Train Horn Noise Mitigation

John W. P. Redden, P. E.
Hanson-Wilson, Inc.
3101 Broadway, Suite 900
Kansas City, MO 64111

Phone: 816.701.3118
Fax: 816.561.0654
Abstract

The locomotive horn is an effective deterrent to accidents at grade crossings. However, the noise associated with the locomotive horn is often a quality of life issue in populated areas where trains operate. This paper examines why the sound from the locomotive horn is both an effective audible alarm and source of community annoyance. This paper also reviews the various FRA approved Supplementary Safety Measures (SSMs) that may be installed at grade crossings to effect the silencing of the locomotive horn. This paper also discusses the Automatic Train Horn that, if approved by the FRA, will also result in the silencing of the locomotive horn. Finally, this paper presents and explains a methodology that evaluates the various SSMs to determine the most cost effective option at a grade crossing that results in the silencing of the locomotive horn.

Key words: noise intensity, decibel, Supplementary Safety Measures, cost per total weighted benefit unit
Introduction

The public, the railroad, governmental agencies and safety specialists agree that
the audible alarm from the locomotive horn is an effective deterrent to accidents at grade
 crossings. Locomotive engineers are required by their railroad’s code of operating rules
and regulations to sound the train horn ¼ mile in advance of a grade crossing. They are
also required to continue to sound the horn until the train arrives at the crossing. If the
train horn is to be an effective warning device for the motorist, it must provide a sound
level capable of initiating a response from the driver when the train is approaching the
crossing. Unfortunately, the sound level required to achieve that response and the
location of the train relative to the crossing creates a significant noise that can impact the
quality of life in a community. 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 (1). However, the
horns on many freight locomotives sound as high as 114 dBA at 100 feet in front of the
train. (2) The Volpe National Transportation System Center suggests that train horns
should sound at 104 dBA at 100 feet in front of the locomotive to sufficiently warn
motorists, at a crossing equipped active traffic control devices, that a train is approaching.
(2)

The train horn is also characterized by a broadband signal that can mask sound
over a wide frequency range thus interfering with conversations. The frequency range for
the most common train horns is between 250 and 8,000 Hz with the greatest intensity in
the range from 500 to 2,500 Hz (3). Speech interference begins to occur when the noise level rises above 70 decibels between the frequency range of 600 to 4800 Hz (4).

The following chart provides a comparison of noise levels from various common noise sources (5). Normal conversation occurs within a range of 60 and 70 dBA. A loud voice must be used between 70 and 80 dBA and one must shout to be heard between 80 and 90 dBA. Audible communication usually ceases above 90 dBA. It is noted that the noise from a train horn has an impact similar to a siren on an emergency vehicle.
<table>
<thead>
<tr>
<th>Noise level (dBA)</th>
<th>Extremes</th>
<th>Home Appliances</th>
<th>Speech at 3 ft</th>
<th>Motor Vehicles at 50 ft</th>
<th>Railroad Operations at 100 ft</th>
<th>General Type of Community Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>Jet Aircraft at 500ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>110</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
<td>Shop Tools</td>
<td>Shout</td>
<td>Diesel Truck (Muffled)</td>
<td></td>
<td>Locomotive</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>Blender</td>
<td>Loud Voice</td>
<td>Automobile at 70 mph</td>
<td></td>
<td>Major Metropolis (Daytime)</td>
</tr>
<tr>
<td>70</td>
<td></td>
<td>Dishwasher</td>
<td>Normal Voice</td>
<td>Automobile at 40 mph</td>
<td></td>
<td>Urban (Daytime)</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>Air Conditioner</td>
<td>Normal Voice (Back to Listener)</td>
<td>Automobile at 20 mph</td>
<td></td>
<td>Suburban (Daytime)</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>Refrigerator</td>
<td></td>
<td></td>
<td></td>
<td>Rural (Daytime)</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Threshold of Hearing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The FRA has modeled how the train horn sound propagates and dissipates from its source (5). The FRA model states that train horn noise is reduced by 4.5 dBA whenever the distance from the train is doubled. This horn noise dissipation is caused by divergence of sound and ground interference. The FRA model also considers shielding from buildings and includes a 3 dBA reduction at the first row of buildings, located 200 feet from the track, and additional 1.5 dBA reductions for each succeeding row at 400, 600, 800 and 1,000 feet. Assuming 104 dBA of horn noise at 100 feet from the train, the following chart shows how the FRA models the dissipation of train horn noise as distance from the grade crossing increases.

