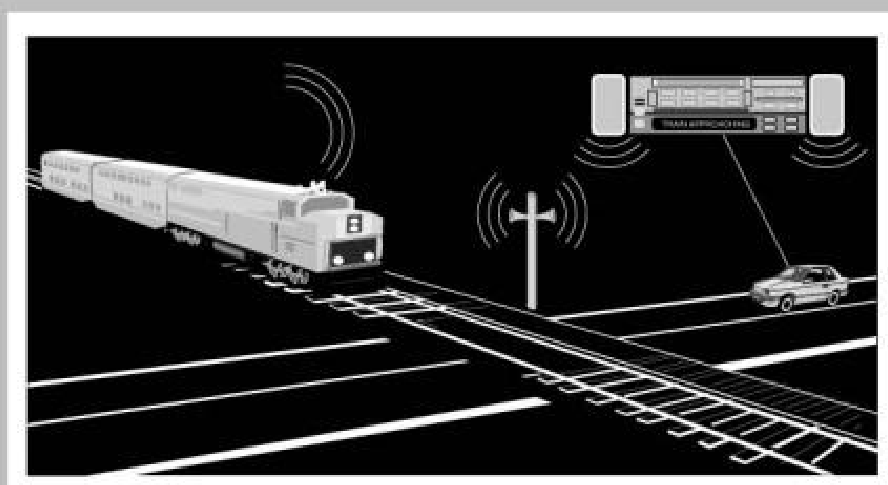
U. S. Department
of Transportation
**Federal Railroad
Administration**

Field Evaluation of a Wayside Horn at a Highway-Railroad Grade Crossing

Office of Research
and Development
Washington, DC 20590

U. S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142



Safety of Highway-Railroad Grade Crossings

**DOT/FRA/ORD-98/04
DOT-VNTSC-FRA-97-1**

**Final Report
June 1998**

This document is available to the public through the National Technical Information Service, Springfield, VA 22161

always expect a train

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*LEAVE BLANK*)

2. REPORT DATE
June 1998

3. REPORT TYPE AND DATES COVERED
Final Report
April 1994 - May 1997

4. TITLE AND SUBTITLE
Field Evaluation of a Wayside Horn at a Highway-Railroad Grade Crossing

5. FUNDING NUMBERS
R8026/RR897

6. AUTHOR(S)
Jordan Multer and Amanda Rapoza

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Canbridge, MA 02142-1093

8. PERFORMING ORGANIZATION
DOT-VNTSC-FRA-97-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Railroad Administration
Office of Research and Development, Mail Stop 20
Washington, DC. 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT/FRA/ORD-98/04

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the National Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The current study represents one of several efforts by the Federal Railroad Administration to evaluate the effectiveness of auditory warnings designed to promote awareness of approaching trains. A stationary horn (or wayside horn) located at the grade crossing was evaluated to learn whether it would reduce community noise impact without adversely affecting motorist safety, compared to a train horn. This report documents the results of two surveys comparing the community noise impact of a wayside horn to a train horn and an analysis of motorist behavior at the grade crossing. Acoustic data were also collected to describe the sound characteristics of each warning signal.

The wayside horn tested was considerably less annoying to the community than the train horn. The lower sound level of the wayside horn compared to the train horn was a significant factor in explaining why it was perceived as less annoying than the train horn. In the safety evaluation, the wayside horn did not result in behavior that put the driver at increased accident risk compared to the train horn. Implementation issues that will impact safety and community noise were also identified. These issues included: activation method, hardware design and standardization.

14. SUBJECT TERMS
auditory warning, community noise impact, highway-railroad grade crossings, safety, train horn, warning device, wayside horn

15. NUMBER OF PAGES
112

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT

PREFACE

The use of auditory warnings to warn motorists at highway railroad grade crossings currently presents a conflict between two community goals: maintaining safety on public roads and maximizing enjoyment of residential living areas through the elimination or reduction of noise pollution. The train horn serves as a safety device to warn motorists and pedestrians of the approaching train. However, the same sound that serves as a warning to motorists may also annoy a significant proportion of the population living near the grade crossing. In some communities, the noise produced by the train horn is unacceptable and has generated community action to address the problem.

The current study represents one of several efforts by the Federal Railroad Administration to evaluate the effectiveness of auditory warnings designed to promote awareness of approaching trains. The purpose was to evaluate whether a stationary auditory warning (referred to as a wayside horn) located at the grade crossing would reduce community noise impact without adversely affecting motorist safety. This report documents the results of two surveys to compare the community noise of a wayside horn to a train horn and an analysis of video data regarding motorist behavior at the grade crossing. Acoustic data were also collected for the wayside horn and train horn to describe the sound characteristics of each warning signal.

A project of this magnitude and complexity was the work of many people. We would like to thank our colleagues and associates for their support in accomplishing this study as well as our partners, the City of Gering, Nebraska and Union Pacific Railroad.

We are grateful to Anya Carroll for her managerial support in getting this project completed on time. We would like to express our appreciation to Robert DiSario and Peter Mengert for their expertise in helping us analyze and interpret the data following the completion of the data collection phase. The many collegial discussions we had resulted in a more focused and polished study. A special debt of gratitude is owed to John Pollard for his development and management of the video equipment, without which the driver evaluation would have been impossible. Special thanks go to Sarah Maccalous for her work putting the survey data into a geographical information system and providing the data needed to properly evaluate the relationship between resident's location and various attributes.

We are deeply grateful to the City of Gering, Nebraska. From their help in recruiting volunteers to collect the survey data to the installation and maintenance of the wayside horn, they made this study a success. The respondents of the two surveys were generous in giving us their time to answer our questions. Wally Baird, Gering City Manager, coordinated our data collection activities with the Union Pacific Railroad, and provided volunteers to collect the survey data. Jim Payne and his staff at the utility department kept the wayside horn in good working order and worked with Union Pacific Railroad when equipment failures occurred.

The actual data collection required the services of many people. We would like to thank Mike Coplen for his professional execution in working with the City of Gering to collect the survey data. We thank Gene Corman for going beyond the call of duty in monitoring the operation of the video equipment and collecting the tapes for us. He kindly included newspaper articles with the videotapes that described what was happening on the tracks during the time the study was underway. Thanks are also owed to the participants who volunteered their time to interview the residents of Gering and contributed to a better understanding of the factors affecting safety at highway-railroad grade crossings. The Union Pacific Railroad also gave us their support in allowing us to test this experimental device. Cliff Shoemaker, Dave McCord, and Bob Rairigh worked with us and the City of Gering to make the field evaluation go as smoothly as possible. We would also like to thank Roger Whitaker, Natalia Kreitzer, Terri Burk, Erica Eichelberg, and Jason Kester of CH_2M Hill and Michael Minor of Sound and Vibration Consulting for their efforts in collecting the acoustical data.

This field study was funded by the Federal Railroad Administration's Office of Research and Development. Garold Thomas provided the direction for this study.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Noise from the train horn is perceived by many residents living near grade crossings as highly annoying. Railroad operating rules require locomotive engineers to sound the train horn as they approach a highway-railroad grade crossing. Locomotive engineers begin sounding the horn approximately 1/4 mile from the highway-railroad grade crossing. This warning exposes a segment of the local community near the tracks to the sound of the train horn as well as motorists and pedestrians who may be approaching the grade crossing. However, residents living near the grade crossing are not the intended target of this auditory warning.

One alternative that has been proposed by some to address the adverse effects of train horn noise is a stationary horn mounted at the grade crossing. The stationary horn, referred to here as a wayside horn, is sounded in place of the train horn as the train approaches the grade crossing. Previous research addressing wayside horns has examined whether the wayside horn is detectable by motorists. Wayside horns evaluated in the past were less detectable than commonly used train horns (Keller and Rickley, 1993).

Previous research on wayside horns centered on their acoustic characteristics. Safety and community noise impact was not addressed, leaving important questions unanswered. One critical question that needs to be answered is whether the wayside horn reduces annoyance to the local community compared to a train-mounted horn or whether it simply moves the area of impact to a different part of the community? Another question that needs to be answered is whether safety is maintained when a wayside horn serves as the auditory warning in place of the train horn? The purpose of our research is to answer both these questions.

The current study evaluates the viability of the wayside horn as a warning concept. Although the study evaluated one particular device in terms of its effectiveness in warning motorists and minimizing community noise impact, the study is intended as a test of a class of auditory warnings located at the grade crossing. To the extent other auditory warnings are designed similarly, comparable performance would be expected.

The study compared the performance of train horns on Union Pacific locomotives (Leslie 3 chime) to a prototype wayside horn. For the current evaluation, two wayside horns were mounted on a utility pole with each horn directed toward oncoming traffic, at each of three grade crossings in Gering, Nebraska.

Community Noise Impact

To evaluate the community noise impact of the wayside horn, two surveys were administered by telephone. The first survey measured the impact of the train horn on community noise. The second survey measured the impact of the wayside horn on community noise. Data from the two surveys were compared to evaluate the difference between the two warning devices on community noise impact.

The wayside horn tested was considerably less annoying to survey respondents than the train horn. The wayside horn reduced noise to levels that were more acceptable to the community. The wayside horn was less likely to interfere with activities inside or outside the home and generated fewer actions to minimize the noise. The variable that best predicted if someone was highly annoyed was the frequency with which the horn was heard. The greater the horn count, the more likely a resident was to be highly annoyed. High annoyance level was also related to the activities which were interfered with. The relationship between activity interfered with and high annoyance varied by time of day. During the day, interference with conversation contributed to high annoyance. During the evening, inference with both conversation and reading contributed to high annoyance. Finally, during the night, only interference with sleep contributed to high annoyance.

Acoustic Analysis

The acoustic analysis was performed to document the sound level and frequency content of the in-service locomotive horn and the wayside horn being evaluated for their effects on driver safety and community noise impact in Gering, Nebraska. In addition, the acoustic data collected was compared to the community noise impact data collected from the survey of the local residents to examine the relationship between noise level and annoyance. The objectives were met by conducting sound level measurements of both the locomotive horn and the wayside horn at fourteen sites surrounding the three grade crossings in Gering, NE.

At peak sound levels, the wayside horn was approximately 13 dB quieter than the train horn. The lower sound level of the wayside horn compared to the train horn was a significant factor in explaining why the wayside horn was perceived as less annoying than the train horn. Unlike the train horn, the wayside horn did not meet the minimum sound level required of train horns. The frequency distribution of the wayside horn was similar to the train horns measured in this study.

For the 14 sites where sound measurements were collected, the wayside horn had a negative community impact only during nighttime hours using guidelines developed by the Federal Transit Administration (FTA). Only the sites defined as severe impact resulted in community annoyance high enough to require action to mitigate the noise. For the wayside horn, the location of the sights defined as severe were all within 100 feet of the track. By contrast, locations defined as severe impact for the train horn were located up to 1000 feet from the track. Clearly, the wayside horn impacted residents over a smaller geographical area.

Evaluation of Driver Behavior

The use of an alternative warning device to the train horn must also provide an effective warning to the motorist, if accidents are to be prevented. The primary objective of the driver behavior evaluation was to assess the safety of the wayside horn. To meet this objective, we observed driver behavior at the grade crossing for both the train horn and the wayside horn. Using video cameras, we observed when motorists drove through the grade crossing following activation of the warning systems. We measured both the frequency of the violations and the time to collision.

The safety evaluation suggests that the wayside horn will not result in behavior that puts the driver at increased risk compared to the use of the train horn. The frequency of violations was lower for the wayside horn than the train horn, while the time to collision and violation time was not statistically or practically different for either warning system.

In both the train horn and wayside horn conditions, driver behavior was determined in part by the presence of the gates. To the extent that gate behavior controls motorist behavior, differences between the two warning devices may have been masked. Data from Richards et al’s (1991) study on optimal warning times indicate that as the time delay increases between when the warning is initiated and the gates completely descend, motorists are more likely to continue through the grade crossing without stopping. The gate descent time in this study was relatively short (10 s).

This short descent time may have reduced the overall violation rate compared to grade crossings with longer descent times.

Implementation Issues

The current study did not set out to evaluate how the wayside horn *should be implemented* to maximize safety while minimizing community noise impact. Nevertheless, a variety of implementation issues will impact safety at the grade crossing as well as community noise. Some of these issues were identified, along with issues they raise and potential solutions. These issues included method of activation, hardware design and standardization.

Two methods of activation were identified: track circuitry and engineer activated. There are tradeoffs that must be considered in selecting either method. The engineer activated method has not been subjected to evaluation in revenue service, but remains a promising approach. Activation by track circuitry, with constant warning times, is a viable approach if the track circuitry is reliable. Assuming the track circuitry is reliable, the opportunity to use this method will depend upon the availability of grade crossings with constant warning track circuitry. Currently, constant warning time track circuits are available at only a small percentage (13%) of the grade crossings protected by active warning systems. Although the auditory warning could also be activated by fixed block track circuits, this approach is problematic. As the time between activation of the warning device and the actual presence of the train increases, motorists are less likely to heed the warning.

The current evaluation also identified several design and maintenance issues related to the wayside horn evaluated for this test. Exposure of the elements impaired the performance of several hardware components. The components of the wayside horn must be designed to withstand the extremes of weather found in the United States. The system also needs to be designed to facilitate ease of maintenance. Important design features that contribute to ease of maintenance include: minimizing the number of components, using modular components that are easy to replace, and designing the housing to facilitate ease-of-access.

As demonstrated by the annoyance measures in the two surveys and the driver behavior data, the wayside horn shows promise as a warning device that can reduce community noise impact without adversely affecting safety. However, there are still important questions that need to be answered before implementing this device as a substitute for the train horn. The implementation issues indicate the need for clarifying how the activation method will impact safety at the grade crossing. The wayside horn also needs to be evaluated at other locations to confirm the benefits of reduced community noise impact and to insure that driver safety is not compromised. Finally, an answer is also needed to the question of what an appropriate sound level is to maintain safety while minimizing community noise impact. Until these questions are answered, the wayside horn is not recommended as a substitute for the train horn at highway-railroad grade crossings.

1. STUDY OVERVIEW

1.1 BACKGROUND

In an effort to alert motorists and pedestrians to the presence of an approaching train and avoid accidents at highway-railroad grade crossings, locomotive engineers regularly sound a train-mounted horn as they approach the intersection. Locomotive engineers begin sounding the temporal (long-long-short-long) sequence that characterizes the warning signal approximately 1/4 mile from the highway-railroad grade crossing. This warning exposes a segment of the local community near the tracks to the sound of the train horn as well as motorists and pedestrians who may be approaching the grade crossing. However, residents living near the grade crossing are not the intended target of this auditory warning, and the train horn noise is perceived by many residents living near grade crossings as highly annoying.

Several attributes contributing to the train horn's effectiveness as a warning for motorists and pedestrians also explain its annoying qualities for residents living near the grade crossing. One attribute is its signal intensity. The listener perceives signal intensity as loudness. To be detected by the listener, the train horn signal intensity must be greater than the background noise level. The higher the signal intensity is above the background noise level, the more likely the listener will detect the signal. Federal regulations require the train horn to be at least 96 decibels (dBA) 100 feet in front of the train in its direction of travel (CFR 229.129, 1992). The background noise levels inside the home may vary between 30 and 50 dB (Sorkin, 1987). A 10 dBA difference between signal and noise is considered adequate to reliably detect a signal (Boff, Kaufman, and Thomas 1986; Sorkin, 1987). For a resident living 100 feet from the grade crossing, the signal may range between 46-66 dBA above the background level outside the house. Thus, the signal has the potential to be very loud in relation to the background noise level. In actual measurements, the signal intensity may be lower due to the directional effects of the train horn signal and obstructions which block the signal from reaching the listener.

The train horn is also characterized by a broadband signal that can mask sound over a wide frequency range, interfering with conversations and listening to radio and TV at moderate levels. The frequency range for the most common train horns lays between 250 and 8,000 Hz with the greatest intensity in the range from 500 to 2,500 Hz (Keller and Rickley, 1993). Speech interference can occur when noise level rises above 70 dB between the frequency range of 600 to 4800 Hz (Bailey, 1989). The intermittent nature of the train horn signal can also disrupt activities that require concentration such as reading, as well as interfering with sleep.

For residents living more than 100 feet from the grade crossing, Table 1 shows how the signal intensity decreases as distance from the grade crossing increases. The signal intensity decreases approximately 6 dBA for every doubling of distance. However, the structure of the house plays an important role in reducing the noise levels experienced inside. The signal loses strength (attenuates) as it passes through walls and windows. Leaving the windows or doors open, minimizes this attenuation. During the warm weather, when residents tend to keep their windows open, they will be exposed to higher train horn noise levels.

Table 1. Relationship between Distance of Listener from Train and Signal Intensity

Distance (feet)	Signal Intensity dB (A)
100	96
200	90
400	84
800	78
1600	72
3200	66

In communities where residents currently perceive the train horn to be annoying, this was not always the case. In some situations, people moved to locations near the grade crossing during a period of relatively little or no railroad activity. Consequently, residents heard few train horns and the level of noise was acceptable. As economic conditions improved and railroad traffic increased, the cumulative exposure to the train horn noise increased resulting in greater impact on the local community. (Borkman, 1991; Sorensen and Hammer, 1983)

The train horn signal is also beyond the direct control of residents. Sounds tend to be perceived as more annoying when they can't be controlled by the individual than when they can (Bailey, 1987).

1.2 SOLUTIONS TO REDUCING TRAIN HORN NOISE

To minimize the impact of train horn noise, residents may take a variety of actions that include: closing their windows, wearing ear plugs, turning up the volume on their TV or radio, building fences, and installing insulation. However, these steps vary in their effectiveness and create additional problems for the resident. Closing windows in hot weather may make the house hotter and more humid, increasing discomfort. Installing insulation, air conditioners and sound barriers imposes a financial burden on the homeowner or landlord.

When enough residents are annoyed, action at the community level may occur. Residents' complaints to government officials may result in a number of solutions being considered. The solutions include grade separation, grade crossing closure and whistle bans. These solutions are discussed briefly.

1.2.1 Grade Crossing Closure

Where grade crossings currently exist, the most effective way to avoid grade crossings accidents is to close the grade crossing. Closing the grade crossings eliminates the intersection between motor vehicle and train and eliminates the need to provide a warning of the train's approach. However, communities may resist grade crossing closures when the perceived costs of closing the grade crossing such as the additional travel time or providing access for emergency vehicles, outweighs the perceived benefits. Thus, it is not always feasible to close the grade crossing.

An alternative to permanent grade crossing closure is temporary closure, in which the crossing remains open during the day when most people tend to drive and is closed at night when most residents sleep. When the crossing is closed, the community can prohibit the horn from sounding. Achieving a temporary closure requires negotiations among the local residents and between the community and the railroad. As with permanent closure, residents who desire access through the grade crossing may resist efforts to close the crossing. The community will also need to negotiate when the crossing will be closed and discuss the impact of this closure on different groups. Railroads need assurance that the crossing will be adequately protected from motorists attempting to enter the closed crossing.

1.2.2 Grade Separation

Separating the grade between motor vehicle and train eliminates the intersection between the two modes of travel and the possibility of collision. By eliminating the grade crossing intersection, it is no longer necessary to warn motorists. The biggest difficulty in implementing this solution is the high cost. The high cost of grade separation in an environment of limited financial resources means that only a small percentage of grade crossings can receive this treatment.

1.2.3 Whistle Bans

Currently there are no Federal regulations that require locomotive engineers to sound the train horn. The requirement for locomotive engineers to sound the train horn as they approach a grade crossing arises from railroad operating rules. In individual states, laws and regulations vary from state to state. In Florida, the state legislature passed a law, allowing communities to ban the sounding of train horns during certain hours of the day. However, the Federal Railroad Administration (FRA) (Florida's Train Whistle Ban, 1992) found that the whistle ban led to an increase in the number of accidents at those grade crossings. Oregon experienced a similar rise in the accident rate when a whistle ban was imposed in Salem and Eugene (Oregon Public Utility Commission, 1990).

While the FRA issued an emergency order to preempt the Florida whistle ban and Oregon repealed their whistle ban, the original problem remains. The daily exposure to train horns for many people living near grade crossing reduces their enjoyment of life. Pressure remains to reduce the annoying effects of the train horn noise. Evaluation of the accident data from the Florida and Oregon whistle bans shows that the train horn plays a significant role in preventing collisions at grade crossings.

Pursuant to a Congressional mandate (Title III of P.L. 103-440, Nov 2, 1994), the FRA is working to define "supplementary safety measures" which will "fully compensate for the absence of the warning provided by the locomotive horn." Once such measures are defined, the FRA must propose regulations which will require the use of train horns at most crossings except those at which the defined supplementary safety measures have been applied.

1.2.4 In-Vehicle Warning Device

A number of trends are leading to the development of in-vehicle warning devices that can alert the motorist to approaching hazards such as police cars, ambulances, fire trucks and trains. Motor vehicles are becoming better insulated from the sounds outside the vehicle, making it more difficult to hear auditory warnings of any kind initiated outside the vehicle. New technology exists that is capable of delivering a warning signal from a moving vehicle or stationary position to a target vehicle within a specified proximity to the moving vehicle. These devices work by transmitting a radio signal within a specified distance of the transmitter. The motor vehicle equipped with the appropriate receiver, picks up the signal when it arrives within the range of the transmitter. This signal can be presented to the motorist as a visual or auditory warning, or both. Motorcyclists, for example, may have difficulty hearing an auditory signal. In this situation, a visual or tactile signal could provide the warning. Providing an in-vehicle warning reduces the need for an auditory warning outside the motor vehicle. However, the application of in-vehicle warning technology does not eliminate the need for an auditory warning for pedestrians and cyclists. In these instances, an auditory warning on the train or at the grade crossing will be needed to warn of the approaching train.[1]

While this technology presents a promising approach to the problem of warning motorists without exerting a negative impact on community noise, it is still only a concept. The effectiveness and reliability of this type of warning device still needs to be evaluated. Thus, it will be some time before these types of systems are implemented. If these systems are implemented, it will take years before all vehicles might be outfitted with these warning systems. In the meantime, an effective auditory warning initiated outside the vehicle will continue to play a role at grade crossings for the foreseeable future.

1.2.5 Wayside (Stationary) Horn

Another solution for reducing the impact of train horn noise on the community is to place a horn at the grade crossing and direct it toward oncoming traffic. Instead of blowing the horn mounted on the train, a stationary, wayside-mounted horn would be activated when the train approaches the grade crossing. For a typical application in which traffic approaches from two opposing directions, two horns would be mounted at the grade crossing, one facing oncoming traffic in each direction. Thus, the noise from the horn would be directed where it is needed most, toward traffic approaching the grade crossing. Residents living near the tracks, but out of the path of the wayside horn, would receive less exposure to the noise from a stationary device located at the grade crossing. However, a smaller number of residents living in the path of the wayside horn might receive greater exposure.

Previous research addressing wayside horns has examined whether the wayside horn is detectable by motorists. Wayside horns evaluated in the past were less detectable than commonly used train horns (Keller and Rickley, 1993). The train horns tested contain a broader band signal that is more difficult to mask than the wayside horn. Rapoza and Rickley (1995), using acoustical data, determined that a wayside horn with a single tone and a maximum sound level of 87 dBA would be less detectable inside a moving motor vehicle than the Nathan 5 chime and Leslie 3 chime train horns that predominate on most locomotives today. Another study (Saurenman and Robert, 1995) evaluating a different wayside horn, but with a maximum sound level of 85 dBA, found similar results. The motorist could detect the audible warning up to 400 feet from the grade crossing when the car was idling. However, for a moving car in which the background noise level was in the 55-65 dBA range, the motorist would fail to detect the wayside horn in time to stop before arriving at the grade crossing.

---

[1] If the auditory warning were intended for pedestrians and cyclists, the sound level of the auditory warning could be lower, since signal loss from road noise and sound barriers would be less of a problem, and the speed at which they would move toward the grade crossing would be lower. Warning pedestrians and cyclists is currently accomplished at actively protected grade crossings by the use of bells located at the crossing.

Saurenman and Robert (1995) also evaluated whether the wayside horn would serve as an effective warning for pedestrians. They asked a focus group to rate the effectiveness of the wayside horn compared to the train horn on a light rail system in Los Angeles. Their results suggest that the wayside horn would be effective in alerting pedestrians to the presence of an approaching train.

The research on wayside horns still leaves many important questions unanswered. Currently, there is no research that specifically addresses whether a wayside horn would reduce the noise impact on the community. If the wayside horn is to be successful, it must minimize the impact of the auditory warning on residents living in the vicinity of the grade crossing. Previous research has addressed the question of effectiveness in maintaining safety by looking at detectability of the horn. A different method of evaluating safety is to examine driver behavior directly. Rapoza and Rickley (1995) suggest that drivers will fail to detect the train horn for traffic conditions commonly found at the grade crossing. However, accident data collected during a study on whistle bans in Florida and elsewhere shows that the train horn is effective in preventing accidents. This paradox suggests that we need to improve how we measure detectability of auditory warnings at grade crossings. In the meantime, observing motorist behavior at the grade crossing will help determine how auditory warnings influence driving behavior. The current study attempts to address this concern by examining how motorists respond in the presence of a wayside horn compared to a train horn.

1.3 PURPOSE OF THE CURRENT RESEARCH

One critical question that needs to be answered before such a device should be implemented is whether safety is maintained when a wayside horn serves as the auditory warning in place of the train horn. Another question that needs to be answered before deciding whether this is an effective solution, is whether the community noise impact of a wayside horn reduces annoyance to the local community compared to a train-mounted horn or whether it simply moves the area of impact to a different part of the community.

