Final Report

Pilot Implementation for Preventing Incorrect Turns at Highway-Rail Grade Crossings

Project No.

FDOT BDV25-977-54

Final Report

Prepared for

Florida Department of Transportation

November 2019

CUTR CENTER FOR URBAN TRANSPORTATION RESEARCH
USF UNIVERSITY OF SOUTH FLORIDA
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Catherine Bradley, P.E., Project Manager

Prepared by

USF Center for Urban Transportation Research (CUTR)

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November 2019

Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

Metric Conversion Chart

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	squareinches	645.2	square millimeters	mm^2
ft^2	squarefeet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

Technical Report Documentation Page

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16. Abstract

Incorrect turns onto railroad tracks may occur if a highway-rail grade crossing is close to an intersection or a freeway on-ramp. This project aimed to evaluate three low-cost countermeasures to prevent incorrect turns onto railroad tracks: (1) elimination of potentially misleading pavement markings and signs before railroad crossings, (2) implementation of straight arrow pavement markings with guidance information before railroad crossings, and (3) installation of Qwick Kurb to prevent drivers from making U-turns at railroad crossings. A surrogate safety measure, hesitation rate in the upstream of at-grade railroad crossings, was developed to represent the risk of incorrect turns onto railroad tracks. A before-after study was conducted to collect and compare the safety measure before and after implementation of proposed countermeasures at eight study sites in Florida Department of Transportation Districts 1, 4, and 7. The study results showed that (1) the replacement of continuous right-turn arrows with straight arrows plus guidance information on pavement can effectively prevent incorrect turns onto railroad tracks; (2) the effectiveness of using straight arrows plus guidance information pavement markings before railroad crossings is more significant at night than that during daytime to prevent incorrect turns of vehicles onto railroad tracks; (3) overall, the proposed countermeasures can reduce hesitation rates by 85% in daytime and 97% in nighttime, at a confidence level of 99.9%; (4) the effectiveness of straight arrows plus guidance information pavement markings may be influenced by external factors, such as upstream driveways near railroad tracks and presence of existing countermeasures (dynamic envelope, etc.); and (5) there were zero incorrect U-turn observations after the installation of Qwick Kurb devices. Based on the research findings, the research team recommended implementation of the pavement markings of straight arrows plus guidance information pavement markings on exclusive turn lanes upstream of at-grade crossings where the risk of incorrect turns exists. Qwick Kurb is suggested to be installed at at-grade crossings where frequent U-turns occur.

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		72	

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Executive Summary

Background

Drivers may misinterpret advance indications and incorrectly turn onto railroad tracks when they are approaching highway-rail grade crossings that are close to intersections or freeway on-ramps. These incorrect turns can result in vehicles stuck on railroad tracks, increasing the risk of fatalities and injuries for road users and rail passengers and operators. The issue is more serious at night due to poor visibility. Turn-arrow pavement markings in upstream railroad grade crossings may cause the most confusion for drivers who turn onto the tracks.

To provide clear indications to drivers and restrict their turning behaviors at railroad crossings, three low-cost countermeasures were proposed, as shown in Table ES-1. The first countermeasure included elimination of potentially misleading pavement markings and signs before railroad crossings, the second was to implement straight arrow pavement markings with guidance information before railroad crossings, and the third was installation of Qwick Kurb to prevent intentional U-turns at railroad crossings.

Table ES-1 Recommended Countermeasures to Prevent Incorrect Turns at Rail Crossings

<table>
<tr><th>Countermeasures</th><th>Sources</th></tr>
<tr><td>Elimination of potentially misleading pavement markings and signs before railroad crossings</td><td rowspan="2">• NCUTCD* proposal to MUTCD (2010)
• MUTCD and successful FDOT experience on wrong-way driving</td></tr>
<tr><td>Implementation of straight arrow pavement markings with guidance information before railroad crossings</td></tr>
<tr><td>Installation of Qwick Kurb to prevent intentional U-turns</td><td>• MUTCD (2009) 2C.64</td></tr>
</table>

*National Committee on Uniform Traffic Control Devices

The major objective of this project was to evaluate the effectiveness of the proposed countermeasures through a pilot implementation in Florida. Specific objectives included the following:

1. Coordinate with Florida Department of Transportation (FDOT) Districts 1, 4, and 7 to implement the proposed countermeasures at selected study sites.
2. Develop appropriate surrogate measures to represent the risk of incorrect turns at railroad crossings.
3. Conduct a before-after study to collect surrogate incorrect turn data at study sites.
4. Perform a statistical analysis to compare surrogate measures for incorrect turns before and after countermeasure implementation.
5. Provide analysis results, research findings, and recommendations to FDOT for future implementations to effectively prevent incorrect turns at highway-rail grade crossings in Florida.

Methodology

A before-after study was conducted at selected sites to evaluate the performance of the proposed countermeasures to prevent incorrect turns at highway-rail grade crossings. The research team collected data, including speed profile and videos, in two stages: *before* – without the proposed countermeasures, and *after* – with the proposed countermeasures. The collected data were reviewed to identify the surrogate incorrect turn measure, hesitation behaviors. A Chi-square, χ^2, hypothesis test was used to compare the hesitation rates before and after implementation to address the effectiveness of the proposed countermeasures.

The before-after study was conducted at eight study sites in FDOT Districts 1, 4, and 7, as shown in Table ES-2.

Table ES-2 Study Sites and Recommended Countermeasures to Prevent Incorrect Turns at Railroad Crossings

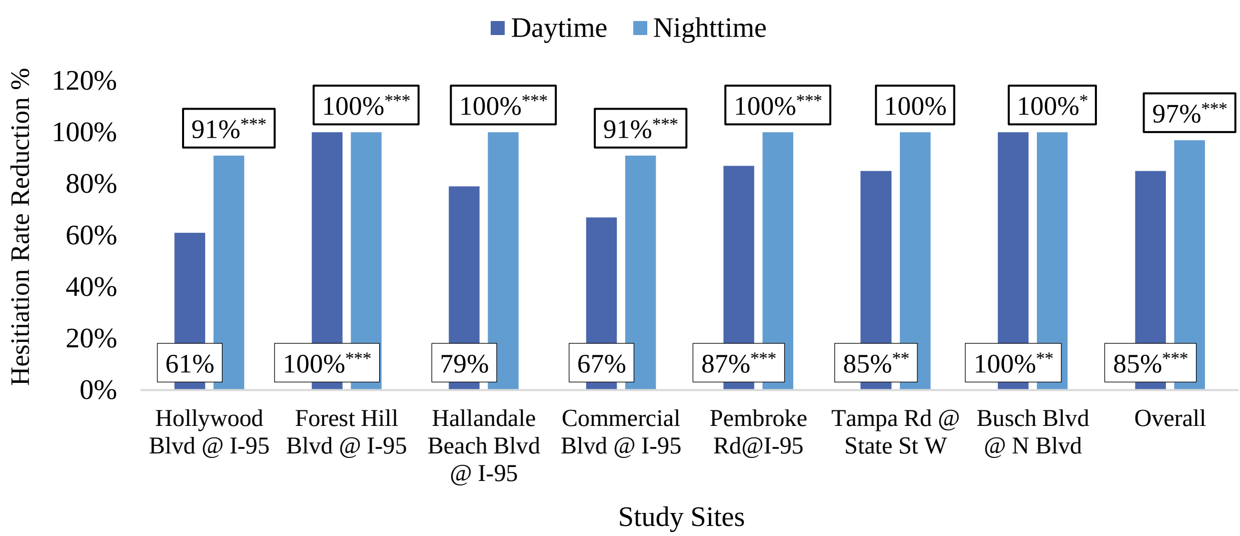
<table>
<tr><th>Site #</th><th>Study Site (Florida)</th><th>FDOT District</th><th>Countermeasure</th></tr>
<tr><td>1</td><td>US-41 @ US-301, Bradenton</td><td>1</td><td>• Install Qwick Kurb</td></tr>
<tr><td>2</td><td>Hollywood Blvd @ I-95, Hollywood</td><td rowspan="5">4</td><td rowspan="5">• Remove continuous right-turn arrows on an exclusive right-turn lane before an at-grade crossing
• Add straight arrows with direction text and I-95 shields pavement marking before an at-grade crossing</td></tr>
<tr><td>3</td><td>Forest Hill Blvd @ I-95, Lake Clarke Shores</td></tr>
<tr><td>4</td><td>W Hallandale Beach Blvd @ I-95, Pembroke Park</td></tr>
<tr><td>5</td><td>W Commercial Blvd @ I-95, Oakland Park</td></tr>
<tr><td>6</td><td>W Pembroke Rd @ I-95, Hollywood</td></tr>
<tr><td>7</td><td>Tampa Rd @ State St W, Oldsmar</td><td rowspan="2">7</td><td>• Add a straight arrow pavement marking before an at-grade crossing</td></tr>
<tr><td>8</td><td>Busch Blvd @ N Boulevard, Tampa</td><td>• Remove a right-turn arrow on an exclusive right-turn lane before an at-grade crossing
• Add a straight arrow with text information of direction and target road name pavement marking before an at-grade crossing</td></tr>
</table>

Findings and Conclusions

Based on the before-after comparison of hesitation rates, the following findings and conclusions were obtained:

- The replacement of continuous right-turn arrows with straight arrows plus guidance information on the pavement in upstream railroad grade crossings as presented for Sites 2-8 can significantly prevent incorrect right-turns onto railroad tracks, as shown in Figure ES-1.
- The effectiveness of using straight arrows plus guidance information pavement markings on exclusive turning lanes or shared lanes before railroad crossings is more significant at night than during daytime to prevent incorrect turns of vehicles onto railroad tracks.
- In some scenarios, the reduction in hesitation rates is not statistically significant due to the influence of external factors such as upstream driveways near railroad tracks and the presence of existing countermeasures (dynamic envelope, etc.).

- Overall, the proposed countermeasures can significantly reduce hesitation rates of drivers at at-grade crossings by 85% in daytime and 97% in nighttime at a confidence level of 99.9%.
- The installation of Qwick Kurb can effectively reduce intentional U-turns at railroad crossings.
- There were zero observations of incorrect U-turns after installing Qwick Kurb at Site 1. The 100% reduction of U-turn intention rate in this study is statistically significant at an 87% confidence level for this countermeasure. The installation of Qwick Kurb can significantly reduce the turning radius, thus reducing the risk of intentional U-turns at railroad crossings.



**90% confidence level; **95% confidence level; ***99% confidence level*

Figure ES–1 Relative reduction of hesitation rates for pavement marking of straight arrow plus guidance information

Recommendations

The before-after study proved the effectiveness of the proposed countermeasures to prevent incorrect turns onto railroad tracks at at-grade crossings. For different scenarios, the proposed countermeasures present different effects. Based on the study, the following recommendations were provided:

- If an at-grade railroad crossing is located upstream of intersections, ramps, or driveways and the distance is short enough to result in the risk of incorrect turns onto railroad tracks, the following treatments are highly recommended:
  - Remove all traffic control signs and pavement markings that lead to driver confusion on the correct turning point from upstream of the crossing, such as turning signs and turning arrow pavement markings.
  - In the upstream of railroad crossings, implement thermoplastic straight arrows plus guidance information pavement markings on exclusive turning lanes or shared lanes following *Manual on Uniform Traffic Control Devices* (MUTCD) standards (Chapter 3B).
  - Implement elongated route shields to provide guidance information. If route shields are not implementable, text can be used as a low-cost alternative for guidance information.

- If intentional incorrect U-turns are frequently observed at at-grade crossings with wide spaces on both sides of railroad tracks, install Qwick Kurb devices to reduce the turning radius to prevent incorrect U-turns. Implement straight arrow pavement markings in upstream skewed rail-highway crossings if a turn point (intersection, ramp, driveway) is adjacent to the crossing downstream.
- The proposed three countermeasures—(1) elimination of potentially misleading pavement markings and signs before railroad crossings, (2) implementation of straight arrow pavement markings with guidance information before railroad crossings, and (3) installation of Qwick Kurb to prevent intentional U-turns—were proven to be highly effective to prevent drivers from turning onto railroad tracks near freeway on-ramps or intersections downstream. It is recommended that FDOT implement these countermeasures at needed locations statewide.

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1 Introduction

1.1 Problem Statement

Preventing incorrect turns at highway-rail grade crossings has received considerable attention in an effort to decrease fatalities and injuries for both road users and rail users/operators. To mitigate serious injuries and fatal collisions due to incorrect turns at highway-rail grade crossings, a previous National Center for Transit Research (NCTR) research project titled “Improved Traffic Control Measures to Prevent Incorrect Turns at Highway-Rail Grade Crossings” successfully identified five major contributing causes of incorrect turns onto railroad tracks:

- Potentially misleading signs and pavement markings near highway-rail crossings
- Darkness and low visibility near or at highway-rail crossings
- Inaccurate following of turn instructions from a GPS device onto railroad tracks
- Skewed highway-rail grade crossings
- Driver distraction

Researchers found that right-turn arrow pavement markings in front of railroad grade crossings could cause the most confusion for drivers who turn onto railroad tracks, as illustrated in Figure 1-1.

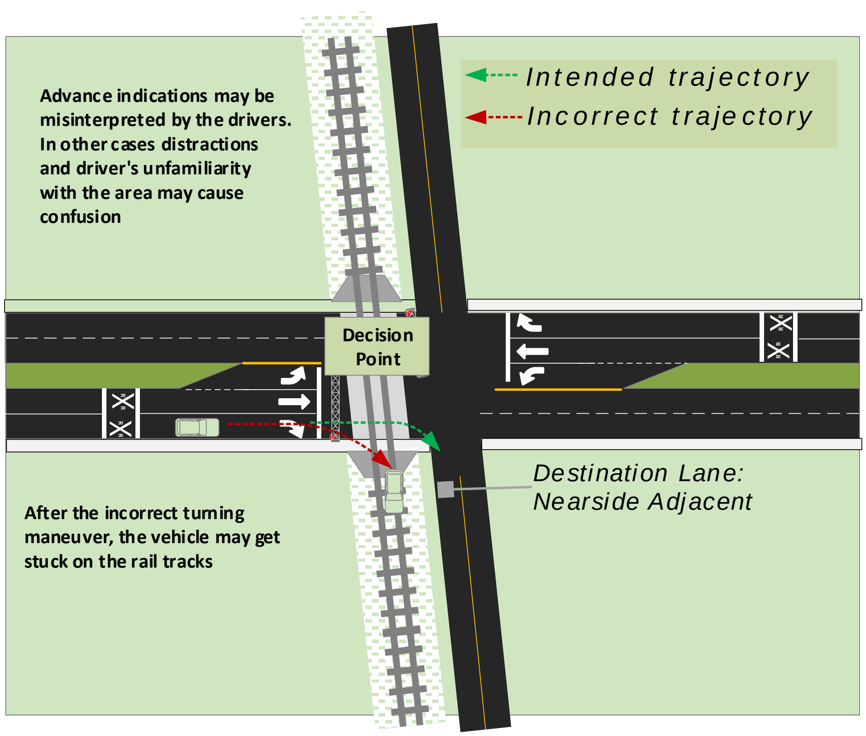

Figure 1-1 Illustration of incorrect turning maneuver near an intersection

Based on the identified causes, the NCTR study developed a set of practical countermeasures to prevent incorrect turns at grade crossings [1]. The major countermeasures for the upstream of a highway-rail grade crossing include advance direction signage, striping, and elimination of potentially misleading pavement markings and signs. Downstream countermeasures consist of guide signs and striping. For critical zones, countermeasures include striping, pavement gate markings, bollards, illumination, etc.

1.2 Low-Cost Countermeasures

Researchers at the Center for Urban Transportation Research (CUTR) at the University of South Florida explored emerging traffic control countermeasures for preventing incorrect turns at railroad crossings based on the following criteria:

- Effective reductions in driver confusion at highway-rail crossings
- Successful FDOT experience on similar safety issues (e.g., wrong-way driving)
- Low-cost implementation
- Compatibility with *Manual on Uniform Traffic Control Devices* (MUTCD) standards or proposals

Based on these criteria and a previous NCTR study [2], three low-cost countermeasures were addressed for preventing incorrect turns at highway-rail grade crossings, as shown in Table 1-1—elimination of potentially misleading pavement markings and signs before railroad crossings, implementation of pavement markings with guidance information before railroad crossings, and installation of Qwick Kurb to prevent intentional U-turns at railroad crossings.

Table 1-1 Low-Cost Countermeasures

<table>
<tr><th>Countermeasures</th><th>Sources</th></tr>
<tr><td>Elimination of potentially misleading pavement markings and signs before railroad crossings</td><td rowspan="2">• NCUTCD* proposal to MUTCD (2010)
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</table>

*National Committee on Uniform Traffic Control Devices

1.2.1 *Elimination of Potentially Misleading Pavement Markings and Signs*

The most recognized regulatory signs and pavement markings in advance of a railroad grade crossing that may confuse drivers are “Right Lane Must Turn Right,” “Left Lane Must Turn Left,” and right-turn-only and/or left-turn-only pavement markings [1]. Figure 1-2 shows an example of these markings before a railroad crossing on W Commercial Blvd near I-95 in Oakland Park, Florida. To eliminate this potential confusion, the National Committee on Uniform Traffic Control Devices (NCUTCD) Technical Committee suggests placing them a minimum of 100 ft in advance of the stop line for a highway-rail grade crossing. The specific recommendation was proposed by the NCUTCD Technical Committee Railroad/Light Rail Transit Technical Committee (RRLRT), Item No. 1 [3]. The proposed changes were supported by the Association of American Railroads (AAR) in a letter to the Federal Highway Administration (FHWA) recommending adoption of the changes to MUTCD.

The purpose of the proposed change was to address several train-auto crashes that occurred several years before the proposal. In all incidents, a roadway user made an improper turn onto the tracks rather than at an adjacent intersection immediately beyond the grade crossing. It is believed that some additional language may be beneficial to guide roadway users at grade crossings. In many of the incidents, an arrow pavement marking denoting an exclusive drop lane was located on the roadway between the stop line for the grade crossing and the track area, causing drivers to misinterpret the curb-cut at the railroad crossing as the location at which they were to turn. It is believed that the proposed change will lead road users to more clearly understand where the turn is to be made, even under adverse conditions [3].

Proposed Section 8B.23 Arrow Markings

Standard: Arrow pavement markings for turn lanes shall not be placed between the stop line for the highway-rail grade crossing and the tracks.

Guidance: Arrow pavement markings, if used, should be placed a minimum of 100 ft in advance of the stop line for the highway-rail grade crossing when sufficient turn lane storage length exists. Arrow pavement markings, if used, should be placed no less than 20 ft beyond the far rail.

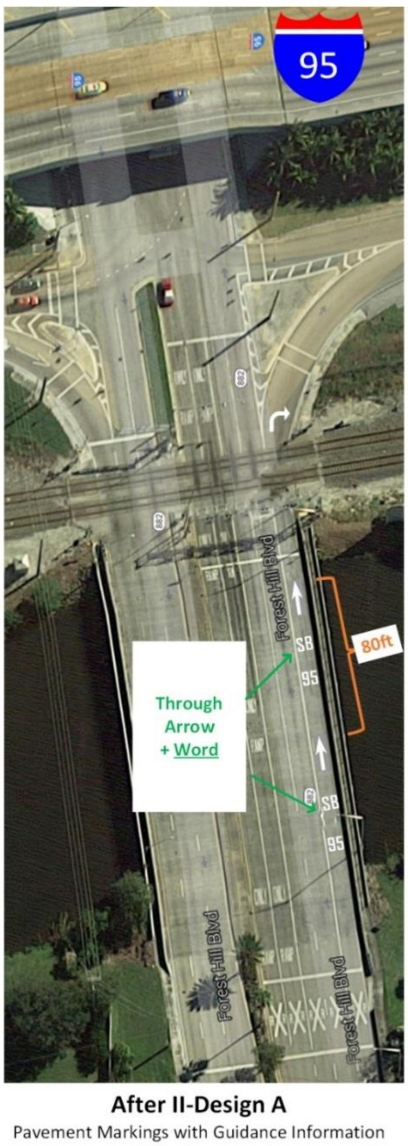
Figure 1-2 Example of potentially misleading right-turn sign and pavement markings

1.2.2 *Implementation of Pavement Markings with Guidance Information*

Pavement words, symbols, and arrow markings are used for the purpose of guiding, warning, or regulating traffic. According to MUTCD, symbol messages are preferable to word messages [4]. In particular, route shield pavement markings are available for use in accordance with the MUTCD Section 3B [4] and FDOT's *Traffic Engineering Manual* (TEM) Section 4.2 [5]. To adopt the suggestion from MUTCD experience on preventing wrong-way driving, CUTR explored two types of designs, including through arrow pavement markings with guidance information (name and direction) to replace turning arrow pavement markings on the upstream of the railroad crossing, as illustrated in Figure 1-3.

As shown in Figure 1-3, Design A uses a combination of word message, cardinal direction, and straight arrow in front of a grade crossing, and Design B uses a combination of a route or interstate shield, cardinal direction, and straight arrow in front of a grade crossing. A word message (Design A) costs less, but a symbol message (Design B) can provide better visibility. Both can provide guidance information for preventing incorrect turns at highway-rail grade crossings. If used, route shield pavement markings must be installed as follows, according to FDOT'S TEM Sections 4.2.3 and 4.2.4 [5]:

- All Route shields shall be pre-formed thermoplastic.
- All Route shield pavement markings shall be 15 feet in length.
- US Route shields shall have contrast for both asphalt and concrete pavement.
- Align the symbol in the center of the lane
- Install the route shields in a single line across the roadway. Do not stagger.
- Arrows or messages (TO, LEFT, RIGHT, NORTH, SOUTH), may be used to supplement route shields and shall follow the route shield.
- Use an 80-foot gap between markings. However, cardinal directions (if used) may be 40 foot from a route shield marking.



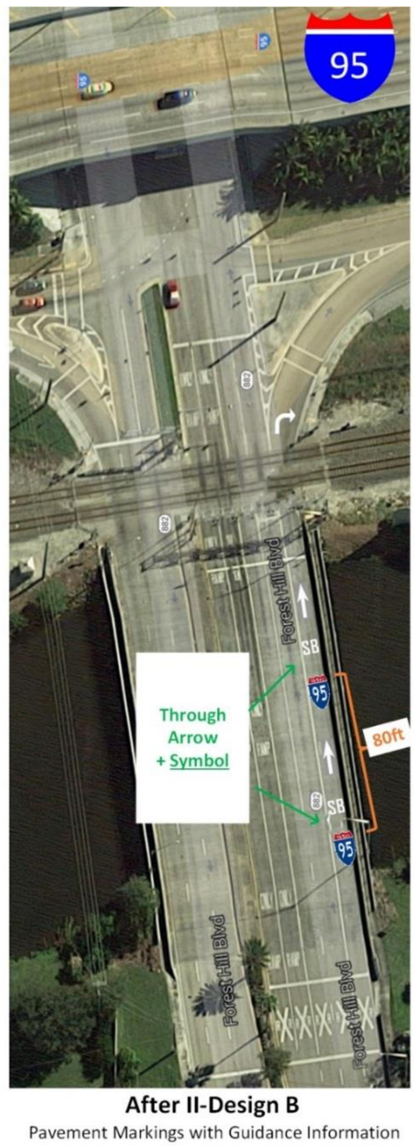


Figure 1-3 Example of implementation of pavement markings with guidance information

1.2.3 *Installation of Qwick Kurb*

At some rail crossings, there is a potential risk of drivers turning around (making a U-turn) using railroad tracks intentionally. An example of an incorrect U-turn is shown in Figure 1-4.

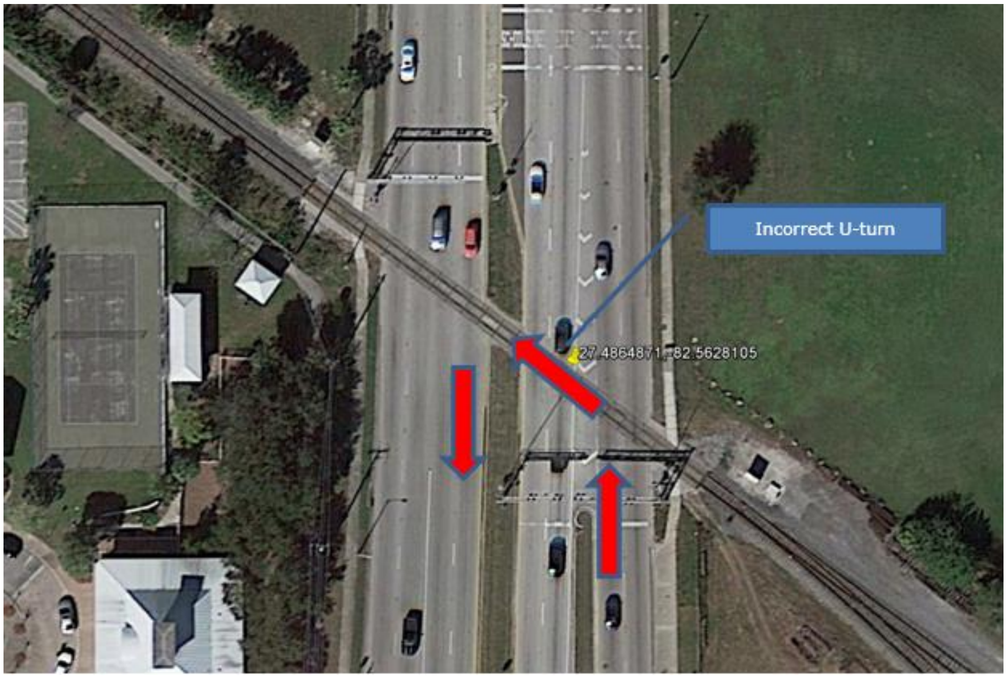


Figure 1-4 Example of incorrect U-turn at railroad crossing

Qwick Kurb can deter motorists from turning around before or at railroad crossings, consequently preventing incorrect U-turns. The U.S. Department of Transportation (DOT) Federal Railroad Administration (FRA) promotes the use of traffic channelization devices (e.g., Qwick Kurb) at highway-rail grade crossings with active warning devices, where applicable. These traffic channelization devices provide a proven safety benefit. A previous study [6] was conducted at locations where driver violations occurred at highway-rail grade crossings and after installation of channelization devices at these locations, resulting in a significant reduction in driver violations. Figure 1-5 shows an example of Qwick Kurb at a railroad crossing.