This model shows that speech interference can begin to occur approximately 7,000 feet from the track when the train horn is sounding. People, outside and closer than 1,500 feet from the track, may have to shout to be heard. Outside conversations, closer than 400 feet from the track usually have to cease until the train passes by.
Train horn noise is understood by remembering that the decibel system is logarithmic and noise intensity is expressed exponentially. Seventy decibels (70 dBA) = $1 \times 10^7$, ninety decibels (90 dBA) = $1 \times 10^9$, etc. The sound intensity of 80 decibels is therefore 10 times greater than 70 decibels, 90 decibels is 100 times greater than 70 decibels and 100 decibels is 1,000 times greater in intensity than 70 decibels. Using the above example, the following Table shows why the train horn noise is so loud in the immediate vicinity of the crossing and how the train horn intensity dissipates as distance from the grade crossing increases.

**Train Noise Intensity vs. Distance from Crossing**

<table>
<thead>
<tr>
<th>DISTANCE (FT)</th>
<th>INTENSITY (dBA)</th>
<th>RELATIVE INTENSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>108.5</td>
<td>$1 \times 10^{10.85}$</td>
</tr>
<tr>
<td>100</td>
<td>104.0</td>
<td>$1 \times 10^{10.40}$</td>
</tr>
<tr>
<td>200</td>
<td>96.5</td>
<td>$1 \times 10^{9.65}$</td>
</tr>
<tr>
<td>400</td>
<td>90.5</td>
<td>$1 \times 10^{9.05}$</td>
</tr>
<tr>
<td>800</td>
<td>84.5</td>
<td>$1 \times 10^{8.45}$</td>
</tr>
<tr>
<td>1000</td>
<td>83.0</td>
<td>$1 \times 10^{8.30}$</td>
</tr>
<tr>
<td>2000</td>
<td>78.5</td>
<td>$1 \times 10^{7.85}$</td>
</tr>
<tr>
<td>4000</td>
<td>74.0</td>
<td>$1 \times 10^{7.40}$</td>
</tr>
<tr>
<td>8000</td>
<td>69.5</td>
<td>$1 \times 10^{6.95}$</td>
</tr>
</tbody>
</table>
**Forthcoming Rules from the Federal Railroad Administration**

Congress enacted Legislation in 1994 that required the sounding of locomotive horns when a train approaches a public crossing. The Federal Railroad Administration (FRA) is currently proposing rules that will address the maximum train horn sound level. As part of the proposed rulemaking, the FRA will sanction the establishment of “quiet zones” where the conventional train horn may be silenced as a result of the installation of one of several approved Supplementary Safety Measures (SSMs). The FRA approved SSMs that will allow the silencing of the locomotive horn entirely include the following:

- Median barriers or channelization devices in combination with two-quadrant gates,
- Four-quadrant gates,
- Video enforcement in combination with two-quadrant gates,
- Temporary crossing closure (during night hours), and
- Paired one-way streets with full closure gates.

Automated Train Horns (ATHs) are also being considered by the FRA as part of the rulemaking. Automated Train Horns, or wayside directional horns as they are also called, are activated by the railroad crossing warning system and replace the locomotive horn with a stationary local alarm that is focused toward the roadway approaches in the immediate vicinity of the grade crossing. ATHs do not eliminate but greatly reduce the amount of train noise in populated areas near rail corridors because they negate the need to sound the locomotive horn.
Supplementary Safety Measures (SSM) Discussion

The following is a discussion of the various FRA approved safety enhancement options that will allow the silencing of the locomotive horn.