The purpose of our research is to answer both of these questions. This project is part of a cooperative effort supported by the FRA and involving the City of Gering, Nebraska, Railroad Consulting Services, Union Pacific (UP), and Volpe National Transportation Systems Center (Volpe Center). The remainder of this report describes how the wayside mounted auditory warning works, the methodology developed to evaluate community noise impact and safety, and presents preliminary observations on the operation of the system and how it affects the local community.

It is important to emphasize that the current research evaluates the viability of the wayside horn *as a warning concept*. Although the study evaluated one particular device in terms of its effectiveness in warning motorists and minimizing community noise impact, the study is intended as a test of a class of auditory warnings located at the grade crossing. To the extent other auditory warnings are designed similarly, similar performance would be expected. Additionally, the current evaluation is not a test of the optimal warning characteristics that might be effective in achieving the safety and community noise reduction goals of a wayside auditory warning system. The optimal acoustical characteristics of an auditory warning for trains will be considered in future research.

1.4 APPROACH

1.4.1 Evaluate Community Noise Impact

To evaluate community noise impact, two surveys were administered to compare the effect of the wayside horn to the train horn. The surveys asked respondents how annoyed they were by the two auditory warning devices, the activities it interfered with and what actions they took in response to the noise.

Acoustic measurements were collected to describe the loudness and frequency distribution of each auditory signal. As part of this data collection effort, acoustic measurements were made at 11 sites where survey data was also collected so the physical noise measurements could be compared to the perceived annoyance levels.

1.4.2 Evaluate Safety

To evaluate safety, video cameras were used to observe motorist behavior at the grade crossing. Safety was measured by observing the frequency with which motorists violated the traffic control devices warning them of the approaching train. Violations were selected rather than accidents because they occur at a much higher frequency than accidents. Accidents at one or two grade crossings occur at too low a frequency to detect performance differences. Motorist violations represent a reasonable surrogate, since this behavior presages accidents in which the train hits the motor vehicle.

1.5 ORGANIZATION OF THE REPORT

Since the auditory warning devices evaluated as part of this study are referred to in each chapter, the description is presented only once, at the end of chapter one, to avoid repeating the description of each device three times. The remainder of this report is divided into five chapters. Chapter 2 describes the assessment of community noise impact, while chapter 3 characterizes the acoustic signals that make up the two auditory warnings. Chapter 4 describes the impact of the wayside horn on driver behavior at the grade crossing. Chapter 5 discusses operational concerns that may arise depending upon how the wayside horn is implemented. Chapter 6 summarizes and integrates the findings from each of the different evaluation tests. Appendices A and B present the surveys assessing the effects of the two auditory warnings on residents' annoyance levels. Appendix C describes how sound is measured and Appendices D and E show the sound measurements for the train horn and wayside horn, respectively.

1.6 DESCRIPTION OF WARNING DEVICES

Two horn systems were evaluated for this study, a train mounted horn and a wayside horn.

1.6.1 Train Horn

The type of train horn evaluated was determined by the type of horn mounted on the locomotive. The majority of the trains observed moving through Gering (approximately 95%) consisted of Union Pacific locomotives carrying coal. These Union Pacific locomotives contained a Leslie 3 chime horn. The engineer typically began sounding the train horn at the whistle post, approximately ¼ mile from each grade crossing. The engineer sounded the horn using a long-long-short-long sequence until the locomotive arrived at the grade crossing.

1.6.2 Wayside Horn

The wayside auditory warning device selected for evaluation was designed by Merrill Anderson of Railroad Consulting Services, Inc. The device, shown in Figure 1, consisted of a Federal Signal Selectone horn (model 302-GCX), a tone module (Federal Signal Universal Tone Module 13) containing the sound recording of an air horn and a control board which received the signal from the track circuitry and activated the horn. On top of the horn case was a Federal Signal strobe light (model 131ST) that served as a visual signal for the locomotive engineer that the wayside horn was sounding. A small circuit board and detector installed inside the horn case activated the strobe light if the horn emitted a signal at least 80 dB. If the wayside horn was less than 80 dB, the strobe light remained off. In this situation, the engineer would blow the train horn.

The activation of the wayside horn was tied to the same circuitry that activated the crossing gates, flashing lights, and crossing bells. Gate descent began approximately two seconds after activation of the flashing lights, bells and wayside horn. When the track circuitry activated the wayside horn, it repeated the following sequence shown in Table 2 until the train reached the grade crossing. When the train reached the grade crossing the wayside horn sounded for five seconds. The system was designed to produce a sound pressure level of 114 dB at 10 feet and 98.9 dB at 50 feet.

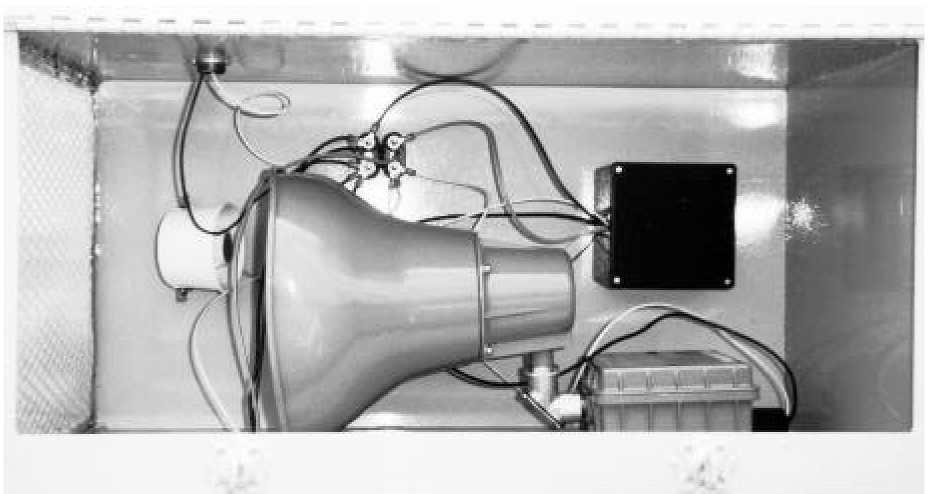


Figure 1. Wayside Horn

Table 2. Wayside Horn Temporal Sequence

Sequence	Duration On (s)	Duration Off (s)
1	3.0	1.5
2	3.0	1.5
3	1.5	1.5
4	3.0	1.5

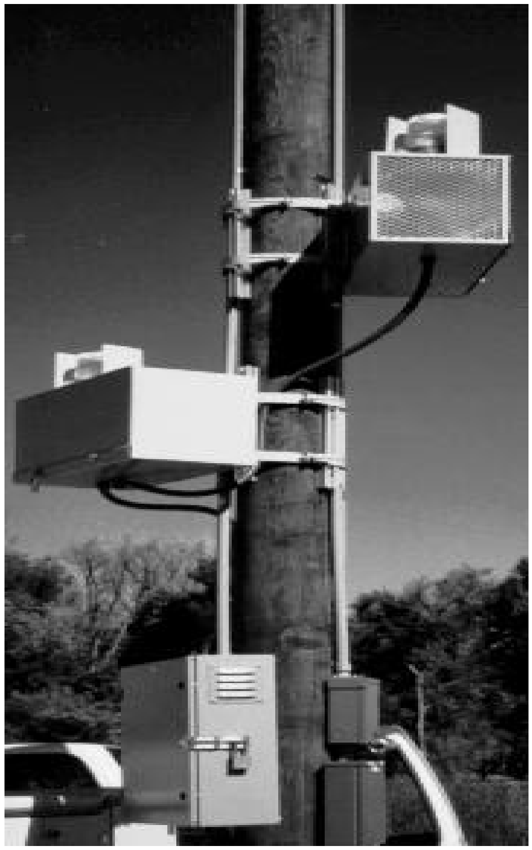


Figure 2. Wayside Horn on Utility Pole

For the current evaluation, two wayside horns were mounted on a telephone pole as shown in Figure 2 with each horn directed toward oncoming traffic, at each of three grade crossings in Gering, Nebraska. Due to budget limitations, we monitored performance at only two of these grade crossings: Tenth Street and Country Club Road. The Tenth Street grade crossing intersects a busy main road (Average Daily Traffic Count = 11,240) running through a commercially zoned part of town. The Country Club Road grade crossing intersects a relatively quiet road (Average Daily Traffic Count = 2,415) running through a residential neighborhood.

2. COMMUNITY NOISE IMPACT EVALUATION

2.1 METHOD

2.1.1 Overview

To evaluate the community noise impact of the wayside horn, two surveys were administered by telephone. The first survey measured the impact of the train horn on community noise levels. The second survey measured the impact of the wayside horn on community noise levels. Data from the two surveys were compared to evaluate the difference between the two warning devices on community noise impact. The two telephone surveys were administered one year apart at the same time of year. The train horn survey was administered in July 1994, while the wayside horn survey was administered in July 1995. Prior to the first survey, the respondents were exposed to the train horn for as long as they lived at their current location. For the wayside horn survey, respondents were exposed to the wayside horn for 5 months prior to the survey.

2.1.2 Sampling Procedures

The sample selected for the two surveys was based upon the distance of the respondent's home to the track. Respondents were randomly selected from the population living within 3200 feet of the track. It was assumed that the sound level from any noise source along the track would be at or near the ambient or background noise level at distances greater than 3200 feet from the track and therefore would be unlikely to annoy residents. Noise levels decrease approximately 6 dB for every doubling of the distance to the noise source. For a noise source with a sound level of 96 dB, 100 feet from the track, the sound level (in a free field environment) should theoretically be 66 dB at 3200 feet from the track. Residents living within this area were considered more likely to be annoyed than residents living outside this area. The actual noise level for different parts of the community were measured as part of acoustic tests after the surveys were completed. The background noise levels varied between 44.0 dB and 74.2 dB, with a mean of 53.9 dB.

For the train horn survey, 580 households were called. Fifty-nine percent (342) of those called completed the survey. The remaining calls consisted of households who could not be reached (36%) and people who refused to participate (5%). For the wayside horn survey, the 342 households who responded to the first survey were called. Of these 342 households, 69% (236) completed the second survey. Four percent of those called in the second survey refused to participated and the remaining 26 percent could not be reached. Of the 236 households who participated in both surveys, 60% (142) consisted of the same respondent. The remaining respondents consisted of a different member of the household. As a percentage of the general population in Gering, the two surveys represent 4% (train horn survey) and 3% (wayside horn survey) of the total.

2.1.3 Survey Design

The two surveys asked the same questions of respondents. The questions addressed demographic characteristics of the respondents and the opinions toward either the train horn or the wayside horn. The questions asking about the train horn or wayside horn can be divided into three groups. One group of questions asked when and how frequently they heard the auditory warning as well as how the noise from the auditory warning affected the respondent. A second group of questions addressed the type of activity the noise interfered with. A third group of questions addressed what actions the respondent took to minimize the negative effects of the noise. Appendixes A and B show the script for conducting the telephone interview and present the questions asked in both surveys.

Before data from the first survey was collected, the survey was pilot tested on a group of five respondents to fine tune the instrument and make sure the questions were understandable. The survey took approximately five minutes to complete.

2.1.4 Interview Procedures

The interviews were conducted by college student volunteers living in and around Gering, Nebraska. Each volunteer received 1-2 hours of training to conduct the telephone interviews that included several sessions practicing their technique. They followed the script shown in Appendixes A and B. The interviewers also received instructions in how to respond to respondents questions about the research and how to handle questions to which they did not know the answers.

During the data collection period, the interviewers were given a list of telephone numbers to call. No names or addresses were given to insure the anonymity of the respondent. If an interviewer recognized a telephone number, the interviewer was asked to give that number to another interviewer. When the interviewer called a respondent, the interviewer introduced his or herself and explained that the purpose of the telephone call was to ask them their opinions about the noise from the train horn (or the wayside horn). The interviewer asked whether the respondent was under 18 years old, and proceeded with the interview only if the respondent was 18 years old, or older. If the respondent was under 18 years old, the interviewer asked to speak to a household member who was 18 years old, or older. The interviewer conducted the interview until the survey was completed or until the respondent terminated the interview. At the conclusion of the interview, the interviewer thanked the respondent for his or her time and answered any questions by the respondent.

2.2 RESULTS AND DISCUSSION

2.2.1 Sample Demographics

Table 3 and Table 4 show the breakdown by gender and age of the respondents for both surveys compared to the data from the 1990 census. Compared to the census data for Gering, Nebraska, a higher percentage of females participated in both surveys, than in the population. While females outnumber males by 6 percent in Gering, as reported by the 1990 census, the number of females participating in the two surveys is more than two times the rate of participation of males.

Table 3. Gender Distribution of Respondents

	Survey		**1990 Census**
Gender	Train Horn	Wayside Horn	
Male	30%	33%	47%
Female	70%	67%	53%

Table 4 shows that the age distributions for the two survey samples was also different than the general population. The age of the respondents was skewed toward older respondents as compared to the general population. The median age was 35 for the general population. However, in the two survey samples, the median age was 53 and 58. This age difference between the two survey samples and the census data in part reflects the interview procedures which avoided using respondents younger than eighteen. For both surveys, less than one percent of the population was younger than 18.

Table 4. Age Distribution of Respondents

	Survey		**1990 Census**
Age	Train Horn	Wayside Horn	
<18	1%	1%	28.8
18-24	6%	3%	7%
25-44	30%	24%	30%
45-64	29%	33%	18%
65+	34%	39%	17%
Median	53	58	35

Table 5 shows how long the respondents have lived at their current address compared to the population of Gering. As with age and gender, the respondents' tenure at their current address differs from the general population. The respondents in both surveys lived at their current address longer than the general population. The percentage of respondents who lived at their current address for 20 years or more was 61% for the train horn respondents and 67% for the wayside horn respondents, while only 40% of the general population lived at their current address for 20 years or more. At the other extreme, only 21% of the train horn respondents and 15% of wayside horn respondents for the two surveys lived at their current address for 5 years or less while 46% of the general population lived at their current address for 5 years or less.

Table 5. Tenure Distribution of Respondents

	Survey		**1990 Census**
Tenure (Years)	Train Horn	Wayside Horn	
1	3%	1%	20%
5	18%	14%	26%
10	17%	17%	14%
20	30%	28%	26%
30	18%	20%	7%
31+	13%	19%	7%

Thus, the picture that emerges of the survey sample is a group that differs from the general population as characterized by 1990 census data. The respondents are predominantly female, older and have lived at their current address longer than the general population.

2.2.2 Comparison of Annoyance Levels

To assess whether the wayside horn reduced the level of undesirable noise compared to the train horn, respondents were asked directly how annoying they found the noise from the two warning devices. Respondents were asked to rank how annoying the noise from the warning device was on a scale from 1 to 5, where 1 was not at all annoyed and 5 was extremely annoyed. The values given by the respondent were then converted to a measure of annoyance that more accurately reflect the influence of acoustical factors on the respondent: percent of the population that is <u>highly</u> annoyed. Shultz (1978) indicates that subjective measurements where noise exposure is extreme results in more agreement among respondents since people have less difficulty sorting out their feelings about the noise from other nonacoustical factors. Respondents were considered highly annoyed if they responded with the answer highly annoyed or extremely annoyed. Respondents were not considered highly annoyed if they answered: not at all annoyed, slightly annoyed or moderately annoyed. The percent highly annoyed was determined by calculating the proportion of highly annoyed respondents to the total number of responses.

Attitudes toward the warning devices were measured for different parts of the day since previous research (Peterson and Gross, Jr., 1974) suggests that people are more sensitive to noise during the evening and night when the background noise level decreases. Time of day was divided into three periods: day (7:00 a.m. to 5:00 p.m.), evening: 5:00 p.m. to 10:00 p.m., night (10:00 p.m. to 7:00 a.m.). Figure 3 shows the percent of highly annoyed people for both warning devices, by time of day. As expected, people were more annoyed in the evening than in the daytime, and most annoyed at night. This pattern was consistent for both the train horn and the wayside horn.

Comparing attitudes toward the two warning devices, the percentage of highly annoyed people was lower for the wayside horn than the train horn, for every time of day. These differences are statistically significant (Day: $z = 6.16$, $df = 98$, $p < .0001$; Evening: $z=6.57$, $df =110$, $p < .0001$; Night: $z=7.98$, $df=1$, $p < .0001$). Another view of this data is displayed in Figures 4 and 5. Both figures show two maps of Gering, NE. The maps illustrate the location of people who were highly annoyed and those who were not highly annoyed, for the train horn and the wayside horn, respectively. Figure 4 shows the location of highly annoyed people during the daytime for both warning devices and Figure 5 shows the location of highly annoyed people at night. In both figures, the circles represent people who were highly annoyed and the X's represent people who were not highly annoyed. In both figures, it is clear that the number of highly annoyed people is far greater with the train horn than with the wayside horn.

Figure 4 and Figure 5 also illustrate several other noteworthy points. First, the location of the highly annoyed residents was not closely related to their proximity to either the track or the grade crossing for the train. This was surprising, given that noise levels tend to decrease with distance. As illustrated in Table 1, in a uniform environment, the noise level decreases 6 dB for every doubling of the distance. It was expected that the number of highly annoyed households would be greatest near the track or grade crossing, and decline as the distance to the track or grade crossing increased. This expectation was not observed for the train horn. Instead, the number of highly annoyed households was distributed throughout the geographical area covered by the surveys.

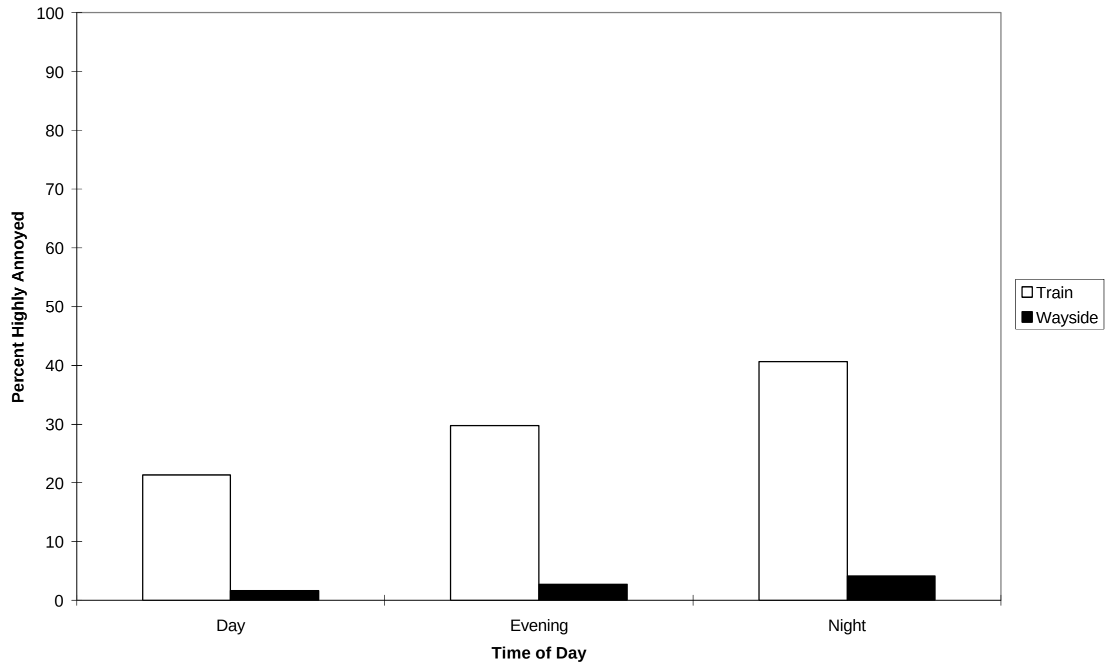


Figure 3. Percent of Highly Annoyed People for Two Warning Devices by Time of Day

This finding may be attributed to a number of factors. First, in the real world, obstructions, the effects of wind, and other weather related events distort the relationship between sound level and distance from the noise source. Obstructions can block the noise path or amplify the noise, while wind may accelerate or block the noise path depending upon its direction. Additionally, the proximity of the survey area to the noise source (3200 feet at the maximum distance) may have been too close to observe this relationship. A survey sample that drew from a large geographical area may have enabled us to detect this relationship.

Prior to the study, it was expected that the wayside horn would shift the distribution of highly annoyed individuals from a relatively broad geographical region to a much smaller geographical region concentrated around the grade crossing. This shift was not observed. The households who were annoyed by the wayside horn were more often than not located in the same areas of Gering, occupied by households who were also annoyed by the train horn. Although located in the same geographical area, respondents who were annoyed by the wayside horn were generally not annoyed by the train horn. There were only two cases in which households who were annoyed by the wayside horn were also annoyed by the train horn.

Given the longer exposure that residents living near each of the grade crossings would have with the wayside horn compared to the train horn, it was hypothesized that these households would experience greater annoyance with the wayside horn compared to the train horn. The data indicates this hypothesis was false. The number of households living near each of the grade crossings which were highly annoyed was lower for the wayside horn than the train horn. While the wayside horn reduced the total number of people who were highly annoyed, it did not appear to concentrate them around the grade crossing.

An interesting question to consider is what factors makes an auditory warning annoying? One obvious factor is proximity to the noise source. The closer one is to the noise source, the louder the horn signal should be. Another contributing factor is the frequency with which the noise source is heard. The more frequently one hears the horn, the more opportunity to become annoyed. These two factors were analyzed, along with two others, age and gender, to determine whether they were effective in predicting high annoyance levels.

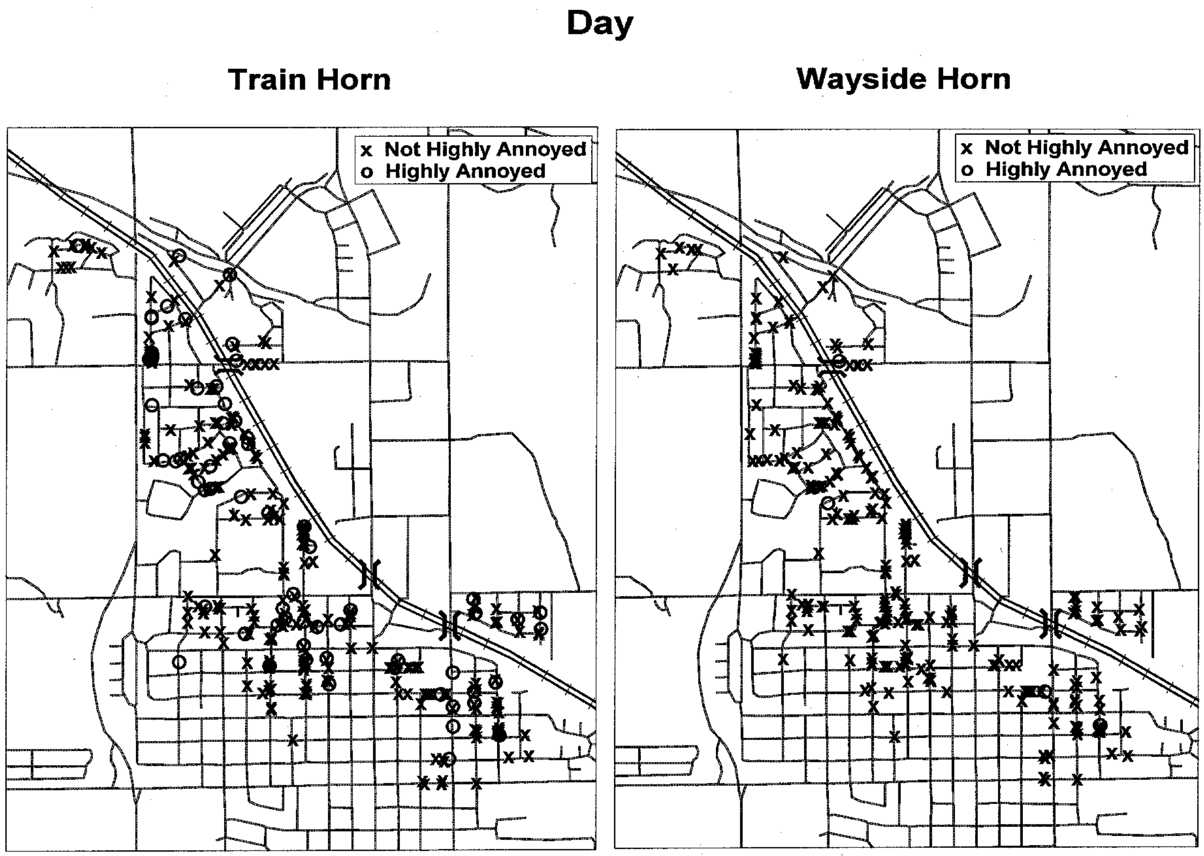


Figure 4. Location of Highly Annoyed People During the Day

Age and gender were examined to determine the degree to which characteristics of the individual contributed to annoyance. Since the sample selection resulted in a sample that differed from the general population, examining the effects of age and gender on annoyance level will address the question: did sample bias affect performance? The relationship between actual sound levels and annoyance was also examined. Chapter 3 discusses this relationship.

These four factors: proximity, frequency, age, and gender were evaluated using a logistic regression procedure. Proximity was measured by either the shortest distance of the respondent's home to the track or the distance of the respondent's home to the closest grade crossing. Both age and gender were unrelated to high annoyance. The fact that age and gender were not significantly related to high annoyance levels suggests that the results of the survey apply to the population as a whole. No relationship between annoyance levels and proximity was found, either. This outcome was surprising, and possible explanations for this result are described earlier. Only the frequency with which respondents heard the horn was related to annoyance levels at statistically significant levels (Night: χ = 27.39 df =1, p, < .00001). The correlation between frequency with which the horn was heard and annoyance level was .41 suggesting a moderately positive relationship between horn frequency and annoyance level. Sorensen and Hammar (1983) also found that train frequency affected annoyance levels. They found that annoyance levels increased up to sixty trains per day and then leveled off with train frequencies greater than sixty.