Figure 1-5 Example of Qwick Kurb ***(Photo courtesy of NCDOT)***

1.3 Research Objectives

The effectiveness of the proposed countermeasures for preventing incorrect turns onto railroad tracks has not been documented. The overall objective of this project was to evaluate the effectiveness of the proposed countermeasures through a pilot implementation in Florida. The specific objectives included the following:

1. Coordinate with FDOT Districts 1, 4, and 7 to implement the proposed countermeasures at selected study sites.
2. Develop appropriate surrogate measures to represent the risk of incorrect turns at railroad crossings.
3. Conduct a before-after study to collect surrogate incorrect turn data at study sites.
4. Perform a statistical analysis to compare surrogate measures for incorrect turns before and after the countermeasure implementation.
5. Provide analysis results, research findings, and recommendations to FDOT for future implementations to effectively prevent incorrect turns at highway-rail grade crossings in Florida.

1.4 Report Organization

Following this introduction, Chapter 2 provides a description of the before-after study, Chapter 3 describes the before-after study results, and Chapter 4 presents conclusions and recommendations for implementing the proposed countermeasures in Florida.

2 Methodology

2.1 Overview of Before-After Study

A before-after study was conducted at selected sites to evaluate the performance of the proposed countermeasures to prevent incorrect turns at highway-rail grade crossings. The CUTR research team collected data, including speed profiles and videos, in two stages: *"before"*—without the implementation of proposed countermeasures, and "after"—with the implementation of proposed countermeasures. A detailed review of the data was conducted to identify the surrogate incorrect turn measures, hesitation behaviors. A χ^2 hypothesis test was used to compare the hesitation rates before and after implementation to evaluate the effectiveness of the proposed countermeasures. Figure 2-1 shows the procedure of the before-after study.

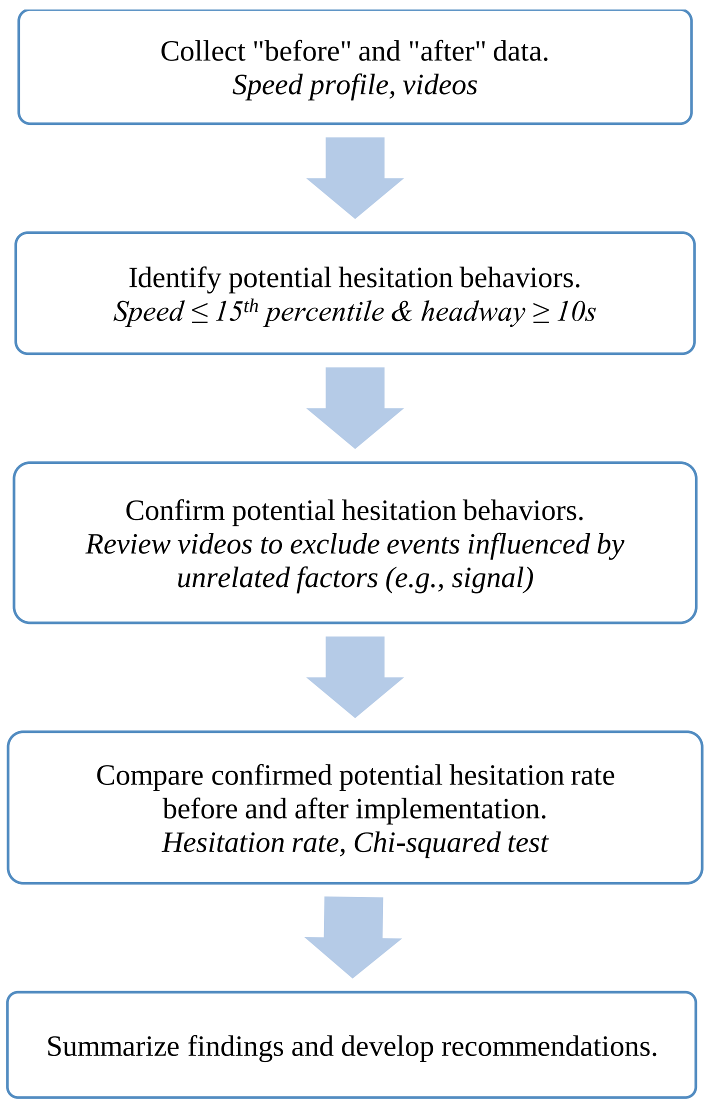


Figure 2-1 Procedure of before-after study

2.2 Data Collection

The data collected in the field included upstream speed profiles near railroad crossings and videos. An example of data collection layout is shown in Figure 2-2.

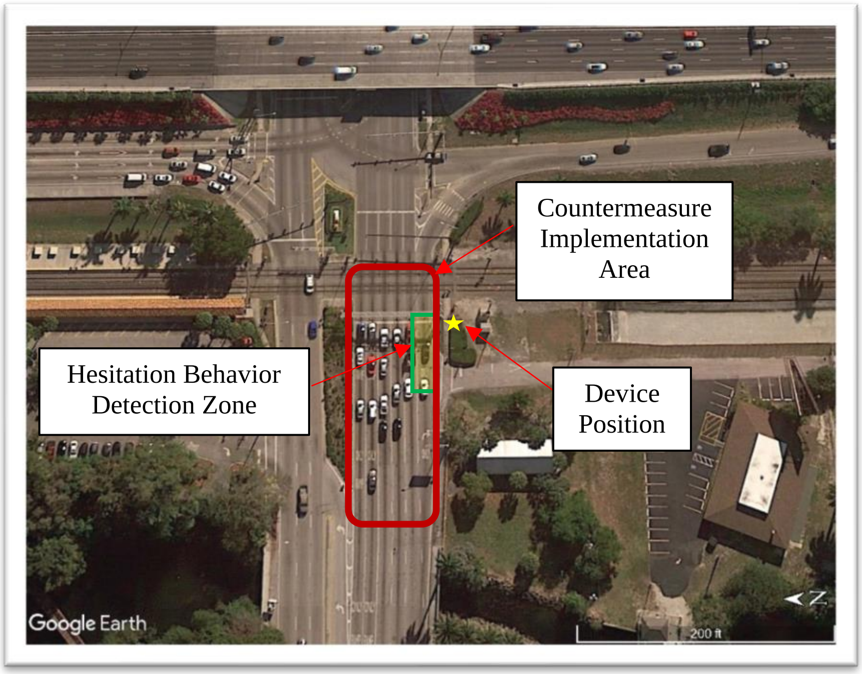


Figure 2-2 Example of data collection layout

As shown in Figure 2-3, installations of a Wavetronix SmartSensor and a GoPro camera on a Pneumatic Locking Telescoping Mast were mounted at each candidate site. The Wavetronix SmartSensor uses the latest radar technology to collect and deliver traffic data, including traffic volume and classification, average speed, individual vehicle speed, lane occupancy, and presence on multiple lanes. Data for individual speeds of cars approaching the railroad crossings were processed to identify hesitation behaviors using the methodology introduced below. Traffic monitoring videos from the camera were used to verify hesitating vehicles. The two devices were powered by a gasoline-powered inverter generator. Researchers configured and monitored the SmartSensor operations on a laptop through the SmartSensor Manager software.

The data collection procedure was as follows:

(1) The research team coordinated with the FDOT Project Manager and FDOT Districts 1, 4, and 7 to request permission for installing the data collection devices on the roadside and determine the countermeasure deployment and data collection schedule.

(2) With the approvals from the FDOT Project Manager and FDOT District representatives, the "before" data collection was conducted at each site including daytime and nighttime hours. Two research assistants set up the devices before data collection, monitored the process during data collection, and detached the devices after data collection.

(3) After completing the “before” data collection, the FDOT Districts or contractors implemented the proposed countermeasures at the study sites.

(4) The research team conducted the second data collection at study sites after the completion of countermeasure implementation. The data collection approach (location, devices, and duration) in the “after” stage was as the same as the “before” data collection.

(5) Speed data from the SmartSensor and videos were reviewed to identify hesitation events that represent the risk of incorrect turns. These data were exported into a project database for analyses.

Figure 2-3 Installation of Wavetronix SmartSensor and GoPro on pneumatic mast

2.3 Data Reduction

2.3.1 *Hesitation Behavior*

It is difficult to observe actual incorrect turn behaviors directly for a short period of time because 1) incorrect turns onto tracks are rare and random events, 2) few incidents of turning onto railroad tracks are reported if no stuck vehicles or collisions occurred, and 3) surveillance devices (e.g., CCTVs) that monitor incorrect turn events are available only at a few grade crossings. Thus, a surrogate indicator was needed to measure the risk of incorrect turns at selected at-grade crossings for this study. Drivers who are confused about the turning point near railroad crossings will present hesitation behaviors that include using significantly slower speeds than normal to search for target turning points and make decisions. It can be hypothesized that the more the hesitation behaviors occur, the higher the incorrect turn risk is.

This study collected hesitation behaviors by measuring speeds of approaching vehicles on exclusive turning lanes near railroad tracks. As shown in Figure 2-4, speed data from Wavetronix radar were filtered by a vehicle with a speed lower than the 15th percentile of the collected sample and a significant long headway of 10 seconds or more to ensure that the slow-moving vehicle was not due to traffic congestion. The identified vehicles were treated as potential hesitation events. A second review (Figure 2-5) was conducted on associated videos to exclude influence from other additional factors (e.g., red traffic signal, incident or lane closure, etc.).

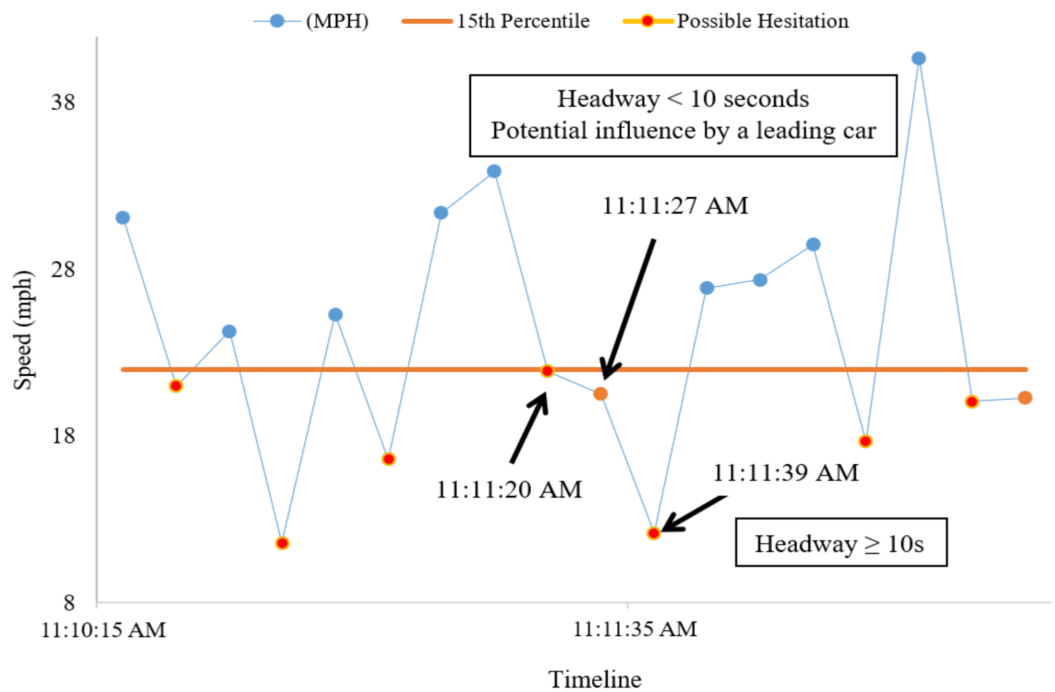


Figure 2-4 Example of visualization of Wavetronix speed data and potential hesitation filter

Free flow of vehicle, no leading car and no influence of signal.

Sudden declaration near the tracks, indication of potential hesitation to turn onto tracks.

Figure 2-5 Example of hesitation behavior verification on videos

2.3.2 *Data Reduction Procedure*

The collected speed data and videos were processed in the lab to identify hesitation behaviors. The data reduction procedure was as follows:

- The speed distribution of vehicles on exclusive right-turn lanes was produced from the collected radar (Wavetronix) files.
- The 15th percentile speed of the sample at each site was used as the threshold for the hesitation speed. Any vehicle traveling at speeds lower than the threshold was selected.
- To exclude the influence of the slow leading vehicle, the selected vehicles with a headway of 10 seconds or more from the leading vehicle were filtered for additional review.
- Videos associated with the filtered vehicles were further reviewed to exclude any "false" hesitations, such as very low speed due to a red traffic signal, a lane closure ahead, and other external factors. The confirmed hesitation vehicles were used in final hesitation rate analysis.

2.4 Statistical Analysis

Hesitation rate ($R_{hesitation}$) is defined in Equation 1. This measure was calculated for "before" and "after" data at each site.

$$R_{hesitation} = \frac{\text{Number of confirmed hesitation behaviors}}{\text{Number of turning vehicles}} \tag{1}$$

A high hesitation rate indicates a high risk of incorrect turns. The Chi-square, χ^2, hypothesis testing of independence was applied to each site to compare the hesitation rate before and after the countermeasure implementation. The null hypothesis (H_0) and alternative hypothesis (H_a) are as follows:

H_0: The "before" hesitation rate is similar to the "after" hesitation rate.
H_a: The "before" hesitation rate is different from the "after" hesitation rate.

The calculation procedure for the χ^2 hypothesis testing is shown in Table 2-1 and Table 2-2.

Table 2-1 Observed Table for Chi-square Test

	Confirmed Hesitation	No Hesitation	Total
After	O_a	O_b	$O_a + O_b$
Before	O_c	O_d	$O_c + O_d$
Total	$O_a + O_c$	$O_b + O_d$	$O_a + O_b + O_c + O_d$

Table 2-2 Expected Table for Chi-square Test

	Confirmed Hesitation	No Hesitation	Total
After	$E_a = \frac{(O_a + O_b) \times (O_a + O_c)}{O_a + O_b + O_c + O_d}$	$E_b = \frac{(O_a + O_b) \times (O_b + O_d)}{O_a + O_b + O_c + O_d}$	$E_a + E_b$
Before	$E_c = \frac{(O_c + O_d) \times (O_a + O_c)}{O_a + O_b + O_c + O_d}$	$E_d = \frac{(O_c + O_d) \times (O_b + O_d)}{O_a + O_b + O_c + O_d}$	$E_c + E_d$
Total	$E_a + E_c$	$E_b + E_d$	$E_a + E_b + E_c + E_d$

O_i is the observation count in cell *i* $(i = a, b, c, and\ d)$, and E_i is the expected count in cell *i*. χ^2statistics were calculated using the following formula:

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i} \tag{2}$$

The degree of freedom for the χ^2 testing was 1. If the χ^2 statistics were greater than or equal to 3.84, the null hypothesis was rejected at a confidence level of 95%. If the statistics were 2.706, the null hypothesis was rejected at a confidence level of 90%. The rejection of the null hypothesis indicates that the difference in hesitation rates between “before” and “after” the implementation was significant.

3 Before-After Study Results

3.1 Site 1: US-41 @ US-301, Bradenton, FL

3.1.1 *Site Characteristics and Countermeasures*

This site was selected due to the potential risk of incorrect U-turns at the at-grade crossing, as shown in Figure 3-1. To prevent the incorrect U-turns, Qwick Kurb devices were installed at the hatched-out median area (Figure 3-2).

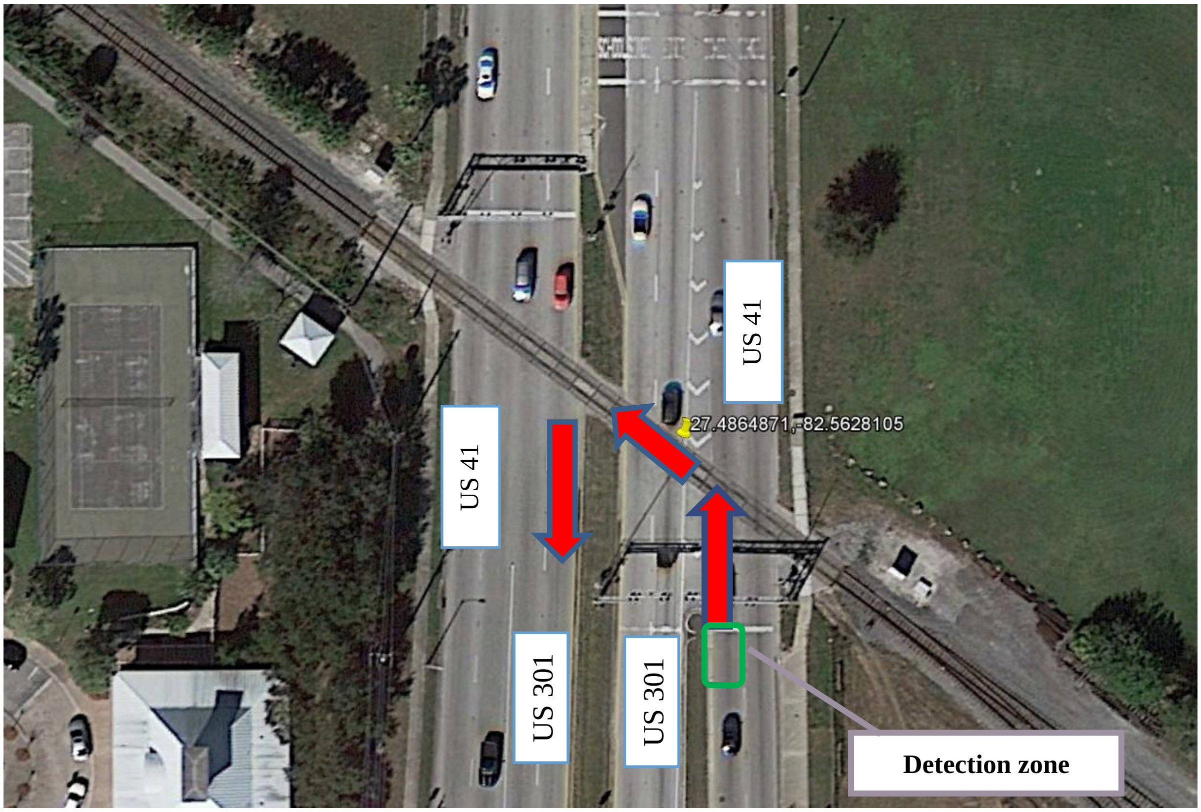


Figure 3-1 Potential incorrect U-turns at Site 1 (US-41 @ US-301, Bradenton, FL)

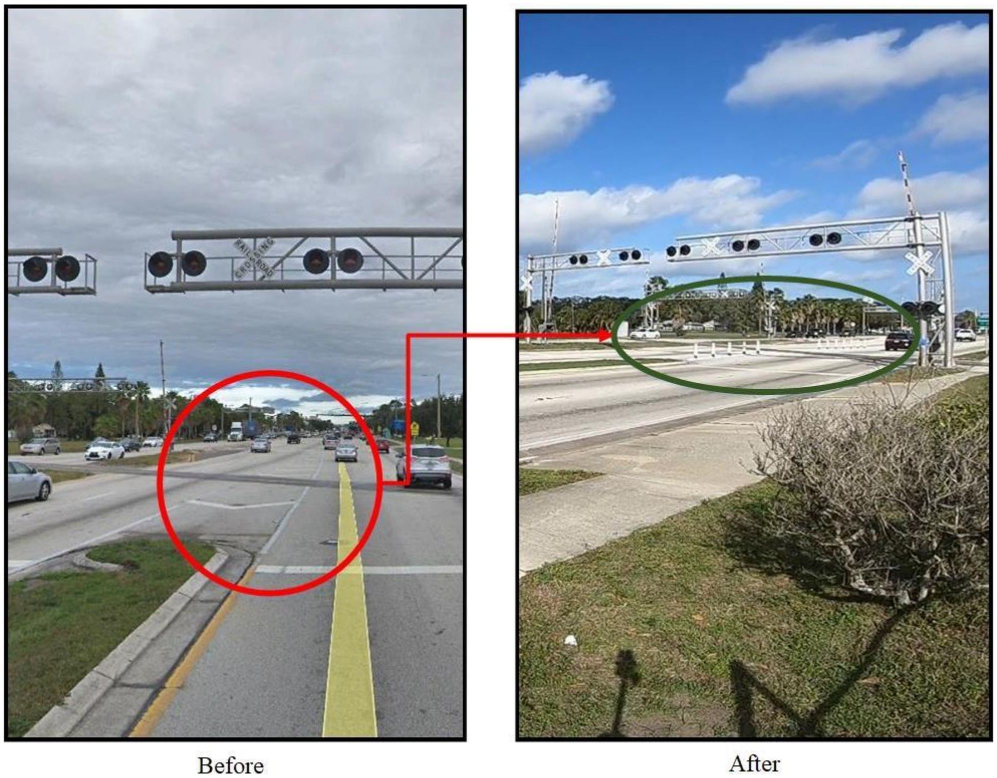


Figure 3-2 Countermeasure implemented at Site 1
(US-41@ US-301, Bradenton, FL)

3.1.2 *Data Collection*

A summary of data collection at Site 1 is presented in Table 3-1. The visualized speed profile and potential hesitation events for daytime and nighttime in the before and after stages are shown in Figure 3-3 through Figure 3-6. U-turns at grade-crossings are usually intentional behaviors. When a driver intends to make a U-turn from the approaching lane, he or she is more likely to slow down speed before turning. Like the hesitation analysis, the U-turn intention behavior can be identified by low speed at detection zone. The same data filtering approach and statistical analysis (Chapter 2) were applied on the U-turn intention data at Site 1.

