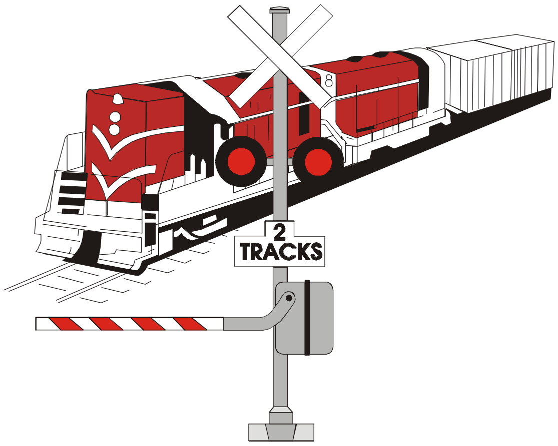
Comparison of Train and Wayside Horns in Mundelein, Illinois: Analysis of Sounds at Highway-Rail Crossings and in Residential Neighborhoods

Executive Summary



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Introduction

Railroad train horns appear to improve safety at highway-rail grade crossings, even ones with crossing gates. However, the loudness of these horns can be a significant nuisance for residents living near the crossings. For this reason, the Village of Mundelein, Illinois, tested the use of an Automated Wayside Horn System (AWHS), which is mounted at the crossings and directs the horn sound down the roadway. The purpose is to alert the motorist of an approaching train while reducing the noise directed toward residential areas.

Current Federal Railroad Administration (FRA) rules require that railroad train horns be capable of generating 96 decibels (dB) at 100 feet (30.5 meters) in the forward direction of the train. While the horns are aligned with the direction of train travel, directivity plots of sound levels show that these sounds radiate with minimal decrease up to 60 degrees to each side. This would mean that persons residing away from the railroad would be subject to approximately the same sound volume as those near the tracks.

The analysis of sound levels and acoustical characteristics heard by motorists show minimal differences between the railroad horn and the wayside horn. Motorists approaching the crossing when the gates are being lowered are more likely to hear the wayside horn because it is much louder than the approaching train's horn. Once the motorist is at the gate, the train horn becomes louder than the wayside horn only when the train is within a few seconds of reaching the crossing.

Frequency and temporal characteristics of both horns are similar, with patterns over the normal ranges for hearing. Finally, residential areas experienced a significant reduction in sound levels once the wayside horns were introduced. In many cases, the wayside horn could not be distinguished from background noises.

Brief Introduction to Measuring Sound

Sound and noise often are used interchangeably to describe a sensation that can be detected by the ear. However, the study of sound (acoustics) often distinguishes between noise as "unwanted sound" and sound as an "auditory sensation produced through the ear by alteration in pressure..."

Sound travels through most media, e.g., air, water, and metal, as a wave that has both amplitude defining loudness, and a cycle length that defines frequency.
Amplitude is the "strength" of a sound wave, and it represents loudness. It is measured as sound pressure. The common measure is decibels and it is known as the sound pressure level (SPL). When comparing similar sounds, a useful set of relationships can be employed in describing the change in loudness of a sound. These are: a 3 dB increase represents a just noticeable difference, a 5 dB change is considered a significant increase, and a 10 dB change represents a doubling of loudness.

Sound also is described by the number of oscillations or cycles per second (notated as Hertz – Hz); this is the frequency. Although the frequency range of hearing is considered to be 20-20,000 Hz, the ear is not equally sensitive to all these frequencies. Frequencies from 1,000 to 4,000 Hz are heard best.

The length of time the sound is heard makes a difference in how the listener perceives the sound. A very loud sound with a very short duration, e.g., a gunshot, may not be as noticeable as a sound with a lower decibel reading but heard over a longer period.

For this study sound was measured using digital audio tape and an "integrating sound level meter." This device captures the sound in a manner similar to how the human hears. It calculates the sound pressure levels over various periods, usually one second, weights the reading, and stores the weighted result for each period.

While the integrating sound level meter can produce many metrics, two are commonly displayed: the "equivalent continuous sound level" denoted by L_{eq} and the maximum sound level, L_{max}. The L_{eq} is the constant level of sound, in dB, that contains the same *energy* as the actual fluctuating noise over a stated time interval. The maximum SPL (denoted by L_{max}) is a metric used to capture the greatest noise level observed over the sampling period. Various levels are used to describe the sound heard over a given period, but the two most common are L_{90} – the level exceeded 90% of the time (often referred to as the background or ambient level) and L_{10} – the level exceeded 10% of the time (or intrusive noise levels).

