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Federal Railroad Administration

Effect of Gate Skirts on Pedestrian Behavior at Highway-Rail Grade Crossings

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Washington, DC 20590

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Final Report
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13. The Federal Railroad Administration was interested in evaluating one type of pedestrian safety device, commonly known as gate skirts, that consists of a secondary horizontal hanging gate under the existing pedestrian gate to better block access to the crossing by pedestrians who gain unauthorized entry by going under the down gates. The Volpe Center participated in a New Jersey Transit rail pilot project to evaluate a prototype design installed at a grade crossing in Matawan, NJ, on May 30, 2012. The purpose of this evaluation was to determine if the addition of gate skirting would result in fewer pedestrians attempting to violate the crossing on the sidewalk after the gates began to descend. Data were collected over a 2-week period before and a 2-week period after the installation of the gate skirts. Pedestrian actions were coded during all train activations that occurred during this 4-week period. The research team found that the total number of pedestrian violations decreased while the gates were descending (78 percent reduction) and horizontal (55 percent reduction), but increased while the gates were ascending (12 percent increase). Additionally, after the installation of the gate skirts, more pedestrians who violated while the gates were descending or horizontal chose to do so in the adjacent street where there were no gate skirts, as opposed to on the sidewalk where the safety enhancement had been added.

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LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

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1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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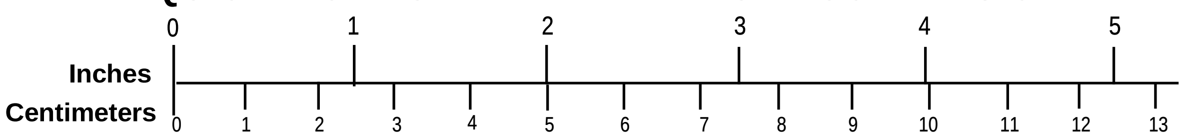
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

The John A. Volpe National Transportation Systems Center (Volpe Center) was tasked by the Federal Railroad Administration (FRA) with evaluating one type of highway-rail grade crossing pedestrian safety device, commonly known as gate skirts, designed to prevent pedestrians from violating the grade crossing while the grade crossing warning protection systems are activated. This treatment consists of a secondary horizontal hanging gate arm under the existing pedestrian gate to better block access to the crossing by pedestrians who gain unauthorized entry by going under the down gates, in the presence of a stationary or moving train.

At the request of FRA, Volpe Center participated in a New Jersey Transit rail safety pilot project to evaluate a prototype design installed at a grade crossing in Matawan, NJ, on May 30, 2012. The purpose of this research effort was to determine if the addition of gate skirting would result in fewer pedestrians violating the crossing on the sidewalk after the gates began to descend.

Data were collected over a 2-week period before the installation of the gate skirts and over another 2-week period after the installation. Pedestrian actions were coded for all train activations (i.e., automatic warning devices activated by the approach of a train) that occurred during this 4-week period. The following are some of the main findings from this data collection:

- A total of 890 pre-installation and 884 post-installation train activations were analyzed.
- A total of 2,461 pre-installation and 2,312 post-installation pedestrian behavior observations were made.
- There was a statistically significant decrease in the number of descending and horizontal violations by pedestrians after the installation of the gate skirts. Descending violations decreased significantly from 80 violations to 19 (a 78 percent reduction). Horizontal violations also decreased significantly from 177 violations to 83 violations (a 55 percent reduction). In contrast, ascending violations rose significantly after the installation of gate skirts from 1,658 violations to 1,887 violations (a 12 percent increase). See Figure E-1 below for the violation rate per train activation pre- and post-installation.

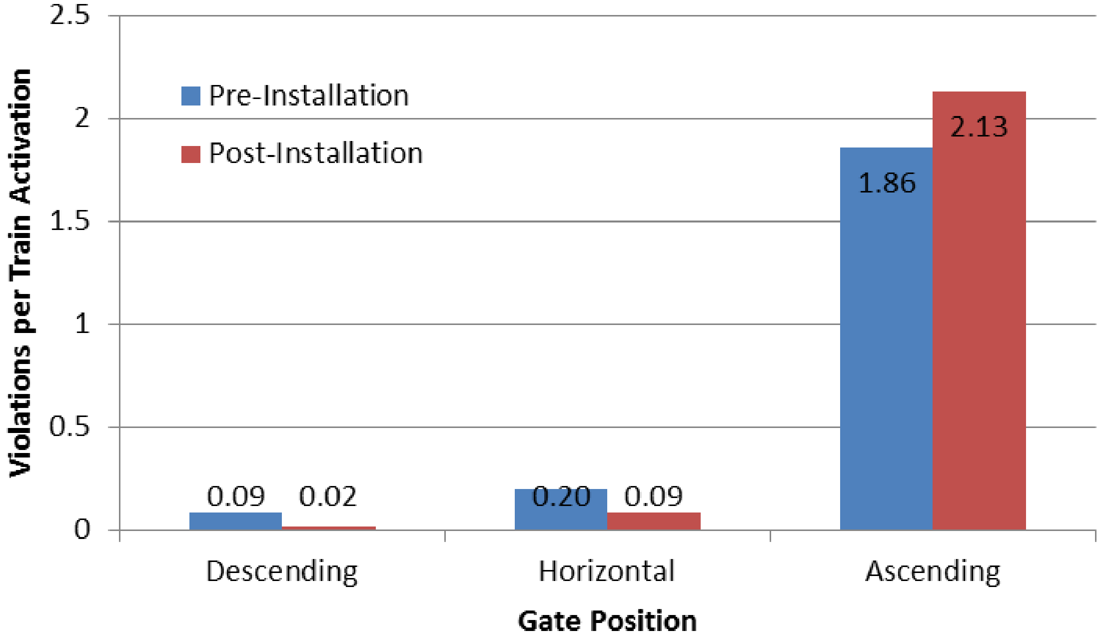

Figure E-1. Violations per Train Activation

- The number of horizontal violations that were initiated on the sidewalk dropped from 80 percent of violations pre-installation to 45 percent post-installation.
- Horizontal violations that began on the street increased from 20 percent of the violations pre-installation to 55 percent post-installation. Descending violations that were initiated on the street increased from 8 percent pre-installation to 21 percent post-installation.
- Horizontal violations that ended on the street increased a significant amount from 23 percent of the violations pre-installation to 51 percent post-installation.

The addition of gate skirts has been shown in this case to reduce the number of pedestrian violations while the gates are descending or in the horizontal position. Ascending violations increased during the study timeframe, though the reason for this increase is not clear. The findings seem to indicate that pedestrians may be more likely to enter and exit the crossing from the street when committing a descending or horizontal violation. This may be because only two of the four street quadrants at the crossing had a vehicle gate and neither of those gates was equipped with a gate skirt; thus, it was easier for pedestrians to violate the crossing on the street. The next steps would be to better understand why pedestrians, especially those committing violations while the gates are horizontal, prefer to enter from the street and then to investigate potential solutions to this workaround. Applying this evaluation plan to different grade crossing sites may also assist in determining if the reduction in descending and horizontal violations is a result of the gate skirts alone or a combination of the gate skirts and the characteristics of the particular crossing.

1. Introduction

The John A. Volpe National Transportation Systems Center (Volpe Center) provides technical support to Federal Railroad Administration's (FRA) Office of Research and Development in the area of railroad infrastructure research. This support includes key research associated with all aspects of the railroad right-of-way (ROW), including the highway-rail intersection (HRI) and trespass issues. One major effort is to develop a more precise understanding of the risks presented by the railroad ROW and then determine how best to mitigate (i.e., decrease or eliminate) the risks.

Within this research area, Volpe Center was tasked with evaluating pedestrian gate enhancements designed to prevent pedestrians from violating the grade crossing while the grade crossing protection systems are activated. One such enhancement is the addition of a secondary gate under the existing pedestrian gate to better block access to the crossing by pedestrians who gain entry by going under the down gates. Figure 1 provides an example of two pedestrians violating a crossing while the gates are down (The two violating pedestrians are circled in yellow.). This gate enhancement, described in the Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices (MUTCD) as a horizontal hanging bar, is referred to throughout this document as a "gate skirt."

Figure 1. Pedestrians Violating Grade Crossing at Atlantic Ave., Matawan, NJ

In response to a series of trespass fatalities in late 2011, the New Jersey Department of Transportation (NJDOT) Leadership Oversight Committee set up an engineering subcommittee to address safety concerns at the State's rail crossings. The goal was to draw on expertise and look at best practices to develop effective and measurable strategies for improving safety along the State's rail lines. Volpe Center participated at the request of FRA and was tasked with providing support to the NJDOT engineering implementation effort [1]. The effort included a pilot program of enhanced engineering safety treatments through which the concept of gate skirts would be trialed. Volpe Center was specifically tasked to determine the effectiveness of the addition of gate skirts to the pedestrian gates at a New Jersey Transit Rail (NJ Transit Rail) grade crossing. The purpose of this research effort was to determine if the addition of gate skirting would cause fewer pedestrians to violate the crossing on the sidewalk after the gates began to descend. The study measured quadrant-based pedestrian movements, means and rate of violation before and after installation.

1.1 Background

1.1.1 Test Site Location

NJ Transit Rail selected a high-risk grade crossing (grade crossing ID# 856876H) on Atlantic Avenue in Matawan, NJ, along the systems' North Jersey Coast Line, to pilot this pedestrian gate safety enhancement. The crossing, shown in Figure 1, is adjacent to the NJ Transit Rail Aberdeen Matawan train station.