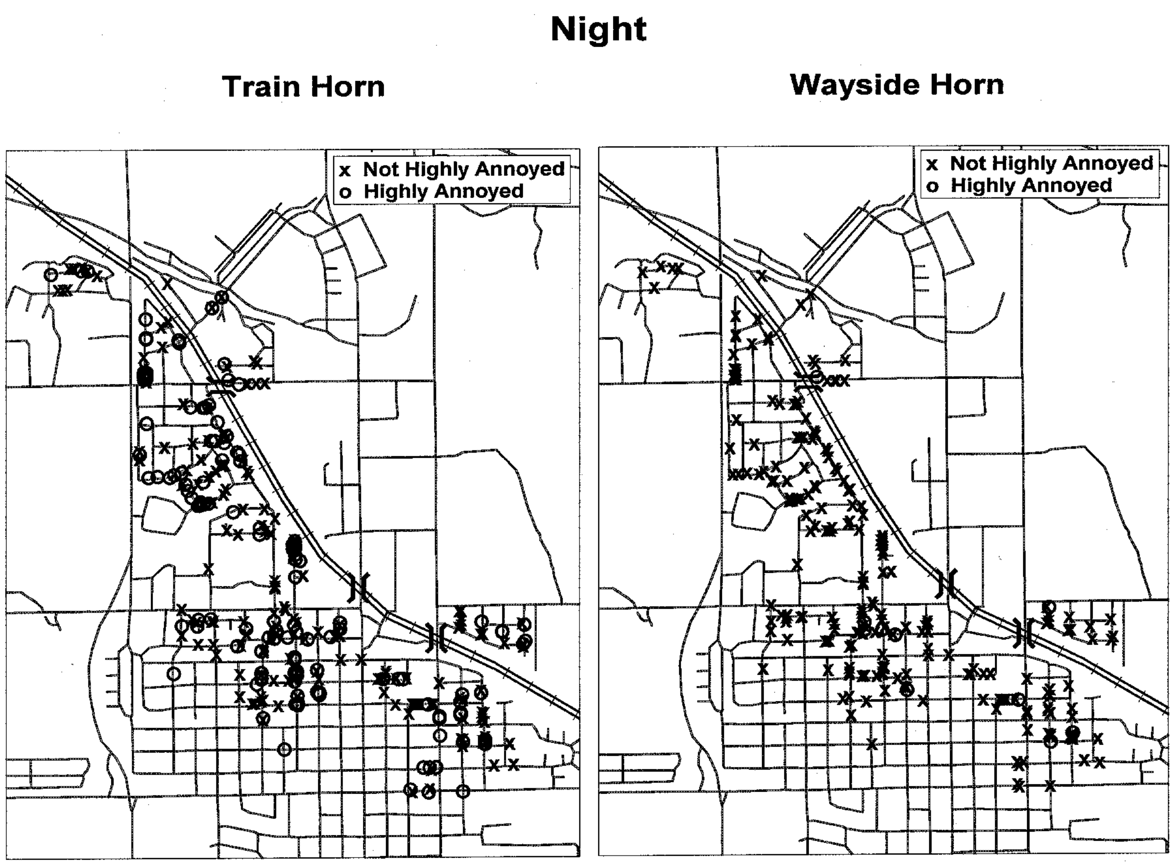


Figure 5. Location of Highly Annoyed People at Night

Interference with activities

Respondents were asked the degree to which the noise from the warning devices interfered with several activities. These activities included the following:

- Sleep
- Opening windows (ventilation)
- Conversation
- Radio and/or TV
- Reading
- Outdoor activities

The two warning devices differed in the degree to which they interfered with activities. Figure 6 shows the percent of households reporting that the warning device interfered with each of six activities. For every activity, fewer respondents reported the wayside horn interfered with activities than with the train horn. McNemar paired comparison tests shown in Table 6 comparing the differences between the two samples, reveal that differences between the two warning devices for each activity were statistically significant. For the train horn, sleep was reported as the activity most interfered with. Sixty percent of the sample reported difficulty with sleeping, compared with 20 percent for the wayside horn. Being able to keep the window open was the second most affected activity, followed by conversation, watching TV or listening to the radio, engaging in outdoor activities, and reading. For every activity except reading, at least 38% of the surveyed households reported interference from train horn noise.

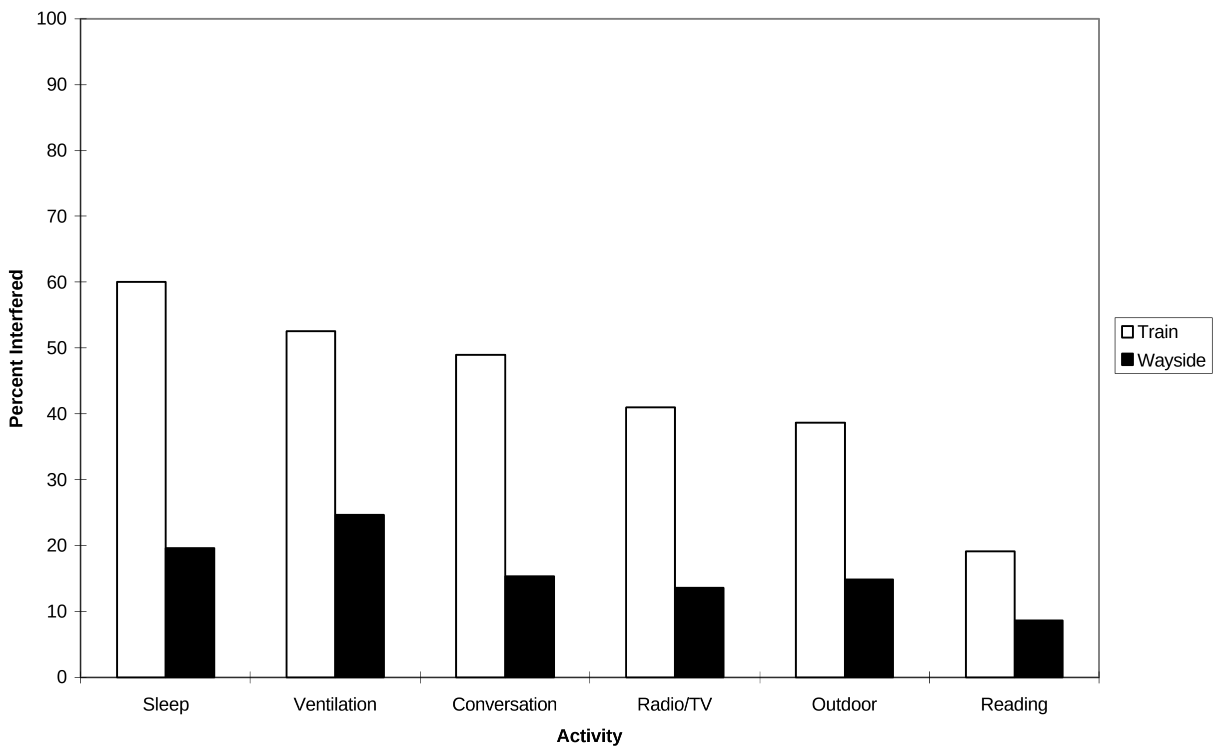


Figure 6. Percent of Households Reporting Interference with Activity

By contrast, the activity interfered with most by the wayside horn, keeping windows open, affects only 25 percent of the households surveyed. Less than 20 percent of the survey sample reports the remaining activities: sleep, conversation, radio or TV, outdoor activities and reading being interfered with.

Table 6. Percent of Households Reporting Interference With Activities

Interference with Activity	Train (%)	Wayside (%)	Chi-square Value	Significance Level *
Sleep	60	19.6	98.02	.0001
Ventilation	52.6	24.7	44.17	.0001
Conversation	49	15.3	75.87	.0001
Radio/TV	41	13.6	58.06	.0001
Outdoor	38.7	14.8	42.92	.0001
Reading	19.1	8.6	18.37	.0001

* Critical Value at 1 degree of freedom = 3.84

Interference with a variety of activities was also examined to understand how they relate to annoyance levels. It is reasonable to hypothesize that high annoyance levels associated with the noise from the warning devices are mediated by the activities with which they interfere. The greater the level of interference in an activity, the greater the level of annoyance. Some activities may have a greater impact on annoyance levels than others. Shultz (1978) summarized survey data from a variety of studies examining the effects of transportation related noise on interference with activities. The data indicates that train noise interferes most with conversation, followed by listening to TV and radio, and sleep. These noise effects also apply to disturbances from aircraft.

The data from both surveys shows that the activities interfered with, which are most closely associated with high levels of annoyance, vary by time of day. During the day, interference with conversations is the only variable associated with high annoyance levels. Table 7 presents the significance level for statistically significant activities. During the evening, interference with both conversation and reading is associated with high annoyance levels. At night, interference with sleep is the only activity associated with high annoyance levels.

Table 7. Percent of Households Reporting Interference with Activities by Time of Day

Time of Day	Interference with Activity	Train (%)	Wayside (%)	Chi Square Value	df	Significance Level
Day	Conversation	23.5	2.5	22.96	1	.0001
Evening	Conversation	32.9	4.3	10.71	1	.0011
Evening	Reading	32.3	4.3	4.92	1	.0265
Night	Sleep	44.8	6.1	68.85	1	.0001

Actions taken

The survey also asked respondents what action they took in response to the noise from the train horn and the wayside horn. Respondents were asked specifically the degree to which they engaged in the following actions:

- stopped talking
- closed windows
- increased volume on audio or video equipment
- covered ears
- wore ear plugs
- complained to local officials or railroad
- landscaped yard
- soundproofed home
- considered moving.

Figure 7 shows the percent of households taking actions to minimize the effects of noise for both of the warning devices. As with interference with activities, noise from the train horn resulted in a much greater impact on residents than noise from the wayside horn. For every activity, a greater percentage of the surveyed households reported taking actions to minimize the effect of the train horn than for the wayside horn. These differences are statistically significant as shown in

Table 8.

Regardless of which warning device residents heard, the actions selected most frequently (stopping conversation, closing windows, and increasing the volume on audio or video equipment) were easy to implement and required little effort. Actions such as landscaping or soundproofing which required greater effort or were relatively expensive, were done by a much smaller percentage of the population and done less often.

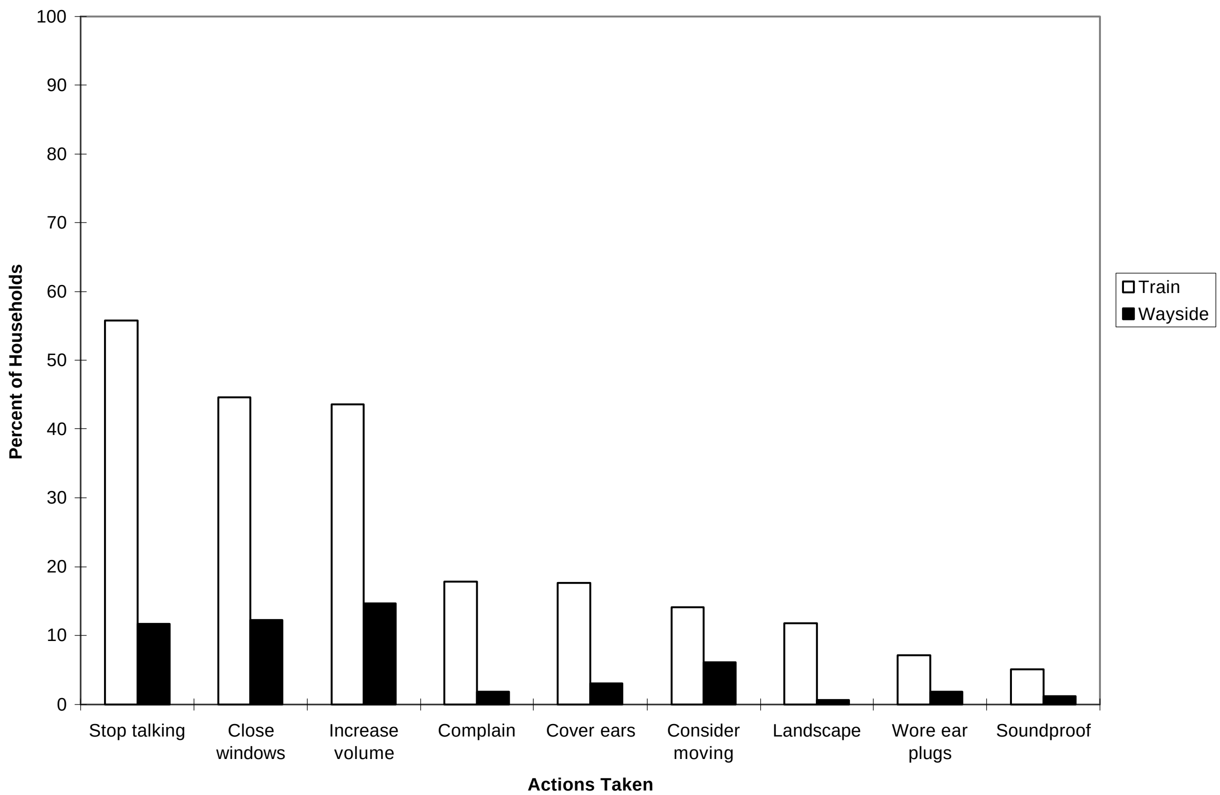


Figure 7. Percent of Households Taking Action to Minimize the Effects of Noise from Warning Device

Table 8. Percent of Households Reporting Actions Taken

Actions Taken	Train(%)	Wayside (%)	Chi-square Value	Significance Level *
Stop talking	55.8	11.7	101.08	.0001
Close window	44.6	12.3	45.13	.0001
Increase volume	43.6	14.7	60.80	.0001
Complain	17.9	1.8	26.69	.0001
Covered ears	17.6	3.1	33.23	.0001
Consider moving	14.1	6.1	18.27	.0001
Landscape	11.8	0.6	22.32	.0001
Wore earplugs	7.1	1.8	5.88	.0153
Soundproof	5.1	1.2	7.69	.0055

* Critical Value at 1 degree of freedom = 3.84

2.2.3 Conclusions

The evaluation of community noise impact indicates that the wayside horn tested is considerably less annoying than the train horn. The wayside horn reduced noise to levels that were more acceptable to the community. The wayside horn was less likely to interfere with activities inside or outside the home and generated fewer actions to minimize the noise.

The variable that best predicted if someone was highly annoyed was the frequency with which the horn was heard. The greater the horn count, the more likely a resident was to be highly annoyed. High annoyance was also related to the activities which were interfered with. The relationship between activity interfered with and high annoyance varied by time of day. During the day, interference with conversation contributed to high annoyance. During the evening, interference with both conversation and reading contributed to high annoyance. Finally, during the night, only interference with sleep contributed to high annoyance.

3. ACOUSTIC ANALYSIS

3.1 METHODOLOGY

3.1.1 Objectives

The objective of the acoustic analysis was to document the sound level and frequency content of the in-service locomotive horn and the wayside horn being evaluated for their effects on driver safety and community noise impact in Gering, Nebraska. In addition, the acoustic data collected was compared to the community noise impact data collected from the survey of the local residents to examine the relationship between noise level and annoyance.

3.1.2 Test Site Selection

The objectives were met by conducting sound level measurements of both the locomotive horn and the wayside horn at 14 sites surrounding the three grade crossings in Gering, NE. It was decided that knowledge of the community noise levels throughout the community could be accurately represented, without becoming too costly, by fourteen measurement sites. These sites were selected on the basis of how annoyed residents were as predicted by their proximity to the grade crossing/track. Annoyance was predicted to increase with proximity to the grade crossing. Of the 14 sites, 3 sites were located in the area predicted to have a very high community noise impact; 3 sites were located in a high impact area; 3 sites were located in a moderate impact area; and 2 sites were located in a low impact area. It was also necessary to locate an additional measurement site 100 ft from each crossing to accurately document the sound levels of the horns without the effects of shielding from buildings and other structures. Table 9 shows the location of each site, its predicted annoyance level, the approximate perpendicular distance from the measurement site to the railroad track, and the approximate distance from the measurement site to the closest grade crossing.

3.1.3 Data Recording Equipment

All 14 sites were instrumented with sound measurement equipment capable of determining the Sound Exposure Level (SEL) and maximum A-weighted sound levels (L_{Amax}) of individual noise events. These sites were also equipped with instrumentation capable of recording the spectral time history of each event.

All 14 sites were instrumented with Bruel and Kjaer Model 2236 sound level meters, set with A-weighting and slow response characteristics, which recorded the Sound Exposure Level (SEL) and maximum A-weighted sound levels (L_{Amax}) of each noise event. Additionally, the sites located 100 ft from each crossing were also equipped with Bruel and Kjaer Model 2148 real-time analyzers which recorded the spectral time history of each event at one second intervals. Wind speed was measured using a wind cup anemometer; temperature and relative humidity were measured using a psychrometer. A Doppler radar gun was used to measure train speed.

3.1.4 Procedures

At least six events were recorded at each microphone location for each horn system. It was desirable to have measurements conducted simultaneously at each location. However, in order to minimize the number of personnel needed, the measurements were broken down into three sets. The first set consisted of locations nearest to the Country Club Road Crossing, namely sites 1-4.

These measurements were conducted on November 7, 1995 and February 7, 1996. The second set consisted of locations nearest to the 10th Street crossing, namely sites 5-9. These measurements were conducted on November 9th, 1995 and February 8, 1996. The third set consisted of locations nearest to the 7th Street crossing, namely sites 10-14. These measurements were conducted on November 8th, 1995 and February 7th, 1996. Although these two sets of data were taken during different seasons, (summer and winter) the atmospheric differences would have a negligible effect on the sound levels at distances where measurements were taken.

Table 9. Measurement Site Locations

Site No.	Location	Predicted Annoyance Level	Distance From Track (ft)	Distance From Crossing (ft)
1	100 ft from Country Club Road Grade Crossing		100	100
2	19 Toluca	High	980	1245
3	2560 Pacific Blvd.	Very High	321	1189
4	2525 Ponder Place	Moderate	1517	1572
5	1225 Pawnee Court	Very High	460	1252
6	1705 Bluff View Dr.	Low	2182	2574
7	1340 T St.	Moderate	1446	1500
8	Gardner Park, corner of 11th and T St.	Very High	919	982
9	100 ft from 10th St. Grade Crossing		100	100
10	100 ft from 7th St. Grade Crossing		100	100
11	Gering Senior High School, corner of 9th and R St.	High	1039	1158
12	500 P Street	High	980	1707
13	McKinley Elementary School, corner of 6th and O St.	Moderate	1503	1928
14	1325 8th Street	Low	2507	2593

Calibration of all acoustic systems occurred before the start of each measurement day and at hourly intervals thereafter. An observer was located at each measurement location to start and stop the data recording capabilities of the sound level meter at the beginning and end of each event. An "event" consisted of the portion of the train pass-by during which the horn could be heard. Due to unforeseen circumstances, the exact time of the train pass by was not known. Often, due to the curvatures of the track, the first indication of an approaching train was the sounding of the horn. Therefore, the first portion of the warning signal may not have been recorded by the sound level meter. Fortunately, because at that time the train was at such a great distance from the measurement locations, the missing portion of the signal would not have contributed significantly to the sound exposure level, and certainly would not have been the maximum sound level. The observer also documented any extraneous noises (car doors, airplanes, etc.) that occurred during an event, and their sound levels relative to the horn. Ambient (background) noise levels were recorded for five to ten minute periods between events.

For consistency, train horn measurements were made only when locomotive speed ranged between 22 and 28 mph. Due to an unforeseen derailment, the speed limit through the area was reduced to 25 mph, and the train speeds recorded were substantially lower than the train speed typical for this section of track. Locomotive speed was monitored and recorded by the observer located 100 ft from the crossing using a Doppler radar gun. Wayside horn system measurements were made between scheduled trains acoustic contamination from the train horns. Personnel from the city of Gering were on hand to actuate the horn system.

Meteorological data including temperature, relative humidity, wind speed, and wind direction was recorded within fifteen minutes of each event by the observer. No acoustic measurements were made if there was any precipitation or snow cover. If the winds were in excess of twelve mph, the data for that event was discarded to avoid acoustic contamination.

3.1.5 Data Reduction

Sound Level

The events recorded by the sound level meters at each microphone location for each horn system were downloaded into a spreadsheet file. Appendix C describes how sound is measured and the practical significance of the sound measures derived for this evaluation. Events were determined to be bad and discarded if: 1) the train speed was not between 22 and 28 mph, 2) the wind was in excess of 12 mph, or 3) the observer noted that traffic or other extraneous noises significantly contaminated the event. An average SEL and L_{Amax} for each warning device at each microphone location was then calculated. The average SEL was used to calculate a day-night average sound level (L_{dn}) at each microphone location, as follows:

$$L_{dn} = SEL + 10 \log (\text{number of trains/day} + 10(\text{number of trains/night})) - 49.4$$

Where SEL is the average SEL for each measurement location. The average number of trains during daytime (7 am to 10 pm) and nighttime (10 pm to 7 am) hours was determined from data collected during the driver evaluation. For a 14 day period, an average of 22 trains traversed the crossings during daytime hours, and an average of 14 trains traversed the crossings during nighttime hours.

Similarly, daytime and nighttime average sound levels, L_{day} and L_{night}, can be calculated as follows:

$$L_{day} = SEL + 10 \log (\text{number of events/day}) - 47.3$$

$$L_{night} = SEL + 10 \log (10 (\text{number of events/night})) - 45.1$$

The average ambient noise level, in terms of L_{eq}, was also calculated for each location. These ambient levels are representative of daytime hours only because data was only collected during the daytime (see Appendix A). An ambient level which is representative of nighttime hours was estimated by subtracting 8 dB from the daytime ambient at locations where traffic was heavy (as noted by the observer) and subtracting 6 dB from the daytime ambient at all other locations (Harris, 1991).

Frequency Spectra

The one-third octave band frequency data recorded at one second intervals for each event were downloaded into a spreadsheet. The time interval where the maximum A-weighted level occurred was determined and the frequency data corresponding to this time was transferred to a separate spreadsheet. This spreadsheet contained the frequency data at the time of L_{Amax} for each event. These spectra were then plotted and analyzed. It was determined that there was no noticeable difference in the horn systems from crossing to crossing. Therefore, an average spectra for the train horn and an average spectra for the wayside horn were computed.

3.2 RESULTS AND DISCUSSION

3.2.1 Sound Level

L_{Amax} was the sound measure selected to describe the maximum sound levels produced by both warning devices. L_{dn} was the sound metric selected to describe the community noise impact of two warning devices. L_{dn} is the metric most commonly used to assess community noise impact. L_{dn} is the most popular measure because it accounts for people's increased sensitivity to noise at night by imposing a 10 dB penalty on all nighttime sounds. The selection of this metric was based upon a large number of research studies conducted by the EPA beginning in the early 1970's on community noise of all types. These conclusions remain scientifically valid and continue to be used by many regulatory agencies.

To determine whether a noise source is sufficiently annoying to warrant action, several regulatory agencies (EPA, HUD, FAA and FTA) defined 65 dBA as the threshold at which noise-induced community annoyance is considered a problem requiring action. Noise levels above 65 dBA require action, while noise levels below this threshold do not. The FTA recently published a report (FTA, 1995) which established more sensitive guidelines for evaluating whether a noise source is sufficiently annoying as to warrant action to reduce the impact on the community. These guidelines take into account not only the absolute level at which many people will be annoyed, but also at what increase over existing ambient (background) noise levels, annoyance will occur. These guidelines enable the user to determine the severity of the impact on the community. Three levels of impact are defined: No impact, impact and severe impact. These impact levels are defined below and shown graphically in Figure 8. The EPA and others have concluded that a 5 dB increase in L_{dn} or L_{eq} is the minimum required for a change in community reaction.

