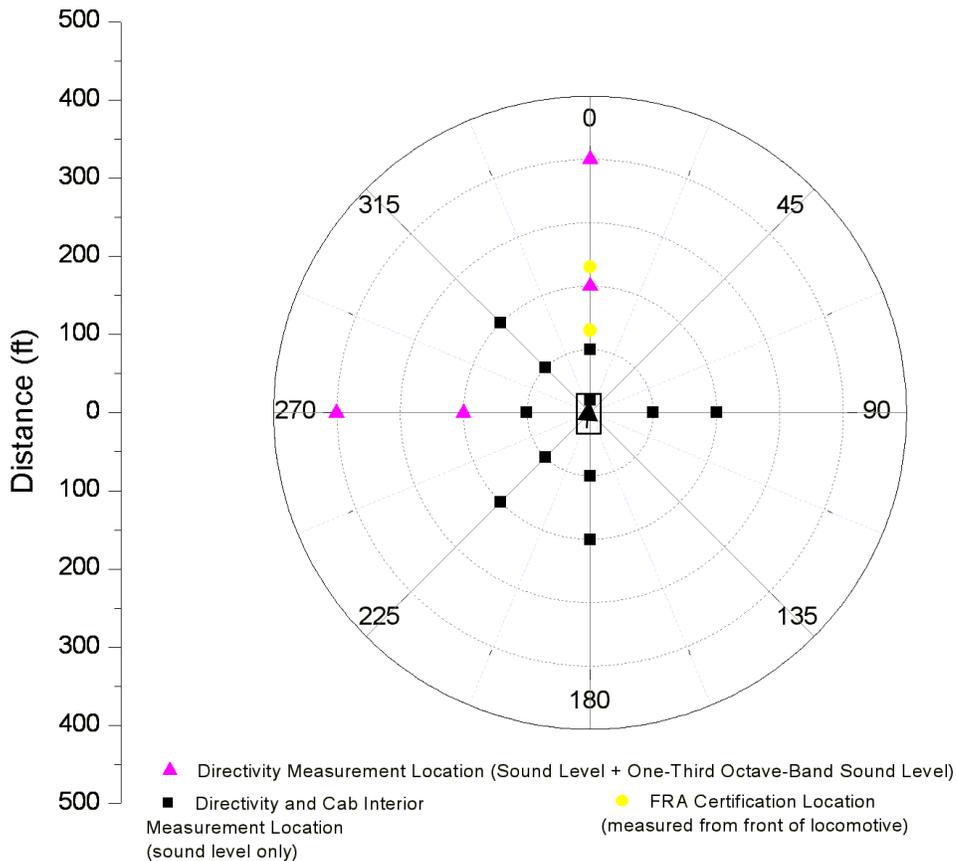


Figure 2. Plan View of Measurement Locations

2.3 TEST MATRIX

Sound levels were measured for each horn/locomotive/installation location combination in accordance with three sound level/air pressure criteria. The first two criteria were such that the sound level output of the horn was adjusted (by adjusting the air pressure delivered to the horn) so that it achieved a specified level at a position 100 ft in front of the locomotive, as follows (*constant level tests*):

- (1.)the horn shall produce a level of 96 dB(A) when measured at a position 100 ft forward of the locomotive; and,
- (2.)the horn shall produce a level of 111 dB(A) when measured at a position 100 ft forward of the locomotive.

The third criteria was such that the horn was set to a constant air pressure (*constant pressure tests*). This allowed for accurate documentation of the barrier effect or shadow zone created by installing the horn in the center position on top of the locomotive. In this case, the air pressure delivered to the horn was 135 psi. This is the maximum pressure that could be consistently maintained in the main air reservoir.

2.4 MEASUREMENT PROCEDURE

Each acoustic measurement system was calibrated and the time-base was synchronized to a master clock at the beginning of each test day. Acoustic data were then measured simultaneously at the 17 positions for the duration of the test day.

A total of six uncontaminated events were measured for each of the specified test criteria. An event was defined as a 30-second period during which the horn was sounded continuously. To ensure the event was acoustically uncontaminated, wind speed and direction were measured continuously; if the wind speed exceeded 10 mph at any time during the event, the event was discarded. Baseline ambient noise levels at the test site, dominated by the idling locomotive, were always less than 65 dB(A). Since horn sound levels exceeded 75 dB(A) even at the farthest measurement locations, acoustic contamination from other noise sources was not a concern.