When the project at the Atlantic Avenue grade crossing was proposed, the crossing already had train activated pedestrian gates, which descend to block the sidewalk when a train is approaching, along with channelization separating the sidewalks from the street. When the pedestrian gate is in the horizontal position (fully descended), it borders a fence that blocks pedestrians from walking around the gate and outer boundary of the sidewalk. This setup, which can be seen in Figure 2, was used as the baseline condition for the current investigation. However, despite these efforts to prohibit pedestrians from violating the crossing when the gates were down, pedestrians were still able to violate the crossing by going under the gates. With the Matawan Train Station platform just west of the crossing, the amount of foot traffic was presumed to be high, with pedestrians rushing to catch their trains on the other side of the crossing. Since pedestrians tend to take the shortest route, the research team concluded that the sidewalk would be the most effective location to create additional barriers. In addition to the proximity of the train platform, there are also large parking lots at three of four sides of the grade crossing itself, which may also contribute to the amount of foot traffic that occurs.

The grade crossing has two vehicle gates, one of which also serves as a pedestrian gate (Zone 3), and three additional pedestrian gates. The pedestrian gates are located next to the vehicle gates (or if there are no vehicle gates, each pedestrian gate is in line with the pedestrian gate on the other side of the street) so that when an activation occurs, the gate will descend into a position that blocks pedestrian traffic from crossing the tracks from all sidewalks. In one quadrant, composed of Zone 1 (sidewalk) and Zone 5 (street), the pedestrian gate and vehicle gate are actually mounted on the same structure. In the diagonal quadrant, composed of Zone 3 (sidewalk) and Zone 7 (street), a vehicle gate is used to block access across both the sidewalk and street. See Figure 3 for an illustration of the Atlantic Avenue grade crossing site characteristics and zones.

Figure 2. All Four Pedestrian Gates at the Atlantic Ave. Crossing before Installation of Gate Skirts

On either side of the sidewalks, across from each of the pedestrian gates, is fencing which prohibits pedestrians from easily going around the gates once they have descended. To better understand the layout of the area, Figure 3 provides an aerial view of the Atlantic Avenue grade crossing. For the purposes of our analysis, the grade crossing is labeled with eight different zones depending on the access and direction a pedestrian will travel through the crossing. There are eight zones in total, labeled from 1 through 8: four zones which cover sidewalk access (Zones 1 through 4) and 4 which cover road access (Zones 5 through 8). Note that the directions provided in Figure 3 are relative to the NJ Transit Rail system and not geographic north. The train that travels eastbound to New York City passes through this crossing from the right to the left. (See the key in the lower left of Figure 3.)

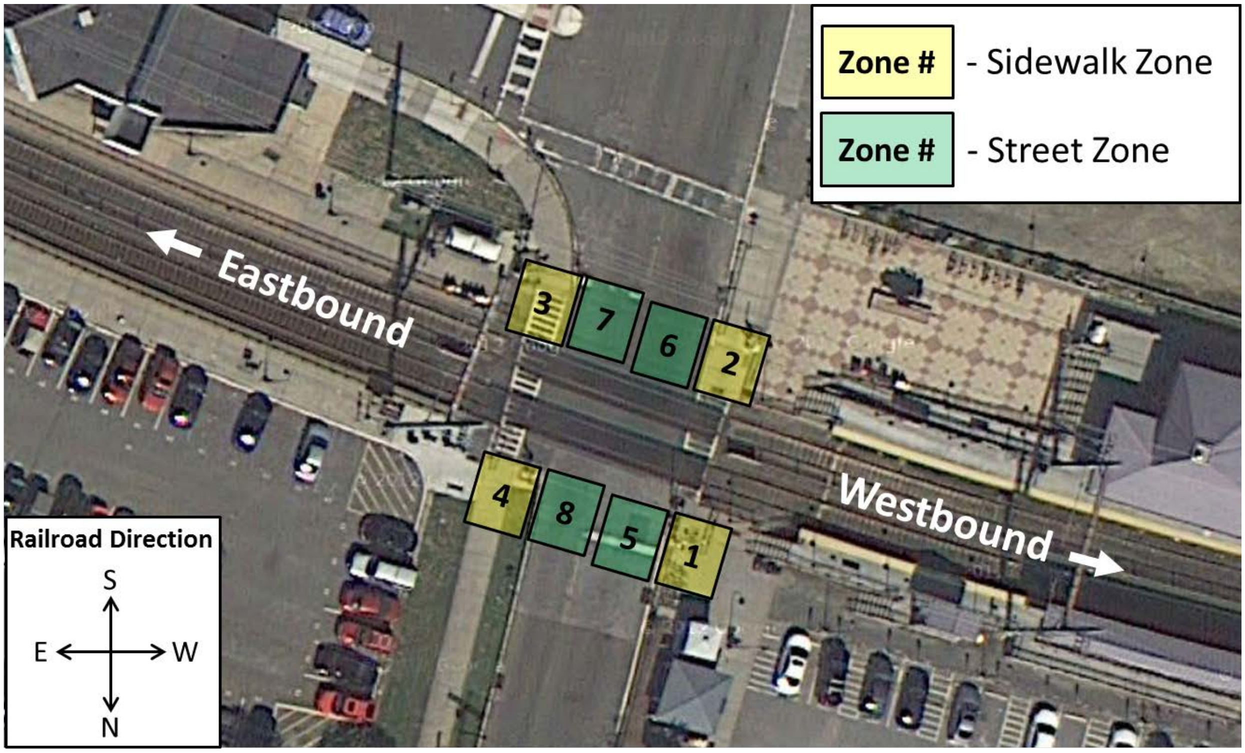

Figure 3. Atlantic Ave. Grade Crossing Site Characteristics and Zones

The Atlantic Avenue grade crossing has experienced two accidents: one in February 1988 and a second in January 2013. The fatality which occurred on January 2013 occurred after the installation of the gate skirts, although the trespasser was struck while trespassing along the street and not on the sidewalk. The site's characteristics and large volume of foot traffic for time-sensitive events (such as a train approaching) lead to an increased safety risk for noncompliant pedestrians.

1.2 Gate Skirts

In the effort to prevent unsafe pedestrian activity, the safety measure chosen for evaluation is a pedestrian gate enhancement, commonly referred to as a gate skirt, consisting of a horizontal bar hanging underneath the existing gate. A gate skirt is a secondary bar (gate) marked with identical striping as the primary gate arm. The skirt hangs down from the pedestrian gate to block more area under the gate arm. This type of safety enhancement, illustrated in Figure 4 [2], is currently under consideration as an additional safety treatment recommended by the FHWA MUTCD.

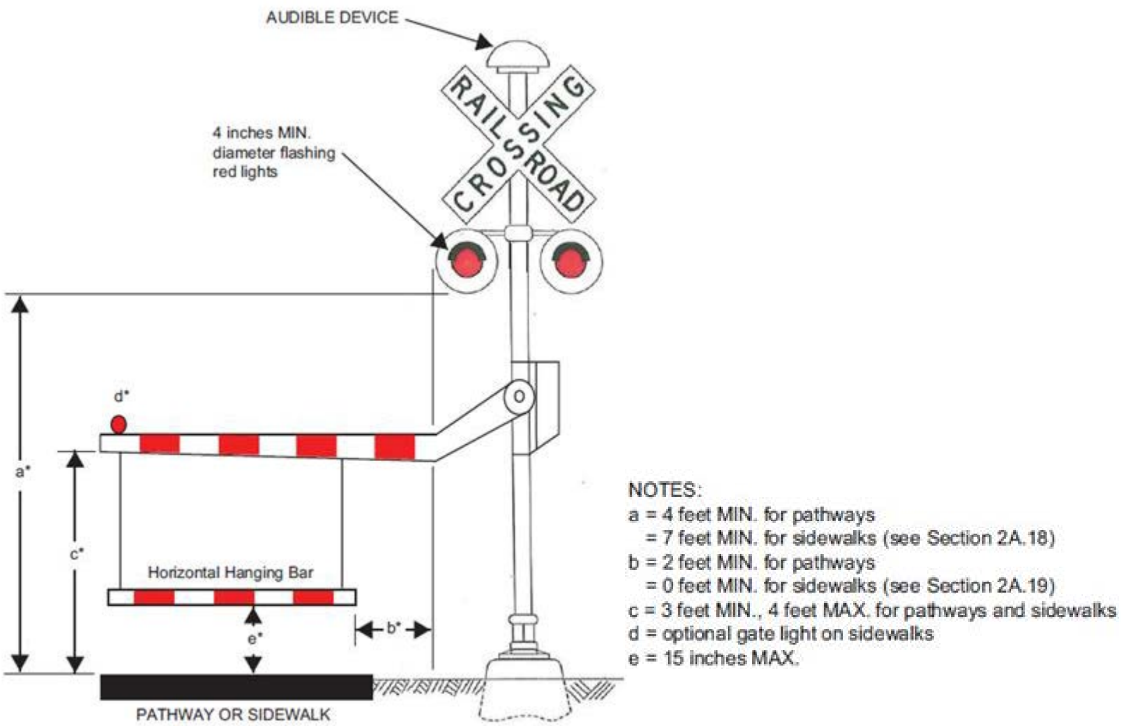

Figure 4. Example of Pedestrian Gate with Horizontal Hanging Bar at a Pathway or Sidewalk Grade Crossing

Gate skirts are thought be a beneficial addition to crossings, especially at locations where there is evidence of pedestrians going under the existing pedestrian gates, or at crossings that many children use. The addition of a gate skirt theoretically makes it more difficult for pedestrians to violate the crossing after the gates have fully descended, especially at crossings where some barrier channelization (e.g., fencing and vehicle gate) exists. While this enhancement does have certain limitations, previous research on its effectiveness in Europe, although limited to one grade crossing, has indicated that it has the potential to reduce risky pedestrian behavior by approximately 70 percent [3].