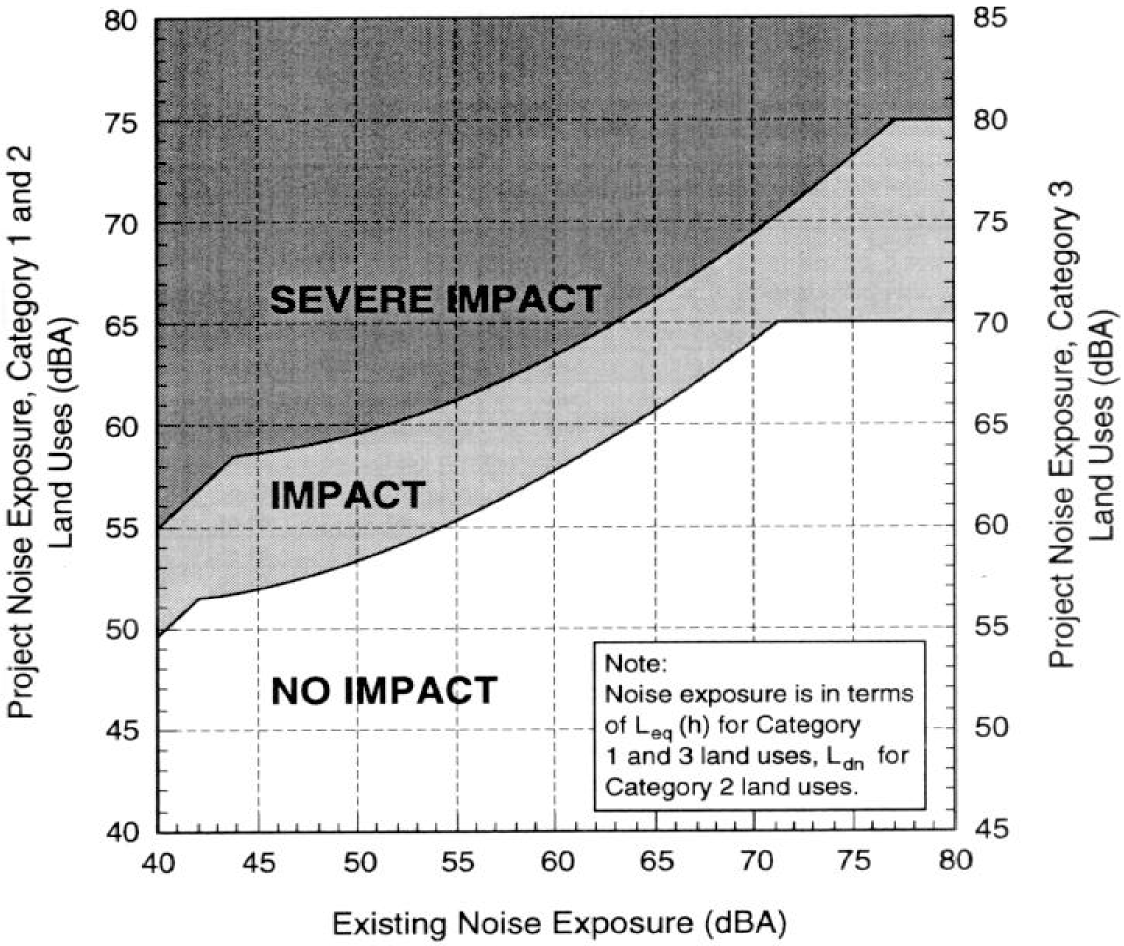


Figure 8. Noise Impact Criteria

Category 1, 2, and 3 land uses are defined as follows:

Land Use Category	Noise Metric (dBA)	Description of Land Use Category
1	Outdoor L_{eq}(h)	*Outdoor $L_{eq}(h)$* Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, as well as National Historic Landmarks with significant outdoor use.
2	Outdoor L_{dn}	*Outdoor L_{dn}* Residences and buildings where people normally sleep. This category includes homes, hospitals and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.

3	Outdoor $L_{eq}(h)$	*Outdoor $L_{eq}(h)$* Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, and churches, where it is important to avoid interference with such activities as speech, meditation, and concentration on reading material. Buildings with interior spaces where quiet is important, such as medical offices, conference rooms, recording studios, and concert halls fall into this category. Places for meditation or study associated with cemeteries, monuments, museums. Certain historical sites, parks, and recreational facilities are also included. Land use for category 3 Outdoor $L_{eq}(h)$ is less sensitive to noise than category 1 Outdoor $L_{eq}(h)$.

- **No impact area** is defined as the threshold at which the percentage of people highly annoyed by the noise (in this instance, the train horn or wayside horn) is not measurable. The increase in noise level results in an insignificant number of people highly annoyed by the new noise.
- **Impact area** is defined as the threshold at which the percentage of people highly annoyed by the noise (in this instance, the train horn or wayside horn) starts to become measurable. The noise level is noticeable to most people, but may not be sufficient to cause strong, adverse reactions from the community.
- **Severe impact area** defined as the threshold when the percentage of people highly annoyed becomes significant. The increase in noise level is likely to produce strong, adverse reactions from the community.

The following discussion uses these guidelines to determine the type of impact on the community for each of the warning devices.

The raw sound level data for each event can be found in Appendixes D and E. The data includes: L_{Amax}, SEL, train speed and meteorological conditions; along with the averages for each location. Federal regulations require that the sound level for the train horn be at least 96 dBA 100 feet from the train. On average, the train horn achieved a maximum sound level of 99.8 dBA, 100 feet from the grade crossing, compared to 86.4 dBA for the wayside horn: a difference of 13.4 dBA. The train horn meets the minimum sound level required of train horns, while the wayside horn fell below this standard.

To determine the community noise impact of the two warnings, the average noise level with and without warning device sounding were compared. The average noise levels with the warning device (L_{dn}, L_{day}, and L_{night}) were calculated from data shown in Appendixes D and E. The ambient noise levels measured between train horn events, were used as the average noise levels without the warning device. Table 10 and Figure 9 show the community noise impact for the daytime period, in which the daytime average sound level, L_{day}, is compared to the measured daytime ambient level. Table 11 and Figure 10 show the community noise impact for the nighttime period, in which the nighttime average sound level, L_{night}, is compared to the estimated nighttime ambient sound level. Table 12 shows the community noise impact for the 24 hour time period, in which the 24 hour average sound level (L_{dn}) is compared to the measured daytime ambient level.

It should be noted that L_{dn} and L_{night} are extremely sensitive to the number of nighttime events. For every increase of 1 event, L_{dn} and L_{night} increase approximately 1 dB. This could easily cause a no-impact area to become an impact area, and an impact area to become a severe impact area.

The impact of community noise level varies as a function of time of day. The noise impact is greater at night than during the day for both warning devices. This is reflected in the greater number of impact and severe impact ratings for the nighttime and 24 hour measurements, compared to the daytime measurements. This time of day effect reflects people's greater sensitivity to noise at night, when the background noise level tends to be lower.

Table 10. Community Noise Impact During Daytime

Location	Measured Average Daytime Ambient (dBA)	Train Horn		Wayside Horn	
		Calculated L_{day} (dBA)	Type of Impact	Calculated L_{day} (dBA)	Type of Impact
1	62	70	Severe	59	Impact
2	54	39	None	Not Audible	None
3	47	66	Severe	24	None
4	48	40	None	22	None
5	46	62	Severe	30	None
6	56	47	None	Not Audible	None
7	52	36	None	28	None
8	52	48	None	30	None
9	66	68	Severe	64	Impact
10	66	71	Severe	59	Impact
11	52	45	None	26	None
12	49	42	None	28	None
13	51	47	None	31	None
14	57	42	None	28	None

Table 11. Community Noise Impact During Nighttime

Location	Estimated Average Nighttime Ambient (dBA)	Train Horn		Wayside Horn	
		Calculated L_{night} (dBA)	Type of Impact	Calculated L_{night} (dBA)	Type of Impact
1	54	81	Severe	70	Severe
2	48	49	None	Not Audible	None
3	41	76	Severe	34	None
4	42	50	None	33	None
5	40	72	Severe	41	None
6	50	57	Impact	Not Audible	None
7	46	46	None	39	None
8	46	59	Impact	41	None
9	58	79	Severe	75	Severe
10	58	82	Severe	69	Severe
11	46	56	Impact	37	None
12	43	53	Impact	39	None
13	45	57	Impact	42	None
14	51	52	None	39	None

There are also differences in the community impact of the noise by type of warning device. During the day, the wayside horn only had an impact on the sites closest to the crossing. These sites were 100 feet from the crossing, with a direct line of sight to the wayside horn. During the night, the wayside horn has a severe impact at only three sites. These three sites represent the locations closest to the grade crossing. All these sites are 100 feet from the grade crossing. By contrast, the train horn has an impact or severe impact at five sites during the day. Three of these sites are located 100 feet from the grade crossing. The other two sites are less than 500 feet from the track. At night, the number of locations in an impact or severe impact area increases to ten. These sites are up to 1000 feet from the track, with the exception of one site. The site at location #6 was located 2152 feet from the track, but there were no intervening buildings or structures to attenuate the signal from the train horn. For severe impact areas, where community action is likely, the train horn affects residents living up to 1000 feet from the track. Although the effects of the train horn is not geographically uniform, the noise is more annoying from the train horn than from the wayside horn.

Table 12. Community Noise Impact Over 24 Hour Period

Location	Measured Average Daytime Ambient (dBA)	Train Horn		Wayside Horn	
		Calculated L_{dn} (dBA)	Type of Impact	Calculated L_{dn} (dBA)	Type of Impact
1	62	76	Severe	66	Severe
2	54	45	None	Not Audible	None
3	47	72	Severe	30	None
4	48	46	None	29	None
5	46	68	Severe	37	None
6	56	53	None	Not Audible	None
7	52	42	None	34	None
8	52	55	Impact	36	None
9	66	75	Severe	71	Severe
10	66	75	Severe	65	Impact
11	52	52	None	66	None
12	49	49	None	35	None
13	51	53	None	37	None
14	57	48	None	35	None

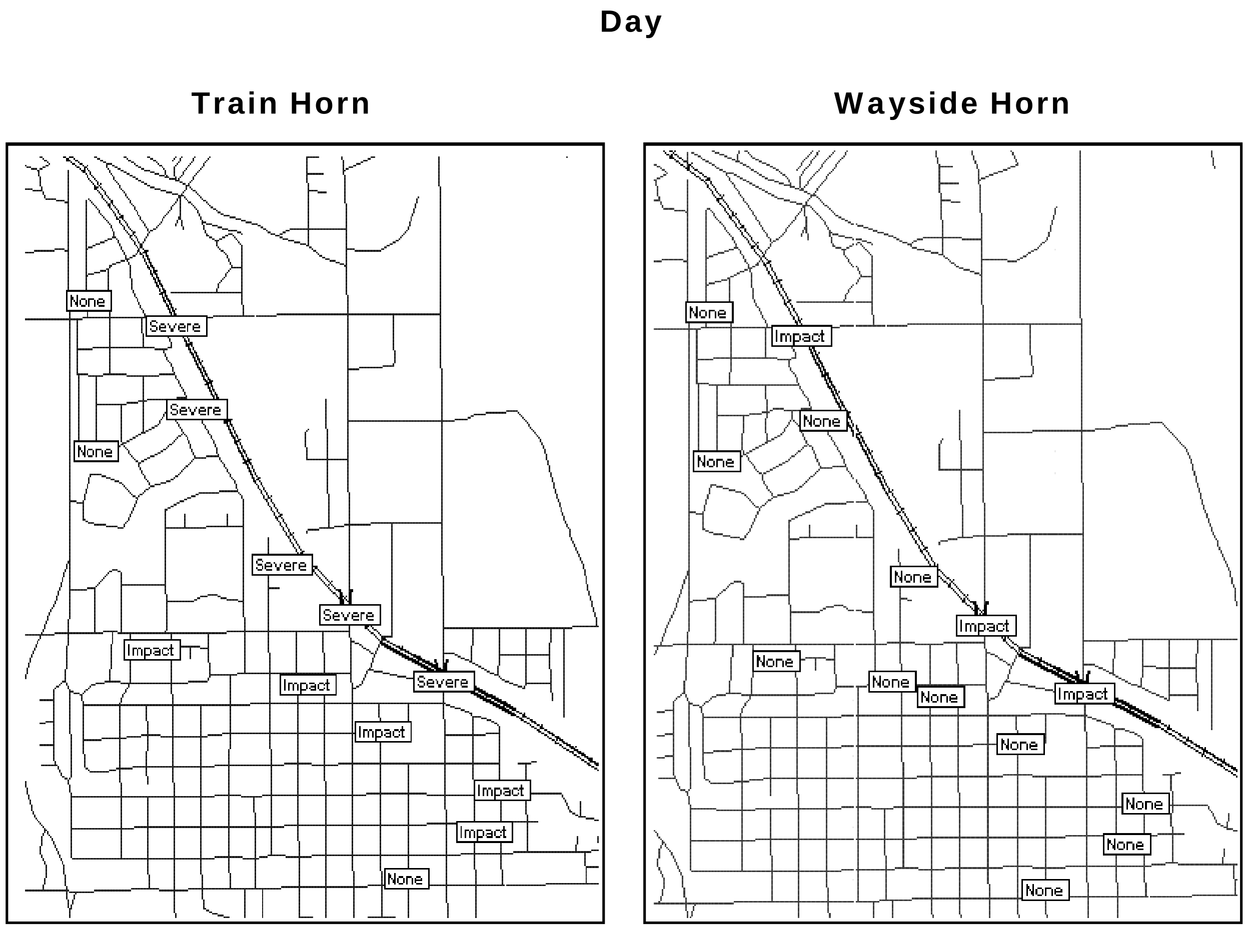


Figure 9. Daytime Noise Impact of Warning Devices

Night

Train Horn | **Wayside Horn**

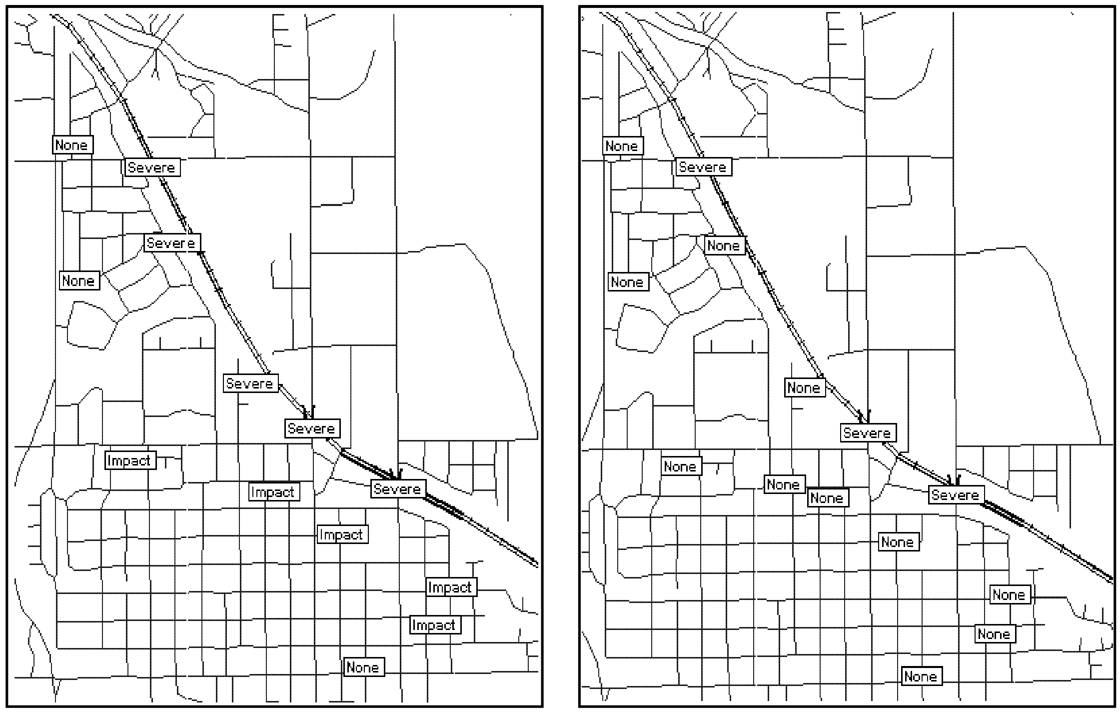


Figure 10. Nighttime Noise Impact of Warning Devices

3.2.2 Frequency Distribution

Figure 11 shows the average train horn and wayside horn frequency spectra. It shows that the wayside horn very closely imitates the train horn, at a sound level 5-25 dB below the train horn. The most common model of train horn used by the Union Pacific railroad is the Leslie three-chime. This horn emits three distinct tones and their harmonics, which, when sounded together, create a relatively broadband signal which can overcome most masking noise. The wayside horn system emits a signal consisting of only one distinct tone and its associated harmonics. This creates a signal that is less broadband and more tonal than the train horn. Due to limitations of this system, it is especially lacking at frequencies above 4000 Hz. Further research is needed to determine the optimal acoustical signal for the wayside horn, whether or not the wayside horn should sound like a train horn, and what type of signal is best able to alert the motorist.

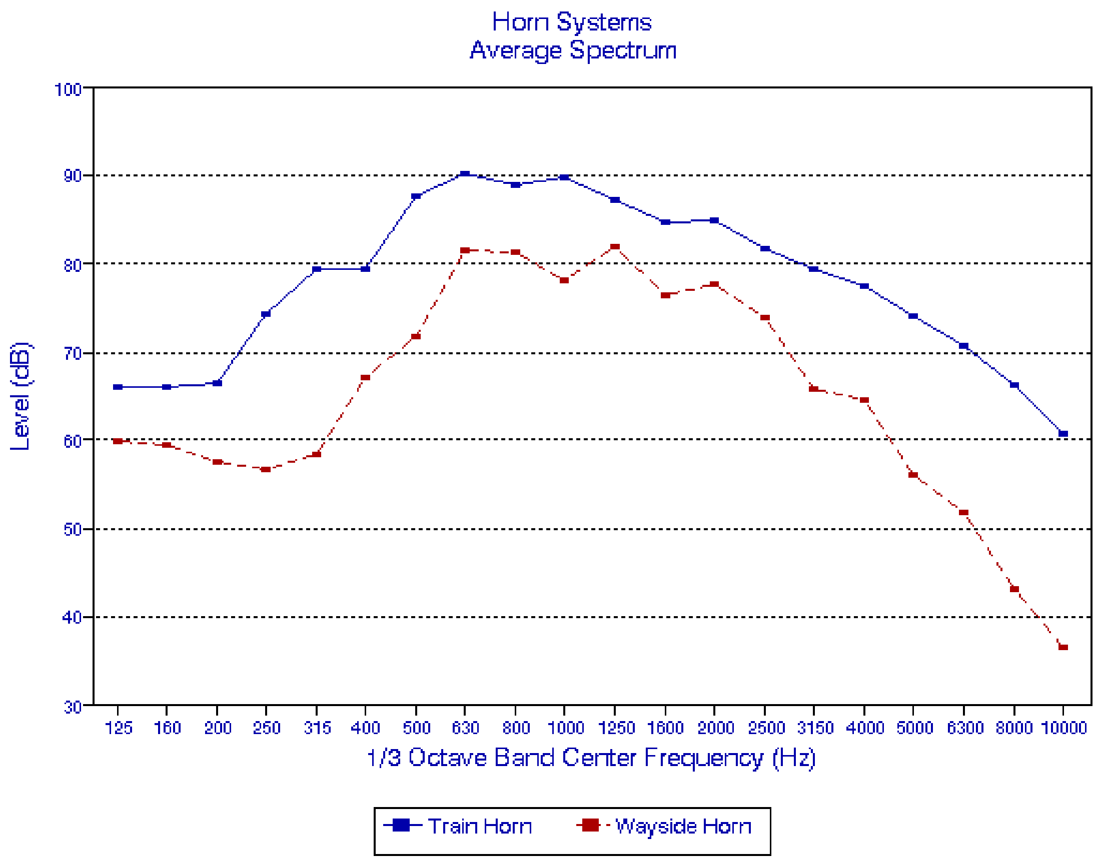


Figure 11. Frequency Spectra for Warning Devices

3.2.3 Relationship between Noise Level and Perceived Annoyance

It was expected that there would be a systematic relationship between noise exposure and annoyance level. As noise exposure increases, individuals are expected to become more highly annoyed. Based upon the inverse square law, it was expected that the number of highly annoyed households would be directly related to their proximity to the noise source. The closer to the noise source, the greater the number of highly annoyed households. However, analysis of the survey data indicates that distance to the noise source was not related to annoyance level. It was suggested that proximity to the noise was a poor predictor of annoyance level due to environmental factors such as trees and buildings and weather related factors such as wind, that can change the amount of noise reaching the listener.

To better establish the relationship between noise level and annoyance level , the same measurements collected at 14 sites in Gering, Nebraska were compared to the survey data collected near those sites. Figure 12 shows the daytime noise levels for each site. For both surveys, noise levels were assigned to a household using the same procedure[2]. For each of the 14 sites where noise measurements were collected, respondents living within a specified distance from the noise measurement site were assigned that noise level. The area within which a respondent was assigned a particular noise measurement was defined by a circle, with a radius equal to half the distance to the track from the measurement site. For example, if the distance from the measurement site to the track was 500 feet, the radius of the circle was 250 feet. This area contains a 3 dB measurement error around the measurement site. When respondents overlapped two measurement sites, they were assigned a number for each site. Only a small subset of the total survey population was assigned to one or more measurements sites.

These data were analyzed using a logistic regression procedure. No statistically significant relationship was found between noise level and annoyance level. This lack of relationship between noise level and annoyance level may be due in part to measurement error in assigning estimated noise levels to a respondent. For example, take the case where two households lived 250 feet from the measurement site. One household lives between the noise source and the measurement site. This household is 250 feet from the noise source. The second household lives on the opposite side of the measurement site, but 750 feet from the noise source. These two households may experience two different noise levels, but they were assigned the same value in the analysis.

Previous studies have also had difficulty establishing a clear relationship between noise level and annoyance level. Isumi and Yano (1991) found that noise level explained less than 20 percent of the variation in annoyance levels. Shultz (1978) suggested that noise measurements are poor predictors of annoyance level because they may not be indicative of the noise levels to which a household is actually exposed. Shultz hypothesizes that a large part of the total noise exposure is generated indoors, and fluctuations between indoor and outdoor noise levels may vary by 30 dB.

[2] This procedure did not take into account environmental differences that may occur between seasons. Unless dense enough to completely block the receiver’s line-of-sight to the source, foliage will have a negligible effect on measured sound levels. Relative temperature changes between seasons can cause differences in sound attenuation, but these differences will be negligible over the propagation distances of concern. Weather related effects such as temperature and wind gradients can cause sound waves to be refracted upwards or downwards, thereby changing the sound levels. These conditions do not occur often, and are not included in a generalized model, such as the one used to calculate the values in Figure 12.

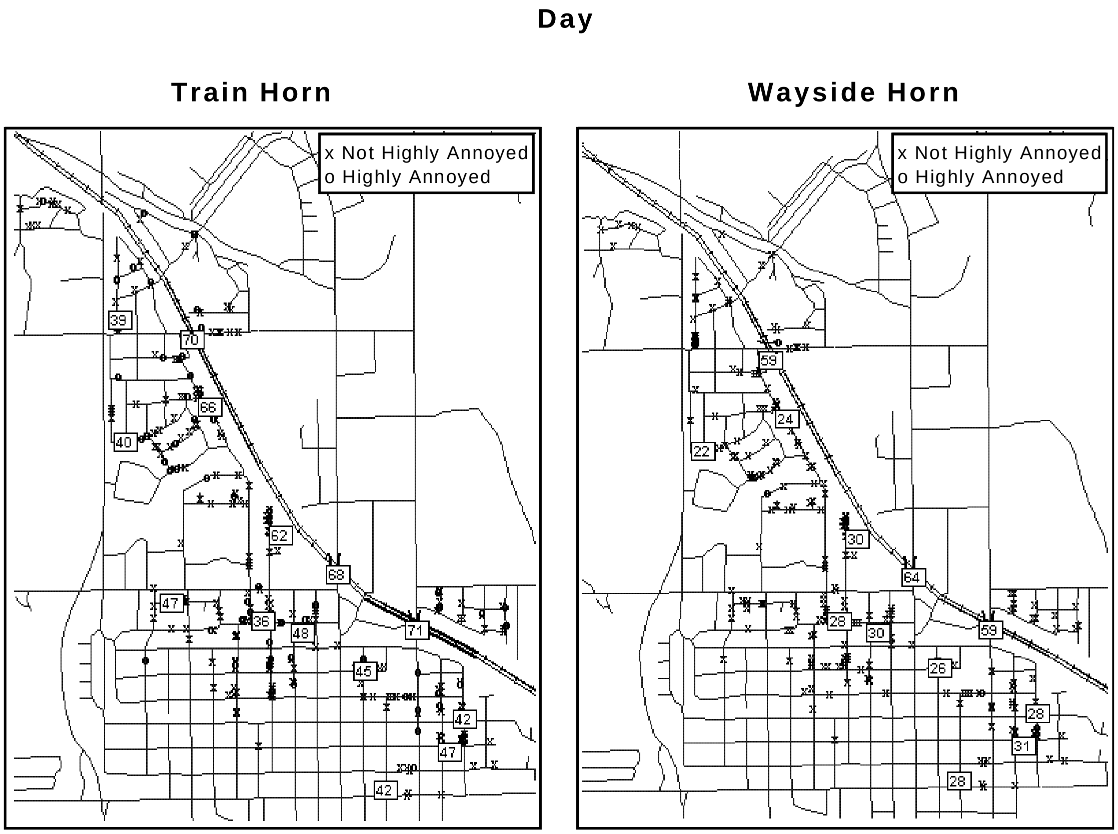


Figure 12. Noise Levels (L_{day}) Overlayed over Annoyance Level for Daytime

While noise measurements were not predictive of annoyance level, they do appear to discriminate when activities are interfered with. Shultz (1978) found that the threshold when train noise interferes with activities like conversation, listening to TV and radio, and sleeping begins at an L_{dn} of 50 dB. For the train horn, noise measurements were predominantly above this level, while the wayside horn noise measurements were predominantly below this level.

3.2.4 Conclusions

At peak sound levels, the wayside horn was approximately 13 dB quieter than the train horn. The lower sound level of the wayside horn compared to the train horn was a significant factor in explaining why the wayside horn was perceived as less annoying than the train horn. Unlike the train horn, the wayside horn did not meet minimum sound level required of train horns. This study did not directly answer what the actual sound level should be for motorists to reliably detect this signal inside the vehicle. The frequency distribution of the wayside horn was narrower than the train horns measured in this study.

For the 14 sites where sound measurements were collected, the wayside horn had a negative community impact during both daytime and nighttime hours using guidelines developed by the FTA. Only the sites defined as severe impact resulted in community annoyance high enough to require action to mitigate the noise. For the wayside horn, the location of the sights defined as severe were all within 100 feet of the track. By contrast, locations defined as severe impact for the train horn were located up to 1500 feet from the track. Clearly, the wayside horn impacted residents within a smaller geographical area.

The current study was unable to establish a relationship between measured sound level and perceived annoyance value, as measured in the two surveys. In part, this is due to measurement error in assigning sound level values to each respondent. However, previous research has been unable to attribute more than a small portion of the variance (20%) in perceived annoyance to physical noise levels. Other factors such as frequency with which the horns are heard and the activities the respondent is engaged in at the time the horn sounds also plays a role.