Because the measurement setup consisted of measurement systems that were both a constant distance from the horn and a constant distance from the front of the locomotive, a realignment of the locomotive and certification measurement systems was performed when the horn installation location was changed. In this manner, the horn and directivity measurement systems were kept at a fixed relative location for the duration of the study.

3.0 ACOUSTIC DATA REDUCTION

The contiguous, 1-second, A-weighted sound level data measured at each location were examined to determine the start and stop time for each event, as defined by the 10 dB-down period. The Maximum A-weighted Sound Level with slow time-weighting ($L_{A_{smx}}$) and Equivalent A-weighted sound level ($L_{A_{eq}}$) metrics for each event were calculated and transferred to a spreadsheet. The six events comprising each test criteria were arithmetically averaged in the spreadsheet to determine a representative $L_{A_{smx}}$ and $L_{A_{eq}}$ for each criteria.

4.0 DATA ANALYSIS

The ground surface over which the sound propagates, if it is acoustically soft (as was the case in this study), will generally absorb some of the sound, resulting in excess ground attenuation. The lower the height of the sound source, the greater the attenuation. Likewise, the locomotive body can effect sound propagation by diffracting the sound wave and creating a sound level reduction,

or ‘shadow’ at some locations around the locomotive; and reflecting the sound wave and creating sound amplification at other locations. These effects together are termed the horn installation effect. The sound level reduction in front of the locomotive, when the horn is installed in the center, is of particular concern. This reduction is greatest at close distances, decreasing with increasing distance.

Because a horn operating at a fixed pressure will, theoretically, always produce the same sound level output at a given measurement location, the sound level data measured for the *constant pressure* test criteria data should be identical for all horn/locomotive installations. Any relative differences in these data are caused by the horn installation effect and/or excess ground attenuation. Sections 4.1 and 4.2, respectively, describe how the constant pressure sound level data were used to empirically derive the horn installation effect and the excess ground attenuation.

4.1 HORN INSTALLATION EFFECT

The magnitude of the sound level reduction in front of the locomotive for the center-installed horn was determined by comparing the sound level data measured 100, 200 and 400 ft directly in front of the locomotive for the center installation with the comparable data measured for the cab-roof installation. Because the cab-roof installed horn is at the same height as the center-installed, it was assumed that there was no difference in the excess ground attenuation, and any differences between these installations could be attributed to the horn installation effect. A similar comparison was performed for the other directivity angles.

Figure 3 graphically depicts the installation effect, showing the average L_{Aeq} as a function of angular directivity. In general, it can be seen that the presence of the locomotive body (a GP-40 in this example) results in a 10 dB(A) reduction in sound level 100 feet from the front of the horn (70 feet from the front of the locomotive). For this particular horn/locomotive combination, the reduction in sound level drops to 9 dB(A), 200 ft from the front of the horn, and 8.1 dB(A), 400 feet from the front of the horn. This graphic shows that there is a slight increase (0.2 to 0.7 dB(A)) in sound level at the 45-degree position (this increase, however, is negligible) and there is essentially no effect at the 90-degree position.