This type of safety treatment is used widely in Europe as an additional safety measure for both pedestrian as well as vehicle gates. In the United Kingdom, the Rail Safety and Standards Board provides guidance on the installation of gate skirts for all locations where "there is a significant risk of pedestrians deliberately passing under the lowered barriers" [4]. In the United States, research was done in the 1980s on the use of gate skirts as part of a four-quadrant gate system. A prototype, as shown in Figure 5, was field tested at the Cherry Street crossing in Knoxville, TN [5]. Currently, use of gate skirts in the United States thought to be limited to two grade crossings in Dallas, TX, along the Dallas Area Rapid Transit's Blue Line. Figure 6 shows the installation at Waco Avenue, one of the two locations.

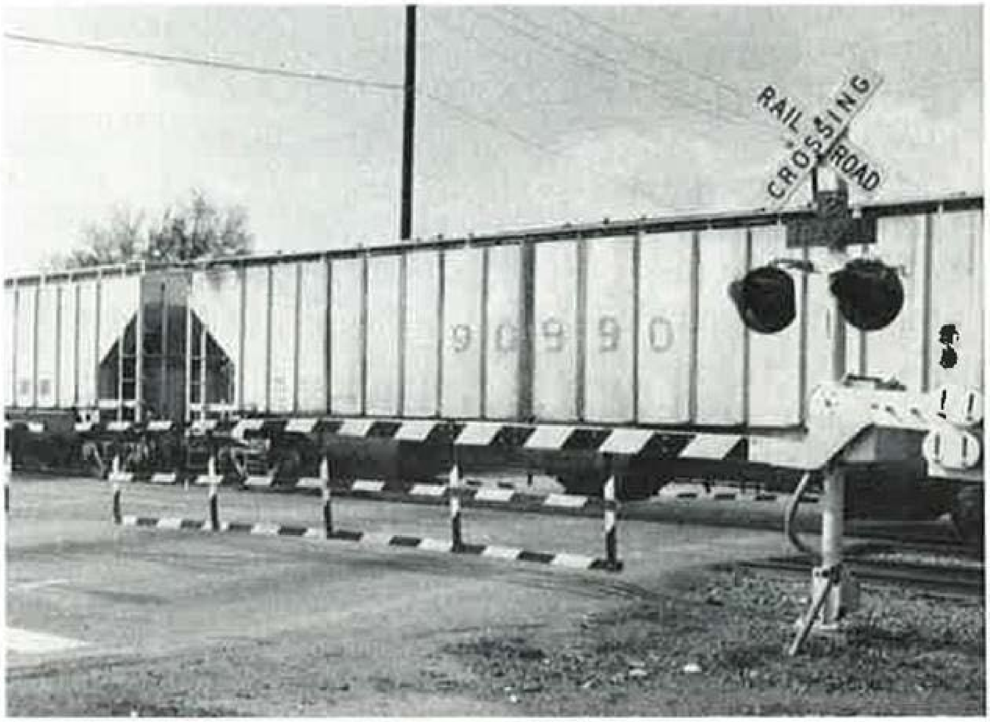

Figure 5. Prototype Gate Arm and Skirt Assembly at Cherry St. Crossing, Knoxville, TN

Figure 6. Gate Skirt Installation at Waco Ave., Dallas, TX

1.2.1 New Jersey Transit Prototype

The system evaluated in this study consisted of a prototype developed internally by NJ Transit Rail and installed at all four pedestrian quadrants of a grade crossing on May 30, 2012. The system was adapted to fit the existing infrastructure at the crossing. It consisted of a grade crossing gate section secured by two rods placed approximately 10–12 inches (there was an approximately 2-inch installation variation across the four gates) below the existing gate. The gap between the lower gate and the ground ranged from 26 to 29 inches. Additionally, channelization via a pedestrian fencing system was already in place at all four sidewalks leading up to the crossing.

Figure 7 through Figure 10 show the installation on all four pedestrian zones. As shown in Figure 7, gate maintenance and pedestrian access issues forced the secondary gate in Zone 1 to be substantially shorter than the existing gate, thereby leaving an approximately 2-foot gap uncovered by the gate skirt. A bollard was installed to block this area but a significant gap still remained. It should also be noted that the secondary gate in Zone 3, as shown in Figure 9, was installed under the long gate used to block access from both the sidewalk and street.

Figure 7. Prototype Pedestrian Gate Enhancement at Atlantic Ave. – Zone 1.

Figure 8. Prototype Pedestrian Gate Enhancement at Atlantic Ave. – Zone 2

Figure 9. Prototype Pedestrian Gate Enhancement at Atlantic Ave. – Zone 3

Figure 10. Prototype Pedestrian Gate Enhancement at Atlantic Ave. – Zone 4

1.3 Data Collection Equipment

The data collection equipment consisted of two small video cameras magnetically mounted on the roof of the signal bungalow to the northwest (relative to the train movement) of the crossing and closest to Zone 1, as shown in Figure 11, and connected to a digital video recorder installed within the structure, as shown in Figure 12. This vantage point allowed for surveillance of the entire grade crossing and provided a constant power source as well as physical protection for the equipment. Additionally, the visible parts of the surveillance system had a very low profile and were therefore believed not to have any impact on pedestrian behavior.

The system was configured for continuous video data recording, 24 hours per day, although data was only analyzed when a grade crossing activation occurred. It was installed on April 12, 2012, and remained operational through August 8, 2012. The 2-week pre-installation test period ran April 15–21 and May 6–12, 2012, and the 2-week post-installation test period ran July 8–21, 2012. The post-installation data collection was conducted 5 weeks after the installation of the gate skirts to allow for the novelty of the new gate enhancement to dissipate.

Figure 11. Video Camera Placement

Figure 12. Digital Video Recorder

The view from the two cameras can be seen in Figure 13 and Figure 14, below. Figure 13 shows the view from the first camera with each of the visible zones labeled (Zone 4 and Zone 8 are out of the camera's view.). The view from the second camera, as seen in Figure 14, shows the two zones not seen from the first camera (Zone 4 and Zone 8) and a better angle of Zone 3.

Figure 13. View of Zones from First Camera

Figure 14. View of Zones from Second Camera

2. Results

To assess pedestrian behavior at the Atlantic Avenue grade crossing before and after the gate skirt pedestrian gate enhancements were installed, data was collected both pre- and post-installation for a 2-week period and analyzed to answer three main research questions:

- Do the gate skirt enhancements significantly reduce the number of pedestrians who violate at the crossing?
- Do the gate skirt enhancements systematically lower all types of violations (ascending, descending, horizontal)?
- Does pedestrian movement though the crossing change with the installation of gate skirt enhancements? Specifically, do the pedestrians access the crossing differently and do the paths through the crossing differ pre- and post-installation?

To answer these three questions, the findings from the video analysis before and after installation of gate skirting will be discussed in the following three sections. The first section will cover all of the high level characteristics of the data collected to better understand the environment in which the pedestrians were moving. The second section will focus on the violations that occur at the grade crossing. The third and final section will focus on the quadrant-based pedestrian movements and if these movements differed before and after installation.

2.1 Data Characteristics

The final dataset consists of 336 total hours of video recordings—168 pre-installation and 168 post-installation hours. The number of activations that occurred before and after installation of the gate skirts is listed in Figure 15. Gate activations occurred because of a single train approaching, two trains approaching, or a false activation during which no train approached or passed through the crossing. False activations were moderately common at this crossing (n = 651 or 27 percent of all activations) since a train arriving at the nearby station before traversing the crossing would trigger a gate activation; however, this activation would "time out" after 60 seconds if the train did not move. The number of total activations before and after installation of the gate skirts was similar (1,196 versus 1,229, respectively). The only exception was found for second train activations which were more than twice as likely post- installation (18 versus 41, respectively).

The majority of activations occurred during a weekday, as opposed to the weekend, for both pre- and post-installation conditions (85 percent pre-installation and 90 percent post-installation). All pre-installation second train events occurred during a weekday and all but one post-installation second train events occurred during a weekday. False activations were not included in the following analyses because false activations possibly elicited a higher number of violations in cases where a train was presently unloading at the station and those passengers did not wait for the crossing arms to ascend.

Two types of train activations were identified for this crossing: (1) single train activations where one train traverses the crossing during the gate activation and (2) second train activations where two trains traverse the crossing during a single activation. Single train activations were more common before installation, with approximately 872 single train activations and 18 second train activations, as shown in Figure 15. The direction of the trains was divided almost equally between eastbound and westbound, with no difference by type of activation. Type of train was predominantly commuter, with only 1 percent (n = 10) involving freight train single activations and 11 percent (n = 9) involving freight for second train activations. Overall, there was approximately the same number of activations, with 890 pre-installation and 884 post-installation used in this analysis.