Table 3-1 Summary of Data Collection at Site 1

	Before		**After**	
	Day	***Night***	***Day***	***Night***
District	District 1			
Coordinates	27.486494, -82.562907			
Start Time	10:30:33 AM	7:59:36 PM	11:25:04 AM	7:22:00 PM
End Time	2:57:35 PM	11:55:33 PM	2:26:25 PM	10:41:57 PM
Total Hours	4:27:02	3:55:57	3:01:21	3:19:57
Total Vehicles	3,875	1,236	3,162	992

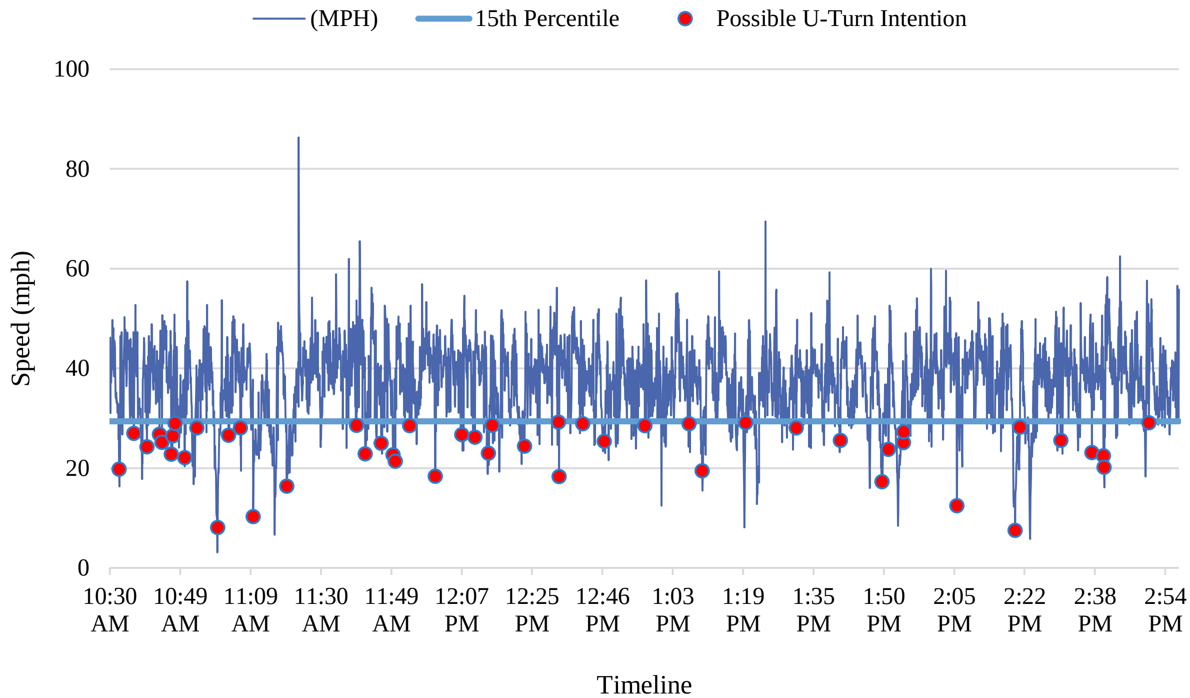


Figure 3-3 Speed profile at US-41 @ US-301, Bradenton, FL (before, daytime)

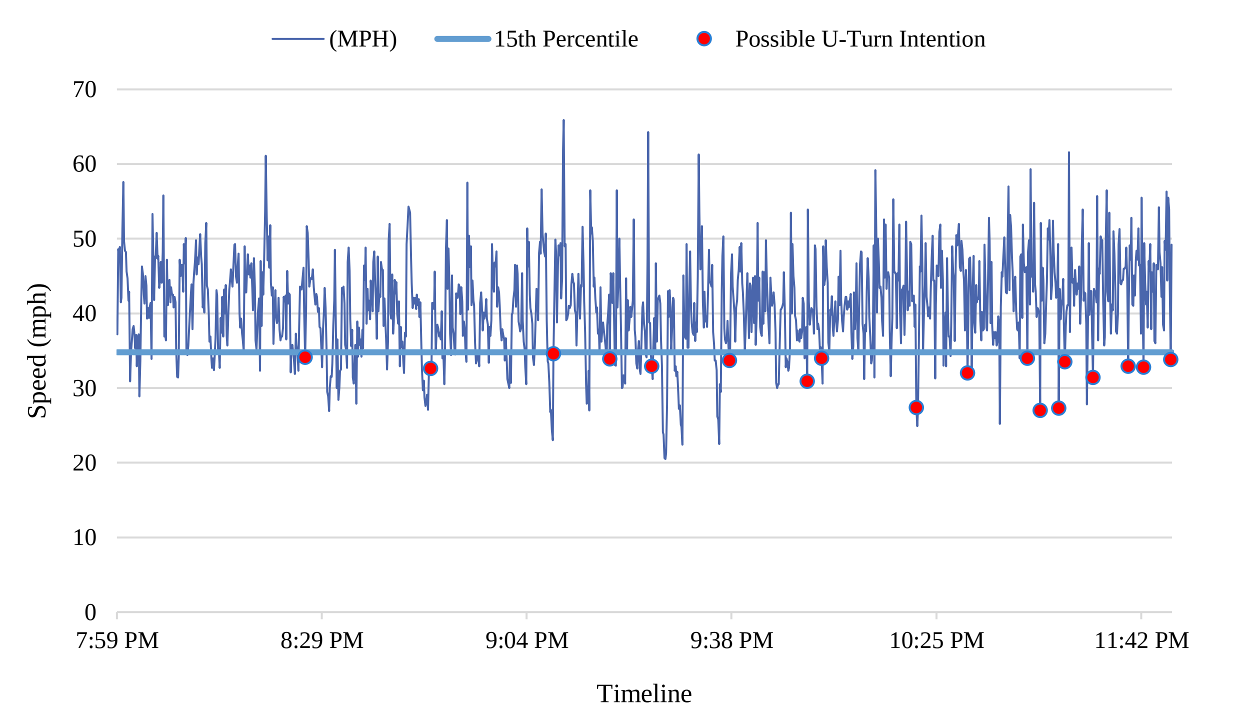


Figure 3-4 Speed profile at US-41 @ US-301, Bradenton, FL (before, night)

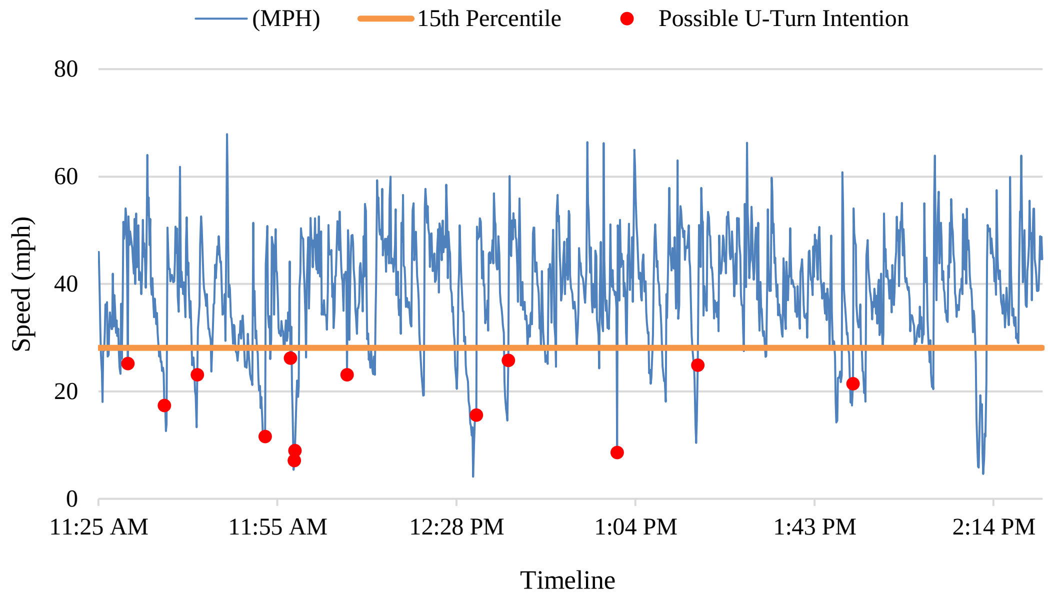


Figure 3-5 Speed profile at US-41 @ US-301, Bradenton, FL (after, daytime)

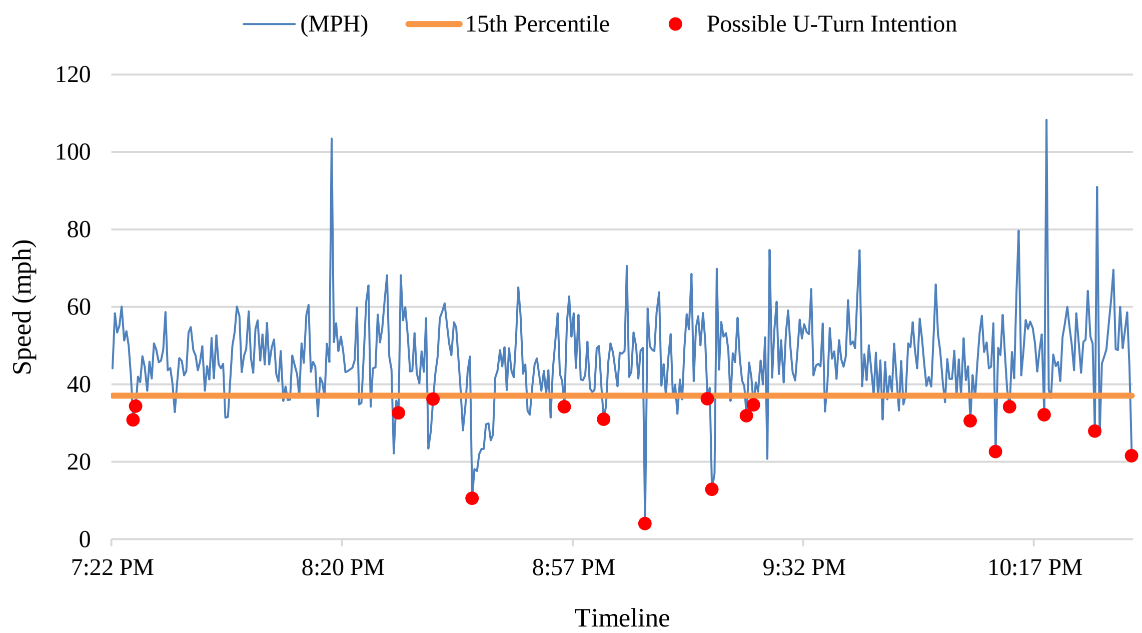


Figure 3-6 Speed profile at US-41 @ US-301, Bradenton, FL (after, nighttime)

3.1.3 *Chi-square Statistics Results*

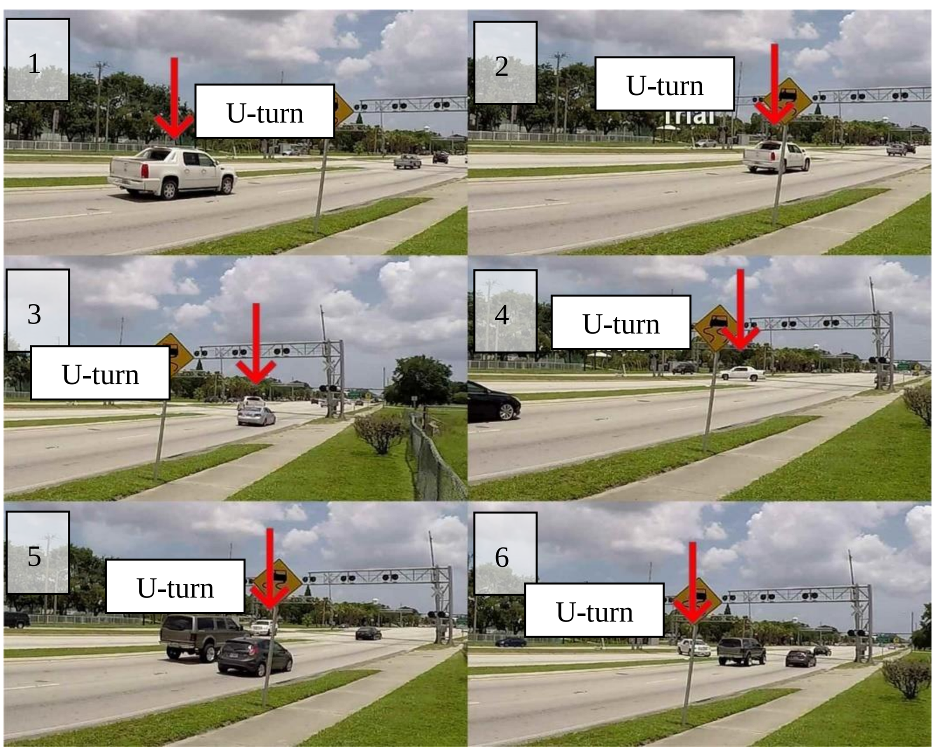
Table 3-2 shows the before-after comparison of confirmed U-turn intension and U-turn intention rates at Site 1. Although the 100% reduction of U-turn intention rate during daytime is not statistically significant at 90% confidence level, it is statistically significant at an 87% confidence level for this countermeasure. As shown in Figure 3-7, two incorrect U-turns were observed in the "before" stage:

- Incorrect U-turn 1 – A white pickup truck intended to make a U-turn from the inner lane of US-41 NB onto US-301 SB. After realizing that it was the wrong way (the truck turned onto US-301 NB), the pickup truck returned to US-41 NB.
- Incorrect U-turn 2 – A white van made a U-turn on the track area from US-41 NB onto US-41/US-301 SB.

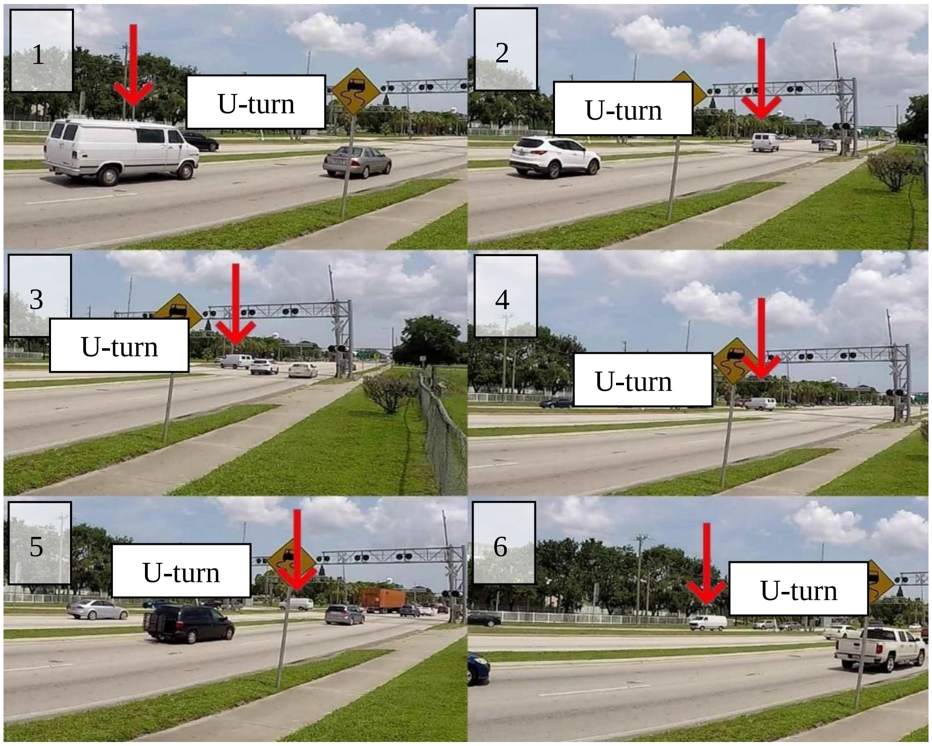
No U-turns were observed in the "after" stage. This observation can be attributed to the installation of Qwick Kurb that reduced the turning radius to prevent incorrect turns on at-grade crossings.

Table 3-2 Before-After Comparison of U-turn Intention Rate at Site 1

Time	Period	Confirmed U-turn Intention	No U-turn Intention	Total	Intention Rate	χ^2	*p-value*
Daytime	After	0	3,162	3,162	0.00%	2.45	0.12
	Before	3	3,872	3,875	0.08%		
	Absolute Reduction of Intention Rate				0.08%		
	Relative Reduction of Intention Rate				***100%***		
Nighttime	After	0	992	992	0.00%	N/A	N/A
	Before	0	1,236	1,236	0.00%		
	Absolute Reduction of Intention Rate				0.00%		
	Relative Reduction of Intention Rate				***0%***		



A. Incorrect U-turn 1



B. Incorrect U-turn 2

Figure 3-7 Observed incorrect U-turns in “before” data collection at Site 1

3.2 Site 2: Hollywood Blvd @ I-95, Hollywood, FL

3.2.1 *Site Characteristics and Countermeasures*

The site of Hollywood Blvd @ I-95 has an exclusive right-turn lane connecting to the I-95 SB on-ramp. There is a potential risk of drivers being susceptible to turning onto railroad tracks from the right-turn lane. To prevent incorrect right turns, FDOT District 4 and CUTR implemented the following countermeasures (Figure 3-9):

- Remove continuous right-turn arrows on the exclusive right-turn lane before the at-grade crossing.
- Add straight arrows with guidance information plus I-95 shields in the upstream of the crossing.

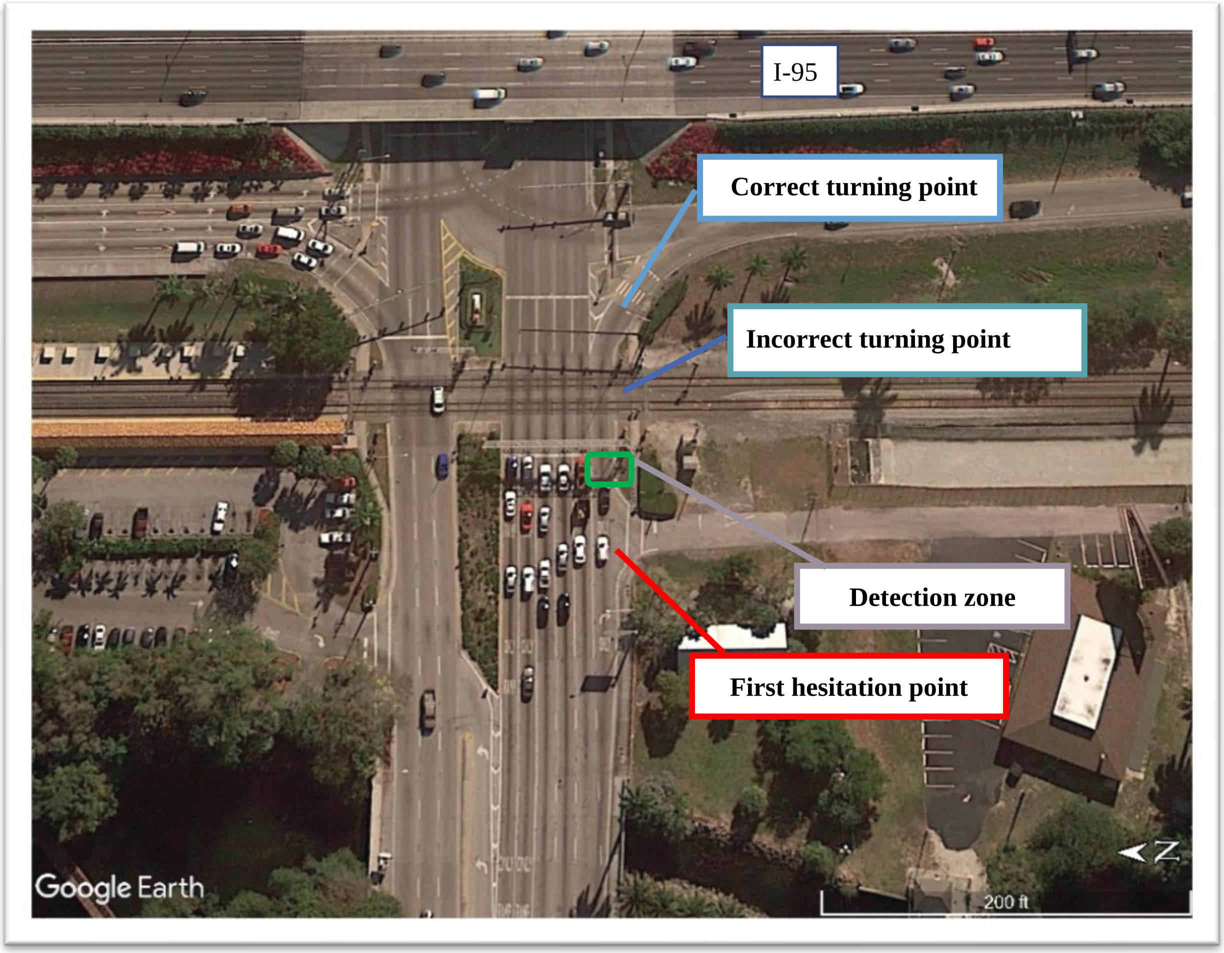


Figure 3-8 Layout of Site 2 (Hollywood Blvd @ I-95)

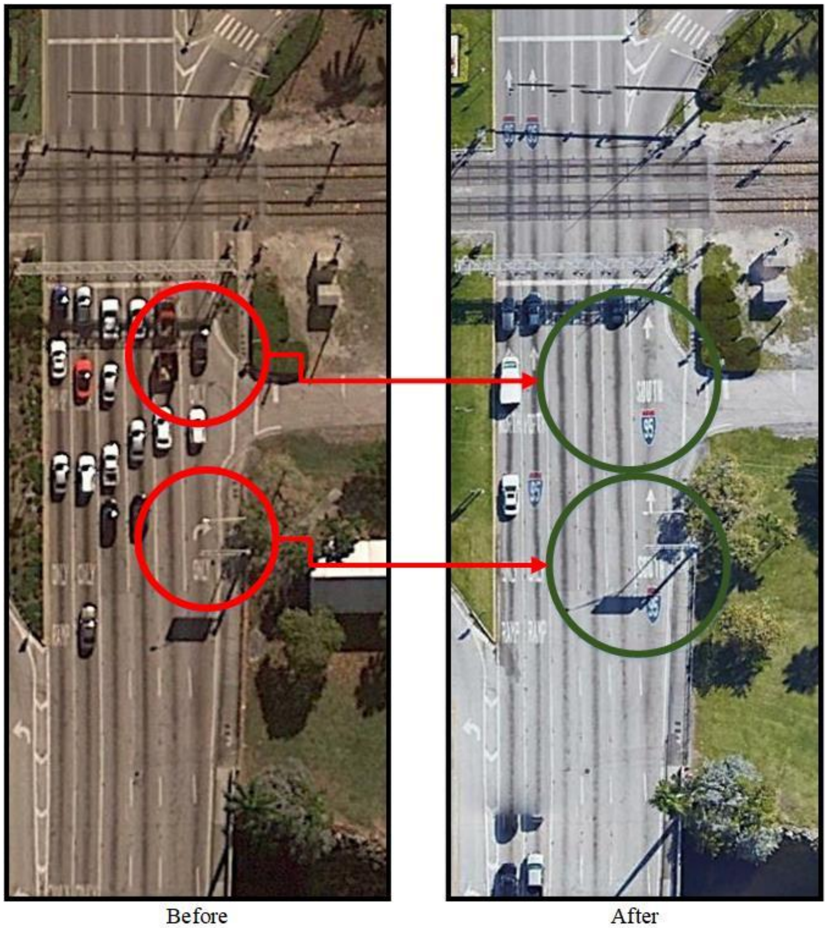


**Figure 3-9 Countermeasures implemented at Site 2
(Hollywood Blvd @ I-95, Hollywood, FL)**

3.2.2 *Data Collection*

The summary of data collection at Site 2 is presented in Table 3-3. The visualized speed profile and potential hesitation events for daytime and nighttime in the before and after stages are shown in Figure 3-10 through Figure 3-13.