4. SAFETY EVALUATION

The primary purpose of sounding the horn as the train approaches the grade crossing is to avoid an accident by providing an auditory warning to motorists, bicyclists and pedestrians. At passive crossings, this auditory warning may serve as the only warning that approaching motorists receive. At active crossings, the auditory warning is an additional warning that complements the visual warnings provided by the flashing lights and/or gates that block the grade crossing. Analysis of accident data by the Federal Railroad Administration (1992, 1995) suggests that the auditory warning provided by the sounding of the train horn is an effective deterrent to accidents. When a whistle ban was in effect in Florida, there was a three-fold increase in the accident rate. Analysis of whistle bans in other parts of the country supports this effect (Federal Railroad Administration, 1995).

The use of an alternative warning device to the train horn must also provide an effective warning to the motorist, if accidents are to be prevented. The primary objective of the driver behavior evaluation was to assess the safety of the wayside horn. Is the wayside horn as effective as the train horn in warning motorists and others approaching the grade crossing? To meet this objective, we observed driver behavior at the grade crossing for both the train horn and the wayside horn. We observed when motorists drove through the grade crossing following activation of the warning systems. We measured both the frequency of the violations and the time to collision. Time to collision measures how far away the train is from the grade crossing, in seconds, when the motor vehicle is in the grade crossing.

4.1 METHOD

Video data of motorist behavior at two grade crossings was collected to determine how frequently motorists drove through the grade crossing as the gates descended or around the gates after the gates descended.

4.1.1 Experimental Design

We used a Pretest-Posttest design to compare the wayside horn to the train horn. The pretest condition measured the effect of the train-mounted horn on driver behavior. The posttest condition measured the effect of the wayside horn on driver behavior. Following the completion of the pretest data collection, the wayside horn was activated in place of the train horn when the locomotive approached the grade crossings under observation. There was a three month gap between the pretest measurements and the posttest measurements to give motorists and the locomotive engineers time to adjust to the new wayside horn.

For both conditions, our goal was to collect 12 weeks (84 days) of video data. However, VCR equipment failures at each of the grade crossings as well as problems with the track circuitry at one of the grade crossings (Tenth Street) resulted in a longer data collection period so that a sufficient data sample could be collected. These problems are discussed in more detail in the Data Reduction and Analysis section. Data was collected for a period of 60 seconds following activation of the grade crossing warning devices.

4.1.2 Site Characteristics

Two grade crossings were selected to observe driver behavior: Tenth Street and Country Club Road. The Tenth Street grade crossing is a four lane road located in a commercially zoned part of Gering, with an average daily traffic (ADT) count of 11,240 (2/94). The Country Club Road grade crossing is a two lane road located in residential area. Country Club Road has an ADT count of 2,415.

4.1.3 Equipment

A video camera (Panasonic model WV-CL354) with a 4.5 mm wide angle lens was mounted on a utility pole at each of the grade crossings to record driver behavior. The camera was mounted 35 feet above the ground at Tenth Street and 20 feet above the ground at Country Club Road. Each camera was mounted on the same utility pole as the wayside horn, but at a higher elevation. In each case, the video camera could show driver behavior on both sides of the road between the gates on either side of the track. The video camera fed the signal to a time-lapse Super-VHS VCR (Panasonic model AG6760) located in protected housing at the grade crossing. Each tape recorded 6 hours worth of data. The tapes were changed approximately every 6 days.

The track circuitry responsible for activating the gates, flashing lights and wayside horn also activated a timer attached to the video equipment to begin recording. The video equipment recorded the scene for 60 seconds for each event. The track circuitry activated the gates, flashing lights and video equipment approximately 35-40 seconds before the train arrived at the crossing.

4.1.4 Data Reduction and Analysis

For the pretest period, driver behavior was monitored from November 1, 1994 to January 29, 1995. For the posttest period, driver behavior was monitored from May 24, 1995 to October 22, 1995. During each of the two data collection periods, a number of equipment problems plagued our effort to collect the data.

During the pretest data collection period, the VCR recording the data at Tenth Street failed on several occasions. A replacement VCR was installed while the defective VCR was being repaired. More significantly, problems with the track circuitry at Tenth Street contributed to a number of problems that resulted in this data being discarded entirely. Errant electrical signals due to a shunt in the track ballast produced multiple false alarms in which the warning system was activated, but no train was present. Additionally, problems in the signal equipment also produced *tail ring* in which the warning system was activated a second time after the train passed through the grade crossing. The numerous false activations may have altered driver behavior, so the data was discarded.

During the posttest period, the VCR’s at both grade crossings failed on several occasions. A replacement VCR was installed while the defective unit was repaired; however, this resulted in some loss of data.

After the recording of each videotape was completed, an observer viewed each tape and tabulated the data we wanted to collect. The observer recorded the following events shown in Table 13. A second observer also reviewed the tapes to check the reliability of the recorded data. The data was entered into a spreadsheet to calculate descriptive and inferential statistics.

Table 13. Data Recorded

Event Name	Description
Date	Date event occurred
Violation: Type 1	vehicle went through the grade crossing during descent
Violation: Type 2	vehicle went through the grade crossing after gate descent
Train/False Alarm	whether a train arrived at the grade crossing
Gate Descent Time	time when the gate began its descent
Motor Vehicle Arrival Time	time when the motor vehicle arrived at the grade crossing
Train Arrival Time	time when train arrived at the grade crossing

To evaluate the safety of the two auditory warning devices, two types of performance measures were considered: frequency with which the motorist violated the grade crossing after the warning was given and the proximity of the train to grade crossing when the vehicle was in the grade crossing, as measured by time to arrival. The frequency of motorist violations was also separated by whether the driver went through the grade crossing before the gates completely descended (Type 1) or after the gates descended (Type 2). Type 2 violations are considered more dangerous or risky, since the train should be closer to grade crossing than with Type 1 violations, and therefore, more likely to collide with the train.

The three time events shown above: gate descent time, motor vehicle arrival time, and train arrival time were used to generate three performance measures: warning time, time-to-collision, and violation time. Warning time measures the amount of time the motorist has to respond to the various warnings at the grade crossing until the train arrives at the grade crossing, and was a function of the constant warning time system at the grade crossing. The other two performance measures assessed human performance at the grade crossing. Time to collision measures how far away the train is from the grade crossing when the vehicle is in the grade crossing. The smaller the time to collision, the greater the risk of a collision. Violation time measures how long after the gates begin their descent that the motor vehicle arrives at the grade crossing. The larger the violation time, the greater the risk of a collision.

Since the purpose of the driver behavior evaluation was to assess whether wayside horn was equal to or better than the train horn, a result showing that there was no difference between the two warning systems could have important practical implications for use of an alternative to the train horn. However, measuring no differences between the two warning systems, does not mean that differences do not exist. The evaluation may not have been sensitive enough to detect those differences. To address this concern, a power analysis was performed to determine an adequate sample size so that the evaluation would detect any differences if they exist. This analysis, which is described in detail in Cohen (1977), assumes a Type I error rate of .05, an effect size of w = 0.10. and a power to detect an effect of 0.90. The Type 1 error rate represents the likelihood we will reject the hypothesis that no differences exist between the train horn and the wayside horn, when the hypothesis is true (in this case 5 in 100). Effect size represents the magnitude of the differences in the effects between the train horn and wayside horn, if they are different. The larger the effect size, the more easily we should detect those differences. The effect size of 0.10 is a small effect size and was selected to maximize the likelihood that differences would be detected if they exist. The Type II error rate represents the likelihood that we will accept the hypothesis that there are no differences between the train horn and the wayside horn, when there are differences. A Type II error rate of .10 means that we will accept the null hypothesis 10 times in 100 when it is false. Based upon these assumptions, a sample size of 1051 trains must be used in both the pretest and posttest conditions. The actual sample size of 6481 trains (2552 for the train horn condition and 3929 for the wayside horn condition) exceeded this requirement. In the current study, this means that if the results show no differences between the two warning systems, there is only a 1% chance that real differences between the two warning systems do exist.

4.2 RESULTS AND DISCUSSION

4.2.1 Frequency Based Performance

Table 14 shows the frequency of violations and false activations for both the train horn and wayside horn. The data in Table 14 shows both the actual frequencies and the frequencies normalized by train frequency. The discussion of the results will focus on the normalized data since it controls for the number of opportunities that a motorist could violate the grade crossing.

Table 14. Frequency of False Activations and Violations for Two Warning Devices

	Actual Frequency		Frequency/1000 Trains		Chi-square Value	Significance Level *
	Train	Wayside	Train	Wayside		
False Activations	53	41	21	10	10.50	.0012
Type 1 Violations	48	35	19	9	11.22	.0008
Type 2 Violations	4	18	2	5	3.31	.0688

* Critical Value at 1 degree of freedom = 3.84

The frequency of violations decreased for both warning devices as one goes from Type 1 to Type 2 violations. Thus, fewer motorists appear willing to risk going through the grade crossing after the gates have completely descended than when they are still descending. This data is consistent with data collected by Richards et al. (1991) showing that the percentage of drivers who crossed without stopping decreased as the warning period lengthened. In their study, Richards et al. (1991) found that 32 percent of drivers stopped and waited at the crossing before the gates completely descended, while 60 percent of drivers stopped after the gates were lowered. In the current study, all the Type 1 violations consisted of drivers who crossed without stopping. Only in the Type 2 violations were there events in which the motorist stopped before going around the gates.

Closer examination of the Type 2 violations reveals that risk was not borne by motorists alone, and may be lower than the data in Table 14 suggests. For two of the violations, the motorist went around the gate after the vehicle on the track passed through the grade crossing, but before the gates returned to their vertical position. The vehicle on the track was a highrailer. After the highrailer passed through the grade crossing, the track circuitry failed to trigger the gate to return to its normal resting position. In another instance a train never arrived at the grade crossing or took longer than 60 seconds to arrive. Finally, one Type 2 violation occurred when a flagger waived the motorist through the grade crossing. Thus, only 18 of 22 violations can be classified as true Type 2 violations. Of these remaining Type 2 violations, six consisted of pedestrians or bicyclists rather than motorists.

The Type 1 violation frequency was greater with the train horn than with the wayside horn. Using the normalized data, there were more than twice as many violations with the train horn than with the wayside horn. These differences are statistically significant as indicated in Table 14. The Type 2 violation frequency was greater for wayside horn than for the train horn. However, this difference is not statistically significant. This data suggests that for the observed test conditions, the wayside horn does not result in unsafe driving behavior compared to the train horn.

An interesting question is why were motorists and pedestrians more likely to violate the grade crossing in the train horn condition than in the wayside horn condition? Was this a chance occurrence or was this behavior due to some phenomena that may affect performance with the wayside horn, as well. One possibility is suggested by the frequency of false activations in the two conditions. As with the violation frequency, the false activation frequency was greater in the train horn condition than in the wayside horn condition. The false activations may contribute to lower credibility of the warning system, and thus, motorists may be more willing to go around the gates, in the belief that a train is not approaching, or is so far away that it poses an insignificant risk.

4.2.2 Time Based Performance

Time based performance measures were also evaluated to determine whether there were differences between the two types of warning devices. Table 15 shows the relationship between warning device and warning time. For both types of warning devices, the warning time was consistent for both Type 1 and Type 2 violations. The mean warning time was slightly longer for the wayside horn (25 s) than the train horn (24 s). However, these differences were not statistically significant. The warning time ranged between 18 and 38 seconds for both devices and falls within the warning time range (between 20 and 40 seconds) recommended by Richards, Margiotta, and Evans, (1991) to maximize compliance behavior.

It was not possible to determine whether the differences between the two warning devices for the Type 2 violations were statistically significant because the sample size for the train horn condition was too small.[3] From the motorist's perspective, the difference between the two warning conditions of 0.8 seconds is probably insignificant.

---

[3] In two of the four violations, the track vehicle, a highrailer, passed through the grade crossing before the motor vehicle went around the gates. In another instance, no train actually arrived at the grade crossing before the video camera stopped recording. In only one out of the four Type 2 violations was a train observed arriving at the grade crossing after someone went around the gates and this case involved a pedestrian, rather than a motorist. A sample size of one is too small to draw any meaningful comparisons as well as making it impossible to draw any statistical inferences. This situation applies to the time to collision measure, as well.

Table 15. Mean Warning Time for Two Warning Devices

Violations	Train Horn (s)	Wayside Horn (s)	t-value	Significance level (p)
Type 1	23.8	25.2	1.700	0.0929
Type 2	24.0	24.8	-	-

Table 16 shows the relationship between warning device and time to collision. As expected, the mean time to collision was greater for the Type 1 violations than the Type 2 violations. The shorter time to the grade crossings indicates that there was greater risk of a collision with Type 2 violations than with the Type 1 violations.

For both types of violations, the mean time to collision was greater for the wayside horn than the train horn. However, the differences between the train horn and the wayside horn were not statistically significant.[4]

Table 16. Mean Time to Collision for Two Warning Devices

Violations	Train Horn (s)	Wayside Horn (s)	t-value	Significance level (p)
Type 1	21.6	22.6	1.409	0.1627
Type 2	10.0	14.2	-	-

Table 17 shows the mean violation time by type of warning device. As expected, the violation time was higher for the Type 2 violations than the Type 1 violations. The higher the violation time, the greater the risk of a potential collision with the train. A comparison of the two warning devices shows that the mean violation time for the Type 1 violation is the same for the two warning devices. The differences between two warning devices for the Type 2 violations are statistically significant. Here the violation time is much greater in the train horn condition. However, in 2 out of the 4 violations, the vehicle on the tracks had already passed through the grade crossing. The vehicle on the track was a highrailer and the gate failed to return to its non warning state after the vehicle passed through the grade crossing.

Table 17. Mean Violation Time for Two Warning Devices

Violations	Train Horn (s)	Wayside Horn (s)	t-value	Significance level (p)
Type 1	2.3	2.3	0.000	1.0000
Type 2	42.3	10.1	7.034	0.0001

An important question which cannot be answered directly by this evaluation, is whether the results of the driver behavior evaluation can be generalized to other regions of the country? Gering,

[4] The sample size of one for the wayside horn Type 2 violations was too small to make statistical inferences.

Nebraska may be different from a large urban city in terms of the accepted norms of driving behavior. The residents may be more (or less) law abiding than drivers in other parts of the country. More importantly, will drivers respond in the same way to both auditory warnings as the drivers who passed through the grade crossings in Gering, Nebraska? Is there something unique about the grade crossings in Gering, NE. that is not likely to be found elsewhere? For example, sufficient numbers of residents complained about the annoying qualities of the train horn and sought a more suitable alternative from their public officials. These residents, when driving in their motor vehicles, may be more receptive to the wayside horn than drivers who are not.

Although the performance differences between the two warning devices are not statistically significant, there is an important caveat. Due to the small number of violations as shown in Table 14, it is possible that real differences between two warning systems for both total warning time and time to collision do exist. A power analysis for both time related measures suggests that there is only a 17 percent chance of finding differences between the horn systems, if they exist. This analysis was based upon a Type I error of .05, an effect size of .20 and a sample size of 52.[5] Thus, the possibility exits that the evaluation was not sensitive to measure differences in behavior between the two systems.

Although data was also collected at the Tenth Street grade crossing for both the train horn and the wayside, the data for the train horn condition was discarded due to equipment problems discussed earlier. However, the wayside horn data for both grade crossings was evaluated to learn how driver behavior changed as a function of the grade crossing. To make the evaluation as similar as possible, data missing at one site due to failure of the data collection equipment was also eliminated for the same time period at the other grade crossing. Table 18 shows how false activations and crossing violations vary by grade crossing. Looking at the normalized data, there were fewer Type 1 violations and false activations at Country Club Road than at Tenth Street. These differences were statistically significant. There were no statistically significant differences for the Type 2 violations. Since the warning device was the same at both grade crossings, the differences in Type 1 violations are due to differences that existed between the two grade crossings. These factors could be track related or traffic related. The higher number of false activations at Tenth Street, alone, or in combination with the traffic related differences, could have contributed to the higher level of Type 1 violations. Again, the false activations may have lowered the motorists faith in the “accuracy” of the warning system, resulting in a higher rate of noncompliance with the warning system. Getty, Swets, Pickett and Gonthier (1995) suggests that people are sensitive to the rate of false alarms and behave in a way that takes into account the rate of false alarms.

[5] An observed effect size of .23 was calculated from the data on time to collision and supports the assumption of an effect size of 0.20 used in the power analysis.

Table 18. Frequency of False Activations and Violations for the Wayside Horn at Two Grade Crossings

	Actual Frequency		Frequency/1000 motor vehicles/day		Chi-square Value	Significance Level *
	Tenth St.	Country Club Rd.	Tenth St.	Country Club Rd.		
False Activations	274	24	0.387	0.158	223.64	.0001
Type 1 Violations	58	12	0.082	0.079	35.63	.0001
Type 2 Violations	2	10	0.003	0.066	3.27	.07

* Critical Value at 1 degree of freedom = 3.84

4.2.3 Conclusions

This evaluation of motorist behavior suggests that the wayside horn will not result in behavior that puts the driver at increased risk compared to the use of the train horn. The frequency of Type 1 violations was lower for the wayside horn than the train horn, while the time to collision and violation time was not statistically or practically different for either warning system.

During the evaluation period, the constant warning time system worked properly at both grade crossings and did not appear to affect motorist behavior. However, an increased level of false activations at one grade crossing may have contributed to an increased level of noncompliance. Motorists were more likely to drive around the gates when the number of false activations increased.

A future study should also examine whether driving behavior varies with track circuitry that lacks constant warning time. Bowman (1987) indicates that consistent operation of warning systems is a key factor in commanding the respect and hence compliance with those warning systems. Grade crossings that lack constant warning time track circuitry have more motorist violations and more accidents than grade crossings that contain constant warning time warning systems.

In both the train horn and wayside horn conditions, driver behavior was determined, in part, by the presence of the gates. To the extent that gates control motorist behavior, differences between the two warning devices may have been masked. Data from Richards et al. (1991) study on optimal warning times indicates that as the time delay increases between when the warning is initiated and the gates completely descend, motorists are more likely to continue through the grade crossing without stopping. The gate descent time in this study was relatively short (10 s). This short descent time may have reduced the overall violation rate compared to grade crossings with longer descent times. Motorist behavior with the two warning systems may or may not vary as gate descent time increases. Evaluating the two warning systems with longer gate descent times would provide an answer to this question. An evaluation of the two warning devices without gates at the crossing would indicate how these devices compare without the influence of gates.

5. IMPLEMENTATION CONSIDERATIONS

The wayside horn must be viewed as part of a grade crossing system, not simply a safety device that operates in isolation. Included in this system are a variety of warning devices, protective barriers, roadway, track, lighting, operators and vehicles. Changing one part of the system may impact safety directly, as well as indirectly, through its interaction with other components of the system. For example, replacing the train horn with the wayside horn will affect performance by localizing the auditory warning to a smaller geographical region, closer to the motorist. It will affect the safety of the system indirectly through the method by which the auditory warning is activated.

The current study did not set out to evaluate how the wayside horn *should be implemented* to maximize safety while minimizing community noise impact. Nevertheless, the method of implementation will impact safety at the grade crossing as well as community noise. Some of these problems are identified, along with issues they raise and potential solutions.

5.1 ACTIVATION METHOD

Perhaps the most significant implementation issue affecting warning effectiveness and human behavior is how the auditory warning will be activated. Currently, the locomotive engineer bears the responsibility for activating the train horn.

Two methods have been proposed for activating the wayside horn. In the first method, the track circuitry that triggers the flashing lights and gates also triggers the wayside horn. In the second method, the engineer in the locomotive cab activates the wayside horn. The locomotive engineer presses a control button that sends a signal to the wayside horn. This signal triggers the wayside horn. Older locomotive cabs enable the engineer to moderate the loudness and duration of the train horn signal. Some current generation cabs limit the flexibility to control the loudness level of the horn. Saurenman and Robert (1995) describe one company's implementation of this approach. Their approach uses a radio signal to activate the wayside horn. The wayside horn returns a signal to the locomotive cab indicating whether the wayside horn has sounded. If the wayside fails to activate, the train horn activates. If the wayside horn sounds, the train horn remains silent. Activation by track circuitry was the method used in the current study.

Both methods will impact the motorist and locomotive engineer in different ways. For the track circuitry method of activation, the automatic process by which wayside horn is activated would reduce <u>physical</u> workload by relieving the engineer of this activity. Currently, the engineer begins sounding the train horn at the whistle post, approximately ¼ mile away from the grade crossing. For the engineer, removing the need to sound the horn at some active grade crossings with wayside horns will increase mental workload and may increase operator errors. Mental workload will increase because the engineer must remember which grade crossings have the wayside horn and which do not. As the engineer learns to avoid sounding the horn at crossings with the wayside horn, he or she may forget to sound the horn at crossings without the wayside horn or confuse crossings with the wayside horn with those that do not have the wayside horn. These errors can contribute to fewer auditory warnings at some crossings without the wayside horn and too many auditory warnings at others.

The method of activation also impacts when the warning is issued and consequently the amount of time available for the motorist to respond. In the situation in which the engineer activates the train horn or wayside horn, the warning is sounded when the locomotive arrives at the whistle post. The whistle post, located at a fixed distance from the grade crossing (typically 1/4 mile), means that the warning time varies with train speed.[6] For warnings activated by fixed block track circuitry, warning time also varies with train speed. Above a certain train speed, the motorist receives a warning with insufficient time to respond. Conversely, below a certain train speed, warning time may be so long that the motorist disregards or ignores the warning. The variability in warning time is likely to contribute to a loss of respect for the warning system. As Richards et al., (1991) documented, this warning time above 40 seconds results in greater number of motorist violations at the crossing and increased risk of accidents.

However, if the wayside horn is tied into track circuits that contain constant warning time controls, the motorist would be more likely to receive the warning with sufficient time to respond safely. Ideally, the motorist would always receive the same amount of warning time. Currently, constant time warning track circuitry is installed at only 13% of grade crossings 1994 (Volpe National Transportation Systems Center and PRC Inc., in preparation).

In the current evaluation, a number of problems with the track circuitry contributed to false activations of the warning system. Salt placed on the road by snow plows leached into the track ballast. When the salt reached a sufficient concentration it would shunt the track circuits, activating the warning devices and resulting in a false activation. In another situation, the wayside horn was reactivated after the train passed through the grade crossing. These false activations may have decreased the motorists respect for the warning devices and increased undesirable behavior. In some instances, the track circuitry failed, resulting in no warning activation when the train approached.

Part of the success of the train horn may result from the motorist's association of the auditory warning with the locomotive. Since the train horn is attached to the locomotive, the motorist knows the auditory warning means the locomotive is nearby. However, for the wayside horn, the motorist will learn that the auditory warning is not always associated with a nearby locomotive, to the extent that false activations occur. The implications of this association are threefold. First, the motorist may be more likely to disregard auditory warnings at crossings with wayside horns. Second, the motorists' disregard for auditory warnings may generalize to situations where the auditory warning is on the train. Third, the noise associated with the wayside horn may draw the motorist's attention toward the source of the noise at the grade crossing, and away from the train. All three of these implications suggest that the wayside horn could increase the probability of an accident at the grade crossing.

---

[6] Location of the whistle post varies from state to state (Tustin, Richards, McGee, and Patterson, 1986; Jennings, 1995). Some states have no regulations regarding whistle post location. The predominant locations is 1/4 mile from the grade crossing found in 19 states. In 14 other states, the whistle post location varies from 300 feet to 1800 feet from the crossing.

Another problem with activation by track circuitry was related to the need for feedback that the wayside horn was operating properly. Because the engineer could not hear the horn at the crossing, he or she relied on a visual signal (a strobe light) to indicate that the wayside horn was operating properly. However, several engineers expressed a lack of confidence that the wayside horn was operating even when the wayside horn was operating properly and the strobe light was on. As a result, these engineers would sound the horn. Some engineers felt it was important to sound the horn even if the wayside horn was operating properly. Several factors may be affecting the engineer's behavior in this situation. First, the engineer bears some legal responsibility in an accident. Several engineers expressed concerned that they would be found at fault in an accident if the wayside horn sounded, but they did not sound the horn. Second, sounding the train horn remains one of the few actions an engineer can take to warn approaching motorists. The train horn warning may become particularly important should the warning system fail at a grade crossing protected by active warning systems. The wayside horn activated by track circuitry takes away this control and redundant warning system, while the responsibility remains. It also eliminates a redundant warning, making the system more vulnerable to operator errors when a breakdown in one of the components occurs.

During the wayside horn observation period, a related feedback problem occurred with trains traveling slower than 28 mph. Below 28 mph, the train would reach the whistle post before the warning system was activated. Since the engineer did not see the strobe light, indicating that the wayside horn was working, the train horn was sounded. Shortly thereafter, the wayside horn would sound and the gates and lights were activated. Thus, both auditory warnings would sound, increasing the community noise impact above what it would be with the train alone.

By contrast, the activation method in which the engineer activates the wayside horn, leaves the engineer in control of the auditory warning system. Giving the engineer control over the environment is important, given the engineer's responsibility to operate safely. This method also keeps the engineer actively involved and is helpful in maintaining situational awareness. It also addresses the problem of additional information processing workload by keeping the engineer's task the same regardless of the type of crossing the train is approaching.