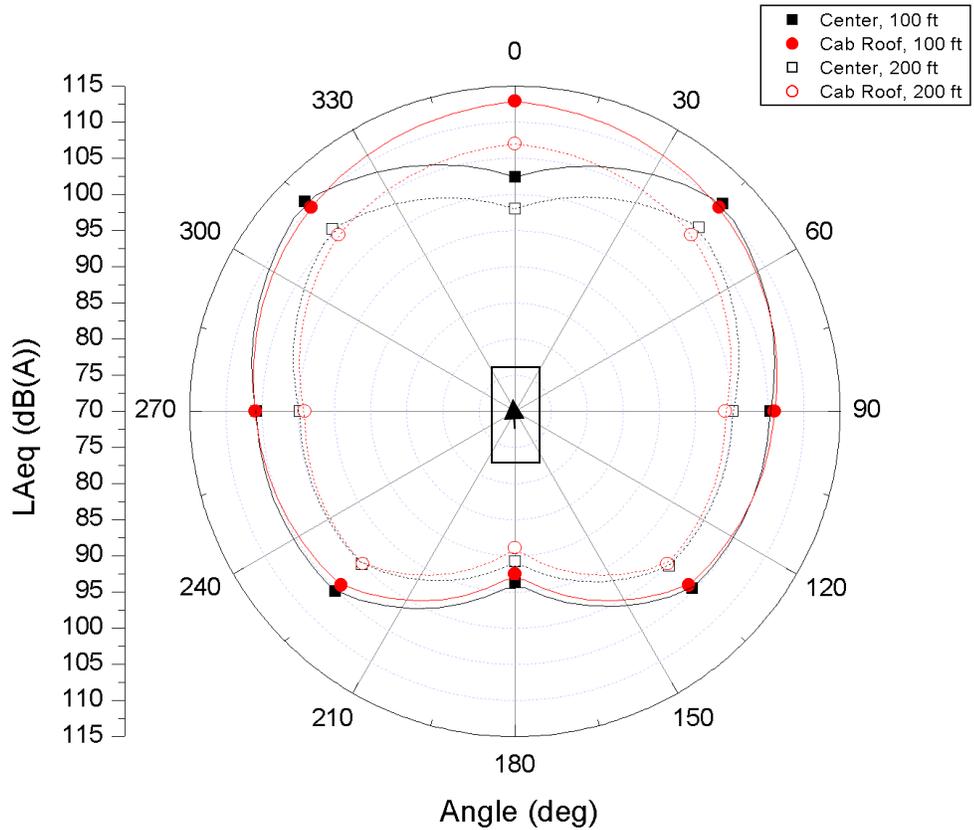


Figure 3. Center-Installed vs. Cab Roof Installed Sound Levels

Table 1 summarizes the magnitude of the installation effect for each horn / locomotive combination tested for the measurement positions directly in front of the locomotive. In general, it can be said that the magnitude of the installation effect decreases 1 to 2 dB(A) for every doubling of distance. Theoretically, because the line of sight to a 4-foot high receiver will always be blocked, the sound level reduction will never be less than about 5 dB(A)².

Table 1. Summary of Installation Effect

Horn	Engine	Distance from Horn to Front of Locomotive (ft)	Installation Effect dB(A)		
			Distance from Horn (ft)		
			100	200	400
K-5-LA	GP-40	30	-10	-9	-8.1
K-5-LAR24	GP-40	30	-10.8	-9.1	-9.5
RS-3L	GP-40	30	-9.8	-7.9	-6.8
K-5-LA	MAC-60	40	-18.3	-15.7	-15.1

4.2 EXCESS GROUND ATTENUATION

The reduction in sound level over distance, caused by excess ground attenuation, geometric spreading, and atmospheric absorption, is usually reported in terms of a drop-off rate (X dB per distance doubling). Geometric spreading by a point source, such as a locomotive horn, follows the inverse square law and results in a 20 log distance reduction in sound level, or 6 dB for each doubling of distance. Atmospheric absorption can be effectively neglected for the small distances and low frequencies examined in the current study. Any variance measured in drop-off rate from 6 dB(A) can therefore be attributed to excess ground attenuation.

An analysis was performed to determine the average drop-off rate for each horn installation location. As expected, the drop-off rate increases with decreasing horn height, that is to say that the drop-off rate is higher for propagation paths closer to the acoustically soft ground. The average drop-off rates were determined to be 5.7 dB, 6.3 dB, 7.3 dB, and 8.4 dB for the horn placed at heights of 16 ft (center), 16 ft (cab roof), 12 ft (front hood), and 3 ft (knuckle), respectively. Because the cab-roof-installed and center-installed horns were at the same height, the results were averaged together. As a result, for the 16 ft height, the average drop-off is 6.0 dB; this signifies that there is no excess ground attenuation at 16 ft, whereas there is 1.3 dB and 2.4 dB excess ground attenuation for the 12 ft and 3 ft heights, respectively.

4.5 LOCOMOTIVE CAB INTERIOR NOISE LEVELS

Figure 4 illustrates the average sound levels measured in the locomotive cab interior for the six horn / locomotive model combinations. In general, the following observations can be made:

- There is a negligible difference in interior levels between the cab roof and front hood positions.
- Moving the horn from the cab-roof to the center of the locomotive or the front knuckle will provide a substantial reduction in interior levels, usually between 3 and 11 dB(A).
- Closed windows provide between 5 and 15 dB(A) of sound level reduction. This is consistent with previous research on the sound level reduction of automobile windows².
- Levels in the newer SD60MAC average 5.5 dB(A) lower than in the older GP-40.