Table 3-3 Summary of Data Collection at Site 2

	Before		After	
	Day	***Night***	***Day***	***Night***
District	District 4			
Coordinates	26.010787, -80.167641			
Start Time	9:58:28 AM	7:45:39 PM	9:03:31 AM	7:23:58 PM
End Time	2:59:05 PM	11:58:31 PM	12:21:42 PM	11:25:56 PM
Total Hours	5:00:37	4:12:52	3:18:11	4:01:58
Total Vehicles	1,756	958	916	887

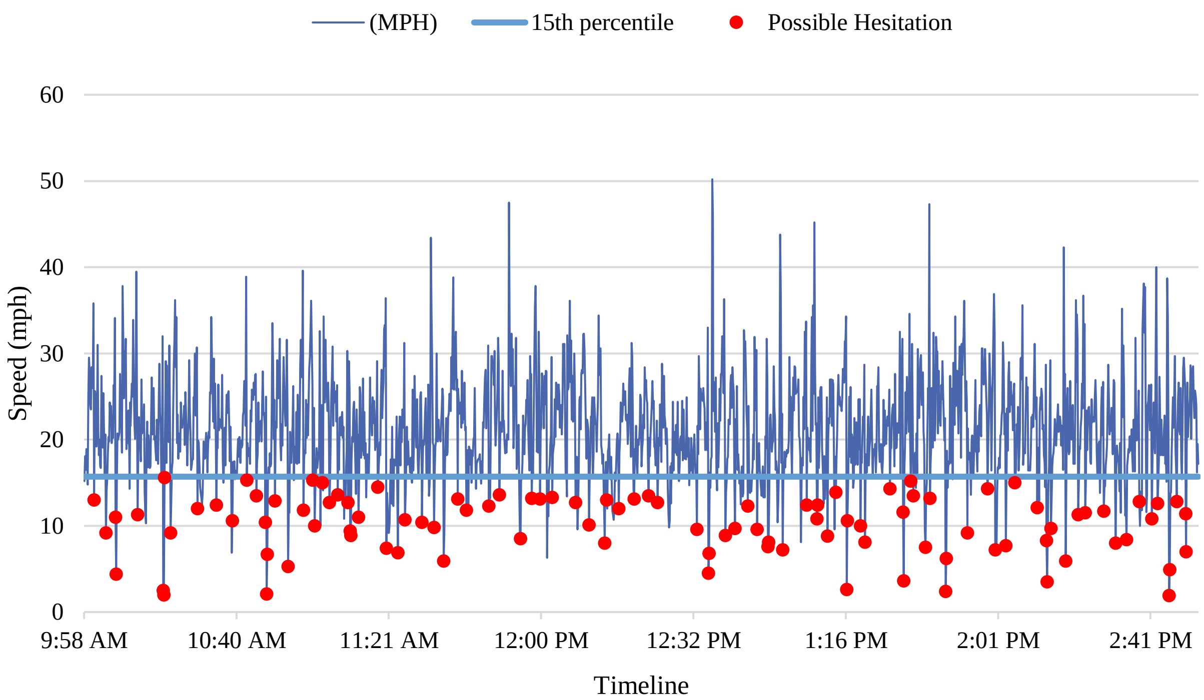


Figure 3-10 Speed profile at Hollywood Blvd @ I-95 (before, daytime)

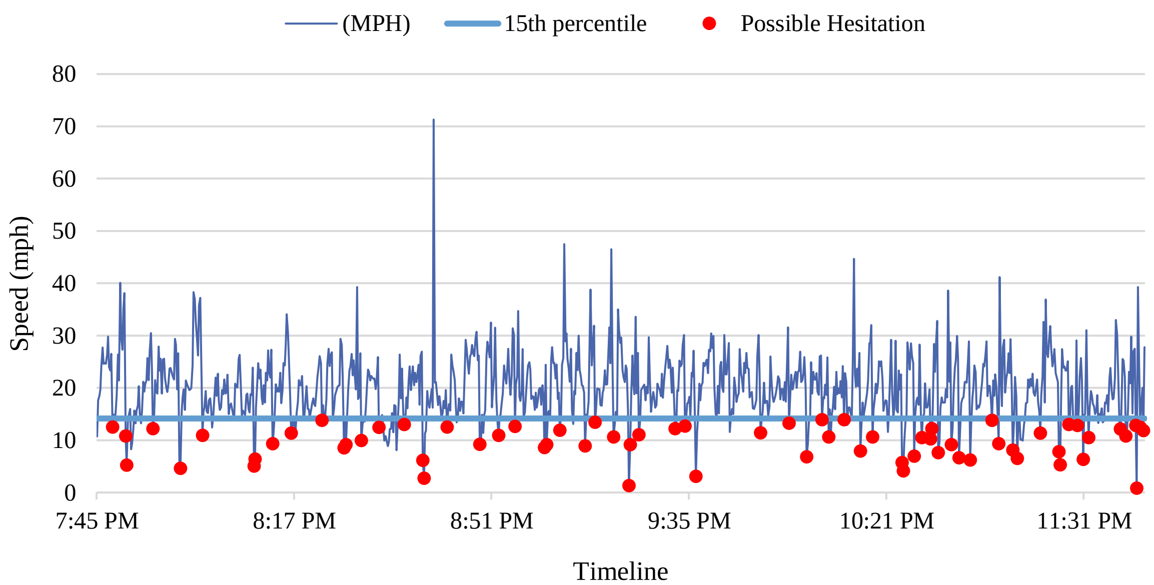


Figure 3-11 Speed profile at Hollywood Blvd @ I-95 (before, nighttime)

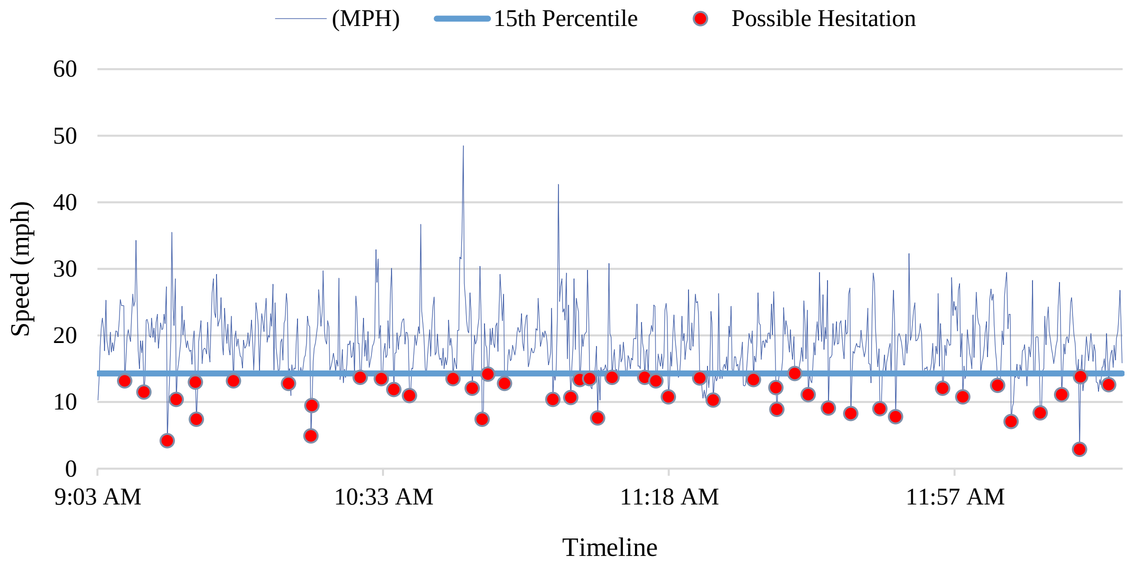


Figure 3-12 Speed profile at Hollywood Blvd @I-95 (after, daytime)

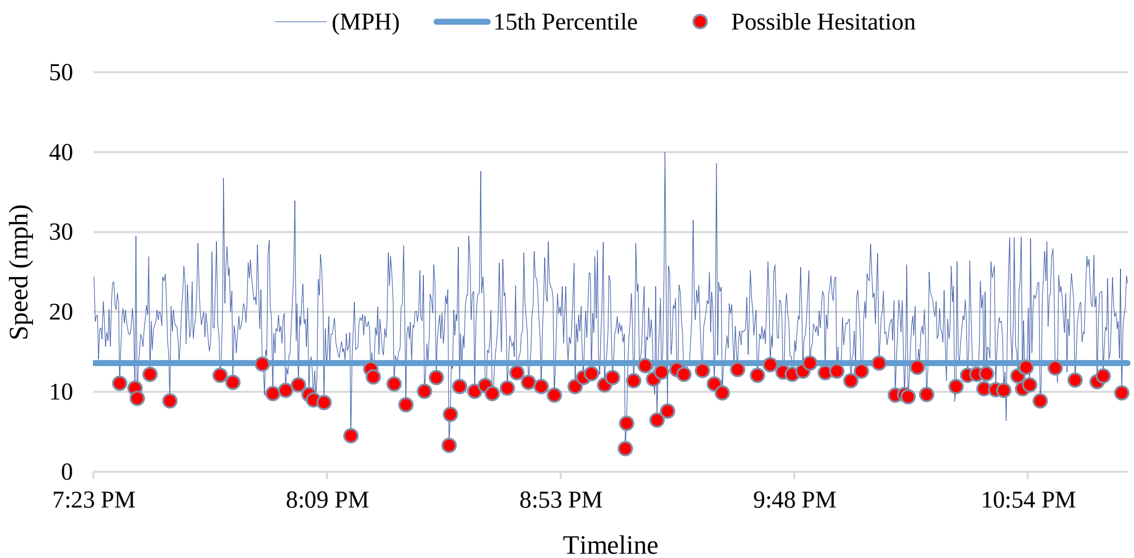


Figure 3-13 Speed profile at Hollywood Blvd @ I-95 (after, nighttime)

3.2.3 *Chi-square Statistics Results*

The countermeasure of straight-arrows plus guidance information on pavement was implemented at Site 2 to prevent incorrect right-turns onto railroad tracks. In the previous subsection, potential hesitation events for daytime and nighttime in the before and after stages were identified for Site 2. The research team further reviewed the videos of these events to exclude those vehicles that are slow-moving due to a red traffic signal indication at the nearby downstream intersection or other factors.

The number of confirmed hesitation vehicles and non-hesitation vehicles before and after the countermeasure implementation for both daytime and nighttime periods at Site 2 were obtained and are shown in Figure 3-4. The hesitation rates were computed using these data, and the χ^2 hypothesis testing was conducted. Table 3-4 provides the before-after comparison of hesitation rates, showing that both daytime and nighttime hesitation rates were reduced (61% and 91%, respectively) by the countermeasure. The reduction of hesitation rates was significant at a confidence level of 99.7% at night.

Table 3-4 Before-After Comparison of Hesitation Rate at Site 2

<table>
<tr><th>Time</th><th>Period</th><th>Hesitation</th><th>No Hesitation</th><th>Total</th><th>Hesitation Rate</th><th>χ^2</th><th>p-value</th></tr>
<tr><td rowspan="4">Daytime</td><td>After</td><td>2</td><td>914</td><td>916</td><td>0.22%</td><td rowspan="4">1.66</td><td rowspan="4">0.20</td></tr>
<tr><td>Before</td><td>10</td><td>1,746</td><td>1,756</td><td>0.57%</td></tr>
<tr><td colspan="4">Absolute Reduction of Hesitation Rate</td><td>0.35%</td></tr>
<tr><td colspan="4">Relative Reduction of Hesitation Rate</td><td>61%</td></tr>
<tr><td rowspan="4">Nighttime</td><td>After</td><td>1</td><td>886</td><td>887</td><td>0.11%</td><td rowspan="4">8.55</td><td rowspan="4">0.003</td></tr>
<tr><td>Before</td><td>12</td><td>946</td><td>958</td><td>1.25%</td></tr>
<tr><td colspan="4">Absolute Reduction of Hesitation Rate</td><td>1.14%</td></tr>
<tr><td colspan="4">Relative Reduction of Hesitation Rate</td><td>91%</td></tr>
</table>

As shown in Figure 3-8, the railroad crossing is the second curved edge opening after a driveway. Some drivers who may be confused by the turning points hesitate at the driveway. When approaching the railroad crossing, driver speeds are low; thus, the hesitation rate may not present a significant difference for the countermeasure during the day. However, before the installation, drivers presented more hesitation behaviors at the railroad crossing at night due to poor visibility of the countermeasure. Consequently, the countermeasure effectively reduces the hesitation rate at night even with the influence of the driveway.

3.3 Site 3: Forest Hill Blvd @ I-95, Lake Clarke Shores, FL

3.3.1 *Site Characteristics and Countermeasures*

At Site 3, there is a potential risk that drivers would turn right onto the railroad tracks. Thus, this site was recommended by FDOT District 4. Two countermeasures were implemented, as shown in Figure 3-15:

- Remove continuous right-turn arrows on the exclusive right-turn lane before the at-grade crossing.
- Add straight arrows with direction text and I-95 shields.

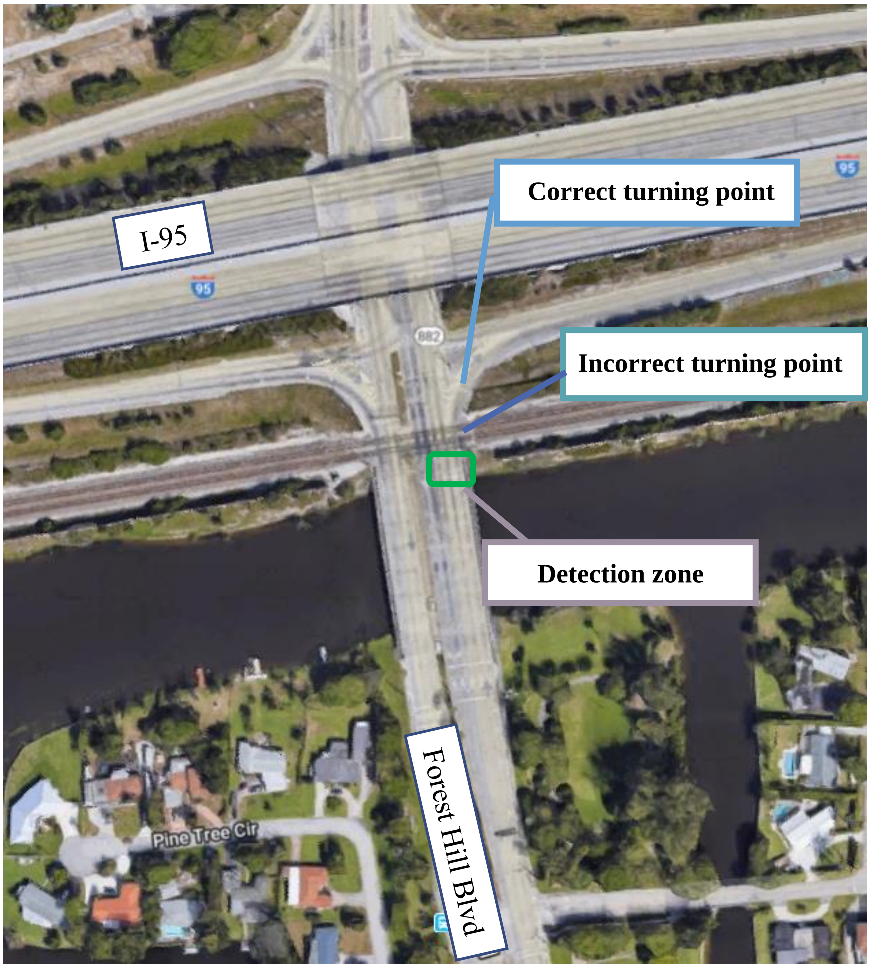


Figure 3-14 Layout of Site 3 (Forest Hill Blvd@ I-95)

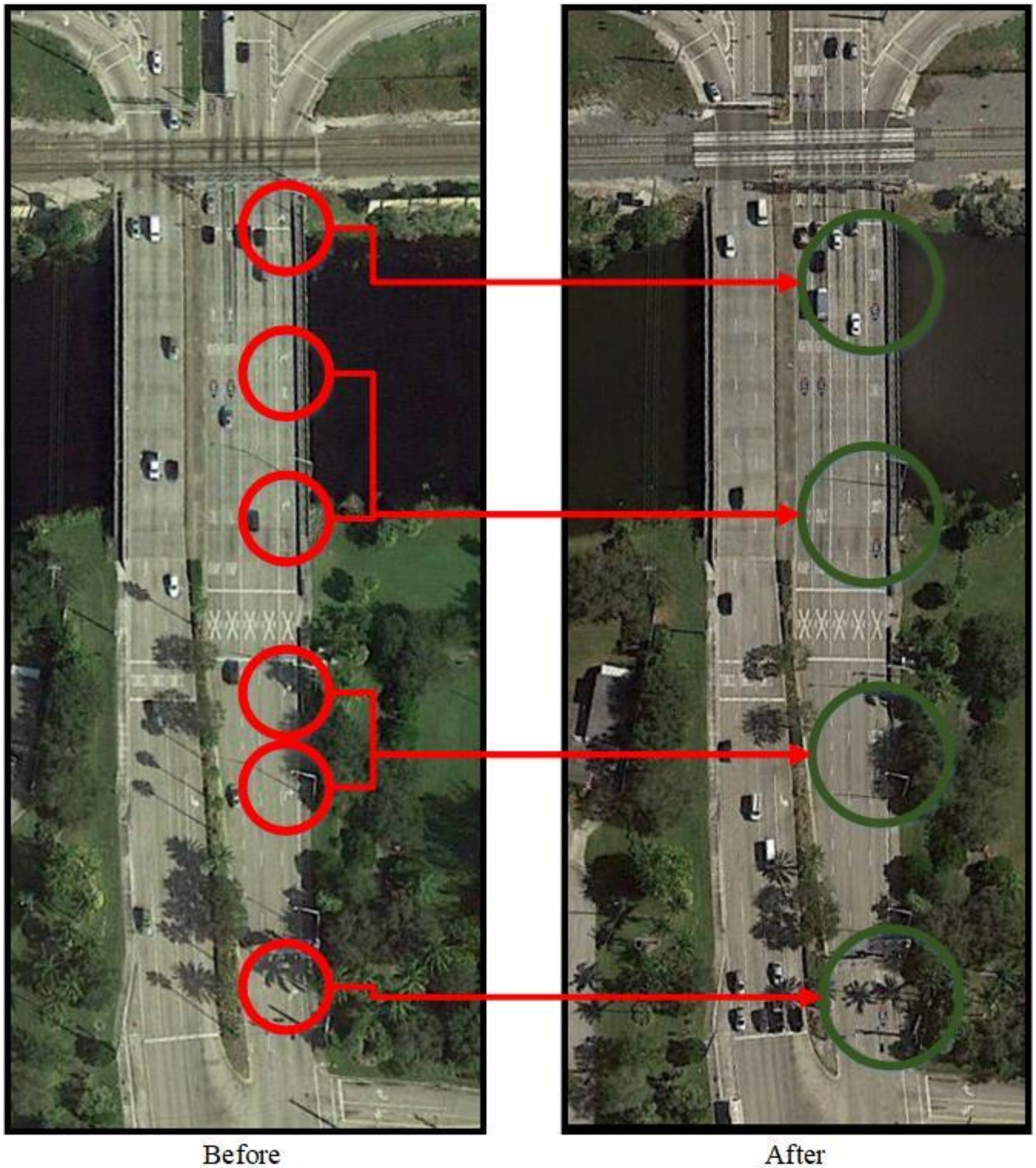


Figure 3-15 Countermeasures implemented at Site 3
(Forest Hill Blvd @ I-95, Lake Clarke Shores, FL)

3.3.2 *Data Collection Results*

A summary of data collection at Site 3 is presented in Table **3-5**. The visualized speed profile and potential hesitation events for daytime and nighttime in the before and after stages are shown in Figure 3-16 through Figure 3-19.

Table 3-5 Summary of Data Collection at Site 3

	Before		After	
	Day	***Night***	***Day***	***Night***
District	District 4			
Coordinates	26.655189, -80.070444			
Start Time	9:50:49 AM	7:55:03 PM	10:12:58 AM	8:37:09 PM
End Time	3:00:33 PM	12:11:51 AM	1:27:13 PM	11:38:09 AM
Total Hours	5:09:44	4:16:48	3:14:15	3:01:00
Total Vehicles	1,899	894	1,320	661

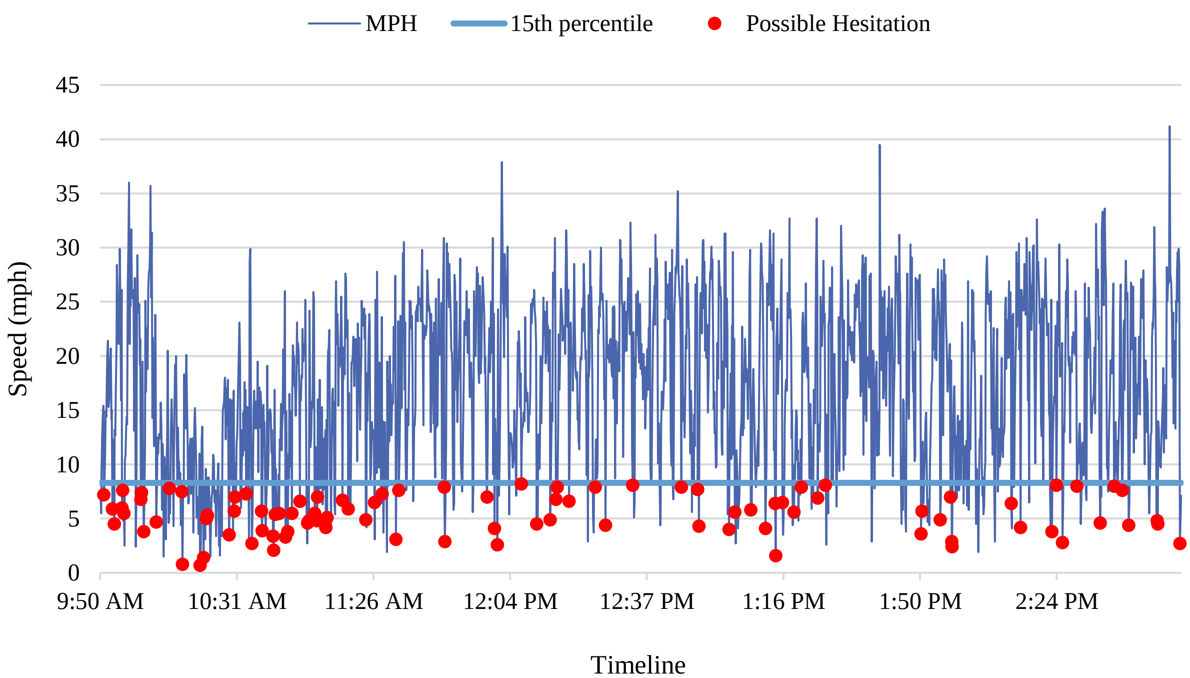


Figure 3-16 Speed profile at Forest Hill Blvd @ I-95, Lake Clarke Shores, FL (before, day)

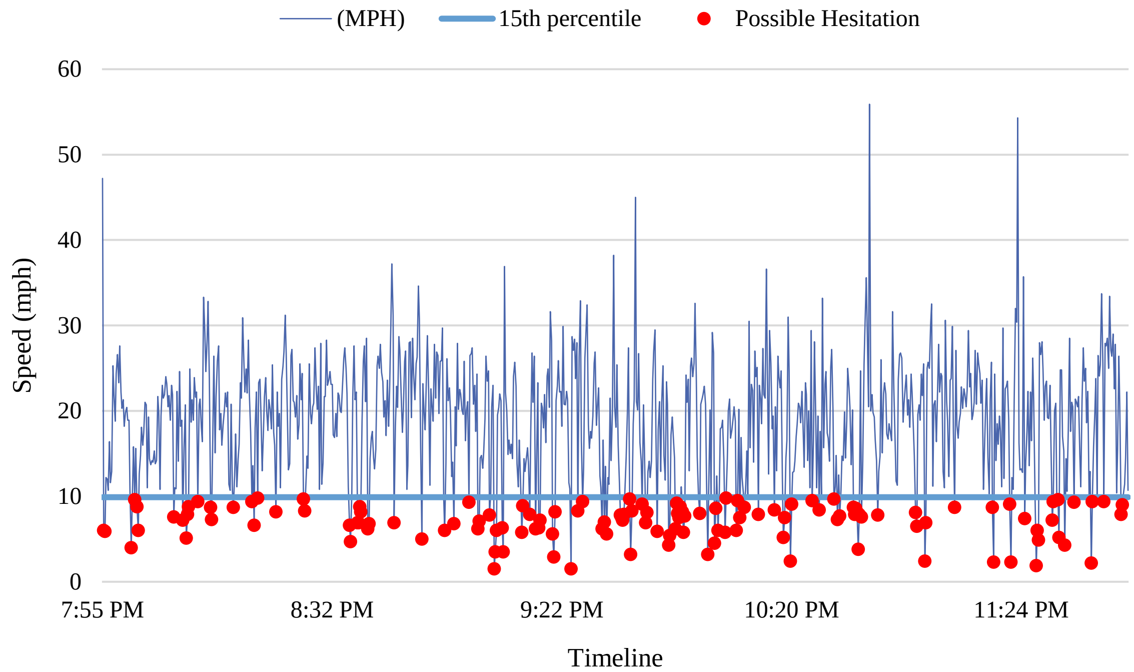


Figure 3-17 Speed profile at Forest Hill Blvd @ I-95, Lake Clarke Shores, FL (before, night)

In the “after” stage, data collection for daytime was conducted from 10:12 AM to 1:27 PM; for nighttime, data collection began at 8:37 PM and lasted for three hours. The results are shown in Figure 3-17 and Figure 3-18.

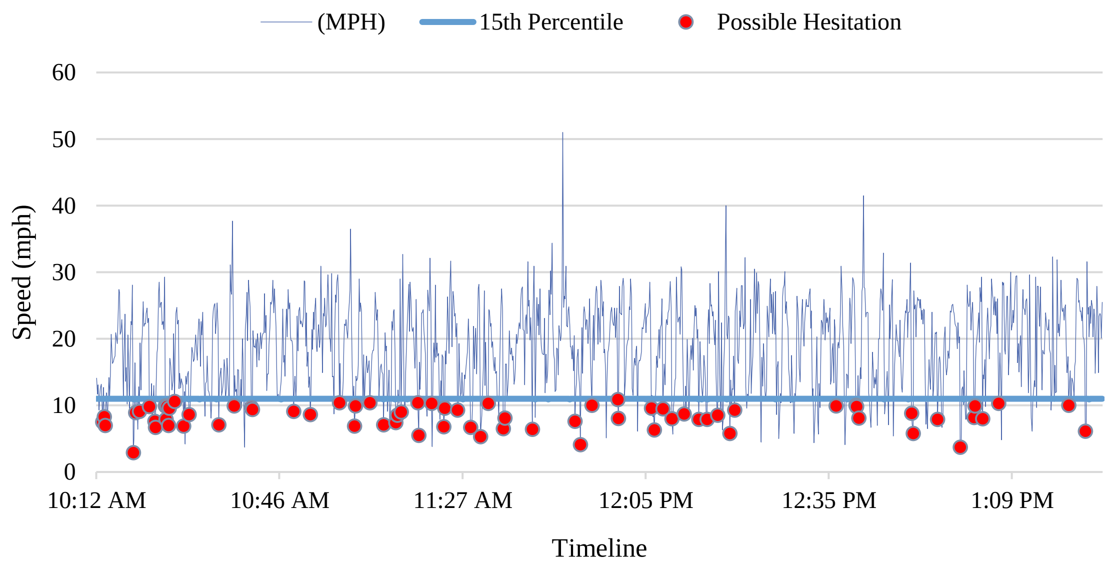


Figure 3-18 Speed profile at Forest Hill Blvd @ I-95, Lake Clarke Shores, FL (after, day)

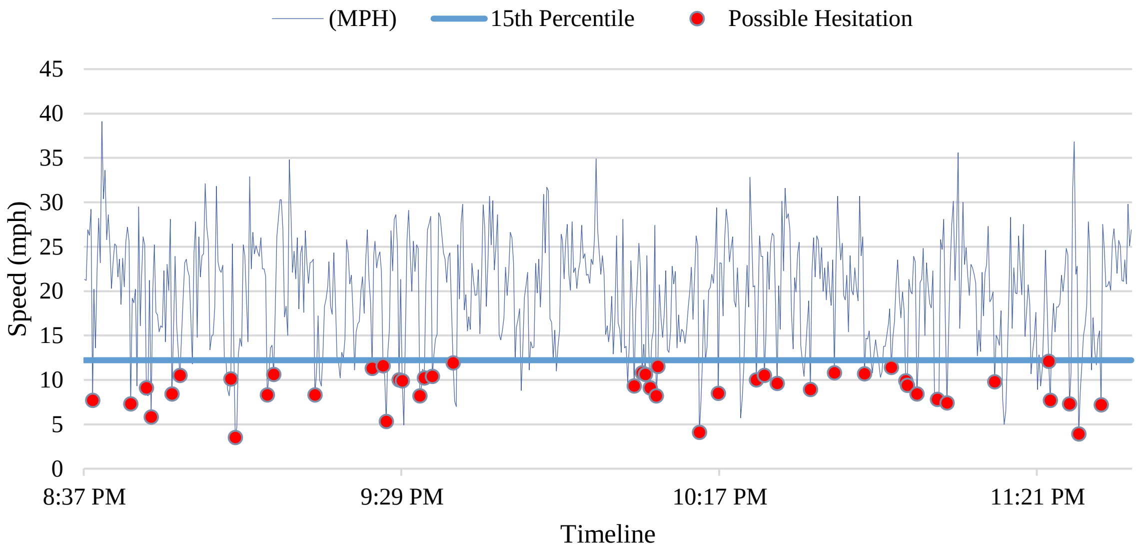


Figure 3-19 Speed profile at Forest Hill Blvd @ I-95, Lake Clarke Shores, FL (after, night)

3.3.3 *Chi-square Statistics Results*

The countermeasure of straight-arrows plus guidance information on pavement was implemented at Site 3 to prevent incorrect right-turns onto railroad tracks. Similar to Table 3-4 for Site 2, Table 3-6 presents the comparison of hesitation rates before and after the implementation of the countermeasure for Site 3. These results show that both daytime and nighttime hesitation rates were reduced by 100% with the countermeasure at a 99.9% confidence level. It can be concluded that the proposed countermeasure can effectively reduce the risk of incorrect right turns onto railroad tracks.