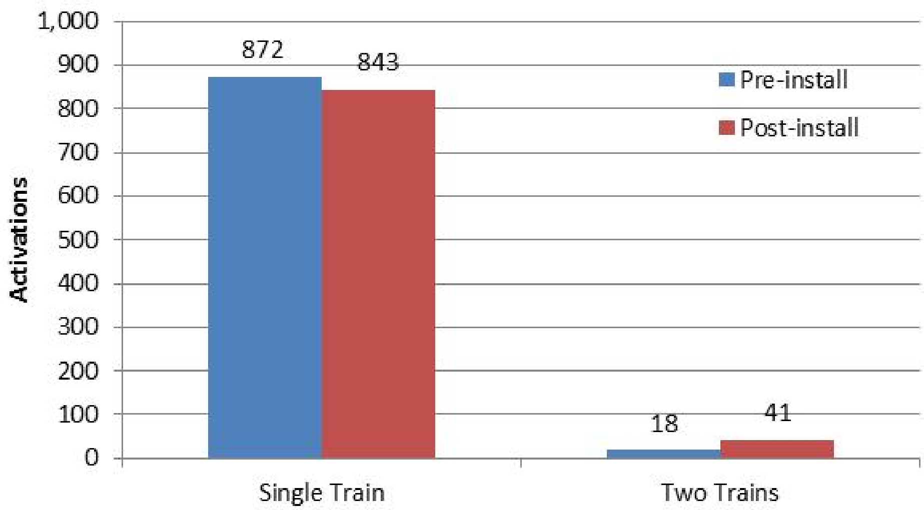

Figure 15. Number of Trains per Activation Pre- and Post-Installation

Since commuter trains passing through the Atlantic Avenue crossing were on a fixed schedule, the times when the single activations occurred were fairly consistent. However, second train activations, although less frequent, were far less consistent. Since the second train activations were less frequent, they did not change the total number of activations.

To record the pedestrian movements through the crossing, the crossing was divided into eight zones. Zones 1 through 4 included the sidewalk and Zones 5 through 8 included the area on the street (see Figure 3).

As seen in Figure 3 and discussed earlier in the report, the zones are highlighted in yellow if they include the sidewalk and green if they include the road. All zone boundaries back up to each other to cover all of the area of the crossing. This configuration allows us not only to track the areas through which pedestrians enter the crossing, but also the paths they take to traverse and eventually to exit the crossing.

First, we will examine which zones the pedestrian first encounters the crossing; we refer to this as the "arrival zone." The most common arrival zone for pedestrians was Zone 1 (58 percent both pre- and post-installation), followed by Zone 2 (17 percent pre- and 18 percent post-installation), and then Zone 4 (15 percent pre- and 13 percent post-installation). See Figure 16 for a breakdown by zone of pedestrian arrivals at the crossing. As shown in Figure 16, pedestrians were far more likely to arrive at a crossing on the sidewalk than on the street. However, Zone 5, a street zone, was found to have more pedestrian arrivals than Zone 3, a sidewalk zone. This was true in both the pre-installation period (86 sidewalk Zone 3 arrivals versus 106 street Zone 5 arrivals) and the post-installation period (64 sidewalk Zone 3 arrivals and 111 street Zone 5 arrivals). A chi-square statistical test showed a significant difference in the number of pedestrians at the arrival zone after the installation of the gate skirt (χ^2 (7, N = 4,773) = 24.11, P < .01). This change may be attributed in large part to the increase in pedestrian arrivals at Zones 6 and 8, both street zones[1]. Since the overall number of pedestrians is lower after installation of the gate skirt, this finding lends credibility to the conclusion that more pedestrians arrived at the crossing in the street after gate skirts were installed. Based on the data thus far, we know that pedestrian arrival is affected by the installation of gate skirts, but we do not know if the pedestrians still went on to violate the crossing. The next section will address the effect that gate skirts had on pedestrians violating the crossing.

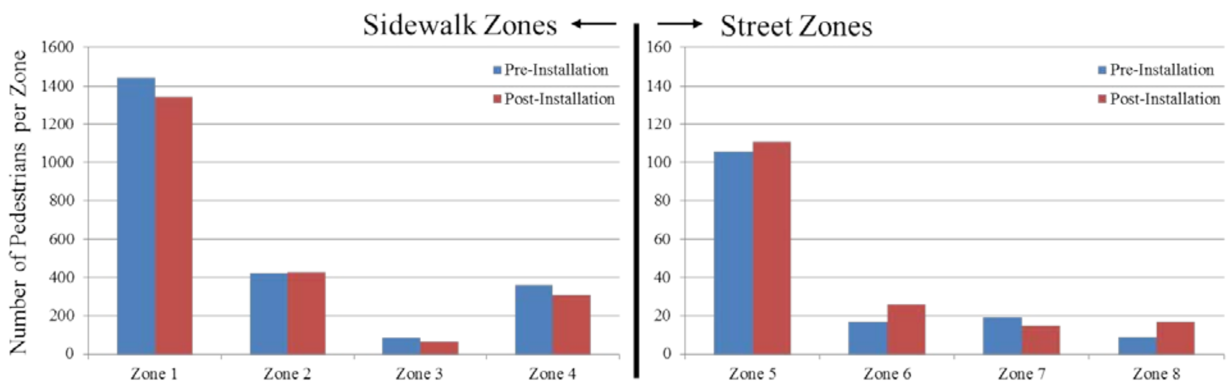

Figure 16. Number of Pedestrians per Arrival Zone Pre- and Post-Installation

2.1.1 Violations

The goal of the sidewalk gate skirts is to lower the number of violations that occur by pedestrians when in proximity of a train approaching the crossing. To evaluate the effectiveness of the gate skirts, we need to look at violations in two ways: overall change in rate of violations and how the violations occurred. If the rate of violations dropped, then gate skirts would be considered effective. However, if rates went down but only in situation-specific conditions (e.g., violations that occurred only when the gates were horizontal, or only at a specific zone) this would necessitate a reexamination of the effectiveness of gate skirts during train activation events.

Findings show that there was some consistency in the occurrence of activations with at least one violation: 448 (51 percent) pre-installation activations with a violation and 463 (55 percent) post-installation activations with a violation. Violations were split into three categories based on when the pedestrians went through the crossing:

- Descending violation: a pedestrian goes under or around the gates as they are descending prior to the arrival of the train.
- Horizontal violation: a pedestrian goes under or around the gates after the gates have fully descended and are in a horizontal position.

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[1] Although not found to be statistically significant.

- Ascending violation: a pedestrian goes under or around the gates as they are ascending after the train has already passed through the crossing.

Example images of each of these types of violations, both with and without gate skirts, can be seen in the examples provided below. Examples of descending violations can be seen in Figure 17. In the pre-installation example (left panel), a total of five pedestrians went under the gate after descent had initiated. The woman on the left arrived at the crossing at the same time as the violating pedestrians, but chose to wait until after the activation had completed. In the post-installation example (right panel), the man in the blue shirt is running underneath the gate as they descend and continues through the crossing, exiting in the street in Zone 6.

Pre-Installation Post-Installation

Figure 17. Examples of Descending Violations Pre- and Post-Installation

Examples of horizontal violations can be seen in Figure 18. In the pre-installation condition (left panel) a pedestrian is going under the horizontal gate in Zone 2. This pedestrian crossed the tracks and exited the crossing by going under the gate in Zone 1. In the post-installation example (right panel), the pedestrian is ducking underneath the original gate in the space where the gate skirt does not extend. This pedestrian, like the man in the post-installation example described above for the descending violation, exited the crossing by walking to the street and exiting in Zone 6.

Pre-Installation Post-Installation

Figure 18. Examples of Horizontal Violations on the Sidewalk Pre- and Post-Installation

During both horizontal and descending violations, it was possible for pedestrians to violate the crossing from the street. During horizontal violations, pedestrians could go around or under the vehicle gate (as seen in the left panel of Figure 19), or they could avoid the gates entirely in Zone 6 or Zone 8, as seen in the right panel of Figure 19 with a cyclist riding from Zone 8 to Zone 6.

Figure 19. Examples of Horizontal Violations in the Street

Lastly, examples of ascending violations can be seen in Figure 20. In both pre- (left panel) and post- (right panel) installation examples, a large group of pedestrians is going underneath the gates as they ascend after a train passes through the crossing. The gates are all fully raised by the time these pedestrians reach the other side of the crossing, so they were not restricted in any way in terms of how they exited the crossing.

Pre-Installation Post-Installation

Figure 20. Examples of Ascending Violations Pre- and Post-Installation

Of the three types of violations, the ascending violation is least likely to result in a dangerous situation since the train has in most cases left the crossing area. However, in second train situations where the gates start ascending but reverse direction before fully vertical, the pedestrian may get caught inside of the gates, creating a highly dangerous situation. One such case occurred on April 17, 2012, during the pre-installation phase of observation. In that event, as shown in Figure 21, three pedestrians started to cross after the gates started ascending. However, the gates reversed direction approximately 3 seconds later (at about 45 degrees), and one pedestrian was forced to remain within the crossing past Zone 1 while the train passed.