Paired One-Way Streets with Full Closure Gates

This option consists of paired one-way streets with full closure gates that completely block all approach lanes to the crossing. The gate arm, in the horizontal position, must extend across the road to within 1-foot of the far edge of pavement if one gate is used. In this situation, the edge of the road opposite the gate mechanism must have a barrier curb to prevent motorists from veering onto the shoulder and driving around the descended gate. If two gates are used, one on each side of the road, the ends of the gate arms in the down position must leave a gap of no more than 2-foot of each other if no median is present. If a median is present, the ends of the gate arms in the down position must leave a gap of no more than 1-foot of each other. The FRA also proposes that this SSM include constant warning time circuitry and signs alerting motorist that the train horn does not sound. The following schematic shows the Paired One-Way Streets Option.
Paired One-Way Streets

ONE WAY

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ONE WAY
Median Barriers or Channelization Devices with Two-Quadrant Gates

Median barriers or channelization devices in combination with two-quadrant gates are intended to constrain vehicles to wait in their lane until the train passes through the grade crossing. The line of median barriers begins at the end of the railroad gate when in its horizontal (down) position, thus obstructing the gate runaround scenario. The FRA recommended length of the line of median barriers is 100 feet, with 60 feet minimum. Therefore, median barriers will impact traffic maneuverability to and from entrances or driveways if they are located in the near vicinity of the grade crossing. Median barriers are relatively inexpensive as compared to other safety enhancement options. The following schematics shows the Median Barrier Option.
Without Median Barrier

DOUBLE YELLOW STRIPING - VEHICLE DRIVES AROUND GATE.
RAISED MEDIANS PHYSICALLY PREVENT MOTORISTS FROM DRIVING AROUND THE LOWERED CROSSING GATEE.
Four-Quadrant Gates

Four quadrant gates are intended to completely block all road lanes on both sides of the tracks at the grade crossing and thus eliminate the gate runaround scenario. The following schematic shows the four-quadrant gate option. They are effective in preventing accidents but could conceivably trap slow moving vehicles in the railroad zone after the gates descend. Vehicle Presence Detectors (VPD) are often installed that sense the presence of slow moving vehicles to keep the “supplemental” exit gate arms in the vertical position until all vehicles have cleared the track crossing area. The cost for a four-quadrant gate system is relatively expensive compared with other SSM options. The FRA also proposes that four quadrant gates include constant warning time circuitry and signs alerting motorist that the train horn does not sound. The following schematic shows the four-quadrant gate option.
CROSSING WITH
FOUR QUADRANT GATES
**Video Enforcement**

The installation of video equipment that monitors the vehicle traffic flow at the grade crossing is intended to record traffic violations and thus discourage motorists who may consider driving around the railroad gates. This option is always used in combination with two-quadrant gates. The surveillance system is intended to be constant but the camera only activates and records an event when a violation is detected. However, the video enforcement does not provide any complimentary physical protection to compensate for the elimination of the train horn warning, which is what other Supplemental Safety Measures provide such as median barriers, paired one-way streets and four quadrant gates. Video enforcement is an “after the fact” safety enhancement option. Video enforcement will not prevent accidents at multiple track crossings when the first train has just vacated the crossing on one track and an impatient driver, who hears no train horn warning, attempts to maneuver around the horizontal gates as the second train arrives in the opposite direction on the second track. Although local driver responsibility may improve due to the awareness of video enforcement, out of town vehicle behavior may be at risk since there is no audible alarm, except for bells. There is also the concern that a judge may not accept video enforcement to convict errant or negligent drivers. Without court enforcement, this alternative would fail to provide the intended safety enhancement. It is also noted that video equipment requires continuous monitoring and ongoing maintenance by the City.

**Temporary Crossing Closure**

The temporary closing of the crossing during the same period every 24 hours will allow the locomotive engineer to silence the train horn during the period when the
crossing is closed. Movable barriers would have to be either closed manually or by a timer system. Once the gate is locked a relay automatically activates the “crossing closed” signal. The trains are instructed to whistle unless the see the “crossing closed” confirmation signal activated. The confirmation signal does not require any interconnection into any crossing signals or track wayside signals.