Table 3-6 Before-After Comparison of Hesitation Rate at Site 3
(Forest Hill Blvd @ I-95, Lake Clarke Shores, FL)

Time	Period	Hesitation	No Hesitation	Total	Hesitation Rate	χ^2	*p*-value
Daytime	After	0	1,320	1,320	0.00%	13.29	<0.001
	Before	19	1,880	1,899	1.00%		
	Absolute Reduction of Hesitation Rate				1.00%		
	Relative Reduction of Hesitation Rate				***100%***		
Nighttime	After	0	661	661	0.00%	20.32	<0.001
	Before	27	867	894	3.02%		
	Absolute Reduction of Hesitation Rate				3.02%		
	Relative Reduction of Hesitation Rate				***100%***		

3.4 Site 4: W Hallandale Beach Blvd @ I-95, Pembroke Park, FL

3.4.1 *Site Characteristics and Countermeasures*

Site 4, Hallandale Beach Blvd @ I-95, has potential risks of drivers susceptible to turn onto railroad tracks from right-turn lane, as shown in Figure 3-20. Thus, this site was recommended by FDOT District 4. Two countermeasures were implemented, as shown in Figure 3-21.

- Remove continuous right-turn arrows on the exclusive right-turn lane before the at-grade crossing.
- Add straight arrows with direction text and I-95 shields.

Figure 3-20 Layout of Site 4 (W Hallandale Beach Blvd @ I-95)

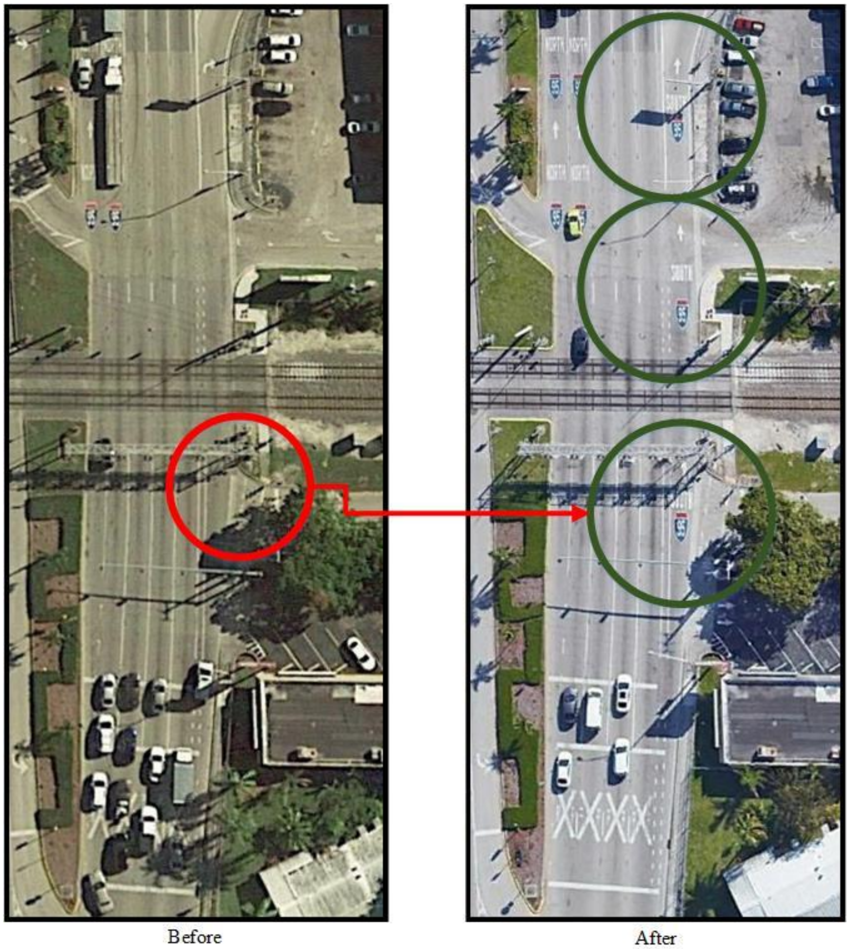


Figure 3-21 Countermeasures implemented at Site 4
(W Hallandale Beach Blvd @ I-95, Pembroke Park, FL)

3.4.2 *Data Collection Results*

The summary of data collection at Site 4 is presented in Table 3-7. The visualized speed profile and potential hesitation events for daytime and nighttime in the before and after stages are shown in Figure 3-22 through Figure 3-25.

Table 3-7 Summary of Data Collection at Site 4

	Before		**After**	
	Day	***Night***	***Day***	***Night***
District	District 4			
Coordinates	25.984767, -80.166899			
Start Time	9:52:09 AM	7:56:38 PM	10:18:52 AM	7:47:49 PM
End Time	3:45:29 PM	11:54:37 PM	1:13:25 PM	11:02:49 PM
Total Hours	5:53:20	3:57:59	2:54:32	3:15:00
Total Vehicles	1,260	441	370	368

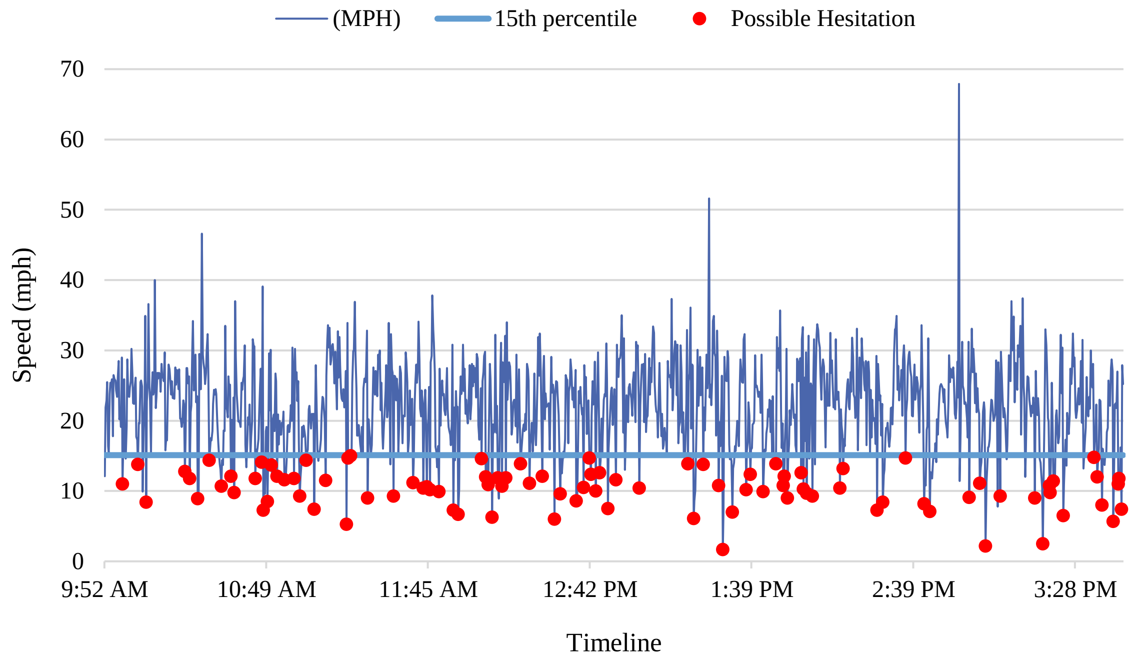


Figure 3-22 Speed profile at W Hallandale Beach Blvd @ I-95, Pembroke Park, FL (before, day)

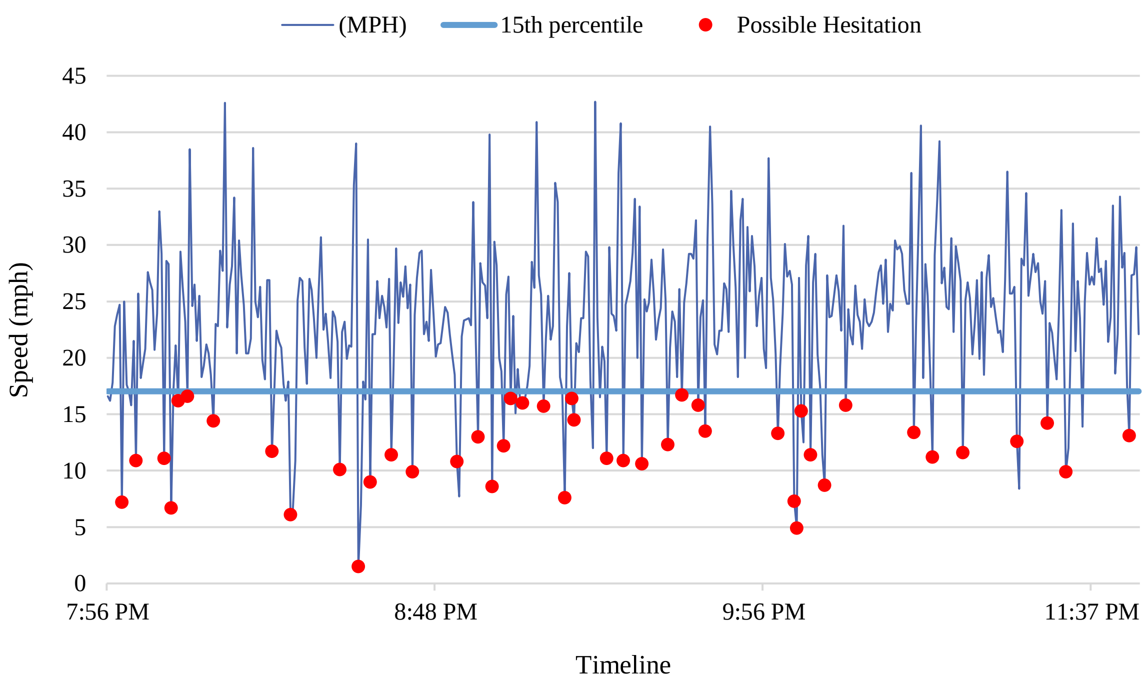


Figure 3-23 Speed profile at W Hallandale Beach Blvd @ I-95, Pembroke Park, FL (before, night)

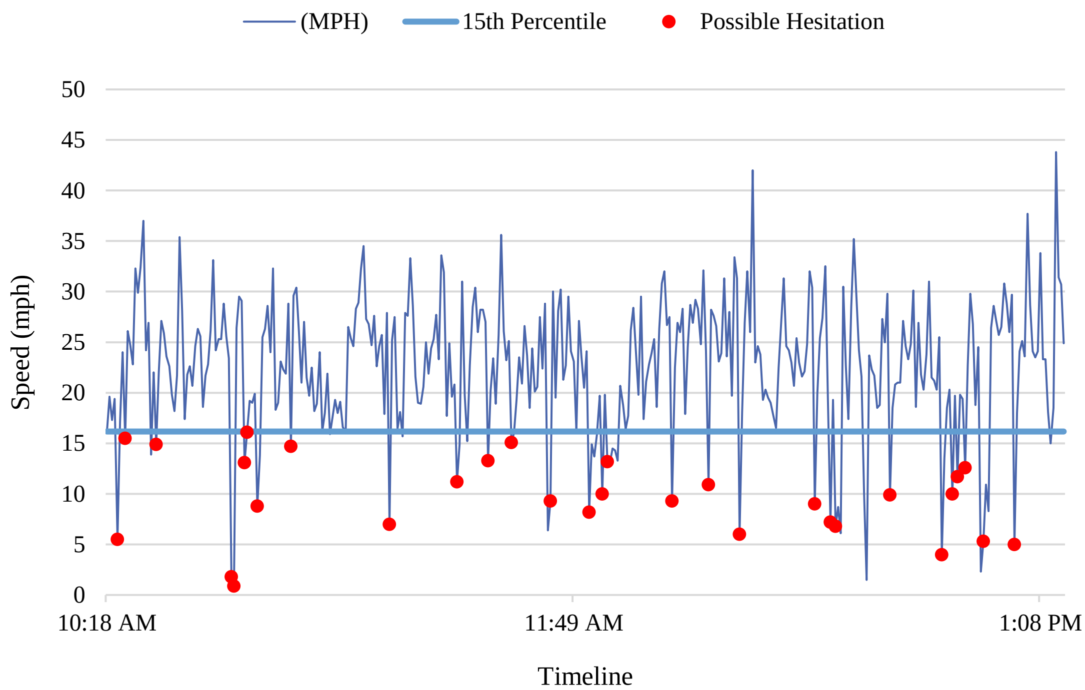


Figure 3-24 Speed profile at W Hallandale Beach Blvd @ I-95, Pembroke Park, FL (after, day)

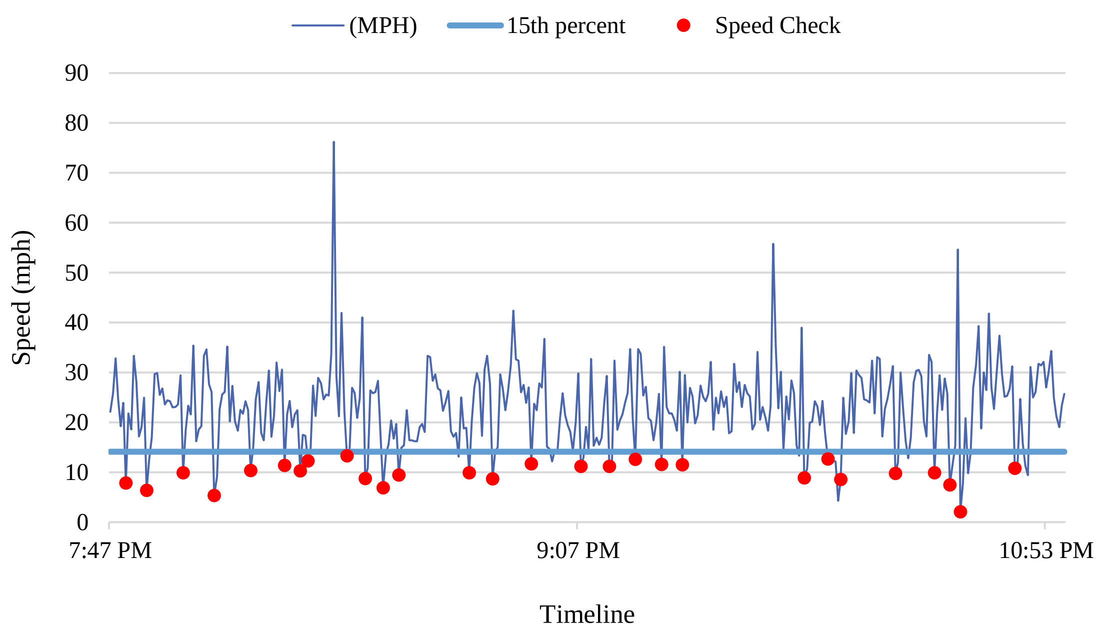


Figure 3-25 Speed profile at W Hallandale Beach Blvd @ I-95, Pembroke Park, FL (after, night)

3.4.3 *Chi-square Statistics Results*

The countermeasure of straight-arrows plus guidance information on pavement was implemented at Site 4 to prevent incorrect right-turns onto railroad tracks. Similar to Table 3-4 for Site 2 and Table 3-6 for Site 3, Table 3-8 presents the comparison of hesitation rates before and after implementation of the countermeasure, showing that both daytime and nighttime hesitation rates were reduced by 79% and 100%, respectively, with the countermeasure. The reduction in hesitation rates was significant (confidence level of 99.99%) at night.

Similar to Site 2, an upstream side street is close to the railroad crossing, and the length of the exclusive right-turn lane is very short (112 ft). All right-turning vehicles must decelerate to enter the right-turn lane and do not have enough space to maintain a certain speed before reaching the hesitation point. All vehicles, either hesitated or non-hesitated, ran at a low speed on the exclusive lane. The two external influences may result in the insignificant difference before and after the implementation of the countermeasure in daytime.

Table 3-8 Before-After Comparison of Hesitation Rate at Site 4
(W Hallandale Beach Blvd @ I-95, Pembroke Park, FL)

Time	Period	Hesitation	No Hesitation	Total	Hesitation Rate	χ^2	*p*-value
Daytime	After	0	370	370	0.00%	1.77	0.18
	Before	6	1,254	1,260	0.48%		
	Absolute Reduction of Hesitation Rate				0.48%		
	Relative Reduction of Hesitation Rate				***100%***		
Nighttime	After	0	368	368	0.00%	10.16	<0.001
	Before	12	429	441	2.72%		
	Absolute Reduction of Hesitation Rate				2.72%		
	Relative Reduction of Hesitation Rate				***100%***		

3.5 Site 5: W Commercial Blvd @ I-95, Oakland Park, FL

3.5.1 *Site Characteristics and Countermeasures*

Site 5, W Commercial Blvd @ I-95, has potential risks of drivers being susceptible to turn onto railroad tracks from the right-turn lane, as shown in Figure 3-26. This site was recommended by FDOT District 4. Two countermeasures were implemented, as shown Figure 3-27:

- Remove continuous right-turn arrows on the exclusive right-turn lane before the at-grade crossing.
- Add straight arrows with direction text and I-95 shields.

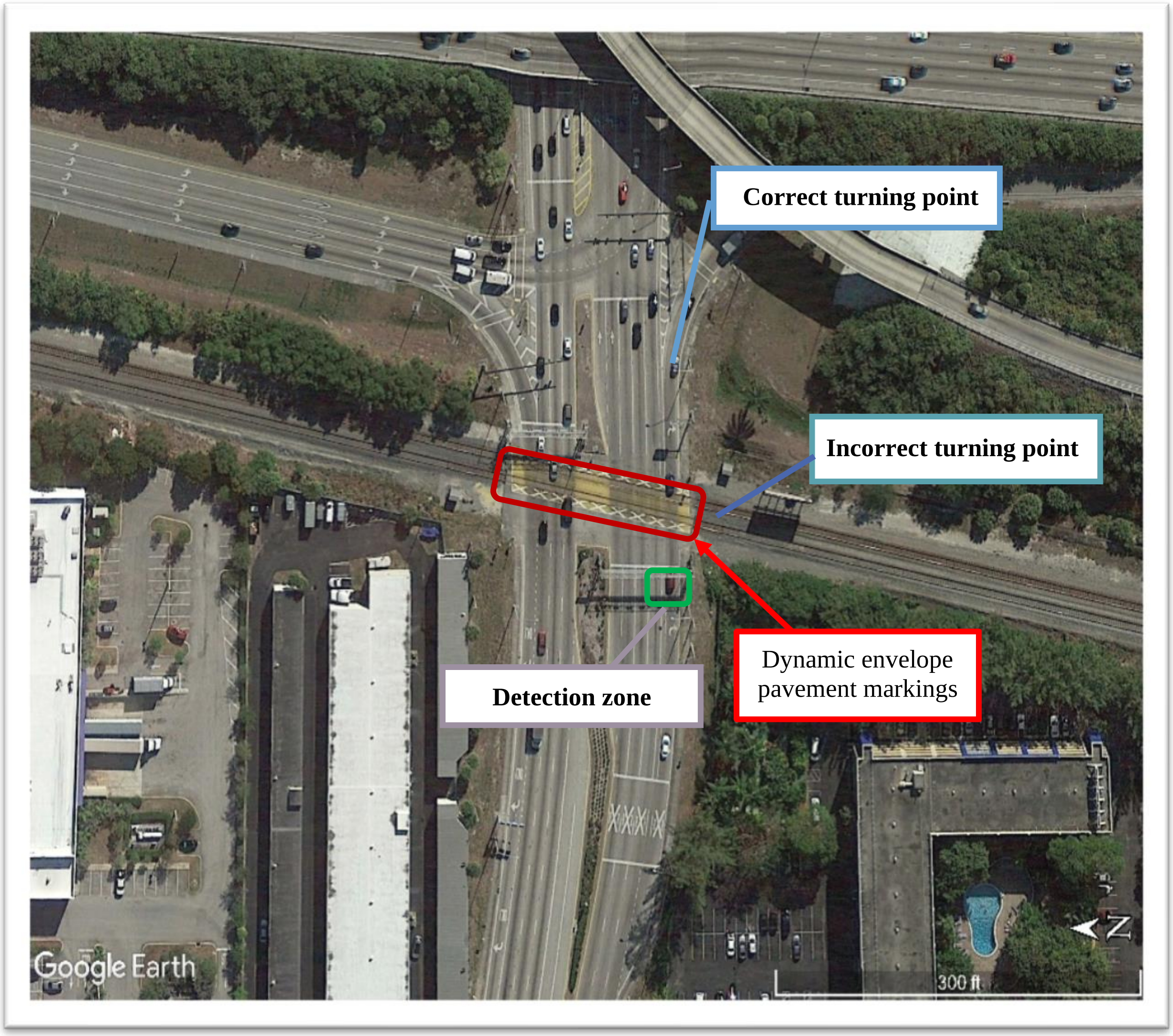
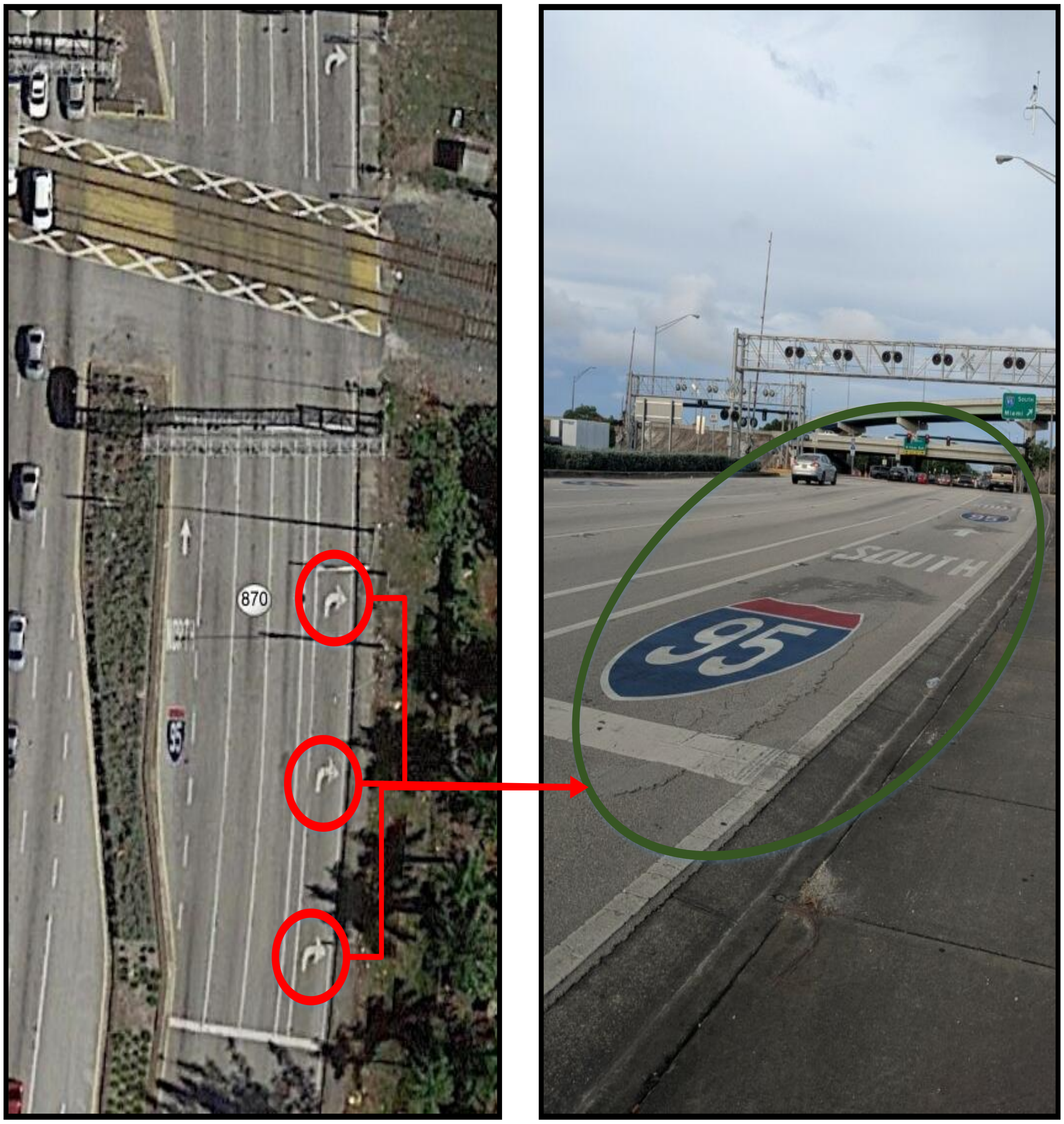


Figure 3-26 Layout of Site 5 (W Commercial Blvd @ I-95)



Before After

Figure 3-27 Countermeasures implemented at W Commercial Blvd @ I-95, Oakland Park, FL

3.5.2 *Data Collection Results*

A summary of data collection at Site 5 is presented in Table 3-9. The visualized speed profile and potential hesitation events for daytime and nighttime in the before and after stages are shown in Figure 3-28 through Figure 3-31.