Figure 21. Example of Second Train Activation

Given the total number of pedestrians who approached the crossing during an activation (2,461 before installation and 2,312 after installation) there was a significant difference in the number of violations that occurred before installation (1918 violations) and after installation (1,988 violations), (χ^2 (2, N = 3904) = 19.23, P < .001). Although the overall number of violations was higher post-installation, there was a statistically significant decrease in the number of descending and horizontal violations after the installation of gate skirts, as shown in Figure 22. Descending violations decreased significantly from 80 (4 percent) violations to 19 (<1 percent) violations (χ^2 (1, N = 96) = 49.27, P < .001). Horizontal violations also decreased significantly from 177 (10 percent) violations to 83 (4 percent) violations (χ^2 (1, N = 268) = 55.01, P < .001). In contrast, ascending violations rose significantly after the installation of gate skirts from 1658 (86 percent) violations to 1887 (95 percent) violations (χ^2 (1, N = 3,904) = 16.52, P <.001).

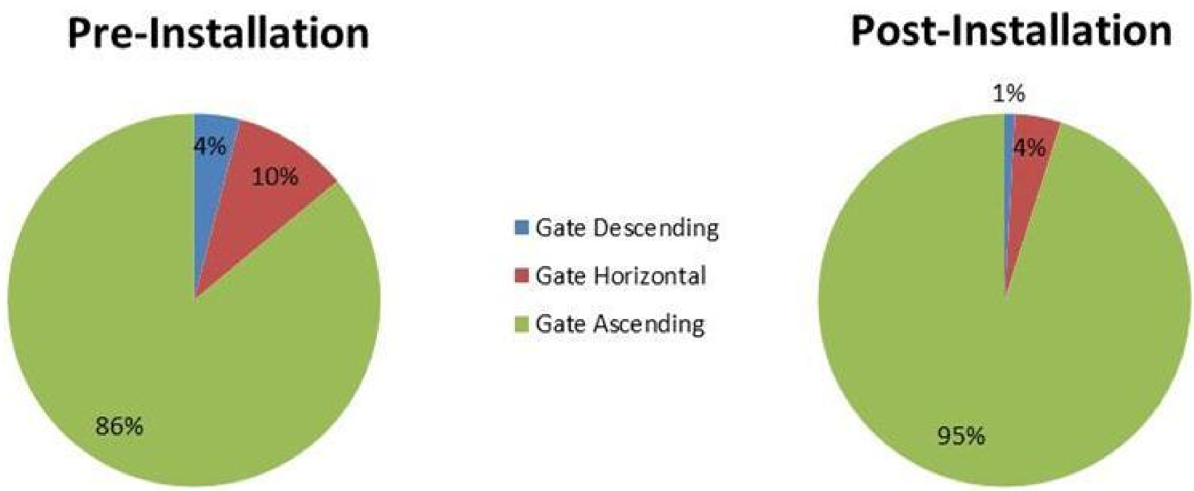

Figure 22. Frequency of Violations per Activation Phase Pre- and Post-Installation

To examine pedestrian movements as they violated the grade crossing, the research team implemented the same zone assignments from Figure 3 (where Zones 1–4 include sidewalks and Zones 5–8 include the street). For pedestrians to cross the tracks, they must depart from a zone on one side of the railroad tracks and ultimately arrive in a zone on the opposite side of the track, although the route they take will vary.

2.1.2 Entering the Crossing

Focusing only on descending and horizontal gate violations, Table 1 breaks down the number of pedestrians who initiated violating the crossing from sidewalk or street by type of violation (descending or horizontal). Pedestrians that violated the crossing while the gates were descending were found to enter the crossing more often from the sidewalk than the street. This was true both before and after installation of the gate skirts. For descending violations, the pedestrians generally entered from the sidewalk, accounting for 74 of 80 violations before installation and 15 of 19 violations after installation. The most significant difference, however, was found to be for descending street violations; there were only two less violations initiated in the street after installation, even though the total number of post-installation violations increased by approximately 92 percent (χ^2 (1, N = 96) = 4.65, P < .05). The majority of horizontal violations also began on the sidewalk with 141 of 176 pre-installation violations and 36 of 80 post-installation violations. This difference was found to be significant both before and after installation with a drop from 80 percent of the pre-installation violations starting on the sidewalk to 45 percent post-installation (χ^2 (1, N = 190) = 12.31, P < .001). Additionally, violations that began on the street jumped from 20 percent of pre-installation violations to 55 percent post-installation (χ^2 (1, N = 76) = 49.60, P < .001). Both of these findings illustrate that violating pedestrians overall enter more frequently from a sidewalk although the rate at which pedestrians enter from the street increased significantly after installation of the gate skirts. This is found for both descending and horizontal violations with a larger increase in violations while gates are in the horizontal position.

Table 1. Street and Sidewalk Entrance Zones

	Pre-Installation Descending Violations	Post-Installation Descending Violations	Pre-Installation Horizontal Violations	Post-Installation Horizontal Violations
Sidewalk Entrance Zone	74 (93%)	15 (79%)	141 (80%)	36 (45%)
Street Entrance Zone	6 (8%)	4 (21%)	35 (20%)	44 (55%)

Additionally, the research team was able to look not only at where the pedestrians violated, but how the pedestrians violated (e.g., under or around the gates). The overall number of descending violations was seen to drop after the installation of gate skirts when the pedestrian went under a pedestrian gate or at the zone where no gates were installed (e.g., Zone 6 and Zone 8). Figure 23 illustrates the different ways a pedestrian could violate the crossing while the gates were descending. There are no instances of pedestrians going around either the pedestrian or street gates for descending violations because the gates have yet to fully descend; therefore, pedestrians cannot go around them. The largest reduction in descending violations occurred for going under pedestrian gates: from 76 (95 percent) of all pre-installation violations to 16 (84 percent) of post-installation violations. A slight increase was seen for post-installation violations when pedestrians went under vehicle gates: from one pre-installation violation to two post-installation.

Horizontal violations (depicted in Figure 24) when the pedestrian went under a pedestrian gate also dropped in number after the installation of gate skirts: from 147 (84 percent) of all pre-installation violations to 38 (46 percent) of post-installation violations. A large increase (12 or 7 percent pre-installation to 30 or 37 percent post-installation) was seen in the percentage of pedestrians who violated in Zone 6 or Zone 8, which both have no gates installed. A smaller increase was seen in horizontal violations after installation when pedestrians went under vehicle gates: from 6 (3 percent) violations before installation to 9 (11 percent) after installation.

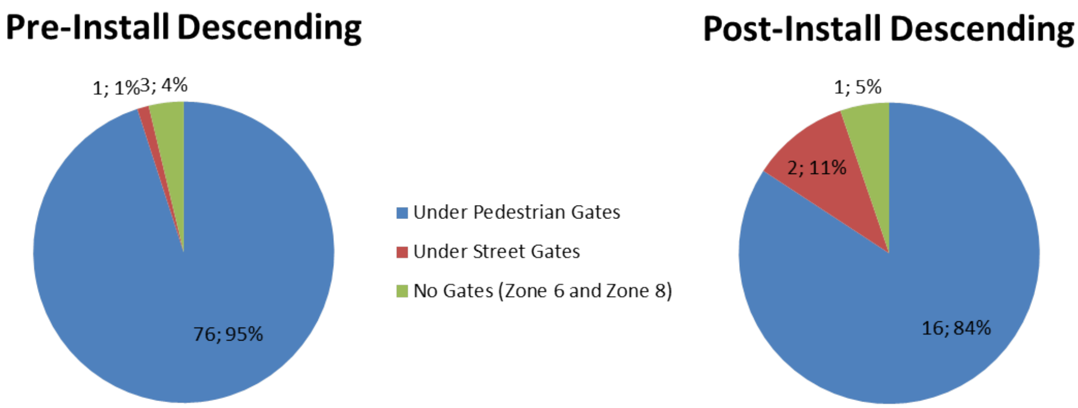

Figure 23. How the Pedestrian Violated for Descending Violations

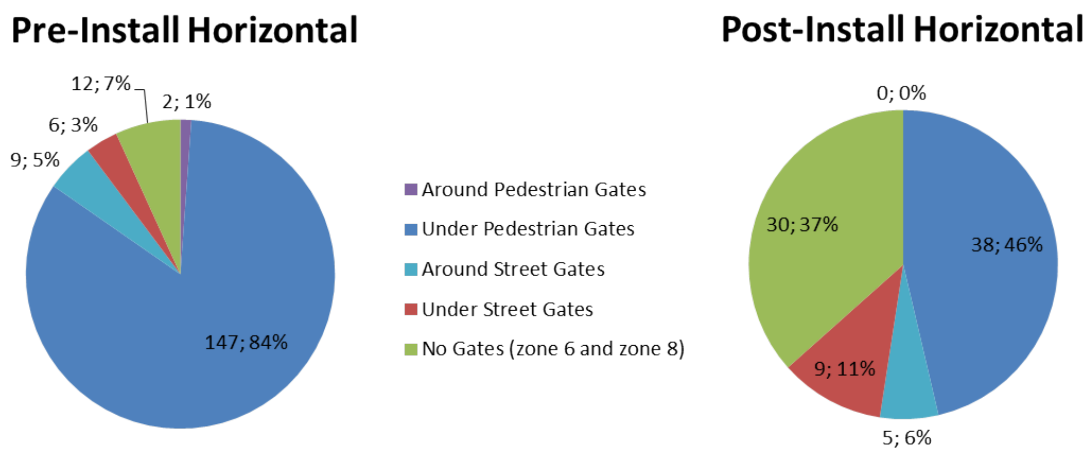

Figure 24. How the Pedestrian Violated for Horizontal Violations

2.1.3 Exits

Pedestrians that violated the crossing, either while the gates were descending or horizontal were found to exit the crossing more often from the sidewalk than the street. This was true both before and after installation of the gate skirts. Descending violations largely ended on the sidewalk, with 58 out of 80 violators exiting on the sidewalk during the pre-installation period and 9 of 19 exiting on the sidewalk post-installation. This difference between pre- and post-installation sidewalk exit was not found to be significant (χ^2 (1, N = 99) = 1.65, P = 0.20); however, the increase in street exits was found to be significant (χ^2 (1, N = 99) = 4.36, P <0.05). The majority of horizontal gate violators also exited on the sidewalk: 136 of the 176 pre-installation violations and 39 of 80 post-installation violations. This difference was found to be significant both before and after installation, with a drop from 77 percent of the violations exiting on the sidewalk before installation to 49 percent after installation ($\chi2$ (1, N = 268) = 8.4, P<0.01). Additionally, horizontal violations that ended on the street jumped a significant amount from 23 percent of the violations before installation to 51 percent after installation ($\chi2$ (1, N = 268) = 28.64, P<0.001). This increase in pedestrians exiting in the street after violating the crossing could indicate that pedestrians took the shortest route without an obstruction through the crossing when violations occurred while the gate was horizontal. See Table 2 for the number of pedestrians exiting the crossing from sidewalk or street based on type of violation (descending or horizontal).