Automated Train Horns

The installation of automated train horns (ATHs) at a grade crossing, in combination with two-quadrant gates, will permit the locomotive engineer to cease activation of the train horn at that grade crossing. Automated Train Horns, or Wayside Horns as they are sometimes called, will be addressed in the FRA Rulemaking regarding Train Horns. ATHs were recently installed at nine grade crossings in Mundelein, Illinois. This test installation was evaluated for the FRA and the Volpe Center by the Center for Public Safety at Northwestern University. (8) From available information, the test installation was successful in terms of safety enhancement and noise mitigation. The Federal Highway Administration has recently determined that the Automated Train Horn is a traffic control device and must be included in the Manual of Traffic Control Devices. In the meantime, the FRA has determined that new installations may move forward as experimental installations.

The automated train horns are part of a stationary alarm system that is interconnected to the railroad’s warning circuitry at the crossing. Coordination and agreement with the railroad is required to interconnect the ATH system within the railroad’s traffic control warning circuitry and issue instructions to their train crews.
regarding the silencing of the train horn. The circuitry at the crossing must be designed
to provide a constant warning time regardless of the train’s speed. The installation of
constant warning time circuitry can be a significant additional expense if this type of
circuitry does not already exist.

The ATHs are mounted on poles at the crossing and emit a louder, longer and
more consistent audible alarm in the immediate vicinity of the crossing than the
conventional train horn. The ATH noise is directed right toward motorists and
pedestrians on the roadway. Automated train horns typically provide a minimum of 25 to
30 seconds of audible warning. The automated train horns are designed to sound like a
train horn. The circuit control board, upon receipt of the signal from the railroad’s signal
house, cycles through the standard railroad whistle pattern of two long blasts and one
short blast followed by another long blast. This pattern continues until the train reaches
the crossing and then the ATHs stop sounding. When the train activates the crossing
signal system, the ATHs are activated. The horn confirmation signal is activated if the
speaker located in the horn detects the alarm sound at the required decibel level. As long
as the locomotive engineer can see the horn confirmation signal, he will not be required
to sound the train horn unless he detects some type of emergency. If the locomotive
engineer can not see the horn confirmation signal at the crossing, he is instructed to sound
the train horn.

Some public officials involved with grade crossing safety believe that ATHs are
safer than conventional horns because they focus the audible alarm right at the motorist.
The sound level of the audible alarm in the immediate vicinity of the crossing is louder than the conventional horn located on the locomotive. The following table developed by the manufacturer of the ATH equipment illustrates the sound levels for a motorist at varying distances from a grade crossing when the train is ¼ mile from the crossing. (7) The ATH, which is mounted at the crossing and directed toward the motorist, provides a significantly higher decibel level alarm than the locomotive horn.

<table>
<thead>
<tr>
<th>MOTORIST DISTANCE FROM CROSSING</th>
<th>LOCOMOTIVE HORN</th>
<th>AUTOMATED TRAIN HORN</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 FEET</td>
<td>78.0 dB</td>
<td>98.9 dB</td>
</tr>
<tr>
<td>100 FEET</td>
<td>73.6 dB</td>
<td>93.7 dB</td>
</tr>
<tr>
<td>200 FEET</td>
<td>75.0 dB</td>
<td>84.9 dB</td>
</tr>
<tr>
<td>300 FEET</td>
<td>67.8 dB</td>
<td>79.5 dB</td>
</tr>
<tr>
<td>400 FEET</td>
<td>64.0 dB</td>
<td>73.7 dB</td>
</tr>
</tbody>
</table>

However, some officials involved with grade crossing safety believe that ATHs are less safe than conventional horns because the “Doppler Effect” of the conventional locomotive horn is missing from the ATH system. They point out that the public should be able to conclude from which direction the train is approaching upon hearing the train alarm and their concern has been that the ATH does not provide the public with that recognition. On the other hand, other safety experts in the industry acknowledge that often the public does not know from which direction the train is approaching with the conventional locomotive horn because either the vehicle windows are up, the car radio is on or people are not paying that close of attention.