The drawback to this method accrues primarily to the motorist at the grade crossing. Assuming the engineer sounds the train horn at the whistle post, and the train speed varies from train to train, the motorist will receive a warning that varies in the amount of time before the train arrives at the grade crossing. To provide a constant warning time, the engineer would need information that would indicate when to sound the horn for a given train speed. Currently, no mechanism exists to provide this information. Although a prototype exists using the engineer to activate the wayside horn, it has not been field tested to determine how it performs in revenue operations. Testing will be necessary to identify any problems and determine its impact on motorist behavior and operation in the locomotive cab.

5.2 HARDWARE DESIGN

Pilot testing prior to the field test as well as operation during the field test identified a number of problems with the wayside horn. These problems (Coplen, 1995) can be divided into two categories, design and maintenance. While these problems are specific to this device, they call attention to issues which should be considered in the design of acoustic warnings exposed to the elements, in general.

During pilot testing and the experimental period, several components failed (Coplen, 1995). Some of the components failed because of exposure to the elements. A computer chip failed when the temperature dropped below -10^{o} F. Several other components failed due to condensation and precipitation. Dirt and dust also entered the box and impaired the operation of various electronic parts. To command motorist respect, a traffic control device needs to be reliable. The specifications for an acoustic warning must insure that the system is sufficiently reliable and will withstand exposure to extremes of weather that exist in the United States.

Due to the hardware failures, the wayside horn required frequent maintenance to replace and repair defective parts. The staff responsible for maintaining the wayside horn complained of difficulty accessing parts within the control unit (Coplen, 1995). The box was too small to permit easy access. The staff also complained that the control unit was overly complex. The complexity of the system made it difficult for the local utility employees to diagnose failures since they did not understand its operation. In addition, some parts that needed repair had to be sent to a distant repair site, taking several days. The staff responsible for maintaining the system suggested designing the system to minimize maintenance. They recommended minimizing the number of components and increasing the number of off-the-shelf parts. They also suggested designing the housing to be more accessible. These problems and the proposed solutions demonstrate the importance of testing to identify problems and issues that need resolution as a warning device moves from concept to commercial application.

5.3 STANDARDIZATION

It is possible that the number of auditory warnings for trains will multiply as different devices are developed to selectively address different problems. Wayside horns may be used to reduce community noise, replacing the train horn as the primary source of the auditory warning at grade crossings. As motor vehicle interiors become increasingly well insulated from the exterior environment, in-vehicle auditory and visual warnings may take their place. Finally, the locomotive engineer will continue to sound the train horn to warn trespassers, and as a back-up warning, if the wayside auditory warning fails.

If auditory warnings for trains multiply to serve similar functions in different environments, it is important to ask whether the warning signal should be standardized or varied to distinguish the different contexts in which the warning is given. The advantage of standardizing the signal in different contexts is that the listener will recognize a uniform signal more quickly than a signal that varies with context, resulting in faster response time. For this reason, the Manual on Uniform Traffic Control Devices (Federal Highway Administration, 1978) recommends the standardized presentation of traffic control devices. The disadvantage of a standard signal may occur if the warning signal loses the respect of the motorist. For example, if too many false activations occur with the wayside horn so that it no longer reliably predicts the approach of the train, the listener may ignore the signal in other contexts, even if it is a reliable signal. Multiple warning signals for different contexts would result in loss of respect, only for the situation for which the warning signal was a poor predictor of train arrival.

The optimal solution to the issue of standardization requires a more complex response. Ideally, one would respond to the loss of warning signal credibility by making sure the signal remained credible. Any signal, standardized or not, will fail to command the respect of the listener, if it fails to provide reliable information. The gains made by providing a uniform signal may outweigh the problems associated with the loss of credibility. However, a standardized signal may not need to be identical in all situations. For different situations, small changes in the design of the signal may be made without affecting the association between the signal and the message conveyed. Just as a music sung by two people in two different keys conveys the same melody, but indicates a different source, so too can a warning signal be designed to convey the same message, " a train is approaching" while varying parameters as pitch to indicate a different source. These modified designs can accommodate the constraints of different environments.

5.4 CONCLUSIONS

A number of issues were identified that will affect the effectiveness of a wayside horn to warn motorists and prevent collisions with trains. These issues included method of activation, hardware design and standardization.

Two methods of activation were identified: track circuitry and engineer activated. There are tradeoffs that must be considered in selecting either method. The engineer activated method has not been subjected to evaluation in revenue service, but remains a promising approach. Activation by track circuitry with constant warning times is a viable approach if the track circuitry is reliable. In the current study, track circuits were unreliable at one of two grade crossings monitored. Additionally, constant warning time track circuitry is currently available at only a small percentage of the grade crossings protected by active warning systems. This means that the majority of actively protected grade crossings will warning times that vary as a function of train speed. A significant concern is whether the motorist will no longer associate the auditory warning with the imminent presence of the train when the warning device is located at the grade crossing. To the extent that the warning system operates unreliably, the warning system is likely to lose credibility with the motorist. A similar concern exists for placement of the wayside horn at grade crossings with fixed block track circuitry. The motorist may come to disassociate the appearance of the train with the activation of the warning.

The current evaluation also identified several design and maintenance issues related to the wayside horn evaluated for this test. Exposure of the elements impaired the performance of several hardware components. The components of the wayside horn must be designed to withstand the extremes of weather found in the United States. The system also needs to be designed to facilitate ease of maintenance. Important design features that contribute to ease of maintenance include: minimizing the number of components, using modular components that are easy to replace, and designing the housing to facilitate easy access.

Finally, standardization of the auditory signal was recommended to facilitate quick motorist recognition and action.

6. SUMMARY AND CONCLUSIONS

6.1 DRIVER SAFETY VS. COMMUNITY NOISE IMPACT

There is an inherent conflict in the effects of the train horn on different populations. For motorists, the train horn serves as a warning of the approaching train. For residents living near the grade crossing, the train horn is perceived as annoying. The sound level needed to attract the motorist's attention disrupts and interferes with activities of nearby residents.

The wayside horn evaluated in this study lowered the community noise impact, while maintaining, safety effectiveness at levels similar to the train horn. Significantly fewer residents reported being annoyed by the wayside horn than by the train horn. The wayside horn reduced interference with the normal activities that residents participate in throughout the day. The reduction in community noise impact of the wayside horn can be attributed to two factors. First, placing the horn in a stationary position reduced the number of people exposed to the auditory warning. Second, the actual sound level of the wayside horn was approximately 10 dBA lower than the train horn. A signal which is 10 dB lower will be perceived as half as loud by most people.

As measured by the frequency and time to collision, the wayside horn did not increase the likelihood that motorists would violate the crossing, compared to the train horn. While motorist behavior was similar in both auditory warning conditions, we don't know whether the motorist actually heard the wayside horn. Because we could not separate the effect of the gates and flashing lights from the effect of wayside horn, it is not clear what "controlled" the motorist's behavior. Although accident data (Federal Railroad Administration, 1992; Federal Railroad Administration, 1995) suggests that auditory warnings play a significant role in preventing accidents at these types of crossings, we don't know the relative contributions of each warning device. If the gates and lights were the primary factor affecting motorist behavior at the crossing, differences in motorist behavior due to the two auditory warning devices may have been masked. In a situation where the gates and lights were less effective (for example when the gate descent time is high), the auditory warning may become more salient as a warning to the motorist. In that case, the differences between the two warning devices might have been larger than in the current study.

Since the sound level of the wayside horn is approximately 10 dBA lower than the train horn, we know that the wayside horn is less detectable when measured 100 feet from the crossing. Given the lower sound level, it is reasonable to predict that fewer drivers will hear the wayside horn than the train horn because the wayside horn is 10 dBA lower when measured 100 feet from the crossing. The actual reduction in numbers of motorists who hear the wayside horn will depend upon the difference between the ambient noise level inside the vehicle and the warning signal level inside the vehicle. While the wayside horn appears to provide an effective warning in the current setting, the data from this study does not indicate what an appropriate sound level should be.

Although the wayside horn may reduce the problem of community noise, an important question remains about its long term effectiveness. As motor vehicles become better insulated, it becomes more difficult for sound to penetrate the vehicle, and the listener may fail to detect the warning. However, the controversy over the current community noise impact associated with train horns suggests that the sound level cannot be increased to respond to this problem. Current wayside horn prototypes use a lower sound level than the train horn in an effort to respond to the problem of community noise. However, the signal source is also closer to the motorist. It is unclear how these two changes (closer proximity to the motorist and lower sound level) affect detectability of the warning for the motorist.

6.2 IMPLEMENTATION

Effectiveness of a wayside horn depends upon a number of considerations. One important issue is the credibility of the signal to indicate the approach of the train. Designing the system so that the engineer activates the horn from the train has a number of advantages. First, it gives the engineer control over the system, as he has now. Engineers, like individuals in other settings, need a sense of control over their environment. This situation fosters that need for control. Second, it is helpful to the driver. The auditory warning is not dependent upon the reliability of the track circuitry. While the credibility of the warning will vary with the engineer’s reliability, the association of the auditory warning with the approach of the train remains. In the situation where the auditory warning is triggered by the track circuitry, false alarms will diminish the strength of the association between the approach of the train and the sounding of the horn.

Another problem results from inadequate signal intensity inside the motor vehicle. This is a problem common to all auditory warnings where the source of the auditory warning is outside the vehicle. The background noise level is frequently higher in a moving motor vehicle than in the average household (Bailey, 1989). Noise from inside the vehicle (i.e., people talking, radios,) and outside the vehicle (i.e., road noise from tires and air movement) all contribute to the higher background noise level. Motor vehicles are also being manufactured with better soundproofing. Better soundproofing reduces the effectiveness of an external auditory warning to penetrate the vehicle and alert the motorist.

If new vehicles continue to improve in their sound attenuating characteristics, the effectiveness of auditory warnings located outside the vehicle will continue to decline. Although designers can theoretically increase the signal intensity of auditory warnings to address this problem, there are practical limits to how loud the signal can be. As the signal intensity increases, there is greater likelihood of signal distortion so that the auditory warning no longer sounds the same to the listener. Increasing signal intensity of the warning device will increase the noise exposure level for the community and exacerbate the community noise problem. However, the complaints in many communities regarding train horn noise and the number of communities with local bans (FRA, 1995) suggests that the maximum acceptable noise level is being approached. Current regulations do not address the issue of maximum noise level. The attenuation of the signal reaching the motorist suggests that the wayside horn should be thought of as an interim solution to the use of effective auditory warnings at grade crossings.

As the train approaches the grade crossing, the engineer may not hear the sound of the wayside horn. If the engineer isn’t confident that the wayside horn is operating, he or she may sound the train horn, eliminating the reduction in community noise impact from using the wayside horn. In the current study, a strobe light located at the grade crossing provided a visual signal to the engineer that the horn was working. The strobe light activated when the wayside horn sounded at 80 dB or above. However, it may not be possible to see this signal in situations in which visibility is poor such as when the grade crossing is located around a curve or when bad weather conditions exist. Putting the visual signal at the whistle post may enable the engineer to determine whether the wayside horn was operating properly, in time to respond appropriately. Separating the sound-activated strobe light from the wayside horn creates the need for another method to activate the strobe light when the wayside is working properly. Is there sufficient time to send a signal from the wayside horn to the strobe light so that the locomotive engineer can respond in a timely manner? Is there a locomotive speed above which the strobe light will not activate in time for the locomotive engineer to avoid sounding the train horn? These questions illustrate the difficulty of designing a wayside horn that will work properly under the wide variety of conditions that may exist at highway-railroad grade crossings.

6.3 DIRECTIONS FOR FUTURE RESEARCH

6.3.1 Evaluate Driver Behavior Under Variety of Conditions

One conclusion from the current study suggested that the relatively low number of violations may have been due to the quick gate descent time. If the behavior of the gates was the primary factor, then response to the auditory warning may vary with the effectiveness of the gates. Examination of motorist behavior at other crossings with gate descent times that are greater than in the current study, and with constant warning times that vary more than in the study, will help establish the effectiveness of a wayside horn under a broad set of conditions. A more definitive study would compare the wayside horn to the train horn at crossings without gates. This would eliminate the effect of the gates on motorist behavior. Comparing the two auditory warning systems in a driving simulator would provide an answer to this question, without the risk posed by a field study using real motorists and trains.

6.3.2 Determine Optimal Acoustic Characteristics

It was recommended above that a single uniform signal be used as an auditory warning to promote quick recognition and timely action when a train approaches. Currently, a variety of signals are used that vary in their tonal characteristics. The differences in tonal characteristics are primarily a function of the number of chimes or individual horns on the train. The signal has evolved since the invention of the steam locomotive when a steam "whistle" produced a narrow band signal with relatively high frequencies. By contrast, current generation diesel and electric locomotives use an air horn that produces signals with a relatively broad band signal. If a standard signal is to be used, what should that signal be? Can a signal be designed that will maximize detectability for the motorist, while minimizing the noise impact for the resident? What acoustic qualities make a good warning signal? Research is being planned to determine the acoustic characteristics of an optimal signal. This research will address the loudness, frequency distribution and temporal sequence of that signal.

6.3.3 Evaluate Wayside Horn at Passive Crossings

Currently, the wayside horn concept has been considered solely for active crossings where the infrastructure exists to operate these devices. However, the wayside horn might be effective as a warning device at passive crossings. The primary need is for an energy source to power the warning device and a method for activating the wayside horn. However, new technology may exist which can solve the energy needs of a wayside horn. The need for a wayside horn will depend upon the community noise near passive crossings. Many passive crossings are located in rural areas, where the population density near the grade crossing is relatively low. At these crossings there may be little need for an alternative to the train horn. However, at passive crossings that do experience significant community noise, the wayside horn might reduce this impact. From the motorist's perspective, we do not know how a wayside horn might affect compliance at the crossing. The auditory warning provided by the train is currently the only warning that indicates *the train is approaching*. How would motorists perceive this auditory warning when it comes from a device not located on the train? The location of the auditory warning on the train gives the motorist information about the direction of approach. An auditory warning from a wayside horn would lack this information. Will this lack of directional information affect driver behavior? Can a signal be created which would provide directional information? If the answer is yes, can this feature be included at sufficiently low cost to be practical? An evaluation of auditory warnings at passive crossings would help to answer these questions.

APPENDIX A. COMMUNITY NOISE IMPACT TRAIN HORN SURVEY

Community Noise Impact of Train Horns

Telephone Survey

Column Data Entry Code

1. Subject ID#: ______

   Name of Respondent: ______________________________

   Phone: ________- ____________

2. Address: ____________________________

3. Loudness Range: < 55 dB(A) 55-70 dB(A) > 70 dB(A)

Date	Time	Interviewer	Result of Phone Call	Action Required	Completion Status

Abbreviations

NA=No Answer	CALL=Call back, (when)	C=Complete
REF=Refused (Explain)	NONE=None	I=Incomplete
SR=Spoke w/Respondent	REP=Send Report	
WN=Wrong Number		
DISC= Disconnected		

1. Subject ID #
   1-4 Digit Number

2. Address
   Enter Text

3. Loudness Range
   1 > 70 dB(A)
   2 55-70 dB(A)
   3 < 55 dB(A)

Subject ID# ____

INTRODUCTION

Hello. Is this the (last name) residence?

IF CORRECT HOUSEHOLD IS REACHED	IF INCORRECT HOUSEHOLD IS REACHED
My name is (interviewer's name) . I am calling from the ________________________________ on behalf of the *City of Gering*. We are doing research to find out how the community feels about the sound of the train horns as they pass over the railroad grade crossings in Gering. We announced on radio, TV and in the newspaper that we would call to ask some questions about the train horn and how it affects you. Did you see or hear it?	The number I was calling is ______________________. IF WRONG NUMBER, END CONVERSATION WITH: I am sorry to have bothered you. Good-bye.

PERSON RECEIVED ANNOUNCEMENT	PERSON DID NOT RECEIVE ANNOUNCEMENT
According to the method we use, I need to interview an adult member of your household.	I'm sorry we didn't reach you. It was a brief announcement so people would know we might call them.
Would that be you?	IF PERSON IS NOT A MEMBER OF THE HOUSEHOLD: When may I call back to reach an adult member of the household. ____ So that I will know who to ask for, what is his/her name? ____ REPEAT BACK TO BE SURE YOU HAVE IT AND THE PRONUNCIATION IS CORRECT. IF RESPONDENT OBJECTS TO PROVIDING NAME: We only need the person's first name.

Subject ID# ____

IF PERSON IS ADULT	IF PERSON IS NOT ADULT
BEGIN INTERVIEW.	Is there someone in your household that is at least 18 years old or older?

IF ANOTHER ADULT, IS AVAILABLE	IF ANOTHER ADULT IS NOT AVAILABLE
May I speak with that person?	I am sorry to have bothered you. Thank you for your time. Good-bye.

OTHER HOUSEHOLD MEMBER AVAILABLE TO TALK	OTHER HOUSEHOLD MEMBER NOT AVAILABLE TO TALK
WHEN SELECTED PERSON ANSWERS, REPEAT INTRODUCTION & BEGIN INTERVIEW.	When may I call back to reach him/her? ______________________________ So that I will know who to ask for, what is his/her name? _____________________________ REPEAT BACK TO BE SPELLING AND PRONUNCIATION ARE CORRECT. IF RESPONDENT OBJECTS TO PROVIDING NAME: We only need the person's first name.

BEGIN INTERVIEW

The questions I need to ask should take about 5 minutes. But before starting them I want to mention that I would be happy to answer any question you might have about the study either now or later. Okay?

Subject ID# ____

Column Data Entry Code

EVALUATION OF HORN SYSTEM

1. When you are at home, how many trains a day do you **hear** as indicated by the train blowing its horn?

   IF THE RESPONDENT ANSWERS WITH AN ADJECTIVE SUCH AS "A LOT", ASK THE RESPONDENT TO ESTIMATE WITH A NUMBER. CIRCLE THE NUMERICAL RANGE THAT THE NUMBER FALLS WITHIN.

0	**1-5**	**6-10**	**11-20**	**21-30**	**31-40**	**41-50**	**>50**
0	1	2	3	4	5	6	7

   IF THE NUMBER 0 IS CIRCLED, SKIP TO QUESTION #28

2. What times of day do you hear the train horn at home?

   Do you hear it during the day, between 6:00 am. and 5:00 pm.

   Do you hear it in the evening between 5:00 pm. and 10:00 pm.

   Do you hear the train horn at night, between 10:00 pm. and 6:00 am.

   CIRCLE THE APPROPRIATE CATEGORIES BELOW.

DAY		**EVENING**		**NIGHT**	
6:00 AM. - 5:00 PM.		**5: 00 PM. - 10:00 PM.**		**10:00 PM. - 6:00 AM.**	
NO	YES	NO	YES	NO	YES

4. Horn Count
   0 = 0
   1 = 1-5
   2 = 6-10
   3 = 11-20
   4 = 21-30
   5 = 31-40
   6 = 41-50
   7 = > 50

   Time Horn Heard

5. Day
   0 No
   1 Yes

6. Evening
   0 No
   1 Yes

7. Night
   0 No
   1 Yes

Subject ID# ____

Column Data Entry Code

FOR EACH TIME PERIOD THAT THE RESPONDENT HEARS THE TRAIN, CIRCLE THE RESPONSE THAT INDICATES HOW LOUD THE TRAIN HORN IS.

I would like your opinion on the loudness of the train horn. Is the horn not at all loud, slightly loud, moderately loud, very loud or extremely loud.

	NOT AT ALL LOUD	SLIGHTLY LOUD	MODERATELY LOUD	VERY LOUD	EXTREMELY LOUD
3. **During the day** 7:00 AM - 5:00 PM	1	2	3	4	5
4. **During the evening** 5: 00 PM - 10:00 PM	1	2	3	4	5
5. **During the night** 10:00 PM - 7:00 AM	1	2	3	4	5

Loudness By Time Of Day

8. Day
   1 Not At All Loud
   2 Slightly Loud
   3 Moderately Loud
   4 Very Loud
   5 Extremely Loud

9. Evening
   1 Not At All Loud
   2 Slightly Loud
   3 Moderately Loud
   4 Very Loud
   5 Extremely Loud

10. Night
   1 Not At All Loud
   2 Slightly Loud
   3 Moderately Loud
   4 Very Loud
   5 Extremely Loud

Subject ID# ____ Column Data Entry Code

FOR EACH TIME PERIOD THAT THE RESPONDENT HEARS THE TRAIN, CIRCLE THE RESPONSE THAT INDICATES HOW ANNOYING THE TRAIN HORN IS.

I would like your opinion on the annoyance of the train horn. Is the horn not at all annoying, slightly annoying, moderately annoying, very annoying or extremely annoying.

	NOT AT ALL ANNOYING	SLIGHTLY ANNOYING	MODERATELY ANNOYING	VERY ANNOYING	EXTREMELY ANNOYING
6. **During the day** 7:00 AM - 5:00 PM	1	2	3	4	5
7. **During the evening** 5: 00 PM - 10:00 PM	1	2	3	4	5
8. **During the night** 10:00 PM - 7:00 AM	1	2	3	4	5

Annoyance By Time Of Day

11. Day
    1 Not At All Annoying
    2 Slightly Annoying
    3 Moderately Annoying
    4 Very Annoying
    5 Extremely Annoying

12. Evening
    1 Not At All Annoying
    2 Slightly Annoying
    3 Moderately Annoying
    4 Very Annoying
    5 Extremely Annoying

13. Night
    1 Not At All Annoying
    2 Slightly Annoying
    3 Moderately Annoying
    4 Very Annoying
    5 Extremely Annoying

Subject ID# ____ Column Data Entry Code

Now I would like to ask whether the sound from the train horn interferes with activities you do at home. I'm going to list a series of activities. Please tell me how many times a day the sound from the train horn interferes with any of these activities:

	NUMBER OF TIMES				
9. Listening to the radio or television	0	1-3	4-6	7-9	10+
10. Talking with someone on the phone or in person	0	1-3	4-6	7-9	10+
11. Reading	0	1-3	4-6	7-9	10+
12. Sleeping	0	1-3	4-6	7-9	10+
13. Keeping windows open	0	1-3	4-6	7-9	10+
14. Outdoor activities (for example, entertaining or gardening)	0	1-3	4-6	7-9	10+

Interferes With Activities

14. Radio/TV
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+
15. Conversation
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+
16. Reading
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+
17. Sleeping
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+
18. Keep windows open
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+
19. Outdoor
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+

Subject ID# ____ Column Data Entry Code

Now I would like to ask you how many times a day you have taken any of the following steps to minimize the noise from the train horn on your activities at home:

NUMBER OF TIMES

	0	1-3	4-6	7-9	10+
15. Covered your ears	0	1-3	4-6	7-9	10+
16. Stopped talking	0	1-3	4-6	7-9	10+
17. Turned up the volume of the radio or TV	0	1-3	4-6	7-9	10+
18. Closed a window	0	1-3	4-6	7-9	10+
19. Wore ear plugs	0	1-3	4-6	7-9	10+

Repetitive Actions Taken

20. Covered ears
    - 0 0
    - 1 1-3
    - 2 4-6
    - 3 7-9
    - 4 10+
21. Stopped talking
    - 0 0
    - 1 1-3
    - 2 4-6
    - 3 7-9
    - 4 10+
22. Turned up volume
    - 0 0
    - 1 1-3
    - 2 4-6
    - 3 7-9
    - 4 10+
23. Closed window
    - 0 0
    - 1 1-3
    - 2 4-6
    - 3 7-9
    - 4 10+
24. Wore ear plugs
    - 0 0
    - 1 1-3
    - 2 4-6
    - 3 7-9
    - 4 10+

Subject ID# ____ | Column Data Entry Code

Have you taken any of the following actions because of the noise from the train:

20. Soundproofed the house (for example extra insulation or installing new windows)	NO	YES
21. Landscaped the yard to add sound barrier	NO	YES
22. Complained to someone in an official position (for example, a city official or someone at the Railroad)	NO	YES
23. Looked into moving to another location	NO	YES
24. Considered moving to another location	NO	YES

25. Is the train horn more annoying when you are in the house or out of doors?

INSIDE	OUTSIDE	EQUALLY ANNOYING	NEITHER

26. How annoying is the noise from the train when you are out in public places, say for example when you are shopping, attending religious services, attending a concert or watching a football game? Would you say the noise is not at all annoying, slightly annoying, moderately annoying, very annoying or extremely annoying?

NOT AT ALL ANNOYING	SLIGHTLY ANNOYING	MODERATELY ANNOYING	VERY ANNOYING	EXTREMELY ANNOYING

One Time Actions Taken

25. Soundproofed
    0 No
    1 Yes

26. Landscaped
    0 No
    1 Yes

27. Complained
    0 No
    1 Yes

28. Looked into Moving
    1 No
    2 Yes

29. Considered Moving
    1 No
    2 Yes

30. Where More Annoying
    1 Inside
    2 Outside
    3 Equally Annoying
    4 Neither

31. Public Annoyance
    1 Not At All Annoying
    2 Slightly Annoying
    3 Moderately Annoying
    4 Very Annoying
    5 Extremely Annoying

Subject ID# ____

Column Data Entry Code

DEMOGRAPHIC INFORMATION

27. How long have you lived at this address?

NUMBER OF MONTHS AND OR YEARS ____________

28. What is your age? _______________

29. GENDER

MALE FEMALE

END INTERVIEW

That's all the questions I have. Thank you very much for your time. Do you have any questions? Good-bye.