Table 2. Street and Sidewalk Exit Zones

	Pre-Installation Descending Violations	Post-Installation Descending Violations	Pre-Installation Horizontal Violations	Post-Installation Horizontal Violations
Sidewalk Exit Zone	58 (73%)	9 (47%)	136 (77%)	39 (49%)
Street Exit Zone	22 (28%)	10 (53%)	40 (23%)	41 (51%)

2.1.4 Pedestrian Movement through the Crossings

There are many different paths that pedestrians may take while violating the crossing. To better understand if there is a difference for pedestrians violating before and after installation of gate skirts, the paths of each pedestrian committing a violation while entering or exiting the crossing were collected. It is possible that a horizontal gate seems more formidable, so pedestrians take the shortest path across the railroad tracks, rather than a longer path that takes them closer to their final destination (e.g., train platform).

The three most frequently used zones for initiating a pre-installation violation were sidewalk Zones 1, 2, and 4, which account for 91 percent of all descending violations and 77 percent of horizontal violations. After gate skirt installation, pedestrians who violated while the gates were descending initiated their violation from Zones 1, 2, and 4 79 percent of the time and for horizontal violations 45 percent of the time. However only 1 out of the 19 descending violations (5 percent) that occurred after installation was found to have departed from Zone 4 in contrast to 12 out of 80 (15 percent) total violations before installation. For horizontal violations, an additional change occurred after installation: Zone 6, which includes the street, was frequently used to initiate a violation following the gate skirt installation, accounting for 25 percent of all violations, whereas this zone was not frequently used before the gate skirt installation and accounted for only 5 percent of all horizontal violations. Zone 8 also experienced a large increase in horizontal violations, with only 4 (2 percent) of violations being initiated from Zone 8 before installation and 9 (11 percent) being initiated after.

Before installation of gate skirts, Zones 1, 2, and 4 (sidewalk zones), were used 68 percent of the time to exit the crossing after descending violations, whereas after installation, the zones' usage dropped to 47 percent. For horizontal violations, Zones 1, 2, and 4 were used to exit the crossing for 76 percent of violations before installation and for only 48 percent after installation of the gate skirt. Again, Zone 6 showed a large increase for both descending and horizontal violations after installation. For descending violations, 18 (23 percent) of pre-installation violations and 7

(37 percent) of post-installation violations used Zone 6 to exit the crossing. Despite an overall decrease in the number of violations using Zone 6 to exit, the proportion of violation from Zone 6 to the total number of post-installation violation exits increased by 14%. For horizontal violations, 28 (16 percent) pre-installation violations used Zone 6 to exit the crossing and 33 (41 percent) exited from Zone 6 after installation. This 25 percent pre- to post-installation increase indicates that a larger percentage of pedestrians were using Zone 6 to exit the crossing after installation of the gate skirt. This increase may also in part be explained by a decrease in the adjacent Zone 2: from 35 to 6 percent of pedestrians exiting. Of the 80 post-installation horizontal violations, 38 pedestrians went under the gates to violate and 17 of those violations originated from Zone 1. Of those 17 violations, only 1 pedestrian violated by going under the gate skirt (upper left of Figure 25); the remaining 16 went through the unobstructed area between the gate skirt and the post holding the gate to the left of the cone (upper right of Figure 25). One pedestrian who jumped the fence next to the gate to avoid going under or around (bottom of Figure 25) is not included in the totals above.

Figure 25. Zone 1 Pedestrian Violation Behavior

Additionally, there were 10 violations for which the pedestrian exited the crossing in Zone 1 while the gates were horizontal. Of those 10 violations, the pedestrians went around the gate skirt (to the left of the cone) in 7, under the gate skirt in 1 (see left panel of Figure 26), and 2 pedestrians waited until the gates began to ascend to exit. In three additional cases, the pedestrian went under the vehicle gate to exit (Zone 5) and then squeezed between the gate pole and the fencing to get to Zone 1 (see right panel of Figure 26). However, the movement from Zone 5 to Zone 1 occurred on the same side of the crossing.

Figure 26. Zone 1 Pedestrian Violation Exit Behavior

2.1.5 Pedestrian Path through Crossing

The entrance and exit zones are important for understanding how pedestrians violate the crossing and the path they take to traverse the crossing.

Pedestrian movements (or paths) through the crossing differed by type of violation committed. Figure 27 provides an illustration of the five most frequently used paths during a descending violation before and after installation. Prior to installation of the gate skirts (top half of Figure 27), the most frequented paths were between Zones 1 and 2, in both directions, followed by Zone 1 to Zone 6, Zone 1 to Zone 4, and Zone 4 to Zone 2. After the installation of the gate skirts (bottom half of Figure 27), pedestrians violated between Zone 1 and Zone 6 most frequently, followed by Zone 1 to Zone 2 in both directions, but the other paths were less often used. (Note: only three paths were included in post-installation analysis due to the low overall rate of pedestrians who violated while the gates were descending; all additional paths had an N = 1 or less).

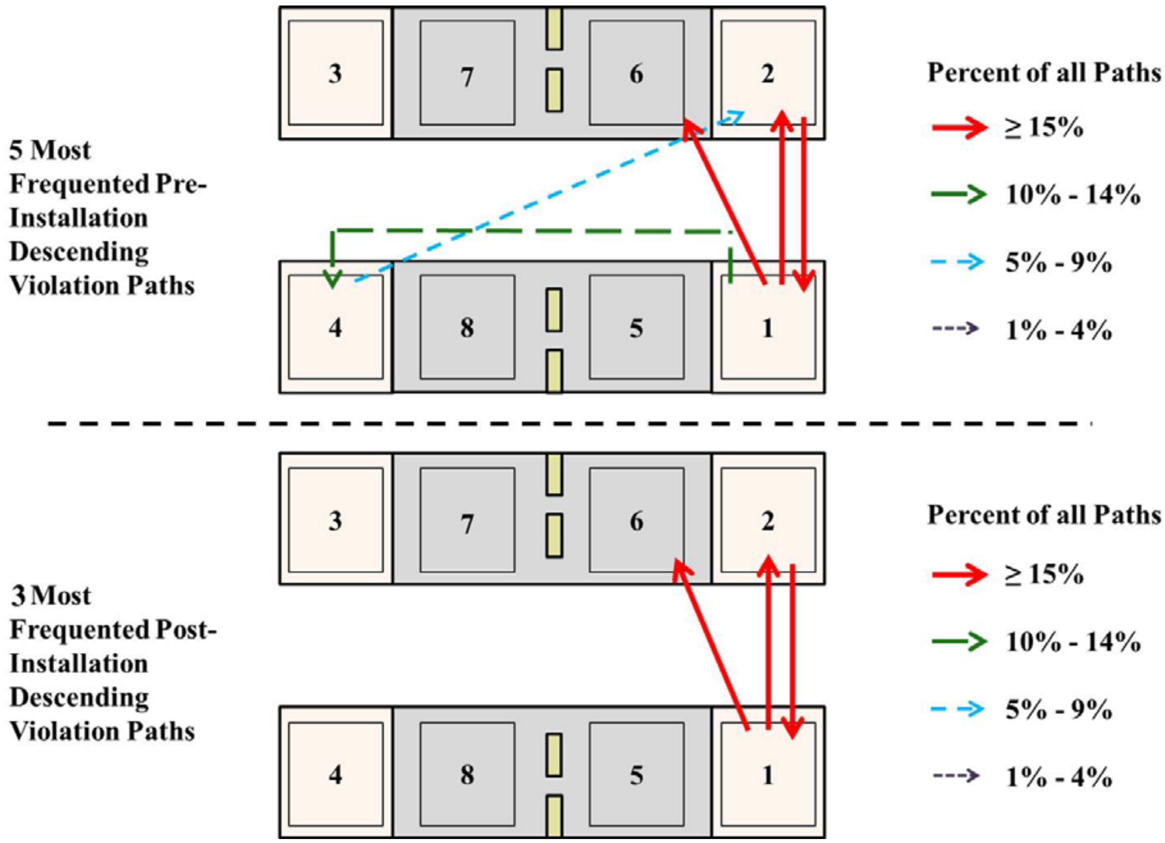

Figure 27. Most Frequent Paths through Crossing during Descending Violation

Horizontal violations were found to be similar to descending violations before installation of the gate skirts, with movement from Zones 1 and 2, in both directions, followed by Zone 1 to Zone 4 being the most frequently travelled (see Figure 28). However, after installation of the gate skirts, pedestrian movements (or paths) changed quite dramatically during horizontal violations. The two most frequent paths after installation were Zone 6 to Zone 1 in both directions, with Zone 6 being a street zone. Neither the path from Zone 1 to Zone 6 nor the path from Zone 6 to Zone 1 was among the top five paths before installation of the gate skirts. This indicates a rise in the number of paths that start or end on the street after the installation of the gate skirts. The next most common post-installation paths were from Zone 5 to Zone 6 and from Zone 8 to Zone 6, both of which are paths that exclusively use the street to traverse the crossing. The path from Zone 2 to Zone 1, which was one of the top two paths before the installation of gate skirts, was tied for the fifth most frequented path after installation, which illustrates a reduction in the number of pedestrians traveling from sidewalk to sidewalk and between those zones. (Note: seven paths were included in the post-installation analysis because three paths tied for the position of fifth most popular).