It is estimated the noise from ATHs impact less than 10% of the area impacted by the noise from a conventional locomotive horn. The following schematics, developed by
the manufacturer of the ATH equipment, indicate the comparative noise footprint of the area impacted by the sound of the conventional locomotive horn vs. the ATH. (7)
The following table, also developed by the manufacturer of the ATH equipment, illustrates this reduction in area affected by horn noise for various decibel levels with the installation of automated train horns. (7)

<table>
<thead>
<tr>
<th>NOISE LEVEL</th>
<th>LOCOMOTIVE HORN</th>
<th>AUTOMATED TRAIN HORN</th>
<th>% REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 80 Db</td>
<td>124.7 AC</td>
<td>3.8 AC</td>
<td>97.0 %</td>
</tr>
<tr>
<td>&gt; 85 Db</td>
<td>55.7 AC</td>
<td>1.8 AC</td>
<td>96.8 %</td>
</tr>
<tr>
<td>&gt; 90 Db</td>
<td>24.8 AC</td>
<td>0.8 AC</td>
<td>96.8 %</td>
</tr>
<tr>
<td>&gt; 95 Db</td>
<td>11.5 AC</td>
<td>0.3 AC</td>
<td>97.4 %</td>
</tr>
<tr>
<td>&gt; 100 Db</td>
<td>5.7 AC</td>
<td>0.2 AC</td>
<td>96.5 %</td>
</tr>
</tbody>
</table>
Situation in DeKalb, Illinois

DeKalb, Illinois, located approximately 60 miles west of Chicago, has a population of 40,000 and is the location for Northern Illinois University. The Union Pacific Railroad’s double track mainline, the Geneva Subdivision, crosses eight streets at-grade in the downtown area with approximately 80 trains per day. The maximum timetable speed is 70 MPH but the average train speed may be approximated at 50 MPH. There are 3,749 feet between the 10th Street crossing at Milepost 58.06 and the 1st Street crossing at Milepost 58.76. Since all the at-grade crossings in DeKalb are less than ¼ of a mile from an adjacent crossing, the noise from the horn of a train, operating at an average speed of 50 MPH, is experienced for approximately 1 minute, 9 seconds from train arrival to train departure. Eighty trains per day at an average speed of 50 MPH equates to approximately one hour and thirty-two minutes of cumulative train horn noise in DeKalb every 24 hours. It is noted that the Occupational Safety and Health Administration (OSHA) requires employers to develop and implement a noise monitoring program when noise levels exceed 100 decibels for a 2-hour period or 80 decibels for a 8-hour period. The following sketch shows the locations of grade crossings in DeKalb.
Supplemental Safety Measure Evaluation Methodology

Hanson-Wilson conducted an investigation to determine the most cost-effective Supplemental Safety Measure (SSM) option that would result in the mitigation of the train horn noise in the City of DeKalb. The following five grade crossings were included in the investigation: 1st Street, the Route 23 and Route 38 Intersection, 6th Street, 7th Street and 10th Street. The 2nd and 3rd Street grade crossings already are paired one-way streets with full closure gates and thus qualify now for silencing of the locomotive horn. Therefore, the 2nd and 3rd Street grade crossings did not receive the full investigative treatment as the other crossings since they presently have approved FRA SSMs. The following four SSMs were evaluated at each crossing: median barriers or channelization devices in combination with two-quadrant gates, four quadrant gates, video enforcement in combination with two-quadrant gates, and automated train horns in combination with two-quadrant gates. The temporary crossing closure option was not included in the investigation because the City wanted to keep all its crossings open at all times and the City was concerned with liability issues associated with this SSM.

Matrices were developed to evaluate the above four SSM options at each of the noted five grade crossings in DeKalb. The evaluation is achieved by comparing the cost per total weighted benefit unit of each of the four SSM options at each of the crossings. The SSM with the lowest cost per total weighted benefit unit provides the most value at the least cost. The evaluation included a multi-step procedure. The following steps, 1 through 13, are involved:
1. Establish the criteria to evaluate the four SSMs.