32. Lived at Address

	# OF MONTHS	= YEARS
0	0 - 6	(0 - ½)
1	7 - 18	(1 ½- 2 ½)
2	19 - 30	(2 ½- 3 ½)
3	31 - 42	(3 ½- 4 ½)
4	43 - 54	(4 ½- 5 ½)
5	55 - 66	(5 ½- 6 ½)
6	67 - 78	(6 ½- 7 ½)
7	79 - 90	(7 ½- 8 ½)
8	91 - 102	(8 ½- 9 ½)
9	103 or more	(9 ½-)

33. Age
Enter Number

34. Gender
1 Male
2 Female

APPENDIX B. COMMUNITY NOISE IMPACT WAYSIDE HORN SURVEY

Community Noise Impact of Wayside Horns

Telephone Survey

Column Data Entry Code

1. Subject ID#: ______

   Name of Respondent: ______________________________

   Phone: ________- ____________

2. Address: ____________________________

3. Loudness Range: < 55 dB(A) 55-70 dB(A) > 70 dB(A)

Date	**Time**	**Interviewer**	**Result of Phone Call**	**Action Required**	**Completion Status**

Abbreviations

NA=No Answer	CALL=Call back, (when)	C=Complete
REF=Refused (Explain)	NONE=None	I=Incomplete
SR=Spoke w/Respondent	REP=Send Report	
WN=Wrong Number		
DISC= Disconnected		

1. Subject ID #
   1-4 Digit Number

2. Address
   Enter Text

3. Loudness Range
   1 > 70 dB(A)
   2 55-70 dB(A)
   3 < 55 dB(A)

Subject ID# ____

INTRODUCTION

Hello. Is this the (last name) residence?

IF CORRECT HOUSEHOLD IS REACHED	IF INCORRECT HOUSEHOLD IS REACHED
My name is (interviewer's name) . I am calling from the ______________________________ on behalf of the *City of Gering*. We are doing research to find out how the community feels about the sound of the wayside horns at the railroad grade crossings in Gering. We announced on radio, TV and in the newspaper that we would call to ask some questions about the wayside horn and how it affects you. Did you see or hear it?	The number I was calling is _____________________. IF WRONG NUMBER, END CONVERSATION WITH: I am sorry to have bothered you. Good-bye.

PERSON RECEIVED ANNOUNCEMENT	PERSON DID NOT RECEIVE ANNOUNCEMENT
According to the method we use, I need to interview an adult member of your household.	I'm sorry we didn't reach you. It was a brief announcement so people would know we might call them.
Would that be you?	IF PERSON IS NOT A MEMBER OF THE HOUSEHOLD: When may I call back to reach an adult member of the household. ______________________________________ So that I will know who to ask for, what is his/her name? ______________________________________ REPEAT BACK TO BE SURE YOU HAVE IT AND THE PRONUNCIATION IS CORRECT. IF RESPONDENT OBJECTS TO PROVIDING NAME: We only need the person's first name.

Subject ID# ____

IF PERSON IS ADULT	IF PERSON IS NOT ADULT
BEGIN INTERVIEW.	Is there someone in your household that is at least 18 years old or older?

IF ANOTHER ADULT, IS AVAILABLE	IF ANOTHER ADULT IS NOT AVAILABLE
May I speak with that person?	I am sorry to have bothered you. Thank you for your time. Good-bye.

OTHER HOUSEHOLD MEMBER AVAILABLE TO TALK	OTHER HOUSEHOLD MEMBER NOT AVAILABLE TO TALK
WHEN SELECTED PERSON ANSWERS, REPEAT INTRODUCTION & BEGIN INTERVIEW.	When may I call back to reach him/her? ______________________________ So that I will know who to ask for, what is his/her name? _____________________________ REPEAT BACK TO BE SPELLING AND PRONUNCIATION ARE CORRECT. IF RESPONDENT OBJECTS TO PROVIDING NAME: We only need the person's first name.

BEGIN INTERVIEW

The questions I need to ask should take about 5 minutes. But before starting them I want to mention that I would be happy to answer any question you might have about the study either now or later. Okay?

Subject ID# ____ Column Data Entry Code

EVALUATION OF HORN SYSTEM

1. When you are at home, how many trains a day do you **hear** as indicated by the sounding of the wayside horn?

   IF THE RESPONDENT ANSWERS WITH AN ADJECTIVE SUCH AS "A LOT", ASK THE RESPONDENT TO ESTIMATE WITH A NUMBER. CIRCLE THE NUMERICAL RANGE THAT THE NUMBER FALLS WITHIN.

0	**1-5**	**6-10**	**11-20**	**21-30**	**31-40**	**41-50**	**>50**
0	1	2	3	4	5	6	7

   IF THE NUMBER 0 IS CIRCLED, SKIP TO QUESTION #28

2. What times of day do you hear the wayside horn at home?

   Do you hear it during the day, between 6:00 am. and 5:00 pm.

   Do you hear it in the evening between 5:00 pm. and 10:00 pm.

   Do you hear the wayside horn at night, between 10:00 pm. and 6:00 am.

   CIRCLE THE APPROPRIATE CATEGORIES BELOW.

DAY 6:00 AM. - 5:00 PM.		**EVENING 5: 00 PM. - 10:00 PM.**		**NIGHT 10:00 PM. - 6:00 AM.**	
NO	YES	NO	YES	NO	YES

4. Horn Count
   0 = 0
   1 = 1-5
   2 = 6-10
   3 = 11-20
   4 = 21-30
   5 = 31-40
   6 = 41-50
   7 = > 50

Time Horn Heard

5. Day
   0 No
   1 Yes

6. Evening
   0 No
   1 Yes

7. Night
   0 No
   1 Yes

Subject ID# ____

Column Data Entry Code

FOR EACH TIME PERIOD THAT THE RESPONDENT HEARS THE WAYSIDE HORN, CIRCLE THE RESPONSE THAT INDICATES HOW LOUD THE WAYSIDE HORN IS.

I would like your opinion on the loudness of the wayside horn. Is the horn not at all loud, slightly loud, moderately loud, very loud or extremely loud.

	NOT AT ALL LOUD	SLIGHTLY LOUD	MODERATELY LOUD	VERY LOUD	EXTREMELY LOUD
3. **During the day** 7:00 AM - 5:00 PM	1	2	3	4	5
4. **During the evening** 5: 00 PM - 10:00 PM	1	2	3	4	5
5. **During the night** 10:00 PM - 7:00 AM	1	2	3	4	5

Loudness By Time Of Day

8. Day
   1 Not At All Loud
   2 Slightly Loud
   3 Moderately Loud
   4 Very Loud
   5 Extremely Loud

9. Evening
   1 Not At All Loud
   2 Slightly Loud
   3 Moderately Loud
   4 Very Loud
   5 Extremely Loud

10. Night
   1 Not At All Loud
   2 Slightly Loud
   3 Moderately Loud
   4 Very Loud
   5 Extremely Loud

Subject ID# ____

Column Data Entry Code

FOR EACH TIME PERIOD THAT THE RESPONDENT HEARS THE WAYSIDE HORN, CIRCLE THE RESPONSE THAT INDICATES HOW ANNOYING THE WAYSIDE HORN IS.

I would like your opinion on the annoyance of the wayside horn. Is the horn not at all annoying, slightly annoying, moderately annoying, very annoying or extremely annoying.

	NOT AT ALL ANNOYING	SLIGHTLY ANNOYING	MODERATELY ANNOYING	VERY ANNOYING	EXTREMELY ANNOYING
6. **During the day** 7:00 AM - 5:00 PM	1	2	3	4	5
7. **During the evening** 5: 00 PM - 10:00 PM	1	2	3	4	5
8. **During the night** 10:00 PM - 7:00 AM	1	2	3	4	5

Annoyance By Time Of Day

11. Day
    1 Not At All Annoying
    2 Slightly Annoying
    3 Moderately Annoying
    4 Very Annoying
    5 Extremely Annoying

12. Evening
    1 Not At All Annoying
    2 Slightly Annoying
    3 Moderately Annoying
    4 Very Annoying
    5 Extremely Annoying

13. Night
    1 Not At All Annoying
    2 Slightly Annoying
    3 Moderately Annoying
    4 Very Annoying
    5 Extremely Annoying

Subject ID# ____ Column Data Entry Code

Now I would like to ask whether the sound from the wayside horn interferes with activities you do at home. I'm going to list a series of activities. Please tell me how many times a day the sound from the wayside horn interferes with any of these activities:

	NUMBER OF TIMES				
	0	1-3	4-6	7-9	10+
9. Listening to the radio or television	0	1-3	4-6	7-9	10+
10. Talking with someone on the phone or in person	0	1-3	4-6	7-9	10+
11. Reading	0	1-3	4-6	7-9	10+
12. Sleeping	0	1-3	4-6	7-9	10+
13. Keeping windows open	0	1-3	4-6	7-9	10+
14. Outdoor activities (for example, entertaining or gardening)	0	1-3	4-6	7-9	10+

Interferes With Activities

14. Radio/TV
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+

15. Conversation
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+

16. Reading
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+

17. Sleeping
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+

18. Keep windows open
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+

19. Outdoor
    0 0
    1 1-3
    2 4-6
    3 7-9
    4 10+

Subject ID# ____ Column Data Entry Code

Now I would like to ask you how many times a day you have taken any of the following steps to minimize the noise from the wayside horn on your activities at home:

NUMBER OF TIMES

	0	1-3	4-6	7-9	10+
15. Covered your ears	0	1-3	4-6	7-9	10+
16. Stopped talking	0	1-3	4-6	7-9	10+
17. Turned up the volume of the radio or TV	0	1-3	4-6	7-9	10+
18. Closed a window	0	1-3	4-6	7-9	10+
19. Wore ear plugs	0	1-3	4-6	7-9	10+

Repetitive Actions Taken

20. Covered ears
    - 0 0
    - 1 1-3
    - 2 4-6
    - 3 7-9
    - 4 10+
21. Stopped talking
    - 0 0
    - 1 1-3
    - 2 4-6
    - 3 7-9
    - 4 10+
22. Turned up volume
    - 0 0
    - 1 1-3
    - 2 4-6
    - 3 7-9
    - 4 10+
23. Closed window
    - 0 0
    - 1 1-3
    - 2 4-6
    - 3 7-9
    - 4 10+
24. Wore ear plugs
    - 0 0
    - 1 1-3
    - 2 4-6
    - 3 7-9
    - 4 10+

Subject ID# ____

Column Data Entry Code

Have you taken any of the following actions because of the noise from the wayside horn:

20. Soundproofed the house (for example extra insulation or installing new windows)	NO	YES
21. Landscaped the yard to add sound barrier	NO	YES
22. Complained to someone in an official position (for example, a city official or someone at the Railroad)	NO	YES
23. Looked into moving to another location	NO	YES
24. Considered moving to another location	NO	YES

25. Is the wayside horn more annoying when you are in the house or out of doors?

INSIDE	OUTSIDE	EQUALLY ANNOYING	NEITHER

26. How annoying is the noise from the wayside horn when you are out in public places, say for example when you are shopping, attending religious services, attending a concert or watching a football game? Would you say the noise is not at all annoying, slightly annoying, moderately annoying, very annoying or extremely annoying?

NOT AT ALL ANNOYING	SLIGHTLY ANNOYING	MODERATELY ANNOYING	VERY ANNOYING	EXTREMELY ANNOYING

One Time Actions Taken

25. Soundproofed
    0 No
    1 Yes

26. Landscaped
    0 No
    1 Yes

27. Complained
    0 No
    1 Yes

28. Looked into Moving
    1 No
    2 Yes

29. Considered Moving
    1 No
    2 Yes

30. Where More Annoying
    1 Inside
    2 Outside
    3 Equally Annoying
    4 Neither

31. Public Annoyance
    1 Not At All Annoying
    2 Slightly Annoying
    3 Moderately Annoying
    4 Very Annoying
    5 Extremely Annoying

Subject ID# ____

Column Data Entry Code

DEMOGRAPHIC INFORMATION

27. How long have you lived at this address?

NUMBER OF MONTHS AND OR YEARS ____________

28. What is your age? _______________

29. GENDER

MALE FEMALE

END INTERVIEW

That's all the questions I have. Thank you very much for your time. Do you have any questions? Good-bye.

32. Lived at Address

	# OF MONTHS	=YEARS
0	0 - 6	(0 - ½)
1	7 - 18	(1 ½- 2 ½)
2	19 - 30	(2 ½- 3 ½)
3	31 - 42	(3 ½- 4 ½)
4	43 - 54	(4 ½- 5 ½)
5	55 - 66	(5 ½- 6 ½)
6	67 - 78	(6 ½- 7 ½)
7	79 - 90	(7 ½- 8 ½)
8	91 - 102	(8 ½- 9 ½)
9	103 or more	(9 ½-)

33. Age
Enter Number

34. Gender
1 Male
2 Female

APPENDIX C. HOW SOUND IS MEASURED

Sound is the result of pressure fluctuations in the air from moving or vibrating objects. These pressure fluctuations are measured in microPascals and can range from 20 to 20 million. Because of their large range, these fluctuations, commonly called sound energy, are converted to a logarithmic scale called the decibel scale. A value of 0 decibels is equal to a pressure fluctuation of 20 microPa and corresponds to the threshold of hearing for most humans. A value of 140 dB is equated to a pressure fluctuation of 20 million microPa and corresponds to the threshold of pain for most humans.

Sounds are typically measured over time. Figure 13 shows what a graphic time history of neighborhood sound levels might look like over a one hour period. The peaks and valleys in the level recording indicate a variety of activities. The arrow points to the maximum sound level that occurred, called L_{max}.

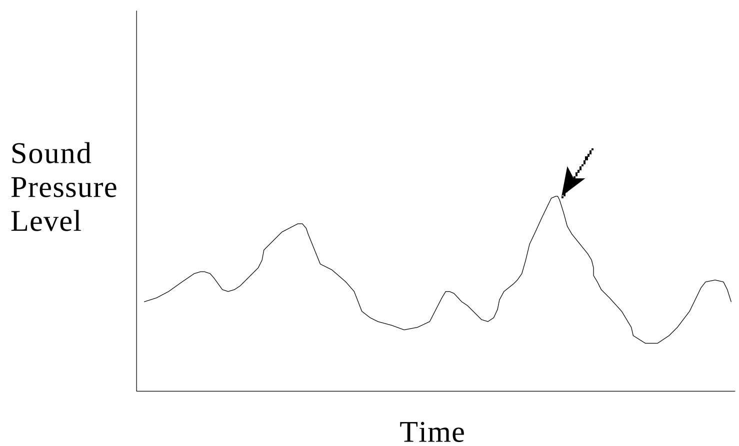


Figure 13. Representation of Sound Level Over Time

Several metrics are commonly used to describe sound. The first is the hourly equivalent sound level, L_{eq1h}. This measure represents the average level for a one-hour period. A second measure is the day-night average sound level (L_{dn}). L_{dn} measures the average sound level that occurs over a 24 hour period, with a 10 dB penalty imposed on those sounds which occur between 10 pm and 7 am. A third measure is the sound exposure level (SEL). SEL measures the cumulative noise exposure from a single event. The fact that SEL is a cumulative measure has two implications First, SEL is directly related to intensity of the noise event. As sound intensity increases, SEL increases. Second, SEL increases with the duration of the event. Given two sound events of the same intensity, people judge longer events to be more annoying that shorter events.

Sound is also characterized by its frequency or tonality. Most humans can hear in a range from 20 Hz to 20 kHz. As a point of reference, the tones generated by a typical 88 key piano range from 28 Hz to 4186 Hz, middle C has a frequency of 261.6 Hz. The human speaking voice has a range of 70 to 400 Hz. Because the human ear is not equally sensitive at all frequencies, community noise is usually measured using an A-weighting network. A-weighted measurements better approximate human sensitivity to sound at different frequencies than other weighted or unweighted measurements. A-weighted measurements emphasize sounds between 1000 Hz and 6300 HZ, and de-emphasize sounds outside this range. Sound levels measured using the A-weighting network are denoted by the symbol dBA.

When sound frequency is measured, it is often measured in one-third octave bands. One third octave bands are used because they most closely imitate the filtering characteristics of the human ear. An octave is defined as a doubling of the frequency value (e.g., a tone at 1000 Hz is one octave above a tone at 500 Hz).

APPENDIX D. ACOUSTIC MEASUREMENTS FOR TRAIN HORN

APPENDIX D. ACOUSTIC MEASUREMENTS FOR TRAIN HORN

Acoustical Measurements for Monitoring Location: 1

Closest Crossing: Country Club Rd.

Address or Location: 100 feet from grade crossing at Country Club Road

Land Use: Residential and Undeveloped

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/06/95	1:05 pm	1:52	83.9	98.5	42.8	104.3	23	50	6-12	0	50
11/06/95	2:23 pm	1:02	87	99.9	54.4	104.9	25	47.8	6-8	0	53
11/07/95	8:05 am	0:52	89	99.4	58.9	106	20	32	4-9	0	64
11/07/95	8:38 am	1:14	82.9	100.4	44	101.5	16	37	4-6	340	74
11/07/95	11:04 am	2:27	84.5	103	63.2	106.1	24	37.2	2-4	340	61
11/07/95	11:33 am	0:53	82.5	95.8	54.8	99.7	22	36.6	1-8	340	55
11/07/95	11:53 am	0:49	87.7	99.9	45.6	104.6	19	37.2	1-3	0	71
Average			85.36	99.56	51.96	103.87					
Standard Deviation			2.53	2.16	7.92	2.39					

Acoustical Measurements for Monitoring Location: 2

Closest Crossing: Country Club Rd.

Address or Location: 19 Toluca

Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/06/95	1:05 pm	1:46	52.7	62.1	44.8	73	23	50	6-12	0	50
11/06/95	2:23 pm	0:53	55.1	61.5	47.8	72.3	25	47.8	6-8	0	53
11/07/95	8:05 am	0:52	56.8	67.9	46.2	74	20	32	4-9	0	64
11/07/95	8:38 am	1:11	59.5	69.4	47.1	78	16	37	4-6	340	74
11/07/95	11:04 am	2:44	51.7	64.4	42.3	73.9	24	37.2	2-4	340	61
11/07/95	11:33 am	0:57	51.3	59.3	42.1	68.8	22	36.6	1-8	340	55
11/07/95	11:53 am	0:49	51.4	59.5	43	68.3	19	37.2	1-3	0	71
Average			54.07	63.44	44.76	72.61					
Standard Deviation			3.17	3.97	2.35	3.32					

Acoustical Measurements for Monitoring Location: 3

Closest Crossing: Country Club Rd.
Address or Location: 2560 Pacific Blvd.

Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/06/95	1:06 pm	1:48	81.5	94.2	45.7	101.9	23	50	6-12	0	50
11/06/95	2:24 pm	0:53	87.1	96.2	67.6	104.4	25	47.8	6-8	0	53
11/07/95	8:05 am	0:56	87	96.4	65	104.5	16	32	4-9	0	64
11/07/95	11:05 am	2:47	69.2	77.6	41.5	91.5	24	37.2	2-4	340	61
11/07/95	11:34 am	0:59	82.8	92.6	57.6	100.6	22	36.6	1-8	340	55
11/07/95	11:54 am	0:51	78.2	88.2	65.8	95.2	19	37.2	1-3	0	71
Average			80.97	90.87	57.20	99.68					
Standard Deviation			6.69	7.16	11.15	5.26					

Acoustical Measurements for Monitoring Location: 4

Closest Crossing: Country Club Rd.
Address or Location: 2525 Ponder Place
Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/06/95	1:06 pm	1:44	56.4	67.8	42.8	76.6	23	50	6-12	0	50
11/06/95	2:24 pm	0:53	63.3	72.9	49.6	80.6	25	47.8	6-8	0	53
11/07/95	8:05 am	0:52	56.6	62.3	43.5	73.8	20	32	4-9	0	64
11/07/95	8:39 am	1:16	53.2	66.7	39.3	71.9	16	37	4-6	340	74
11/07/95	11:05 am	2:47	50	62.7	37.1	72.1	24	37.2	2-4	340	61
11/07/95	11:34 am	0:59	49.3	60.9	41.3	67	22	36.6	1-8	340	55
11/07/95	11:55 am	0:50	56.2	65.4	42	73.2	19	37.2	1-3	0	71
Average			55.00	65.53	42.23	73.60					
Standard Deviation			4.75	4.10	3.92	4.22					

Acoustical Measurements for Monitoring Location: 5

Closest Crossing: 10th Street
Address or Location: 1225 Pawnee Court
Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/09/95	7:20 am	1:23	78.9	91.1	53.9	98.1	18	58	6-8	300	41
11/09/95	4:11 pm	1:09	70.4	85.2	52.5	88.8	22	47.2	6	320	64
11/09/95	4:37 pm	0:50	87.8	98	67.1	104.9	21	46	6	300	74
11/09/95	6:10 pm	1:02	60.9	71.5	46.3	78.9	25	40.4	0	n/a	79
11/09/95	6:26 pm	1:07	81	94.9	57.3	99.3	18	40.4	0	n/a	79
11/09/95	6:45 pm	1:14	85.5	97.5	53.8	104.3	18	39.2	0	n/a	79
Average			77.42	89.70	55.15	95.72					
Standard Deviation			10.10	10.10	6.87	10.07					

Acoustical Measurements for Monitoring Location: 6

Closest Crossing: 10th Street
Address or Location: 1705 Bluff View Drive
Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/09/95	7:22 am	1:20	52.3	58.1	44.1	71.3	18	58	6-8	300	41
11/09/95	4:37 pm	0:48	67.1	75.9	53.7	84	21	46	6	300	74
11/09/95	6:27 pm	0:47	73.1	84.9	47.7	89.7	18	40.4	0	n/a	79
11/09/95	6:44 pm	1:19	58.3	74.4	43.7	77.3	18	39.2	0	n/a	79
Average			62.70	73.33	47.30	80.58					
Standard Deviation			9.22	11.16	4.63	7.99					

Acoustical Measurements for Monitoring Location: 7

Closest Crossing: 10th Street

Address or Location: 1340 T Street

Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/09/95	7:22 am	1:17	53	69.4	43.1	72.1	18	58	6-8	300	41
11/09/95	4:11 pm	0:53	56.8	70.1	46.9	74	22	47.2	6	320	64
11/09/95	4:37 pm	0:43	62.4	72.7	48.4	78.7	21	46	6	300	74
11/09/95	6:10 pm	0:50	56.6	70.6	44.8	73.6	25	40.4	0	n/a	79
11/09/95	6:27 pm	0:41	53.8	62.9	43	69.8	18	40.4	0	n/a	79
11/09/95	6:44 pm	1:06	49.3	58	40.6	49.3	18	39.2	0	n/a	79
Average			55.32	67.28	44.47	69.58					
Standard Deviation			4.42	5.62	2.85	10.36					

Acoustical Measurements for Monitoring Location: 8

Closest Crossing: 10th Street

Address or Location: Gardner Park

Land Use: Park

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/09/95	7:21 am	1:07	65.9	74.1	48.6	84.2	18	58	6-8	300	41
11/09/95	4:10 pm	1:07	62	74.9	48.1	80.3	22	47.2	6	320	64
11/09/95	4:36 pm	1:04	74.8	84.2	48.3	92.8	21	46	6	300	74
11/09/95	6:09 pm	1:04	57.9	67.9	47.2	76.6	25	40.4	0	n/a	79
11/09/95	6:26 pm	0:44	66.9	75.2	45.2	83.4	18	40.4	0	n/a	79
11/09/95	6:43 pm	1:17	58.6	68.8	45	77.5	18	39.2	0	n/a	79
Average			64.35	74.18	47.07	82.47					
Standard Deviation			6.30	5.84	1.59	5.91					

APPENDIX D. ACOUSTIC MEASUREMENTS FOR TRAIN HORN

Acoustical Measurements for Monitoring Location: 9

Closest Crossing: 10th Street

Address or Location: 100 feet from 10th Street grade crossing

Land Use:

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/09/95	7:22 am	1:19	81.6	95.3	52.5	100.6	18	58	6-8	300	41
11/09/95	4:10 pm	1:14	78.8	96.2	53.4	97.5	22	47.2	6	320	64
11/09/95	4:40 pm	1:02	81.4	94.8	58	99.3	21	46	6	300	74
11/09/95	6:10 pm	0:45	90.7	106.1	58.2	107.3	25	40.4	0	n/a	79
11/09/95	6:25 pm	0:56	90.4	104	60.1	107.9	18	40.4	0	n/a	79
11/09/95	7:45 pm	1:24	82	97.6	56.2	101.3	18	39.2	0	n/a	79
Average			84.15	99.00	56.40	102.32					
Standard Deviation			5.08	4.83	2.96	4.30					

Acoustical Measurements for Monitoring Location: 10

Closest Crossing: 7th Street

Address or Location: 100 feet from 7th Street grade crossing

Land Use:

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/08/95	8:19 am	1:21	79.8	93.6	55.2	106.6	20	36	0	n/a	68
11/08/95	8:32 am	1:37	85.6	99.4	52.8	102.1	22	36	0	n/a	68
11/08/95	8:54 am	1:49	87.6	104.5	52	106.8	21	42.8	0	n/a	63
11/08/95	10:07 am	0:48	88.6	96.7	54.9	105.3	22	52.5	5-12	340	55
11/08/95	10:30 am	1:21	83.7	98.5	55.3	105.9	22	55.5	5-12	340	40
11/08/95	1:18 pm	1:26	85.9	103.9	54.7	106.2	22	66.2	8-11	320	31
11/08/95	1:38 pm	2:02	86.6	105.3	54.2	107.6	20	66.4	8-11	320	32
11/08/95	1:57 pm	1:58	90.2	107.6	57.2	110.9	20	66.4	9	300	32
11/08/95	3:45 pm	1:08	84	101.2	55.2	102.3	21	62.6	6-12	320	36
11/08/95	4:00 pm	1:29	81.6	98.2	55.8	101	22	62.6	6-10	320	36
11/08/95	4:15 pm	1:09	84.7	101.6	54.1	103.1	23	61.6	6-10	320	35
Average			85.30	100.95	54.67	105.25					
Standard Deviation			3.01	4.16	1.41	2.90					