Table 3-9 Summary of Data Collection at Site 5

	Before		After	
	Day	***Night***	***Day***	***Night***
District	District 4			
Coordinates	26.188170, -80.153227			
Start Time	9:53:46 AM	7:40:15 PM	10:54:22 AM	8:55:26 PM
End Time	3:00:38 PM	11:59:06 PM	1:01:41 PM	11:22:57 PM
Total Hours	5:06:52	4:18:51	2:07:19	2:27:30
Total Vehicles	962	886	845	878

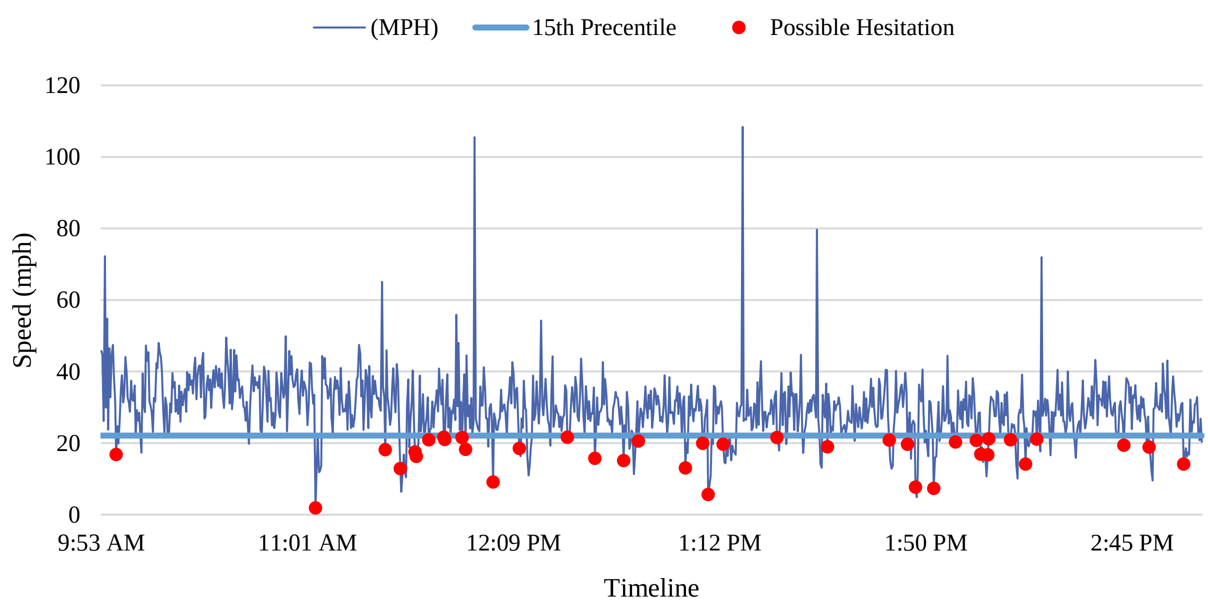


Figure 3-28 Speed profile at W Commercial Blvd @ I-95, Oakland Park, FL (before, day)

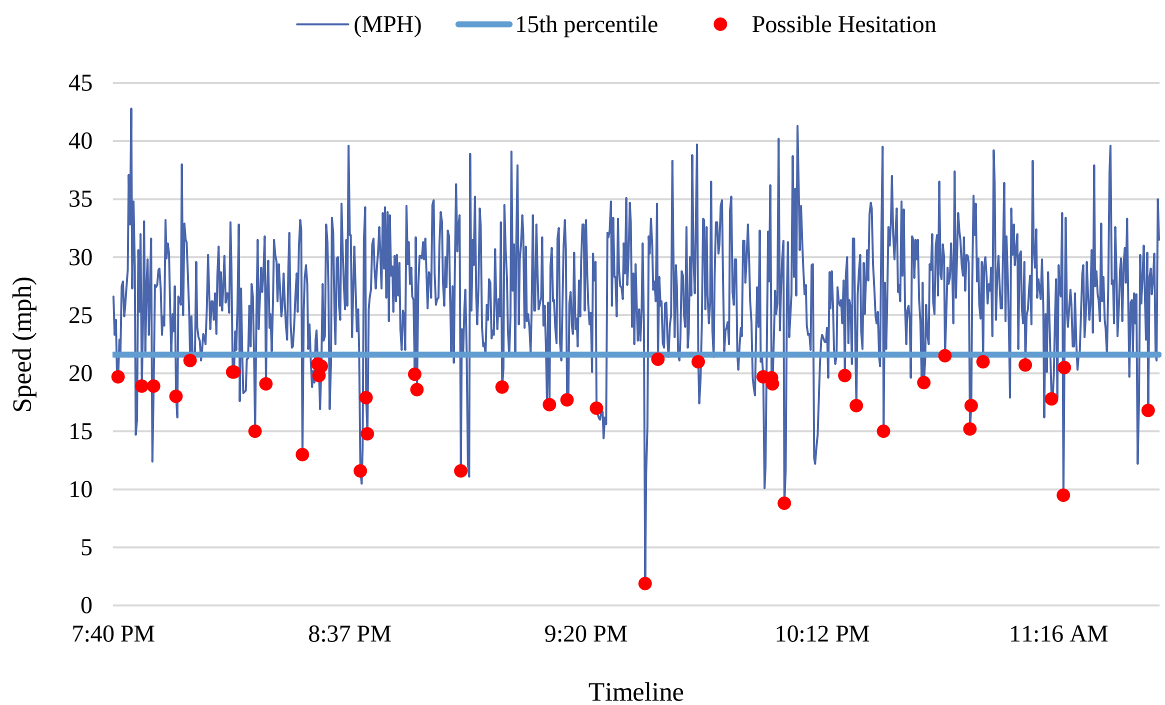


Figure 3-29 Speed profile at W Commercial Blvd @ I-95, Oakland Park, FL (before, night)

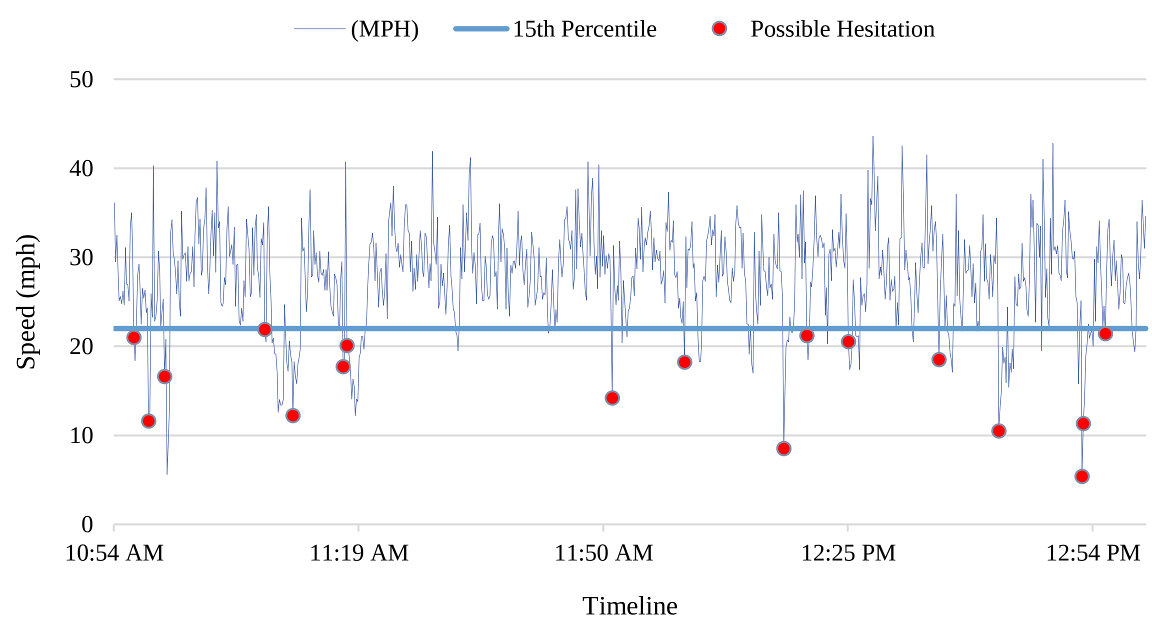


Figure 3-30 Speed profile at W Commercial Blvd @ I-95, Oakland Park, FL (after, day)

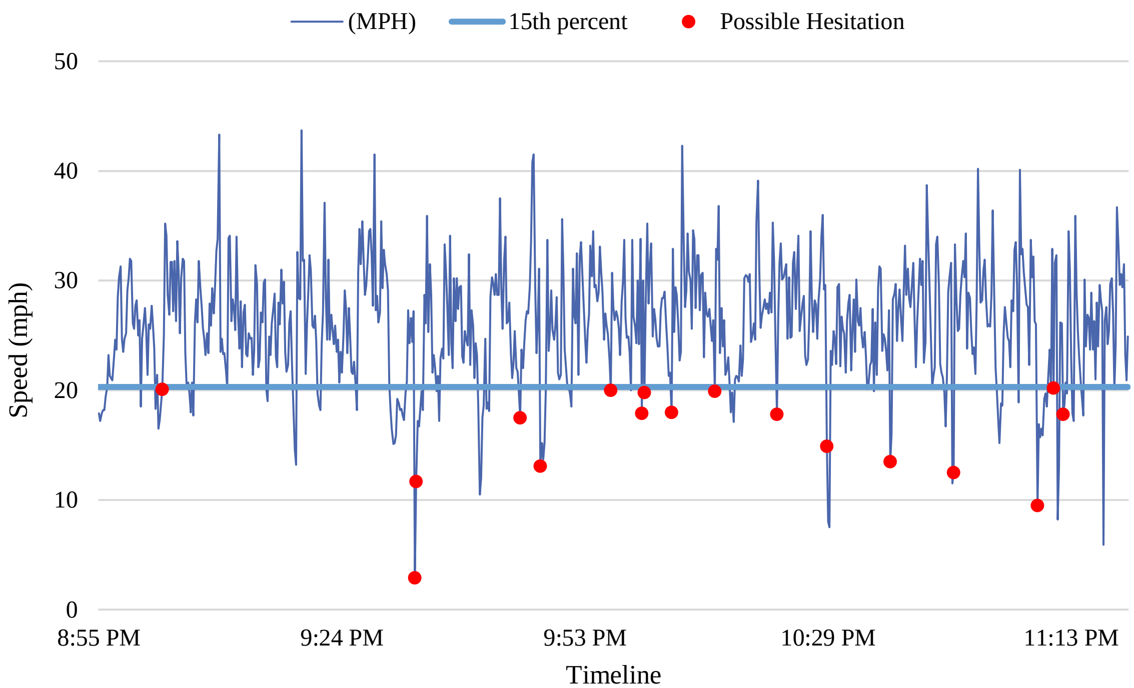


Figure 3-31 Speed profile at W Commercial Blvd @ I-95, Oakland Park, FL (after, night)

3.5.3 *Chi-square Statistics Results*

The countermeasure of straight-arrows plus guidance information on pavement was implemented at Site 5 to prevent incorrect right-turns onto railroad tracks. Table 3-10 presents the comparison of hesitation rates before and after implementation of the countermeasure for Site 5 and shows that both daytime and nighttime hesitation rates were reduced by 67% and 91%, respectively, with the countermeasure. The reduction in hesitation rate was significant (confidence level of 99.6%) at night. As shown in Figure 3-26, a dynamic envelope that indicates railroad track areas was implemented on the crossing before this study. Drivers seeking turning points can know the presence of railroad tracks with and without the implemented countermeasure. Thus, the reduction in hesitation rates on Commercial Blvd was insignificant in daytime.

Table 3-10 Before-After Comparison of Hesitation Rate at W Commercial Blvd @ I-95, Oakland Park, FL

Time	Period	Hesitation	No Hesitation	Total	Hesitation Rate	χ^2	*p*-value
Daytime	After	2	843	845	0.24%	2.19	0.14
	Before	7	955	962	0.73%		
	Absolute Reduction of Hesitation Rate				0.49%		
	Relative Reduction of Hesitation Rate				***67%***		
Nighttime	After	1	877	878	0.11%	8.30	0.004
	Before	11	875	886	1.24%		
	Absolute Reduction of Hesitation Rate				1.13%		
	Relative Reduction of Hesitation Rate				***91%***		

3.6 Site 6: W Pembroke Rd @ I-95, Hollywood, FL

3.6.1 *Site Characteristics and Countermeasures*

Site 6, W Pembroke Blvd @ I-95, has potential risks of drivers being susceptible to turning onto railroad tracks from the right-turn lane, as shown in Figure 3-32. This site was recommended by FDOT District 4. Two countermeasures were implemented, as shown in Figure 3-33:

- Remove continuous right-turn arrows on the exclusive right-turn lane before the at-grade crossing.
- Add straight arrows with direction text and I-95 shields.

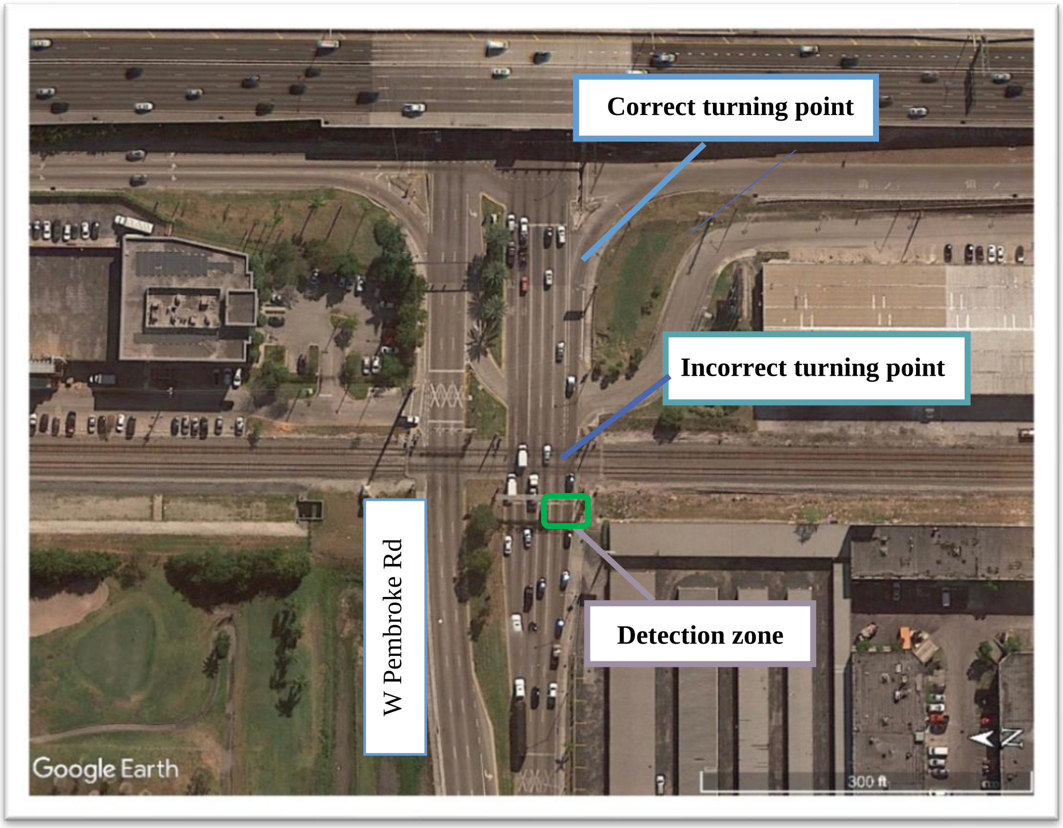
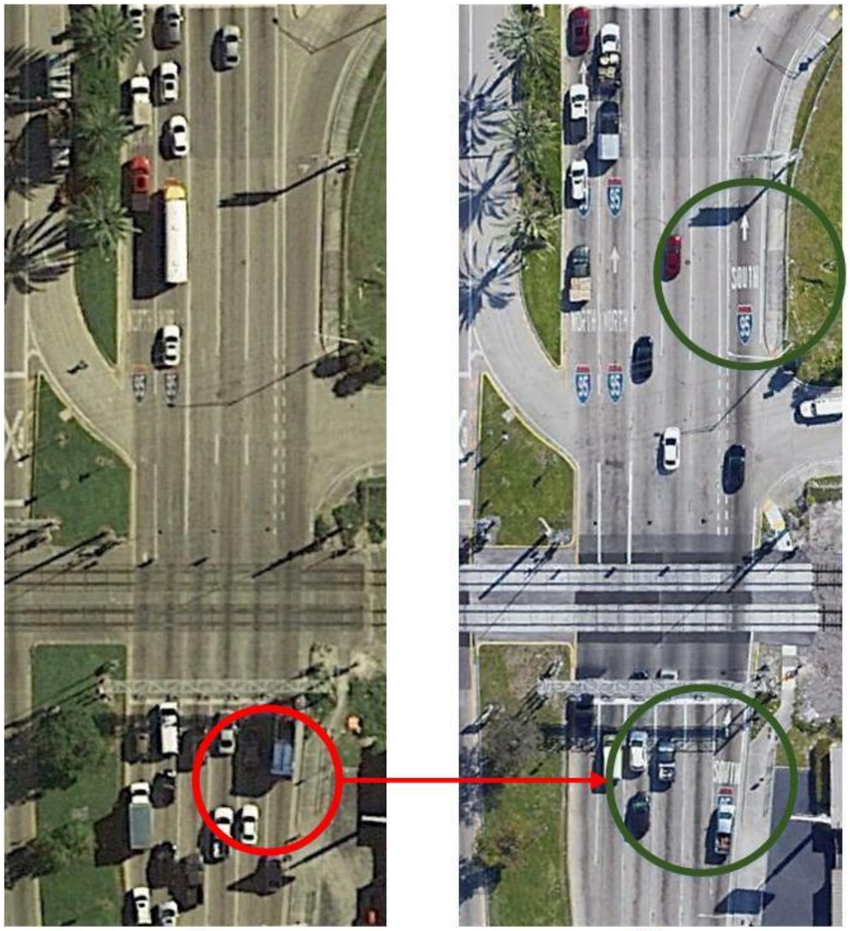


Figure 3-32 Layout of Site 6 (W Pembroke Rd @ I-95)



Before After

Figure 3-33 Countermeasures implemented at Site 6
(W Pembroke Rd @ I-95, Hollywood, FL)

3.6.2 *Data Collection Results*

A summary of data collection at Site 6 is presented in Table 3-11. The visualized speed profile and potential hesitation events for daytime and nighttime in the before and after stages are shown in Figure 3-34 through Figure 3-37.

Table 3-11 Summary of Data Collection at Site 6

	Before		**After**	
	Day	***Night***	***Day***	***Night***
District	District 4			
Coordinates	25.995944, -80.167277			
Start Time	9:55:07 AM	8:01:45 PM	9:13:13 AM	7:54:19 PM
End Time	2:59:14 PM	11:56:33 PM	12:20:54 PM	11:27:18 PM
Total Hours	5:04:07	3:54:48	3:07:41	3:32:59
Total Vehicles	1,689	657	958	588

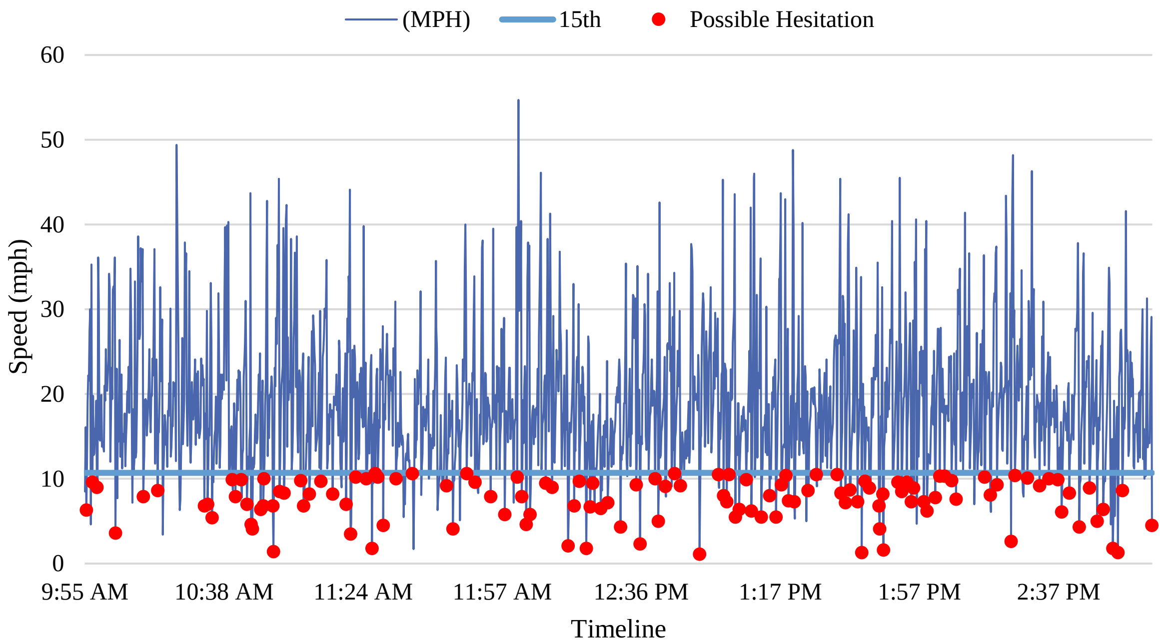


Figure 3-34 Speed profile at W Pembroke Rd @ I-95, Hollywood (before, day)

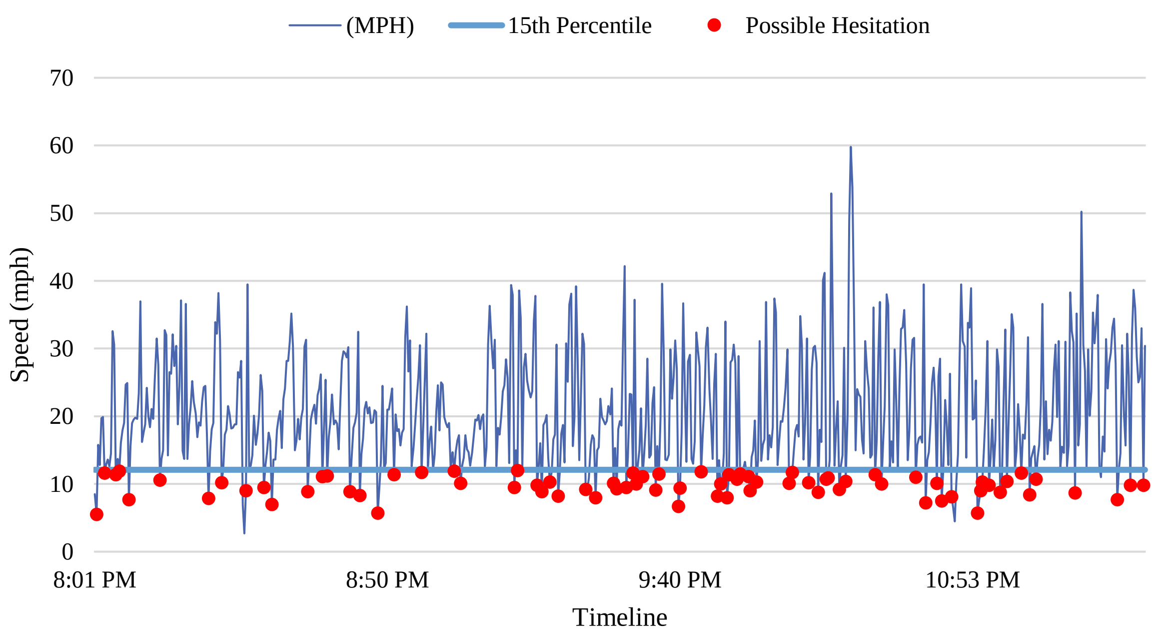


Figure 3-35 Speed profile at W Pembroke Rd @ I-95, Hollywood (before, night)