   The following seven criteria were established to evaluate the four safety enhancement options:

   a. Effect on vehicular public in terms of safety
   b. Effect on Railroad in terms of accident liability
   c. Effect on pedestrian public in terms of safety
   d. Effect on vehicular and pedestrian public in terms of convenience
   e. Effect on emergency vehicles in terms of convenience
   f. Effect on nearby neighborhood in terms of noise annoyance
   g. Effect on City as a whole in terms of noise annoyance

   Although there are numerous criteria that could be studied, all can be categorized into three broad categories: safety, convenience, and noise annoyance.

2. Determine the priority of each criterion.

   Each criterion held a different priority in the evaluation process depending on its importance to meeting the City’s objectives. Therefore, each criterion was assigned a weight (%) to reflect the City’s subjective prioritization. Because the effect of any of the enhancement options can be categorized into safety, convenience, and noise annoyance, the sum total of all the weights was assigned 100%, to represent the whole of the priority assessment. These assigned weights remain constant throughout the evaluation process for each safety enhancement option at each grade crossing. The following priority weights were assigned to each criterion based upon our assessment of the City of DeKalb and its objectives. That assessment was determined through
consideration of the departments of public works, police, and fire and from our field observations of train and vehicular movements at each grade crossing.

a. Effect on vehicular public in terms of safety 25%
b. Effect on Railroad in terms of accident liability 5%
c. Effect on pedestrian public in terms of safety 15%
d. Effect on vehicular and pedestrian public in terms of convenience 20%
e. Effect on emergency vehicles in terms of convenience 5%
f. Effect on nearby neighborhood in terms of noise annoyance 5%
g. Effect on City as a whole in terms of noise annoyance 25%

Total 100%

Criteria a, b and c relate to safety and comprise 45% of the total priority to the City. Criteria d and e relate to traffic maneuverability or convenience and consume 25% of the total priority to the City. Criteria f and g relate to noise annoyance and add up to 30% of the total priority to the City.

3. Assign benefit ratings for each of the seven criteria.

A benefit rating scale from –5.0 to +5.0 was established to evaluate the relative depreciation or improvement of conditions at each crossing as a result of the use of a specific SSM based on the specific criterion. The rating assignments on the scale are defined as follows:
### RATING ASSIGNMENT DEFINITION

<table>
<thead>
<tr>
<th>Rating</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5.0</td>
<td>the maximum depreciation of conditions based on criteria</td>
</tr>
<tr>
<td>-4.0</td>
<td>a significant depreciation of conditions based on criteria</td>
</tr>
<tr>
<td>-3.0</td>
<td>a medium depreciation of conditions based on criteria</td>
</tr>
<tr>
<td>-2.0</td>
<td>a modest depreciation of conditions based on criteria</td>
</tr>
<tr>
<td>-1.0</td>
<td>minimal depreciation of conditions based on criteria</td>
</tr>
<tr>
<td>0.0</td>
<td>no change in conditions based on criteria</td>
</tr>
<tr>
<td>+1.0</td>
<td>minimal improvement of conditions based on criteria</td>
</tr>
<tr>
<td>+2.0</td>
<td>a modest improvement of conditions based on criteria</td>
</tr>
<tr>
<td>+3.0</td>
<td>a medium improvement of conditions based on criteria</td>
</tr>
<tr>
<td>+4.0</td>
<td>a significant improvement of conditions based on criteria</td>
</tr>
<tr>
<td>+5.0</td>
<td>the maximum improvement of conditions based on criteria</td>
</tr>
</tbody>
</table>

4. **Obtain the weighted benefit of each criterion for each SSM at a specific crossing.**

   This is performed by multiplying the weighted priority of each of the seven criterion by its respective benefit rating. It is noted the weighted benefit of a criterion may be less than zero.

5. **Determine the total weighted benefit for a specific SSM at a specific crossing.**

   This is performed by summing the individual weighted benefits for the various criteria developed in Step 4. If the total weighted benefit for a specific safety enhancement option is less than zero, then that specific safety enhancement option is
eliminated from further consideration because it results in a general depreciation of conditions based on the seven criteria.