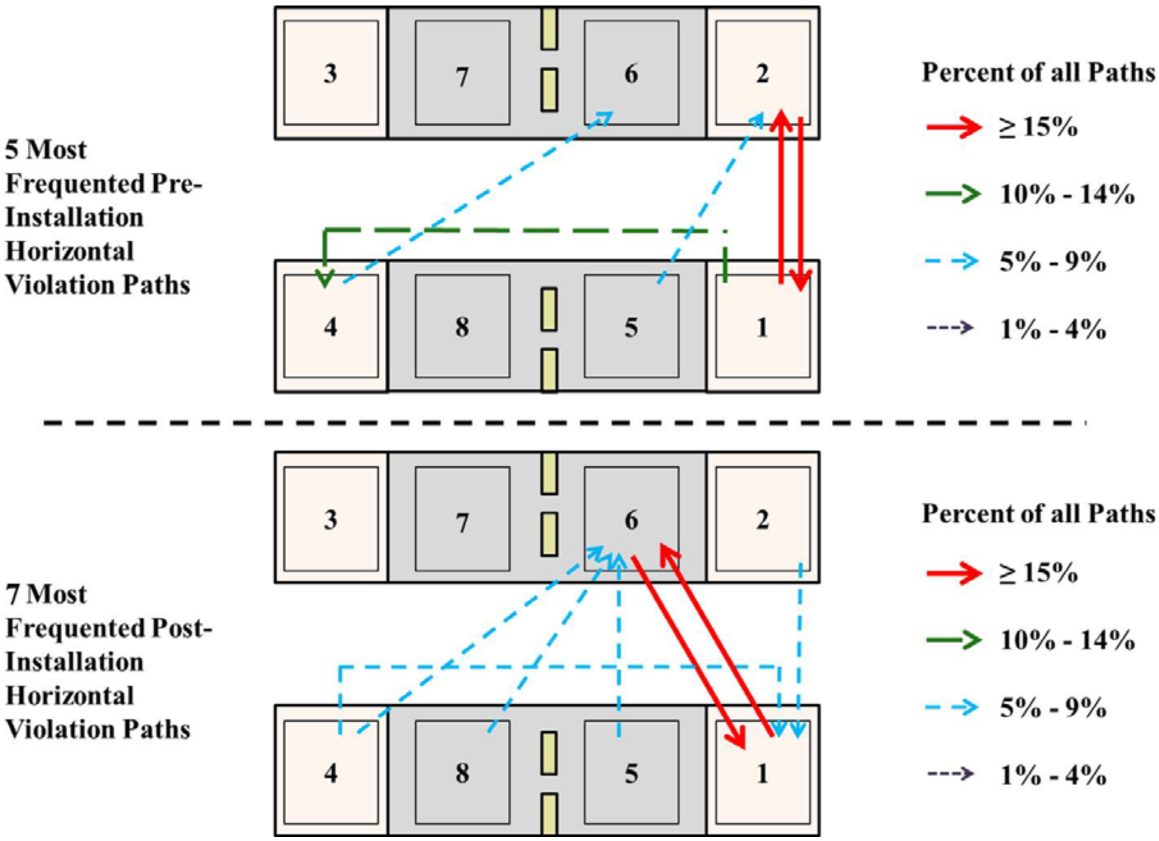

Figure 28. Most Frequent Paths through Crossing during Horizontal Violation

Although the paths taken is known for the pedestrians who violate, the findings above do not take into account if there are differences when the pedestrians are violating alone or with another person. Findings showed a significant increase in the percentage of pedestrians who violated alone while the gates were descending (χ^2 (1, N = 64) = 3.959, P <0.05), as well as a significant decrease in the number of pedestrians who violated the crossing with at least one other person, from 32 (41 percent) before installation of gate skirts to zero after installation (χ^2 (1, N = 32) = 6.886, P <0.01). In horizontal violations, the change between pre- and post-installation was not as dramatic for either a pedestrian violating alone or with another violator. The difference was 137 (74 percent) pre-installation violations involving a lone pedestrian violator to 62 (75 percent) post-install violations involving a lone violator. However, the difference in number of violations with another stays relatively the same with 47 (26 percent) violations before installation to 21 (25 percent) violations after installation of the gate skirts. These results are presented in Figure 29 below. The findings seem to indicate that the gate skirts have a more pronounced effect on pedestrian decision-making when the pedestrians are part of a group approaching a crossing while the gates are actively descending. One possible reason for this may be that the gate skirts make it more difficult for multiple people to go under while the gates are descending. A gate skirt fills the space where trespassers would normally bow down to go under the gates as they descend. Potential trespassers may consider it too difficult to get underneath the descending bar in time, especially if they are travelling with other individuals who would also have to bow down under the gate after them (and would thus have less space and time in which to do so).

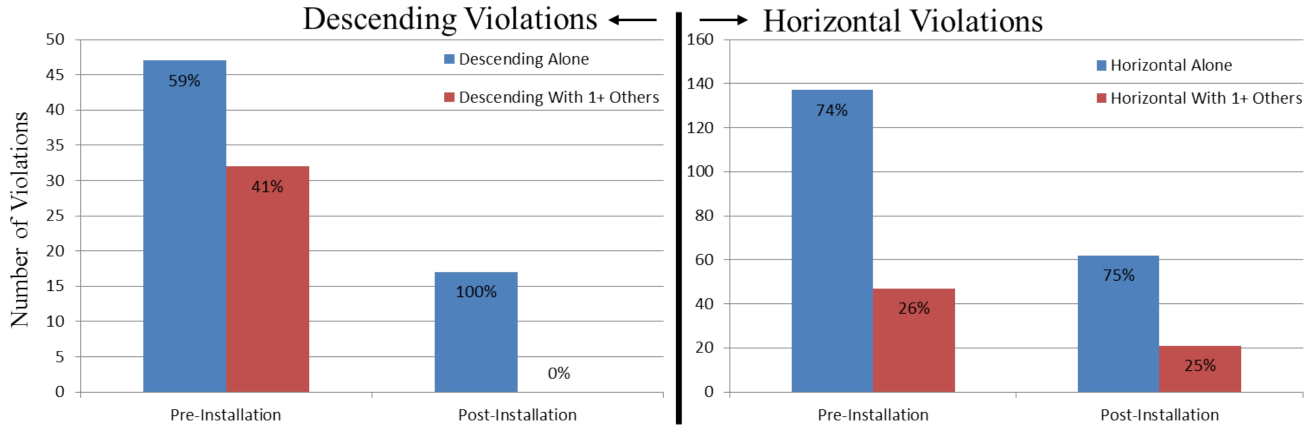

Figure 29. Pedestrians Violating Alone vs. with another Pedestrian

2.2 Summary of Findings

To evaluate the effectiveness of the addition of gate skirts to the pedestrian gates at the Atlantic Avenue grade crossing, a number of questions were sought:

- Do the gate skirt enhancements significantly reduce the number of pedestrians who violate while crossing?
- Do the gate skirt enhancements systematically lower all types of violation (ascending, descending, horizontal)?
- Does pedestrian movement though the crossing change with the installation of gate skirt enhancements? Specifically, do the arrival points and paths differ before and after installation?

Results showed there was a significant increase in total number of violations after installation of the gate skirts. However, this finding is predominately due to an increase in ascending violations. Ascending violations increased significantly after installation of the gate skirts although both descending and horizontal violations significantly decreased, as shown in Figure 30. Figure 30 depicts the number of descending, horizontal, and ascending violations per train activation, which allows for comparison of the increase or decrease in the rate of each type of violation. The increase in ascending violations may be due to the fact that the gate skirt blocks access to the sidewalk, so pedestrians are more anxious to get across the crossing once the gates start to ascend because they know it will be harder to do so once the gate comes down. Alternatively, this increase could be due to the increased number of pedestrians waiting to cross because fewer pedestrians were violating while the gates were descending or horizontal.