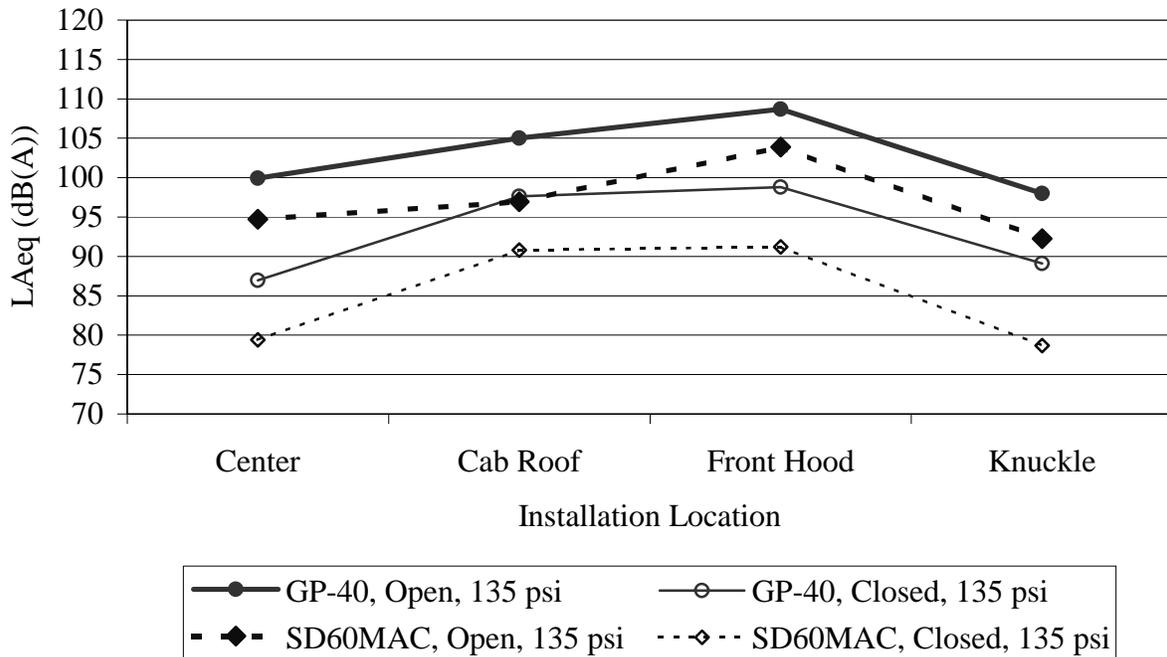


Figure 4. Locomotive Cab Interior Noise Levels

5.0 CONCLUSIONS

Table 2 summarizes the effect of each installation location on the sound levels measured around the locomotive and inside the locomotive cab.

Table 2. Summary of Installation Location Effects

Location	Interior Sound Level (dB(A)), relative difference from cab roof location	Reduction Forward of Locomotive (dB(A))	Excess Ground Attenuation (dB(A) per distance doubling)
Center	-3 to -11	-10 to -18	0
Cab Roof	0	0	0
Front Hood	0	0	1.3
Knuckle	-3 to -11	0	2.4

The cab-roof location appears to best satisfy all current criterion. Due to the increased ground effects for both the front hood and knuckle-installations, these locations result in slightly lower sound levels at distance. The forward levels of the center-installed horn, due to the installation effect, are 8 to 10 dB lower for the GP-40 and 15 to 18 dB lower for the SD60-MAC than the

levels of the forward-installed (i.e., cab roof, front hood, and knuckle) horns (when operated at an equal pressure).

In instances where a center-installation is preferred, the installation should be as far forward and high as possible. The measured data show a significant difference in the sound level reduction between the center-installed horn on the GP-40, where the horn is 30 feet from the front, and there is 9.5 inches between the extreme top of the locomotive and the top of the horn, and the SD60-MAC, where the horn is 40 feet from the front, and there is only 1 inch between the extreme top of the locomotive and the top of the horn (i.e., the horn is lower than some of the fan housings). It is recommended that the FRA continue to encourage manufacturers and the railroad operators to find a location for the horn that, while still removed from the cab, is as far front as possible, and forward of any roof-top obstructions.

6.0 FURTHER STUDY

Ongoing analyses will use the data measured as a part of this study to assess both the change in effect on community noise level and the change in effect on motorist warning. It is anticipated that, together, these analyses will provide the FRA with the empirical information necessary to write a final rule.

7.0 REFERENCES

- 1 . Federal Register, January 13, 2000. *Use of Locomotive Horns at Highway-Rail Grade Crossings; Proposed Rule*. U.S. Department of Transportation, Federal Railroad Administration.
2. Barry, T.M., Regan, J.A., *FHWA Highway Traffic Noise Prediction Model*, Report No. FHWA-RD-77-108, Washington D.C: Federal Highway Administration, December 1978.