6. **Determine the initial capital investment for a specific SSM at a specific crossing.**

7. **Determine the estimated annual cost of the ongoing maintenance for a specific SSM at a specific crossing.**

8. **Determine the capitalized cost of the ongoing maintenance.**

   The capitalized cost of the ongoing maintenance is the amount of money that must be invested today to generate sufficient income to pay for perpetual disbursements for the ongoing maintenance. The capitalized cost of the ongoing maintenance is equated to the establishment of a perpetuity fund (P) to pay for the ongoing maintenance:

   \[ P = \frac{A}{i} \]

   \( A = \text{Estimated Annual Maintenance Cost (from Step 7)} \)

   \( i = \text{Interest rate (7%)} \)
An average investment rate of 7% was used because at times, such as today’s financial climate, interest rates may be as low as 3% and at other times they may be as high as or higher than 10%.

9. **Determine the estimated cost of periodic equipment replacement for a specific SSM at a specific crossing.**

10. **Determine the capitalized cost of the periodic equipment replacement.**

    The capitalized cost of periodic equipment replacement is the amount of money that must be invested today to generate sufficient income to pay for the periodic replacement of equipment for an infinite period of time. The capitalized cost of the periodic equipment replacement is equated to the establishment a perpetuity fund (X) to pay for the periodic replacement of equipment: 

    \[
    (X) = \frac{S}{[(1+i)^n] - 1}
    \]

    \[
    S = \text{Estimated cost of periodic equipment replacement (from Step 9)}
    \]

    \[
    i = \text{Interest rate (7%)}
    \]

    \[
    n = \text{estimated life cycle of equipment (20 years)}
    \]

    A life of 20 years was used for both video enforcement and automated train horn equipment based on discussions with equipment manufacturers.
11. **Determine the total capitalized cost of the specific SSM at a specific crossing.**

   This is performed by summing the initial capital investment, the capitalized cost of the ongoing maintenance (P) and the capitalized cost of the periodic equipment replacement (X) from Steps 6, 8 and 10.

12. **Determine the cost per total weighted benefit unit of a specific SSM at a specific crossing.**

   This is performed by dividing the total capitalized cost of a specific safety enhancement option at a specific crossing by its total weighted benefit.

13. **Determine the most cost effective SSM at a specific crossing.**

   This is performed by ranking the various costs per total weighted benefit unit for each specific safety enhancement option. The SSM with the lowest cost per total weighted benefit unit should be selected at the crossing because it provides the most value at the least cost.

   The cost per total weighted benefit unit for the various Supplementary Safety Measures at each grade crossing in DeKalb is summarized in the following chart. The chart indicates that automated train horns were the most cost effective Supplementary Safety Measure at each crossing.
<table>
<thead>
<tr>
<th>CROSSING NAME</th>
<th>One-Way Street with Full Closure Gates</th>
<th>Median Barriers</th>
<th>Four Quadrant Gates</th>
<th>Video Enforcement</th>
<th>Automated Train Horns</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Street</td>
<td>Not a Safety Enhancement Option</td>
<td>Not a Safety Enhancement Option since Total Weighted Benefit is &lt; 0.</td>
<td>$135,467</td>
<td>$134,877</td>
<td>$93,210</td>
</tr>
<tr>
<td>Second Street</td>
<td>Presently complies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third Street</td>
<td>Presently complies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Route 23 &amp; 38</td>
<td>Not a Safety Enhancement Option</td>
<td>Not a Safety Enhancement Option since Total Weighted Benefit is &lt; 0.</td>
<td>$420,414</td>
<td>$269,754</td>
<td>$186,420</td>
</tr>
<tr>
<td>Sixth Street</td>
<td>Not a Safety Enhancement Option</td>
<td>Not a Safety Enhancement Option since Total Weighted Benefit is &lt; 0.</td>
<td>$135,467</td>
<td>$134,877</td>
<td>$93,210</td>
</tr>
<tr>
<td>Seventh Street</td>
<td>Not a Safety Enhancement Option</td>
<td>Not a Safety Enhancement Option since Total Weighted Benefit is &lt; 0.</td>
<td>$135,467</td>
<td>$134,877</td>
<td>$93,210</td>
</tr>
<tr>
<td>Tenth Street</td>
<td>Not a Safety Enhancement Option</td>
<td>Not a Safety Enhancement Option since Total Weighted Benefit is &lt; 0.</td>
<td>$135,467</td>
<td>$134,877</td>
<td>$93,210</td>
</tr>
</tbody>
</table>