Acoustical Measurements for Monitoring Location: 11

Closest Crossing: 7th Street

Address or Location: 9th and R Street

Land Use: School

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/08/95	8:19 am	1:21	57.4	66.2	48.3	76.5	20	36	0	n/a	68
11/08/95	8:32 am	1:37	57.1	66.6	48.9	77	22	36	0	n/a	68
11/08/95	8:54 am	1:39	56.7	65.9	47.9	76.7	21	42.8	0	n/a	63
11/08/95	10:07 am	0:48	58.8	65.1	52.6	75.7	22	52.5	5-12	340	55
11/08/95	10:30 am	1:21	59.9	70.4	45.3	79	22	55.5	5-12	340	40
11/08/95	1:18 pm	1:26	61.6	74.5	46	81	22	66.2	8-11	320	31
11/08/95	1:38 pm	2:07	60.5	72.3	46.5	81.6	20	66.4	8-11	320	32
11/08/95	1:57 pm	1:56	66.2	79.2	48	86.9	20	66.4	9	300	32
11/08/95	3:41pm	1:22	61.6	74.4	48.4	80.7	21	62.6	6-12	320	36
11/08/95	4:00 pm	1:20	56.2	68	46.6	75.2	22	62.6	6-10	320	36
11/08/95	4:15 pm	1:10	61.7	73.9	49	80.2	23	61.6	6-10	320	35
Average			59.79	70.59	47.95	79.14					
Standard Deviation			2.97	4.60	1.97	3.44					

Acoustical Measurements for Monitoring Location: 12

Closest Crossing: 7th Street

Address or Location: 500 P Street

Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/08/95	8:19 am	1:20	54.7	64.2	46.8	73.1	20	36	0	n/a	68
11/08/95	8:36 am	1:29	60.5	73.6	54.4	77.8	22	36	0	n/a	68
11/08/95	10:07 am	0:48	60.7	69.3	51.9	72.2	22	52.5	5-12	340	55
11/08/95	10:30 am	1:21	57.4	71.5	48.4	77.5	22	55.5	5-12	340	40
11/08/95	1:19 pm	1:22	59.9	70.6	49.3	79	22	66.2	8-11	320	31
11/08/95	1:38 pm	2:07	58.2	73	42.3	79	20	66.4	8-11	320	32
11/08/95	1:57 pm	1:55	61.6	77.7	43.7	82.2	20	66.4	9	300	32
11/08/95	3:41pm	1:12	57.9	73.3	45.1	76.4	21	62.6	6-12	320	36
11/08/95	4:00 pm	1:26	53.3	66.5	41	72.6	22	62.6	6-10	320	36
11/08/95	4:15 pm	1:11	55.6	67.6	44.6	74	23	61.6	6-10	320	35
Average			57.98	70.73	46.75	76.38					
Standard Deviation			2.77	3.97	4.27	3.32					

APPENDIX D. ACOUSTIC MEASUREMENTS FOR TRAIN HORN

Acoustical Measurements for Monitoring Location: 13

Closest Crossing: 7th Street
Address or Location: 6th and O Street
Land Use: School

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/08/95	8:19 am	1:20	56.6	67.4	49.7	75.6	20	36	0	n/a	68
11/08/95	8:32 am	1:29	60.8	70.6	48.8	80.3	22	36	0	n/a	68
11/08/95	8:54 am	1:42	65	76.1	49.4	85.1	21	42.8	0	n/a	63
11/08/95	10:07 am	0:53	62.9	68.1	55.6	80.2	22	52.5	5-12	340	55
11/08/95	1:18 pm	1:16	65.7	79.3	45.5	84.5	22	66.2	8-11	320	31
11/08/95	1:38 pm	2:07	59.6	69.5	45.3	80.6	20	66.4	8-11	320	32
11/08/95	1:57 pm	1:52	67.6	78.4	52	88.2	20	66.4	9	300	32
11/08/95	3:41pm	1:22	62.4	74.6	46.5	81	21	62.6	6-12	320	36
11/08/95	4:00 pm	1:20	53.7	63.2	43.9	72.9	22	62.6	6-10	320	36
11/08/95	4:15 pm	1:10	60.6	70.3	47.2	79.3	23	61.6	6-10	320	35
Average			61.49	71.75	48.39	80.77					
Standard Deviation			4.21	5.19	3.51	4.46					

Acoustical Measurements for Monitoring Location: 14

Closest Crossing: 7th Street
Address or Location: 1325 8th Street
Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Speed	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/08/95	8:19 am	0:47	51.2	55.8	47.4	67.9	20	36	0	n/a	68
11/08/95	8:32 am	1:28	61.4	72.5	47.1	80.9	22	36	0	n/a	68
11/08/95	8:54 am	1:41	65.1	78.2	48.3	85.1	21	42.8	0	n/a	63
11/08/95	10:07 am	0:52	57.7	64	51.4	74.9	22	52.5	5-12	340	55
11/08/95	10:30 am	1:28	53.1	61.9	46	72.5	22	55.5	5-12	340	40
11/08/95	1:18 pm	1:26	60.1	74.1	45.9	79.5	22	66.2	8-11	320	31
11/08/95	1:38 pm	2:12	53.6	64.7	44.2	74.8	20	66.4	8-11	320	32
11/08/95	1:57 pm	1:58	59.1	71	43.9	79.8	20	66.4	9	300	32
11/08/95	3:41pm	1:11	53.9	63.6	45.8	72.4	21	62.6	6-12	320	36
11/08/95	4:00 pm	1:26	51.5	57	45.7	70.8	22	62.6	6-10	320	36
11/08/95	4:15 pm	1:21	54.1	63.8	45	73.2	23	61.6	6-10	320	35
Average			56.44	66.05	46.43	75.62					
Standard Deviation			4.52	7.07	2.11	5.10					

APPENDIX E. ACOUSTIC MEASUREMENTS FOR WAYSIDE HORN

APPENDIX E. ACOUSTIC MEASUREMENTS FOR WAYSIDE HORN

Acoustical Measurements for Monitoring Location: 1

Closest Crossing: Country Club Rd.

Address or Location: 100 feet from the grade crossing

Land Use: Residential and Undeveloped

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
02/07/96	08:57 am	00:12	84.6	88.8	73.1	95.4	52.8	6 - 10	SW	50
02/07/96	08:59 am	00:22	84.2	88.8	73.1	97.6	52.8	6 - 10	SW	50
02/07/96	09:00 am	00:07	83.8	84.9	79.8	92.2	52.8	6 - 10	SW	50
02/07/96	09:02 am	00:09	82.7	83.9	76.6	92.2	52.8	6 - 10	SW	50
02/07/96	09:03 am	00:08	83.2	83.9	80.6	92.2	52.8	6 - 10	SW	50
02/07/96	09:04 am	00:10	83.2	84.8	74.8	95.7	52.8	6 - 10	SW	50
02/07/96	09:05 am	00:11	83.6	85.2	80.1	94	52.8	6 - 10	SW	50
02/07/96	09:06 am	00:12	82.6	84.8	67.4	82.6	52.8	6 - 10	SW	50
11/07/95	10:55 am	00:40	81.8	85.3	40.6	97.8	36.4	3 - 4	320	70
11/07/95	11:49 am	00:10	83.1	86.5		93.1	37.2	1 - 3	0	71
11/07/95	11:50 am	00:09	83.2	86.6		92.2	37.2	1 - 3	0	71
Average			83.27	85.77	71.79	93.18				
Standard Deviation			0.77	1.73	12.44	4.11				

Acoustical Measurements for Monitoring Location: 2

Closest Crossing: Country Club Rd.

Address or Location: 19 Toluca

Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)

Wayside Horn Not Audible

Acoustical Measurements for Monitoring Location: 3

Closest Crossing: Country Club Rd.

Address or Location: 2560 Pacific Blvd.

Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/07/95	10:56 am	0:44	47.1	50.6	39.5	63.6	36.4	3-4	320	70
11/07/95	11:47 am	00:08	44.6	49.9	41.9	53.7	37.2	1 - 3	0	71
11/07/95	11:50 am	00:09	46.4	48.5	42.7	56	37.2	1 - 3	0	71
Average			46.03	49.67	41.37	57.77				
Standard Deviation			1.29	1.07	1.67	5.18				

Acoustical Measurements for Monitoring Location: 4

Closest Crossing: Country Club Rd.

Address or Location: 2525 Ponder Place

Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
02/07/96	08:59 am	00:13	45.8	51.3	43.2	56.94	52.8	6 - 10	SW	50
02/07/96	09:00 am	00:13	45.2	50.8	42.2	56.34	52.8	6 - 10	SW	50
02/07/96	09:02 am	00:12	44.8	46	43	55.59	52.8	6 - 10	SW	50
02/07/96	09:03 am	00:13	47.3	50	43.7	58.44	52.8	6 - 10	SW	50
02/07/96	09:05 am	00:12	44.4	46.2	42.2	55.19	52.8	6 - 10	SW	50
02/07/96	09:07 am	00:12	46.3	47.4	45.1	57.09	52.8	6 - 10	SW	50
11/07/95	10:56 am	00:46	40.2	48.8	33.7	56.9	36.4	3 - 4	320	70
11/07/95	11:50 am	00:11	42.8	55	37.9	53.2	37.2	1 - 3	0	71
Average			44.60	49.44	41.38	56.21				
Standard Deviation			2.23	3.01	3.73	1.57				

Acoustical Measurements for Monitoring Location: 5

Closest Crossing: 10th Street

Address or Location: 1225 Pawnee Court

Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
02/08/96	08:03 am	00:11	67	67.3	62.3	67.01	35.4	calm	n/a	74
02/08/96	08:04 am	00:10	65	65.4	62.3	61.1	35.4	calm	n/a	74
02/08/96	08:05 am	00:09	62.5	63.1	61.5	64.64	35.4	calm	n/a	74
02/08/96	08:07 am	00:10	62.5	62.7	59.4	68.3	35.4	calm	n/a	74
02/08/96	08:07 am	00:10	64.5	65	57.9	62.8	35.4	calm	n/a	74
02/08/96	08:08 am	00:11	64.5	64.8	58.4	64.91	35.4	calm	n/a	74
02/08/96	08:09 am	00:08	60.5	61	59	60.73	35.4	calm	n/a	74
Average			63.79	64.19	60.11	64.21				
Standard Deviations			2.12	2.07	1.87	2.86				

Acoustical Measurements for Monitoring Location: 6

Closest Crossing: 10th Street

Address or Location: 1705 Bluff View Drive

Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
Wayside Horn Not Audible										

Acoustical Measurements for Monitoring Location: 7

Closest Crossing: 10th Street
Address or Location: 1340 T Street
Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
02/08/96	08:03 am	00:12	54	57.5	52.2	64.79	35.4	calm	n/a	74
02/08/96	08:04 am	00:12	51.8	55	49.7	62.59	35.4	calm	n/a	74
02/08/96	08:05 am	00:11	51.8	52.8	51.1	62.21	35.4	calm	n/a	74
02/08/96	08:07 am	00:11	50.3	54.3	48.7	60.71	35.4	calm	n/a	74
02/08/96	08:07 am	00:12	50.7	53.9	48.1	61.49	35.4	calm	n/a	74
02/08/96	08:08 am	00:13	47.9	48.6	47	59.04	35.4	calm	n/a	74
Average			51.08	53.68	49.47	61.81				
Standard Deviation			2.02	2.94	1.94	1.93				

Acoustical Measurements for Monitoring Location: 8

Closest Crossing: 10th Street
Address or Location: Gardner Park
Land Use: Park

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
02/08/96	08:03 am	00:07	54.4	57.8	51.8	62.85	35.4	calm	n/a	74
02/08/96	08:05 am	00:11	53.4	54	51.7	63.81	35.4	calm	n/a	74
02/08/96	08:07 am	00:10	53.5	55.4	52.2	63.5	35.4	calm	n/a	74
02/08/96	08:08 am	00:13	53.9	55.3	51.1	65.04	35.4	calm	n/a	74
02/08/96	08:09 am	00:11	54.3	55.1	53.5	64.71	35.4	calm	n/a	74
Average			53.90	55.52	52.06	63.98				
Standard Deviation			0.45	1.39	0.90	0.89				

Acoustical Measurements for Monitoring Location: 9

Closest Crossing: 10th Street

Address or Location: 100 feet from 10th Street Crossing

Land Use:

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
02/07/96	08:03 am	00:11	87.6	88.5	84.2	98.01	35.4	calm	n/a	74
02/07/96	08:04 am	00:09	87.8	89.4	86.8	97.34	35.4	calm	n/a	74
02/07/96	08:05 am	00:11	86.9	87.9	82.5	97.31	35.4	calm	n/a	74
02/07/96	08:07 am	00:11	87.8	88.3	84.6	98.21	35.4	calm	n/a	74
02/07/96	08:07 am	00:10	87.4	88.4	86.7	97.4	35.4	calm	n/a	74
02/07/96	08:08 am	00:11	88	88.9	85.9	98.41	35.4	calm	n/a	74
02/07/96	08:09 am	00:21	88	89.2	85.5	101.23	35.4	calm	n/a	74
Average			87.64	88.66	85.17	98.27				
Standard Deviation			0.39	0.53	1.53	1.38				

Acoustical Measurements for Monitoring Location: 10

Closest Crossing: 7th Street

Address or Location: 100 feet from 7th Street Crossing

Land Use:

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
02/07/96	09:38 am	00:23	83.9	86.7	67.4	83.9	55.2	8 - 12	SW	47
02/07/96	09:40 am	00:12	82.4	83.9	72.1	93.2	55.2	8 - 12	SW	47
02/07/96	09:41 am	00:12	82	84.3	65.8	92.8	55.2	8 - 12	SW	47
02/07/96	09:42 am	00:11	82.9	84.6	68.5	93.3	55.2	8 - 12	SW	47
02/07/96	09:43 am	00:13	81.6	83.3	69	92.7	55.2	8 - 12	SW	47
02/07/96	09:44 am	00:13	82.4	84.1	70.6	93.4	55.2	8 - 12	SW	47
02/07/96	09:46 am	00:12	82.2	83.7	62.5	93	55.2	8 - 12	SW	47
02/07/96	09:47 am	00:12	83.1	84.7	76	93.8	55.2	8 - 12	SW	47
02/07/96	09:49 am	00:11	82.9	84.8	75.5	93.3	55.2	8 - 12	SW	47
02/07/96	09:51 am	00:08	87.7	88.5	85.5	96.8	55.2	8 - 12	SW	47
Average			??	??	??	92.62				
Standard Deviation			1.74	1.57	6.49	3.11				

Acoustical Measurements for Monitoring Location: 11

Closest Crossing: 7th Street

Address or Location: 9th and R Street

Land Use: School

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
02/07/96	09:41 am	00:12	49.7	51.3	49.2	60.49	55.2	8 - 12	SW	74
02/07/96	09:44 am	00:11	51.7	53.7	50.3	62.11	55.2	8 - 12	SW	74
02/07/96	09:46 am	00:14	50.5	53.9	48.4	61.96	55.2	8 - 12	SW	74
02/07/96	09:49 am	00:02	50.9	51.9	49.7	53.91	55.2	8 - 12	SW	74
02/07/96	09:51 am	00:11	52	53.2	50.6	62.41	55.2	8 - 12	SW	74
11/07/95	08:59 am	00:06	51.6	52.6	51	59.4	42.8	0	n/a	63
11/07/95	09:00 am	00:14	49.4	50	48.5	60.8	42.8	0	n/a	63
02/08/96	08:09 am	00:13	49.7	52.2	48.3	60.84	35.4	calm	n/a	74
Average			50.69	52.35	49.50	60.24				
Standard Deviation			1.02	1.30	1.06	2.74				

Acoustical Measurements for Monitoring Location: 12

Closest Crossing: 7th Street

Address or Location: 500 P Street

Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
02/07/96	09:40 am	00:13	51.6	58.5	46.1	62.7	55.2	8 - 12	SW	74
02/07/96	09:42 am	00:13	49.1	51.7	44.9	60.2	55.2	8 - 12	SW	74
02/07/96	09:43 am	00:14	49.9	54	44.1	61.3	55.2	8 - 12	SW	74
02/07/96	09:46 am	00:14	52	55	45.3	63.5	55.2	8 - 12	SW	74
02/07/96	09:49 am	00:13	49.3	52.8	45.2	60.4	55.2	8 - 12	SW	74
02/07/96	09:51 am	00:12	52.6	55.6	50.4	63.4	55.2	8 - 12	SW	74
11/08/95	09:00 am	00:08	50.8	52.7	47.7	62.5	42.8	0	n/a	63
11/08/95	09:01 am	00:09	51.3	59.3	48.9	63.6	42.8	0	n/a	63
Average			50.83	54.95	46.58	62.20				
Standard Deviation			1.28	2.75	2.20	1.39				

Acoustical Measurements for Monitoring Location: 13

Closest Crossing: 7th Street
Address or Location: 6th and O Street
Land Use: School

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
11/07/95	09:00 am	00:19	52	54.7	49.8	64.8	42.8	0	n/a	63
Average			52.00	54.70	49.80	64.80				

Acoustical Measurements for Monitoring Location: 14

Closest Crossing: 7th Street
Address or Location: 1325 8th Street
Land Use: Residential

Date	Time	Duration	Leq	Lmax	Lmin	SEL	Temp (F)	Wind (mph)	Wind Direction	Humidity (%)
02/07/96	09:40 am	00:15	53.6	59	47.3	65.36	55.2	8 - 12	SW	74
02/07/96	09:41 am	00:14	51.7	59.4	45.4	63.16	55.2	8 - 12	SW	74
02/07/96	09:43 am	00:13	52.2	58.9	47.8	63.34	55.2	8 - 12	SW	74
02/07/96	09:44 am	00:12	51.5	54.3	49.5	62.29	55.2	8 - 12	SW	74
02/07/96	09:46 am	00:16	49.5	55.8	46.4	61.54	55.2	8 - 12	SW	74
02/07/96	09:49 am	00:11	52.4	54.1	49.1	62.81	55.2	8 - 12	SW	74
02/07/96	09:51 am	00:12	52	55.4	47.9	62.79	55.2	8 - 12	SW	74
11/08/95	09:00 am	00:08	53.4	55.6	48.9	62.4	42.8	0	n/a	63
11/08/95	09:01 am	00:09	49.6	51.3	47.6	59.1	42.8	0	n/a	63
Average			51.77	55.98	47.77	62.53				
Standard Deviation			1.44	2.70	1.31	1.66				

APPENDIX E. ACOUSTIC MEASUREMENTS FOR WAYSIDE HORN

REFERENCES

Antin, J.F., Lauretta, D.J., & Wolf, L.D. (1991). The intensity of auditory warning tones in the automobile environment: Detection and preference evaluations. *Applied Ergonomics*. 22, 13-19.

Bailey, R.W. (1987). *Human Performance Engineering*. (2nd ed.). Englewood Cliffs, NJ: Prentice Hall.

Bjorkman, M. (1991). Community noise annoyance: Importance of noise levels and the number of noise events. *Journal of Sound and Vibration*. Vol. 151 (3), pp. 497-503.

Boff, K.R., Kaufman L., and Thomas. (1986). *Handbook of Perception and Human Performance Vol. 1: Sensory Processes and Perception*. New York: John Wiley and Sons.

Bowman, B.L. (1987). The effectiveness of railroad constant warning time systems. *Transportation Research Record 1114: Traffic Control Devices and Rail-Highway Grade Crossings*. Washington, D.C: Transportation Research Board.

Cohen, J. (1977). *Statistical Power Analysis for the Behavioral Sciences*. New York: Academic Press.

Coplen, M. (1995). *The Automated Horn System: Implementation Issues*. Unpublished report.

Dillman, D.A. (1978). *Mail and Telephone Surveys: The Total Design Method*. New York: John Wiley and Sons.

Federal Highway Administration (1978). *Manual on Uniform Traffic Control Devices*. Washington, D.C: Author.

Federal Railroad Administration. (1992). *Florida's Train Whistle Ban*. Washington, D.C: Author.

Federal Railroad Administration. (1995). *Nationwide Study of Train Whistle Bans*. Washington, D.C: Author.

Federal Transit Administration (1995). *Transit Noise and Vibration Impact Assessment*. Washington, DC: Author.

Fidell, S.(1977). *The Urban Noise Survey*. Washington, D.C: U.S. Environmental Protection Agency: Office of Noise Abatement and Control.

Fidell, S., Barber, D.S., and Schultz, T.J. (1990). Updating a dosage-effect relationship for the prevalence of annoyance due to general transportation noise. *Journal of the Acoustical Society of America*. Vol. 89, (1), pp. 221-233.

Getty, D.J., Swets, J.A., Pickett, R.M. and Gonthier, D. (1995). System operator response to warnings of danger: A laboratory investigation of the effects of the predictive value of a warning on human response time. *Journal of Experimental Psychology: Applied*. Vol. 1 (1), 19-33.

Green, D.M. and Fidell, S. (1990). Variability in the criterion for reporting annoyance in community noise surveys. *Journal of the Acoustical Society of America*. Vol. 89, (1), pp. 234-243.

REFERENCES

Groves, R.M. and Kahn, R.L. (1979). *Surveys By Telephone: A National Comparison with Personal Interviews*. New York: Academic Press.

Haas, E.C. and Casali, J.G. (1993). The perceived urgency and detection time of multi-tone and frequency-modulated warning signals. *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*. Santa Monica CA: the Human Factors and Ergonomics Society, pp. 544-548.

Harris, C.M. (1979). *Handbook of Noise Control (2nd ed.)*. New York: McGraw-Hill Company.

Harris, C.M. (1991). *Handbook of Acoustical Measurements and Noise Control*. New York: McGraw-Hill Company.

Hellier, E., Edworthy, J. And Dennis, I. (1993). Improving auditory warning design: Quantifying and predicting the effects of different warning parameters on perceived urgency. *Human Factors*. Vol. 35 (4), pp. 693-706.

Izumi, K. And Yano, T. (1991). Community response to road traffic noise: Social surveys in three cities in Hokkaido. *Journal of Sound and Vibration*. Vol. 151 (3), pp. 505-512.

Jennings, L.S. (1995). *Compilation of State Laws and Regulation Affecting Highway-Rail Grade Crossings*. 2nd ed. Washington, D.C: U.S. Department of Transportation, Federal Railroad Administration.

Keller, A.S. and Rickley, E. (1993). *The Safety Of Highway-Railroad Grade Crossings: Study of the Acoustic Characteristics Of Railroad Horn Systems*. Report No. DOT/FRA/ORD-93/25. Washington, D.C: U.S. Department of Transportation, Federal Railroad Administration.

Moronoy, T. (February 7, 1993). Freight train whistles drive residents up wall. *Boston Globe*. p. 1.

Miller, M.E. and Beaton, R.J. (January 1994). The alarming sounds of silence. *Ergonomics in Design*. Santa Monica, CA: Human Factors and Ergonomics Society. pp. 21-23.

Momtahan, K, Hetu, R. and Tansley, B. (1993). Audibility and identification of auditory alarms in the operating room and intensive care. *Ergonomics*. Vol. 36 (10), pp. 1159-1176.

National Bureau of Standards. (1971). *Fundamentals of Noise: Measurement, Rating Schemes, And Standards*. Washington, D.C: U.S. Environmental Protection Agency: Office of Noise Abatement and Control.

Oregon Public Utility Commission. (1990). Testimony of Craig Reilly (RX 355) on Eugene Train Whistle Prohibition. Salem, OR: Author.

Peterson, A.P.G. and Gross, Jr., E. E. (1974). *Handbook of Noise Measurement*. Concord, MA. General Radio.

Rapoza, A. and Rickley, E.J. (In Preparation). *The Safety of Highway Railroad Grade Crossings: The Effectiveness of Railroad Horn Systems*. Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration.

Richards, S.H., Margiotta, R.A. and Evans. G.A. (1991) *Warning Time Requirements at Railroad-Highway Grade Crossings with Active Traffic Control*. Report No. FHWA-SA-91-007. U.S. Department of Transportation, Federal Highway Administration.

Saurenman, H. and Robert, W.E. (1995). *Test of Wayside Horn Concept for Audio Warnings at Grade Crossings: Final Report*. Los Angeles, CA: Los Angeles Metropolitan Transportation Authority.

Schultz, T.J. (1978). Synthesis of social surveys on noise annoyance. *Journal of the Acoustical Society of America*. Vol. 64, 377-405.

Society of Automotive Engineers. (1989). *Emergency Vehicle Sirens: SAE recommended practice*. SAE J1849.

Sorensen, S. And Hammar, N. (1983). Annoyance reactions due to railway noise. *Journal of Sound and Vibration*. Vol. 87, 315-319.

Sorkin, R.D. (1987). Design of auditory and tactile displays. *Handbook of Human Factors*. Ed. G. Salvendy. New York: John Wiley & Sons. 549-576.

Tustin, B.H., Richards, H., McGee, H. and Patterson, R. (1986). *Railroad-Highway Grade Crossing Handbook*. 2nd ed. Washington, D.C.: Report No. FHWA-TS-86-215. U.S. Department of Transportation, Federal Highway Administration.

Volpe National Transportation Systems Center and PRC. (In Preparation). *Highway-Railroad Grade Crossing Active Signal Systems Analysis*. Washington, DC. Federal Railroad Administration.

Wilson, D. (1983). *A Study of Sound Level of Train Horns Measured Inside Selected Vehicle Types*. Masters Thesis. Knoxville: University of Tennessee.

Wylie Laboratories. (1971). *Community noise*. Washington, D.C.: U.S. Environmental Protection Agency: Office of Noise Abatement and Control.