Finally, the exposure level (SEL) is an energy average of noise over a certain time interval (like the L_{eq}), but it is normalized to one second. For example, a one-hour L_{eq} is found by averaging the one-second L_{eq}'s for the period, where as the SEL for that period is a summing of the same one-second L_{eq}'s. Because of its normalization the SEL is useful for comparing the effect of events with different maximum levels and durations.

Acoustical Comparison of Train vs. Wayside Horns

This is a comparison of the acoustical parameters of sound generated by conventional train-mounted horns with the wayside pole-mounted horns. To assess the sound levels generated by train-mounted horns vs. wayside horns, sound level data were collected by digital recordings. Two locations within the Village of Mundelein, Illinois, were selected for the recording sites. The Hawley Street crossing was selected because of its location downtown near reflective buildings and residential properties. The second site at the Winchester Road crossing was selected because of its location away from reflective buildings and is also more distant from residential properties.

Two monitoring stations were used; one at 110 feet from the centerline of the crossing and the second location at 300 feet. These represented two different points at which motorists would be expected to respond to train or wayside horns. Data sampling for the locomotive horns were made in December 2001. The sampling for the wayside horns occurred late May/early June 2002.

Train-mounted horns are typically multi-tone, air-driven devices intended to emit a high sound intensity level. Each horn produces a different fundamental frequency (pitch). Usually, these sounds are dissonant meaning that the fundamental frequencies are not musically aligned. This dissonance adds to its alerting function. The wayside horn sound was created from a digital recording of a typical train horn. As such, few differences between the harmonic structures of the two types of horns were expected. However, there are other acoustical characteristics of a train horn that make it different from a wayside horn. This includes a ramp effect - the increase in amplitude as the train approaches, the Doppler Effect - a slight upward shift in frequency as the train approaches the crossing, and interference effects - the fluctuation in amplitude as the sound arrives at the listener by various direct and reflective paths that provide constructive and destructive interference.

It was not the purpose of this study to perform an exhaustive analysis of train and wayside horns. However, it was important to verify that the spectral energy in both cases is similar. These data confirm that, although the angle of incidence is a factor, because the amplitude and frequency content of the two types of horns are similar, the audibility inside a vehicle should also be similar. In other words, the sound transmission loss provided by a vehicle to diminish the intensity of the wayside horn would have the same effect on a train horn signal as well.

Train horns typically produce A-weighted sound levels of about 105 dB(A) at 100 feet. The typical horn is a blast of "long-long-short-long." For the second and third long blasts (when the train is close to or at the crossing) the average SPL was 92 and 103 dB(A), respectively. The 2nd blast is lower simply because of a greater distance to the recording station. The blasts from the wayside horn were uniform. Each ranged from approximately 94 to 97 decibels. The single greatest difference was that the loudness of the train horn increased as the train approached. The wayside horn was constant.

The sound levels at 300 feet (94 meters) from the crossing were lower than those at 110 feet (34 meters) for both train and wayside horns. Additionally, variability of the train horns was greater at this distance because of the opportunity for more factors to influence the sound levels. The wayside horn volumes at 300 feet (94 meters) remained constant.

One major difference between the two horns was duration. While the sequences from the train and wayside horn were each approximately 17 seconds, the wayside horn sounded over two or more complete sequences, some as long as 45 seconds. These findings are important if the purpose of the wayside horn is to match the purpose of the train horn. In other words, it may be insufficient to simply reproduce the static amplitude, frequency, and duration of a train horn blast. Of importance may also be mimicking the dynamic features of a train horn, which would be to include only one sequence, adjusting the onset of the sequence, and providing an amplitude ramp to avoid startling pedestrians.

Comparison of Sound Levels in Residential Areas

To obtain a better understanding of changes in the sound levels in areas near crossings from when the train horn was being used to after the wayside horn began operating, the Northwestern University Center for Public Safety (NUCPS) conducted sound studies in residential yards. The research team used an integrating sound level meter for the recordings. These were taken in one-second intervals over a period of 24 hours for each location. Residents were located between 500 and 2,000 feet (156 to 624 meters) from that portion of the tracks where use of a train horn was expected. Sound samples were taken at a set of residences over a two-week period, in the fall of 2001 and again in the spring of 2002.

With availability of videotapes for drivers at crossings near the sampling sites, the arrival of a train could be linked to the actual recordings. For the train horns, their horn patterns were loud enough to present distinct differences in the loudness of the recorded data. This was not the case for wayside horns where many times, their volume was only slightly louder than the background noise.