It was noted that Median Barriers would have been the most cost effective SSM option if there were no entrance ways or intersections in the near vicinity of the crossing or if the entrance ways could be readily converted to “right turn in and right turn out”. It was also noted that although Four Quadrant Gates have the highest total weighted benefit of all the SSMs, they lost in the evaluation process because the cost per total weighted benefit unit is what governs the selection.

The estimated cost exposure associated with the installation of automated train horns is summarized in the following chart.
The estimated capital cost (Column A) is the initial outlay of funds for engineering, equipment, material, labor including 20% contingencies to install the ATHs. The estimated capitalized cost of the ongoing maintenance (Column C) may be equated to the establishment of a perpetuity fund to pay for the estimated annual maintenance (Column B). The estimated capitalized cost of the periodic replacement of the ATH equipment (Column E) may be equated to the establishment of a perpetuity fund to pay for the periodic replacement of the ATH equipment (Column D). The total capitalized cost is the sum of the initial capital expenditure (Column A), the capitalized cost of the annual maintenance (Column C) and the capitalized cost of periodic replacement of the ATH equipment (Column E).

The total estimated capitalized cost for the automated train horns is $828,000 and includes the up-front cost for the installations ($600,000), the present value of future maintenance disbursements ($90,000) and the present value of future disbursements for equipment replacement ($138,000).

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>First Street</td>
<td>$100,000</td>
<td>$1,000</td>
<td>$15,000</td>
<td>$66,000</td>
<td>$23,000</td>
<td>$138,000</td>
</tr>
<tr>
<td>Second Street</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Third Street</td>
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<td>$15,000</td>
<td>$66,000</td>
<td>$23,000</td>
<td>$138,000</td>
</tr>
<tr>
<td>Seventh Street</td>
<td>$100,000</td>
<td>$1,000</td>
<td>$15,000</td>
<td>$66,000</td>
<td>$23,000</td>
<td>$138,000</td>
</tr>
<tr>
<td>Tenth Street</td>
<td>$100,000</td>
<td>$1,000</td>
<td>$15,000</td>
<td>$66,000</td>
<td>$23,000</td>
<td>$138,000</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>$600,000</strong></td>
<td><strong>$6,000</strong></td>
<td><strong>$90,000</strong></td>
<td><strong>$396,000</strong></td>
<td><strong>$138,000</strong></td>
<td><strong>$828,000</strong></td>
</tr>
</tbody>
</table>
Conclusion

The locomotive horn is an effective deterrent to accidents at grade crossings. However, the loud noise associated with the locomotive horn is often a quality of life issue in populated areas where trains operate. Several Supplementary Safety Measure (SSM) options are available for installation at the crossing to achieve the silencing of the locomotive horn. Automatic Train Horns are also being considered by the FRA as an approved Supplementary Safety Measure. The most cost-effective SSM that results in the silencing of the locomotive horn at a crossing should be selected. This paper presents a methodology that determines that the most cost-effective Supplementary Safety Measure at a crossing is the option with the least cost per total weighted benefit unit.
References

1. 49 CFR 229.129.

2. Use of Locomotive Horns at Highway – Rail Grade Crossings,


5. Questions and Answers About Locomotive Horn Noise Assessment,
   Federal Railroad Administration, U. S. Department of Transportation.

6. Fact Sheet on the Use of Locomotive Horns, Proposed Rule, U. S.
   Department of Transportation, Office of Public Affairs.

7. Railroad Controls Limited.

8. Evaluation of the Automated Wayside Horn System in Mundelein,
   Illinois, Final Report, Northwestern University Center for public