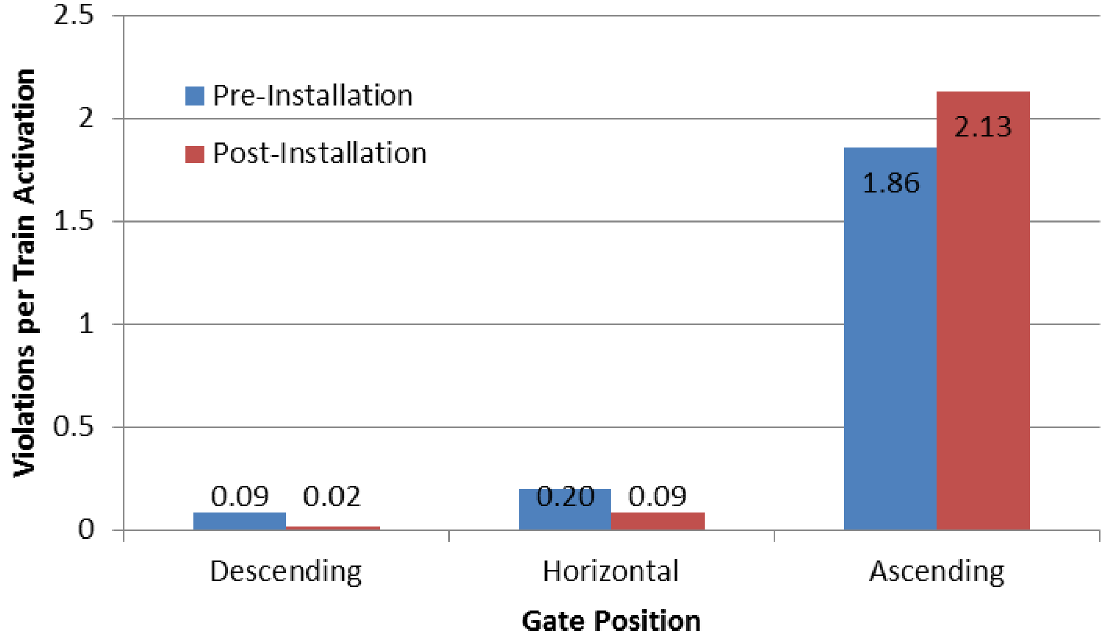

Figure 30. Pedestrian Violation Rate per Grade Crossing Activation

Pedestrian movements were also found to shift after the installation of gate skirts. Before and after the installation of gate skirts, most violating pedestrians entered and exited the crossing using the sidewalk. While the majority of violating pedestrians still tended to enter and exit the crossing on the sidewalks, there was a significant increase in pedestrians' use of the street after the installation of the gate skirts. This finding was strongest when the pedestrians were committing violations while the gates were in the horizontal position, the most difficult to get around. The paths through the crossing also changed after installation of the gate skirts for both descending and horizontal violations. However, the change was much greater for horizontal violations, with many more people entering and exiting the crossing from the street than before installation.

3. Conclusion

A total of 2,461 pre- and 2,312 post-installation pedestrian observations were made with a total of 890 pre- and 884 post-installation train activations analyzed. There was a statistically significant decrease in the number of descending and horizontal violations after the installation. Descending violations dropped significantly from 79 violations to 17. Horizontal violations also decreased significantly from 185 to 83 violations. In contrast, ascending violations rose significantly after the installation of gate skirts from 1,653 violations to 1,887 violations, though the reason is uncertain. The findings illustrate that the addition of gate skirts in this particular case has reduced the number of violations committed while the gates are descending (78 percent reduction in violation rate) or in the horizontal position (55 percent reduction in violation rate), as shown below in Figure 31. The addition of gate skirts may also have changed pedestrian behavior in that pedestrians may now be more likely to enter and exit the crossing from the street when committing a descending or horizontal violation. Horizontal violations (entering the crossing) on the sidewalk dropped from 82 percent of the violations before installation to 47 percent after installation, while violations that began on the street jumped from 18 percent of the violations before installation to 53 percent after installation. Horizontal violations that exited on the street jumped a significant amount: from 19 percent of the violations before installation to 35 percent after installation, though again the reason for this jump is uncertain.

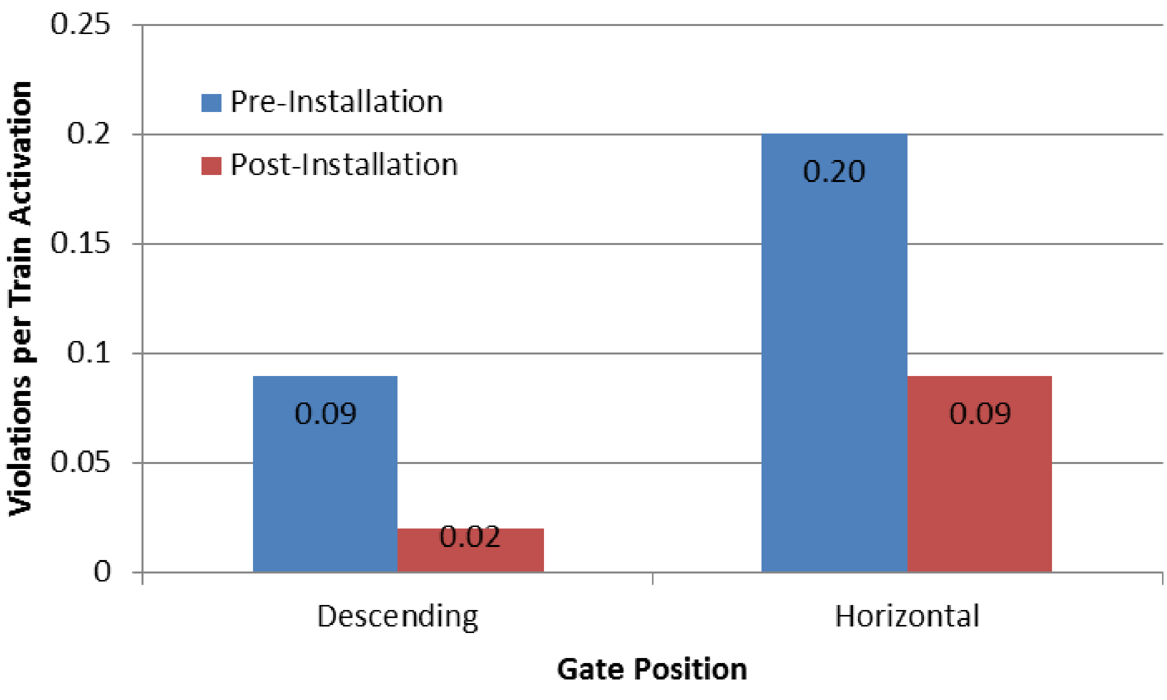

Figure 31. Descending and Horizontal Gate Violation Rate per Grade Crossing Activation

The next step of this research effort is to better understand why pedestrians, especially those committing violations while the gates are horizontal, prefer to enter from the street. In fact, the accident that occurred in January 2013 after the gate skirts had been installed involved a trespasser who violated the crossing in the street and unsuccessfully attempted to cross the street in front of the train. Additional variables in the current dataset, such as pedestrian actions during false activations and the behavior of the pedestrian as they violate the crossing (in terms of running or walking), may provide a more comprehensive picture of pedestrian behavior both before and after installation. Applying this evaluation plan to different grade crossing sites may also assist in determining if the reduction in descending and horizontal violations was caused by the gate skirts alone or was a combination of the gate skirts and the characteristics of the crossing itself. In testing this prototype at other grade crossing sites, it is recommended that careful consideration be given to the design to ensure reduction or elimination in gaps or areas where pedestrians may sneak around the gates. Zone 1 in its current location gave pedestrians a workaround that allowed them to violate around the lower gate, thus reducing its effectiveness. To reduce gaps, use of channelization by installing fencing may be appropriate. Additionally, lowering the gate skirt so it hangs closer to the ground may be critical in stopping individuals who continue to violate under the gate skirt itself.

4. References

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[3] Horst. A.R.A. van der. *Beproeving hangwerk voetpadbomen middels video gedragsobservaties*. (TNO-rapport TNO-DV 2009 C286). July 2009.

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[5] Heathington, K.W., et al, *Field Evaluation of a Four-Quadrant Gate System for Use at Railroad-Highway Grade Crossings*. Transportation Research Record 1244, TRB, National Research Council, Washington, DC, 1989, pp. 39–51.

Appendix A. Additional Data

Table A-1 below shows the number of pedestrians who entered the crossing from each zone, pre- and post-gate skirt installation.

Zone	Pre-Installation Pedestrians Arrival Zone	Post-Installation Pedestrians Arrival Zone
Zone 1 (sidewalk)	1,442 (58%)	1,343 (58%)
Zone 2 (sidewalk)	424 (17%)	428 (18%)
Zone 3 (sidewalk)	86 (4%)	64 (3%)
Zone 4 (sidewalk)	358 (15%)	308 (13%)
All Sidewalk Zones(1-4)	**2,310 (94%)**	**2,143 (93%)**
Zone 5 (street)	106 (4%)	111 (5%)
Zone 6 (street)	16 (1%)	26 (1%)
Zone 7 (street)	19 (1%)	15 (1%)
Zone 8 (street)	10 (1%)	17 (1%)
All Street Zones (5-8)	**151 (6%)**	**169 (7%)**
Total Pedestrians	**2,461**	**2,312**

Table A-1. Number of Pedestrians Arriving at Each Zone

Abbreviations and Acronyms

FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
HRI	Highway-Rail Intersection
MUTCD	Manual on Uniform Traffic Control Devices
NJDOT	New Jersey Department of Transportation
NJ Transit Rail	New Jersey Transit Rail
ROW	Right-Of-Way
U.S. DOT	U.S. Department of Transportation
Volpe Center	John A. Volpe National Transportation Systems
Z	Zone