Although the readings were taken at varying distances from the tracks and subject to varying levels of influence on their loudness (buildings, vegetation, etc.), when the L_{eq} was converted back to an expected level at 100 feet (31 meters) from the front of the train horn, the resulting adjusted dB readings were very similar. They differed by 6 dB from 99 dB to 105 dB. For the wayside horn, conversion back to the horn was within 3 dB of that level recorded at the selected distance of 110 feet.

A four-hour nighttime block from 8:00 p.m. to midnight was chosen for making comparisons because that is when the horns are most likely to be heard by the residents. The maximum decibel reading with train horns during the four nighttime hours for any location was 84 dB at two locations; the highest SEL was 95 dB. Background levels (L_{90}) ranged from 42 dB to 52 dB. The average sound levels of train horns during the four hours ranged between 10 dB and 30 dB above the 10% level, and generally were 30 dB higher than the background level.

The maximum reading of 75 dB for the wayside horn occurred at the Village Hall. It also was the closest location to the wayside horn, as well as directly in line with the direction of the speaker. The lowest maximum reading was 61 dB. On several occasions at a number of locations, the wayside horn could not be distinguished from the background level even when the train was known to be present in part because of the lower level of sound detected at a location and an increase in background noise levels during the spring. With the exception of the Village Hall, all median SEL's decreased. At three locations, the decrease was 3 dB or less; the largest decrease was 27 dB.

Equal contours of loudness were mapped using five contours representing 70, 75, 80, 85, and 90 dB. For example, the 70 dB contour produced by the train horns covered 4.29 square miles (mi^2) representing 37% of the 7.79 mi^2 computed for the entire village. The 90 dB coverage was 0.36 mi^2 or approximately 230 acres. This represented 3.8% of the village area. Because the sound from the train horn radiates fairly constantly over a 180-degree sector, the sound pattern for both directions of travel approximates a slightly flattened circle decreasing by one-half for each 5 dB decrease. Based on the attenuation of sound, a decrease in area by one-half for each 5 dB increase would have been expected.

On the other hand, the wayside horn is very directional with most of the sound energy occurring along the primary speaker axis. Outside that axis, the drop-off in sound is rapid. This is evident in the plot of contours based on sound readings from the wayside horns. The 90 dB reading for the wayside horn cover 0.02 mi^2, approximately 14 acres or 93% less area than the train horn. The decrease in area covered at 70 dB was somewhat less.

Concluding Comments

Use of the wayside horn, from an analysis of sound, is no different from the train horn. It is of equal loudness and covers the same frequency spectra. Given its directionality, the wayside horn may be more likely to be heard by the motorist and less likely by the residents. For those people living in Mundelein, the wayside horn has generated a significant improvement in quality-of-life in terms of a substantial reduction of noise pollution.

Train Horns, Wayside Horns, and Motorists. The sound levels at various frequencies from the wayside horn closely match the train horn. While the wayside horn sounds similar to the train horn, the operation of each is different. With few exceptions, motorists approaching a gated highway-rail crossing always are alerted to the presence of a train prior to when the train horn sounds. The bells, flashing lights, and descending gates serve this function. The train horn normally is not heard until 3 to 5 seconds after the gates fully descend. On the other hand, the motorist approaching a crossing with a wayside horn immediately hears the horn when the signals activate.

One problem is that because the wayside horns sound at the same time the signals start to operate, the motorist has no warning for the loud noise. As a result, the wayside horn has startled and confused people. On at least 12 occasions, motorists stopped on the tracks and proceeded only after the gates had begun to descend.

Residential Sound. Implementation of wayside horns has made a significant difference in the residential quality-of-life from when the train-mounted horns were used. Some residents who were located several hundred feet from the tracks were hearing sounds above 90 decibels (similar to a jackhammer at 5 feet) at all times of day and night. Because of the relatively low background noise level, the train horns were of the magnitude of 8 to 16 times louder than the background. Moreover, the loud sounds were not limited to a relatively small area. The 85 dB curve, for example, covered approximately 0.71 square miles of the village.

Once the wayside horns were installed, sound coverage, especially at higher volumes, decreased by a factor of 10. Those benefiting the most lived at angles of 45^{o} or more from the wayside horn. The problem that has arisen, of course, is that not everyone benefited. In a few cases, the volume recorded actually has increased. More importantly for a larger number of persons the sound exposure level also has remained approximately constant, or, perhaps, even increased. If the wayside horn more closely mimicked the train horn, this would reduce the length of its use as well as gradually increasing in volume.