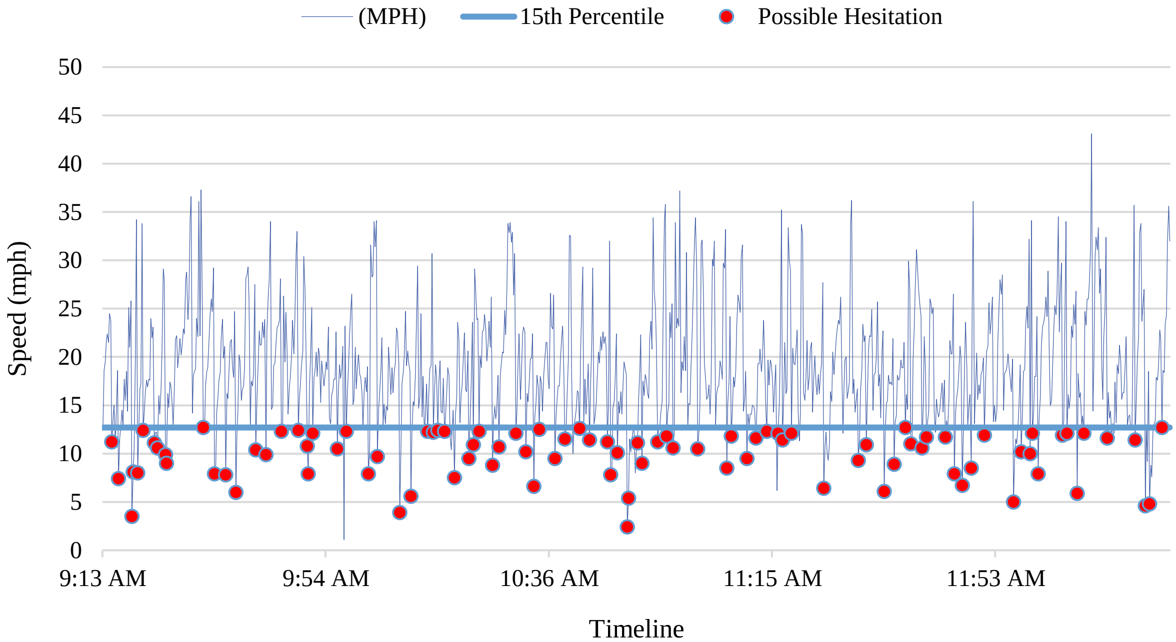


Figure 3-36 Speed profile at W Pembroke Rd @ I-95, Hollywood (after, day)

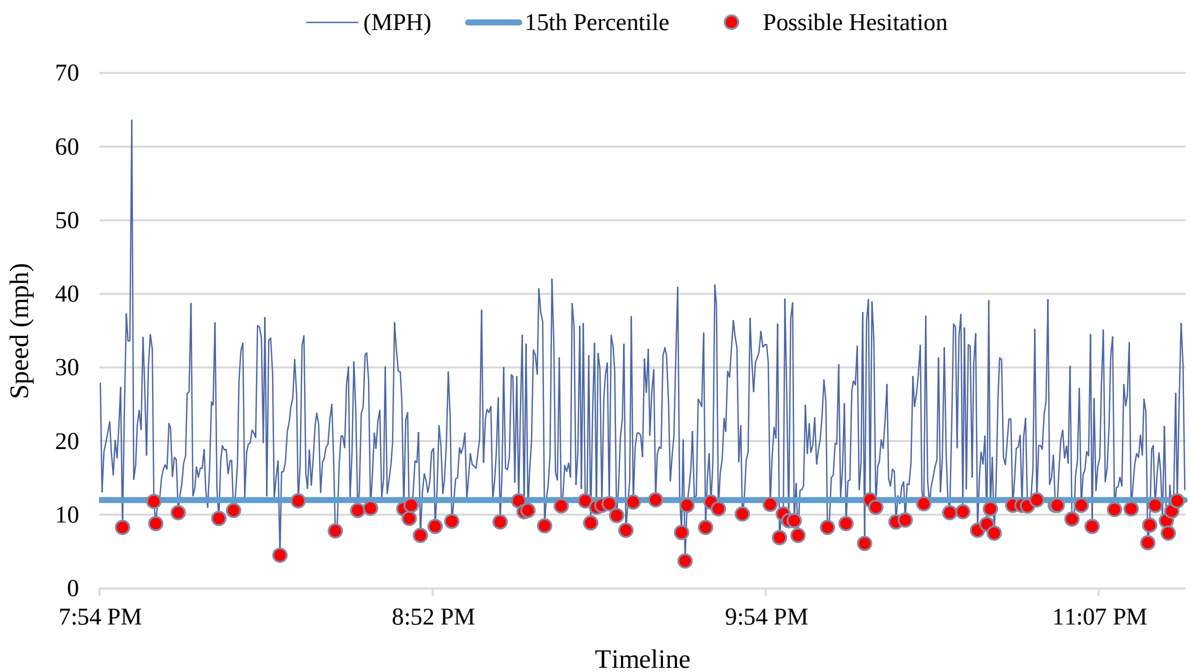


Figure 3-37 Speed profile at W Pembroke Rd @ I-95, Hollywood (after, night)

3.6.3 *Chi-square Statistics Results*

The countermeasure of straight-arrows plus guidance information on pavement was implemented at Site 6 to prevent incorrect right-turns onto railroad tracks.

Table 3-12 presents the comparison of hesitation rates before and after countermeasure implementation for Site 6. The comparison shows that both daytime and nighttime hesitation rates were significantly reduced by 87% (confidence level of 98.0%) and 100% (confidence level of 99.7%) with the countermeasure, respectively.

Table 3-12 Before-After Comparison of Hesitation Rate at Site 6
(W Pembroke Rd @ I-95, Hollywood, FL)

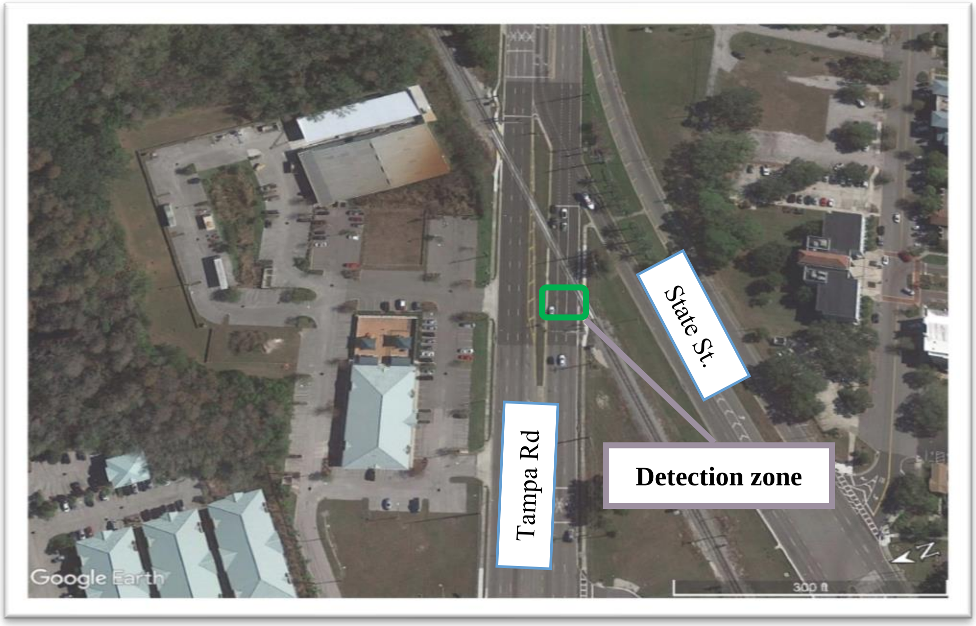
Time	Period	Hesitation	No Hesitation	Total	Hesitation Rate	χ^2	*p*-value
Daytime	After	1	957	958	0.10%	5.14	0.02
	Before	13	1,676	1,689	0.77%		
	Absolute Reduction of Hesitation Rate				0.67%		
	Relative Reduction of Hesitation Rate				***87%***		
Nighttime	After	0	588	588	0.00%	9.02	0.003
	Before	10	647	657	1.52%		
	Absolute Reduction of Hesitation Rate				1.52%		
	Relative Reduction of Hesitation Rate				***100%***		

3.7 Site 7: Tampa Rd @ State St W, Oldsmar, FL

3.7.1 *Site Characteristics and Countermeasures*

Site 7, W Tampa Rd @ State St W, has potential risk of drivers being susceptible to making incorrect turns from the through lane, as shown in Figure 3-38**Error! Reference source not found.**. One countermeasure was implemented, as shown in Figure 3-39:

- Add a straight arrow before at-grade crossing



A: ***Layout of Site 7 (bird's-eye view)***

B: Layout of Site 7 (driver view)

Figure 3-38 Layout of Site 7

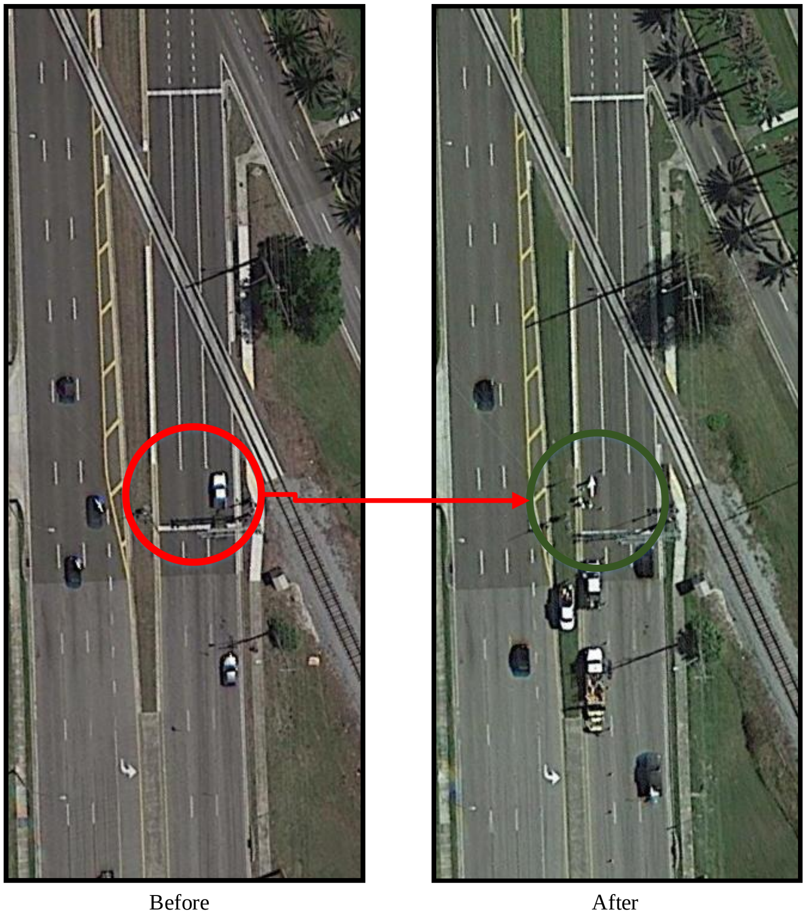


Figure 3-39 Countermeasures implemented at Site 7
(Tampa Rd @ State St W, Oldsmar, FL)

3.7.2 *Data Collection Results*

A summary of data collection at Site 7 is presented in Table 3-13. The visualized speed profile and potential hesitation events for daytime and nighttime in the before and after stages are shown in Figure 3-40 through Figure 3-43.

Table 3-13 Summary of Data Collection at Site 7

	Before		**After**	
	Day	***Night***	***Day***	***Night***
District	District 7			
Coordinates	28.038410, -82.662755			
Start Time	9:51:52 AM	7:38:36 PM	1:46:20 PM	7:54:19 PM
End Time	2:51:45 PM	11:43:31 PM	3:05:27 PM	11:27:18 PM
Total Hours	4:59:53	4:04:55	1:19:07	3:32:59
Total Vehicles	1,982	562	583	317

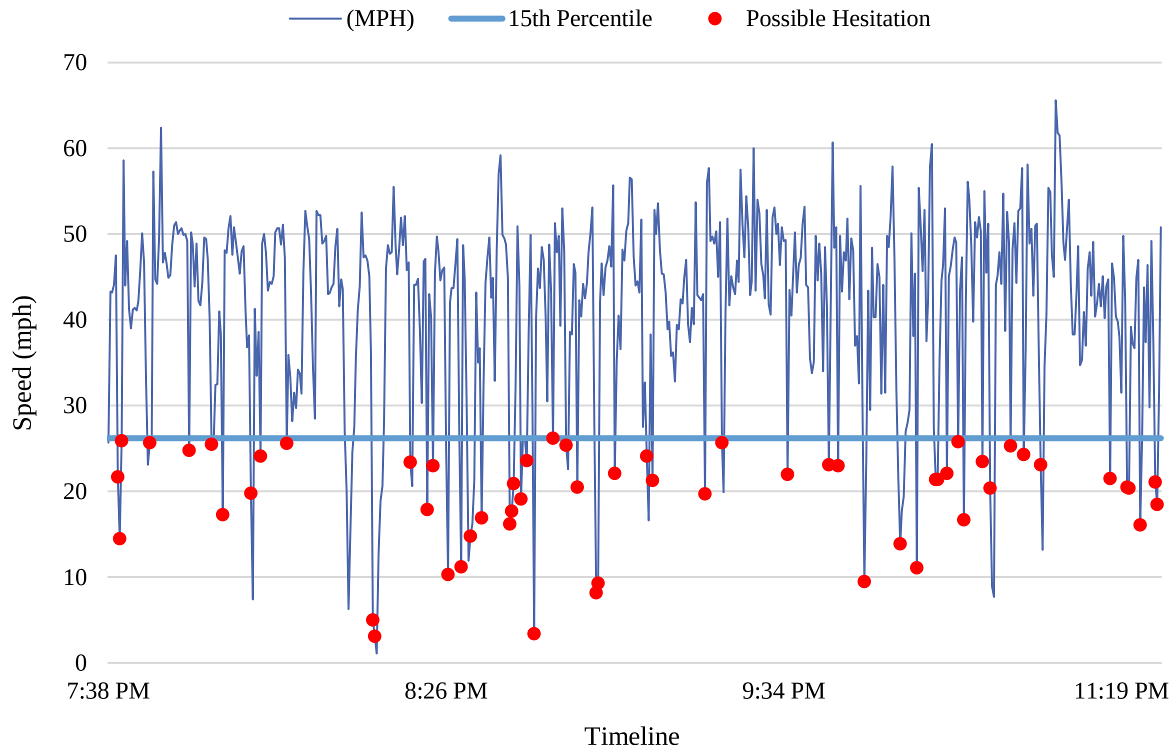


Figure 3-40 Speed profile at Tampa Rd @ State St W, Oldsmar, FL (before, day)

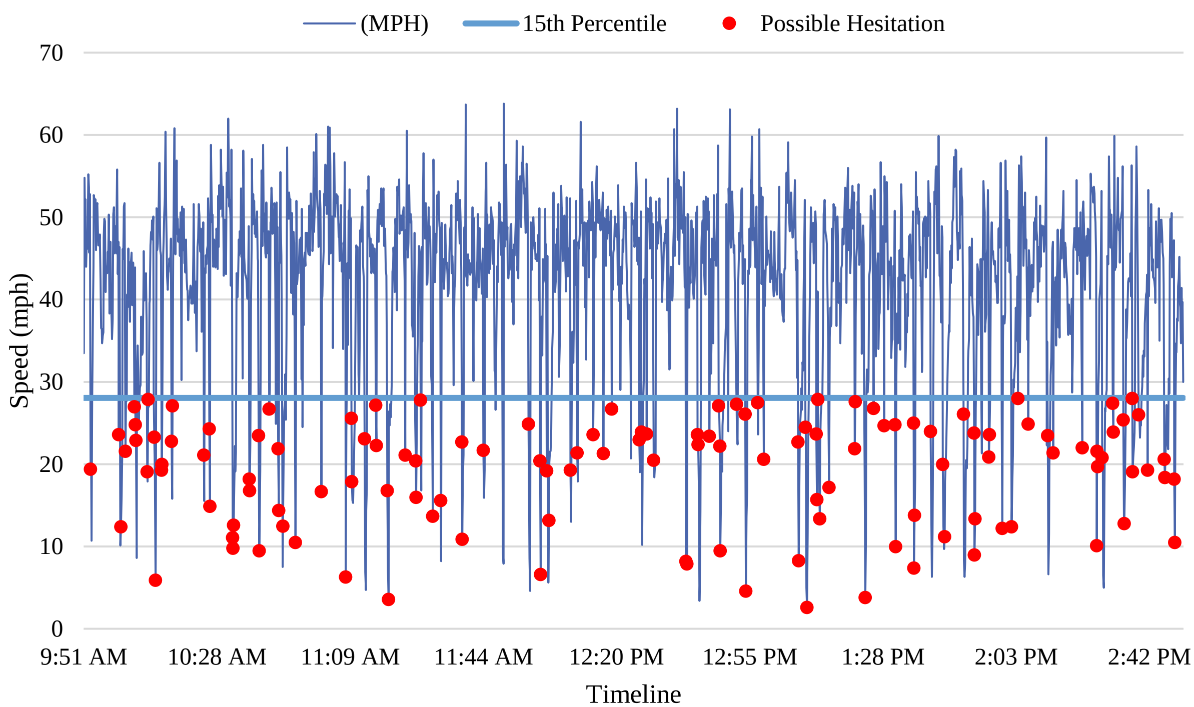


Figure 3-41 Speed profile at Tampa Rd @ State St W, Oldsmar, FL (before, night)

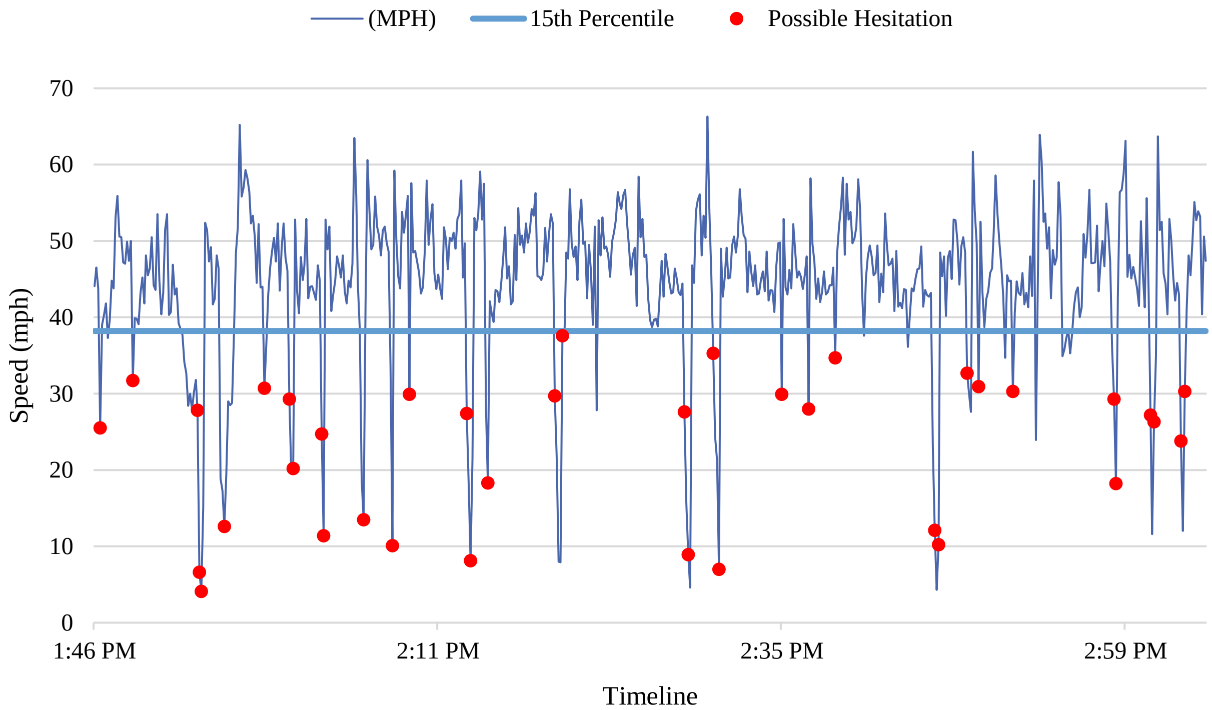


Figure 3-42 Speed profile at Tampa Rd @ State St W, Oldsmar, FL (after, day)

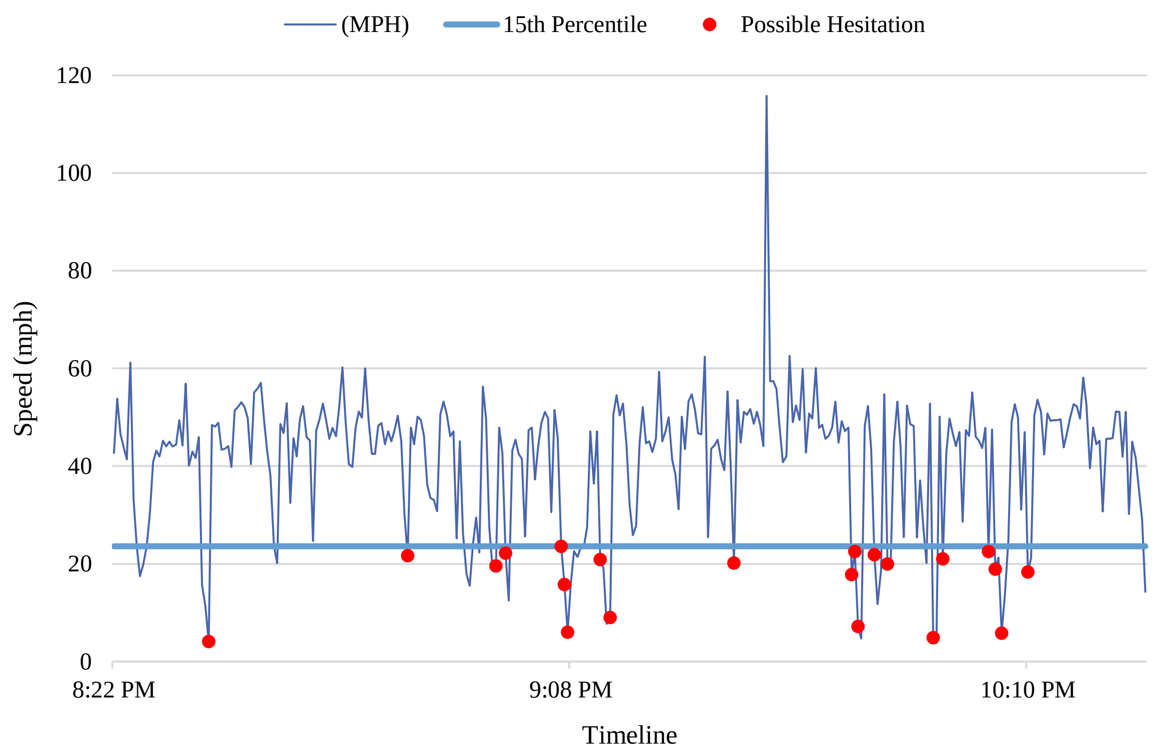


Figure 3-43 Speed profile at Tampa Rd @ State St W, Oldsmar, FL (night)

3.7.3 *Chi-square Statistics Results*

The countermeasure of straight arrows on pavement was implemented at Site 7 to prevent incorrect turns onto railroad tracks. Table 3-14 presents the comparison of hesitation rates before and after countermeasure implementation for Site 7, showing that both daytime and nighttime hesitation rates were reduced, by 74% and 40%, respectively, with the countermeasure, although the reduction is statistically insignificant for both daytime and nighttime.

Table 3-14 Before-After Comparison of Hesitation Rate at Site 7 (Tampa Rd @ State St W, Oldsmar, FL)

Time	Period	Hesitation	No Hesitation	Total	Hesitation Rate	χ^2	*p*-value
Daytime	After	1	582	583	0.17%	1.95	0.16
	Before	13	1,969	1,982	0.66%		
	Absolute Reduction of Hesitation Rate				0.49%		
	Relative Reduction of Hesitation Rate				***74%***		
Nighttime	After	1	316	317	0.32%	0.21	0.65
	Before	3	559	562	0.53%		
	Absolute Reduction of Hesitation Rate				0.21%		
	Relative Reduction of Hesitation Rate				***40%***		

3.8 Site 8: Busch Blvd @ N Boulevard, Tampa, FL

3.8.1 *Site Characteristics and Countermeasures*

Site 8, Busch Blvd @ N Boulevard, has potential risks of drivers being susceptible to turning onto railroad tracks from the right-turn lane, as shown in Figure 3-44. One countermeasure was implemented, as shown in Figure 3-45:

- Remove a right-turn arrow on the exclusive right-turn lane before the at-grade crossing.
- Add one straight arrow with direction text and road information before at-grade crossing.

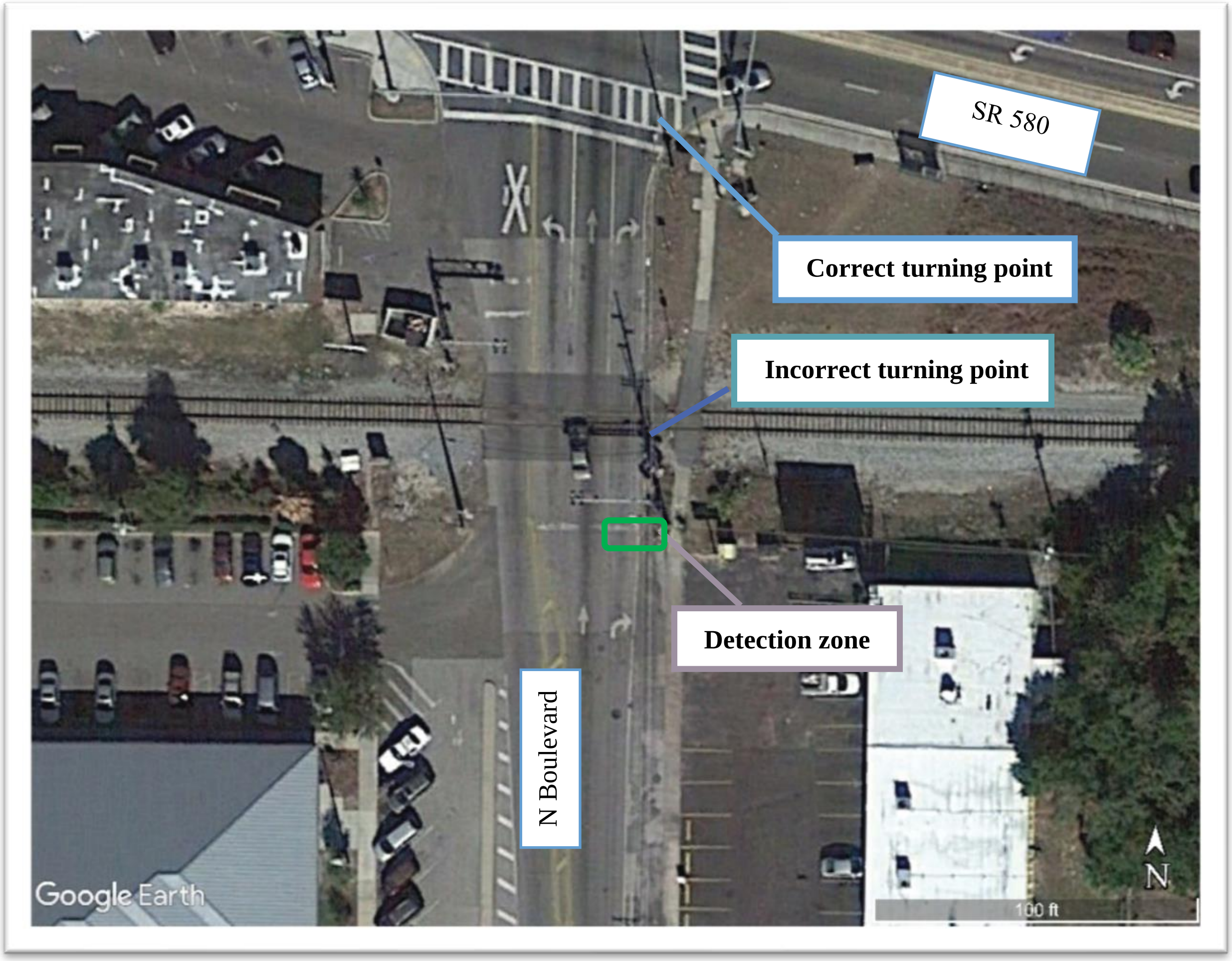


Figure 3-44 Layout of Site 8 (Busch Blvd @ N Boulevard)

Before After

Figure 3-45 Countermeasures implemented at Site 8
(Busch Blvd @ N Boulevard, Tampa, FL)

3.8.2 *Data Collection Results*

A summary of data collection at Site 8 is presented in Table 3-15. The visualized speed profile and potential hesitation events for daytime and nighttime in the before and after stages are shown in Figure 3-46 through Figure 3-49.

Table 3-15 Summary of Data Collection at Site 8

	Before		**After**	
	Day	***Night***	***Day***	***Night***
District	District 7			
Coordinates	28.032842, -82.467808			
Start Time	10:04:53 AM	7:49:46 PM	10:07:04 AM	8:09:16 PM
End Time	2:00:23 PM	11:45:15 PM	12:56:11 PM	10:56:49 PM
Total Hours	3:55:30	3:55:29	2:49:07	2:47:33
Total Vehicles	251	383	143	205

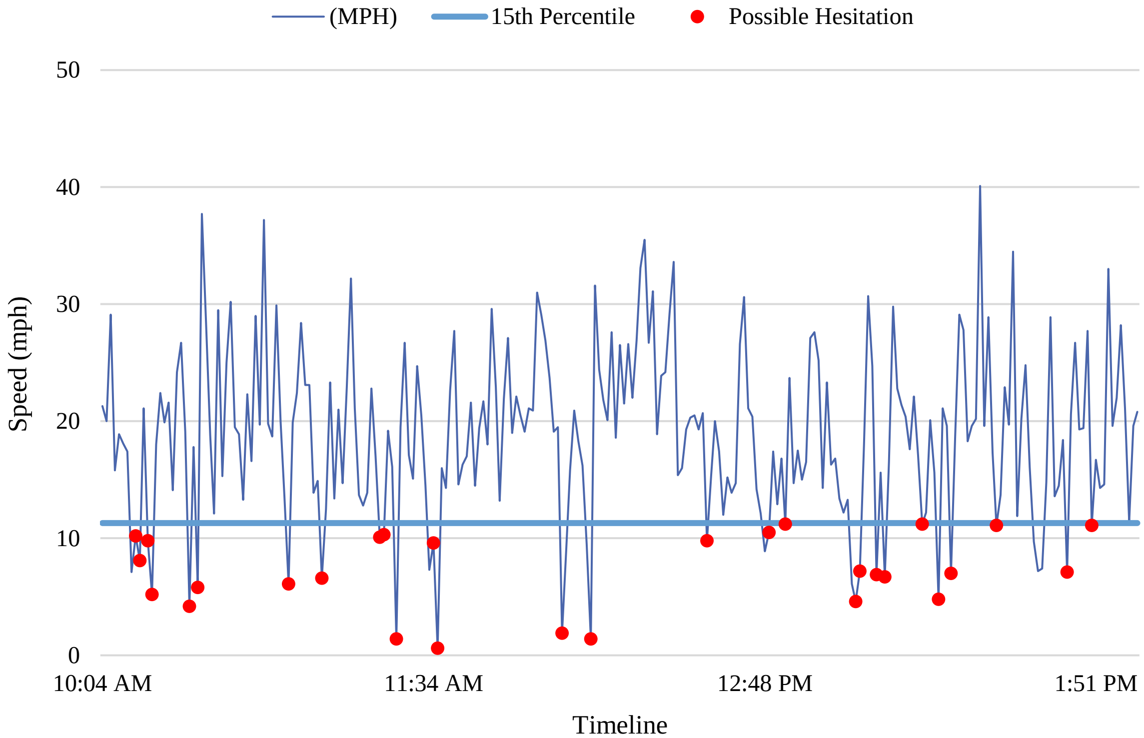


Figure 3-46 Speed profile at Busch Blvd @ N Boulevard, Tampa, FL (before, day)

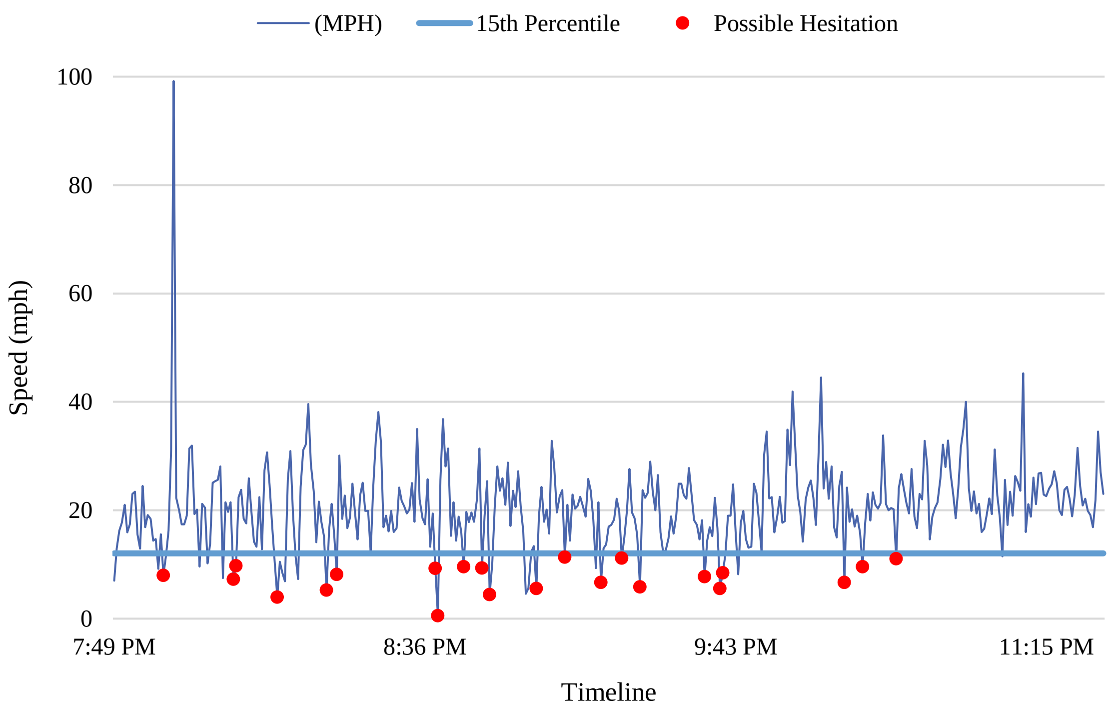


Figure 3-47 Speed profile at Busch Blvd @ N Boulevard, Tampa, FL (before, night)

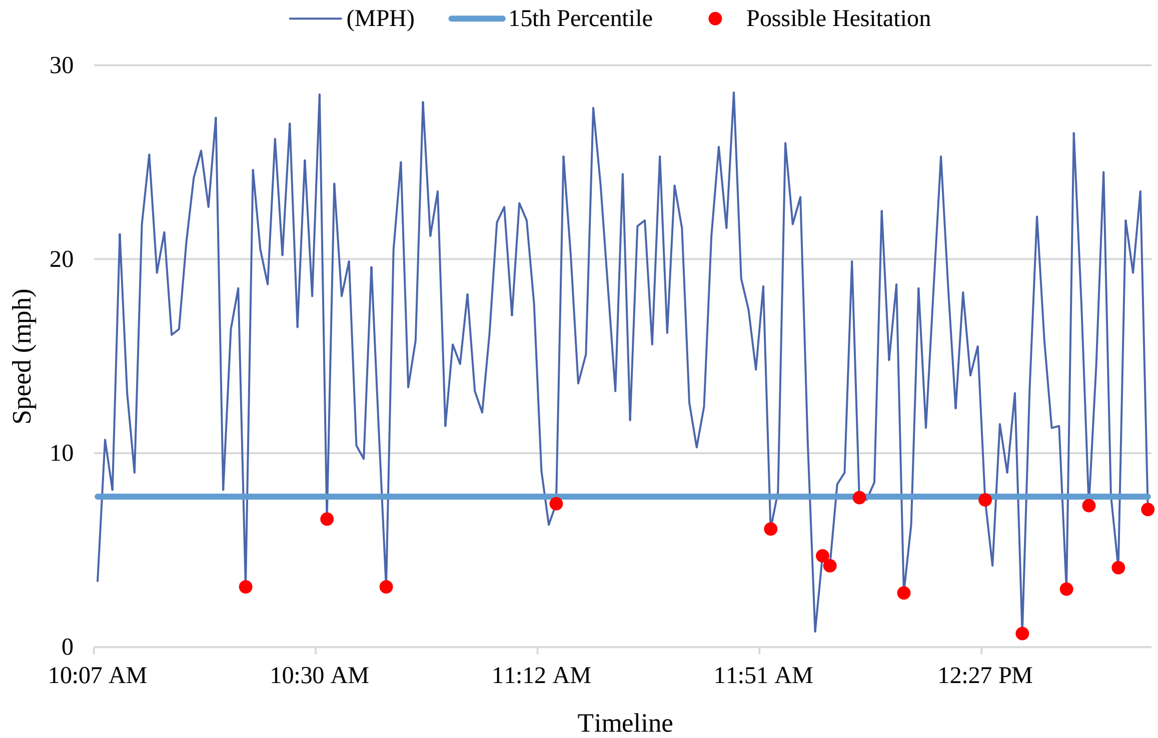


Figure 3-48 Speed profile at Busch Blvd @ N Boulevard, Tampa, FL (after, day)

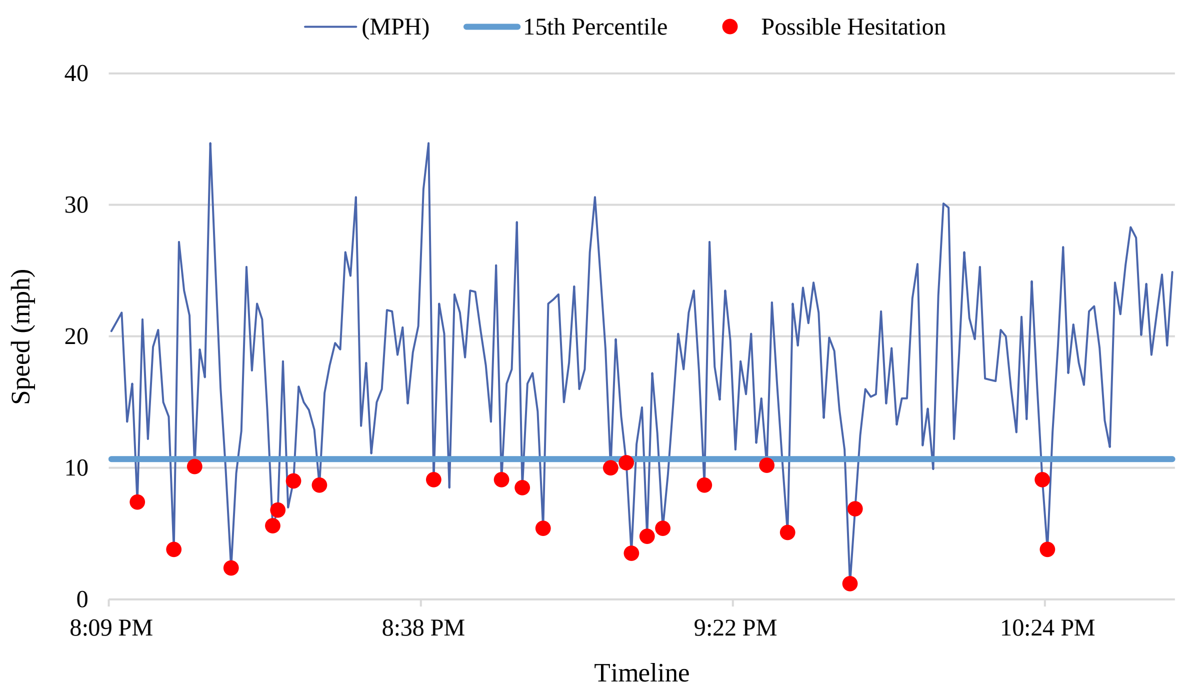


Figure 3-49 Speed profile at Busch Blvd @ N Boulevard, Tampa, FL (after, night)

3.8.3 *Chi-square Statistics Results*

The countermeasure of straight arrows plus guidance information on pavement was implemented at Site 8 to prevent incorrect right-turns onto railroad tracks. Table 3-16 presents the comparison of hesitation rates before and after the countermeasure implementation for Site 8, showing that both daytime and nighttime hesitation rates were significantly reduced by100% (confidence level of 90% or higher) with the countermeasure.

Table 3-16 Before-After Comparison of Hesitation Rate at Site 8 (Busch Blvd @ N Boulevard, Tampa, FL)

Time	Period	Hesitation	No Hesitation	Total	Hesitation Rate	χ^2	*p*-value
Daytime	After	0	143	143	0.00%	4.06	0.044
	Before	7	244	251	2.79%		
	Absolute Reduction of Hesitation Rate				2.79%		
	Relative Reduction of Hesitation Rate				***100%***		
Nighttime	After	0	205	205	0.00%	2.71	0.10
	Before	5	378	383	1.31%		
	Absolute Reduction of Hesitation Rate				1.31%		
	Relative Reduction of Hesitation Rate				***100%***		

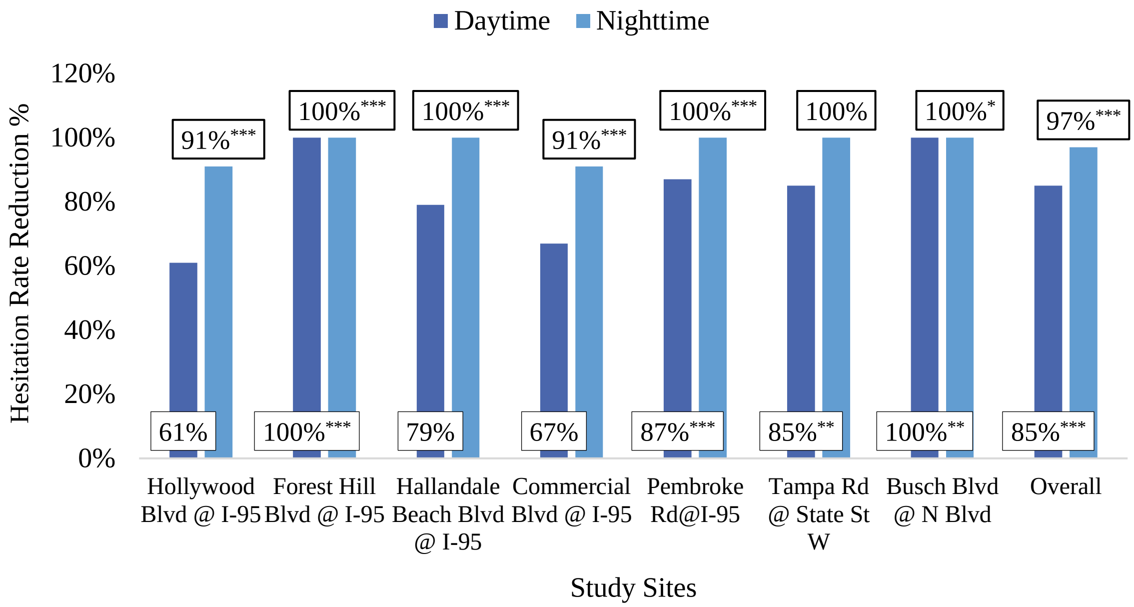
3.9 Overall

Table 3-17 presents the overall before-after comparison of hesitation rates for the countermeasure of replacing continuous right-turn arrows with straight arrows plus guidance information on pavement. The results show that the countermeasure significantly reduced the hesitation rates by 85% and 97%, respectively, in daytime and nighttime at a confidence level of 99.9% for both.

Table 3-17 Before-After Comparison of Hesitation Rates for Pavement Marking Countermeasures

Time	Period	Hesitation	No Hesitation	Total	Hesitation Rate	χ^2	*p*-value
Daytime	After	7	6,116	6,123	0.11%	31.176	<0.001
	Before	75	9,724	9,799	0.77%		
	Absolute Reduction of Hesitation Rate				0.66%		
	Relative Reduction of Hesitation Rate				***85%***		
Nighttime	After	2	3,951	3,953	0.05%	61.264	<0.001
	Before	80	4,701	4,781	1.67%		
	Absolute Reduction of Hesitation Rate				1.62%		
	Relative Reduction of Hesitation Rate				***97%***		

Figure 3-50 shows large reductions of hesitation rates for pavement marking of straight arrow plus guidance information for study sites 2–8. The reductions of hesitation rates were much higher in nighttime than those in daytime. The reduction in hesitation rates in nighttime at each study site after the implementation of the countermeasures was statically significant at a confidence level of 99.9%. The reduction in hesitation rates in daytime at each study site after the implementation of the countermeasures was statically significant at a confidence level of at least 90%, except for two sites with nearby driveways just ahead of the railroad crossings and one site with an existing countermeasure of dynamic envelope.



**90% confidence level; **95% confidence level; ***99% confidence level*

Figure 3-50 Relative reduction of hesitation rates for pavement marking of straight arrow plus guidance information

4 Conclusions and Recommendations

4.1 Conclusions

Incorrect turns at highway-rail grade railroad crossings are serious issues in traffic safety management. According to previous studies, potentially misleading pavement markings and signs upstream of the railroad crossings can cause these issues. This study successfully implemented cost-effective countermeasures aimed at addressing these safety issues and preventing incorrect turns at railroad crossings. The countermeasures include:

- Elimination of potentially misleading arrow pavement markings and signs before railroad crossings
- Implementation of straight arrow pavement markings with guidance information before railroad crossings
- Installation of Qwick Kurb if there is a potential risk of incorrect U-turn at railroad crossings

CUTR closely coordinated with FDOT Districts 1, 4, and 7 to examine the feasibility of the proposed countermeasures and candidate sites for evaluation. Eight highway-rail grade crossings were identified for implementation of the proposed countermeasures and performance evaluation. The CUTR research team developed a detailed deployment and evaluation plan for pilot implementation of selected countermeasures, including candidate sites, proposed countermeasures, estimated costs, data collection plan, and data analysis methodology. With the full support and assistance from FDOT Districts 1, 4, and 7 and the City of Tampa, all proposed countermeasures were successfully implemented at all study sites.

Replacing continuous right-turn or left-turn arrows with straight arrows before at-grade crossings in conjunction with guidance information and the addition of edge lines are low-cost countermeasures to reduce driver confusion in selecting proper turning points as they approach at-grade crossings.

Based on the before-after comparison of hesitation rates, the following conclusions were obtained:

- The replacement of continuous right-turn arrows with straight arrows plus guidance information on the pavement in upstream railroad grade crossings as presented for Sites 2-8 can significantly prevent incorrect right-turns onto railroad tracks.
- The effectiveness of using straight arrows plus guidance information pavement markings on exclusive turning lanes or shared lanes before railroad crossings is more significant at night than that during daytime to prevent incorrect turns of vehicles onto railroad tracks.
- In some scenarios, the reduction in hesitation rates is not statistically significant due to the influence of external factors such as upstream driveways near railroad tracks and the presence of existing countermeasures (dynamic envelope, etc.).
- Overall, the proposed countermeasures can significantly reduce hesitation rates of drivers at at-grade crossings by 85% in daytime and 97% in nighttime at a confidence level of 99.9%.
- The installation of Qwick Kurb can effectively reduce intentional U-turns at railroad crossings.
- There were zero observations of incorrect U-turns after installing Qwick Kurb at Site 1. The 100% reduction of U-turn intention rate in this study is statistically significant at an 87%

confidence level for this countermeasure. The installation of Qwick Kurb can significantly reduce the turning radius, thus reducing the risk of intentional U-turns at railroad crossings.

4.2 Recommendations

The before-after study proved the effectiveness of the proposed countermeasures to prevent incorrect turns onto railroad tracks at at-grade crossings. Based on the study, the following recommendations are provided:

- If an at-grade railroad crossing is located upstream of intersections, ramps, or driveways and the distance is short enough to result in the risk of incorrect turns onto railroad tracks, the following treatments are highly recommended:
  - Remove all traffic control signs and pavement markings that lead to driver confusion on the correct turning point from upstream of the crossing, such as turning signs and turning arrow pavement markings.
  - In the upstream of railroad crossings, implement thermoplastic straight arrows plus guidance information pavement markings on exclusive turning lanes or shared lanes following *Manual on Uniform Traffic Control Devices* (MUTCD) standards (Chapter 3B).
  - Implement elongated route shields to provide guidance information. If route shields are not implementable, text can be used as a low-cost alternative for guidance information.
- If intentional incorrect U-turns are frequently observed at at-grade crossings with wide spaces on both sides of railroad tracks, install Qwick Kurb devices to reduce the turning radius to prevent incorrect U-turns. Implement straight arrow pavement markings in upstream skewed rail-highway crossings if a turn point (intersection, ramp, driveway) is adjacent to the crossing downstream.
- The proposed three countermeasures—(1) elimination of potentially misleading pavement markings and signs before railroad crossings, (2) implementation of straight arrow pavement markings with guidance information before railroad crossings, and (3) installation of Qwick Kurb to prevent intentional U-turns—were proven to be highly effective via this research project to prevent drivers from turning onto railroad tracks near freeway on-ramps or intersections downstream. It is recommended that FDOT implement these countermeasures at needed locations statewide.

References

[1] P.-S. Lin, A. Fabregas, A. Kourtellis, S. Lall, and M. Bato, Improved traffic control measures to prevent incorrect turns at highway-rail grade crossings, National Center for Transit Research (NCTR), 2013.

[2] P.-S. Lin, Z. Wang, V. Abhijit, and S. Deborah, A pilot study for preventing incorrect turns at highway-rail grade crossings, National Center for Transit Research and Florida Department of Transportation, Tampa, 2017.

[3] Federal Highway Administration (FHWA), Part 8: Traffic control for railroad and light rail transit grade crossings, *Manual on Uniform Traffic Control Devices (MUTCD)*, Washington DC, 2012.

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