Final Report

Assessment of Highway-Railroad Grade Crossing Strategies, Countermeasures, and Technologies to Improve Traffic Safety and Mobility in Florida

Final Report

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Edith Wong, P.E. (PM)

Prepared by:

CUTR

USF Center for Urban Transportation Research
Pei-Sung Lin, Ph.D., P.E., PTOE, FITE (PI)
Zhenyu Wang, Ph.D. (Co-PI)
Rama Durga Tammayya Naidu Kolla
Elzbieta Bialkowska-Jelinska, GISP

FIU | FLORIDA INTERNATIONAL UNIVERSITY

Florida International University
Priyanka Alluri, Ph.D., P.E., RSP_{2BI} (Co-PI)
Mostafa Soltaninejad

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CUTR CENTER FOR URBAN TRANSPORTATION RESEARCH

USF UNIVERSITY OF SOUTH FLORIDA

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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

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
		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		
		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")
		TEMPERATURE (exact degrees)		
ºF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	ºC

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16. Abstract

Highway-rail grade crossings (HRGCs) are conflict areas for trains and road users, which present a significant safety concern in Florida. The HRGCs not only affect safety but also have a significant impact on traffic operations. FDOT explored several strategies to improve safety and mobility related to railroad grade crossings, including signage, pavement markings, quadrant gates, and traffic signal preemptions and pre-preemptions, several of which have been implemented by various FDOT districts. This research effort aimed to identify and evaluate traditional countermeasures, Transportation Systems Management and Operations (TSM&O) strategies and ITS technologies, and provide findings and recommendations to improve safety and mobility at HRGCs in Florida. The specific objectives were to: (1) understand safety issues and factors contributing to fatalities and serious crashes at HRGCs; (2) assess the implementation of RDE pavement markings and associated signs at state-owned HRGCs in Florida; (3) investigate the effectiveness of various traditional countermeasures, TSM&O strategies, and ITS technologies to improve safety and mobility at HRGCs; (4) examine and provide a list of HRGCs needed for special treatments and recommend treatments; and (5) provide best practices, analysis results, research findings, and recommendations to FDOT to effectively improve safety and mobility at HRGCs in Florida. The research team conducted four major research tasks, including (1) a comprehensive literature review, (2) detailed HRGC crash analysis,(3) statewide agency interviews, and (4) field visits of HRGCs with high priorities for improvement. By summarizing the research findings from the four tasks, the research team produced project outcomes, including identified contributing factors, effective traditional countermeasures, ITS and TSM&O strategies, technologies, best practices, prioritized specific treatments, and recommendations to improve safety and mobility at Florida HRGCs. The results show that HRGCs in Florida experience four major safety and mobility challenges: (1) vehicles frequently stopped on tracks, (2) wrong turns onto railroad tracks, (3) motorist driving behaviors to “beat” a train or go around lowered gates, and (4) pedestrian trespassing behaviors at and near HRGC locations. To address the challenges, the research team developed recommendations to improve safety and mobility of HRGCs, including traditional countermeasures, ITS and TSM&O strategies, and emerging technologies. The assessment and recommendations for the Florida Operation STRIDE (Statewide Traffic and Railroad Initiative using Dynamic Envelopes) implementation were also provided.

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Executive Summary

Background

Based on Signal Four Analytics data, the 4,500 at-grade highway-rail grade crossings (HRGCs) in Florida experience over 350 crashes and over a dozen fatal and severe injury crashes yearly. HRGCs are conflict areas for trains and road users, which present a significant safety concern in Florida. Vehicles stopping in Rail Dynamic Envelope (RDE) zones constituted 47% of train-vehicle crashes at HRGCs. The HRGCs not only affect safety, but also have a significant impact on traffic operations. These locations also cause increased delays, queue spillbacks at adjacent intersections, and adverse environmental impacts. The Florida Department of Transportation (FDOT) is committed to the safety and mobility of all roadway users.

FDOT explored several strategies to improve safety and mobility related to railroad grade crossings, including signage, pavement markings, quadrant gates, and traffic signal preemptions and pre-preemptions, several of which have been implemented by various FDOT districts. To improve the safety performance of HRGCs and prevent train-vehicle fatalities and injuries at these locations, the FDOT Central Office launched Florida Operation STRIDE (Statewide Traffic and Railroad Initiative using Dynamic Envelopes) in 2019. This initiative is FDOT's commitment and action to improve safety and mobility at HRGCs in Florida. This research project is needed to assess the implementation results from STRIDE and assist FDOT in identifying implementation issues, success stories, best practices, and lessons learned from current deployments to improve and support future deployments.

The results of this research project are essential to support FDOT to understand the benefits of key traditional countermeasures, provide recommendations of effective Transportation Systems Management and Operations (TSM&O) strategies and Intelligent Transportation Systems (ITS) technologies, and explore emerging technologies (i.e., artificial intelligence). This knowledge is critical to FDOT to implement effective treatments for improving safety and mobility at HRGCs in Florida.

Research Objectives

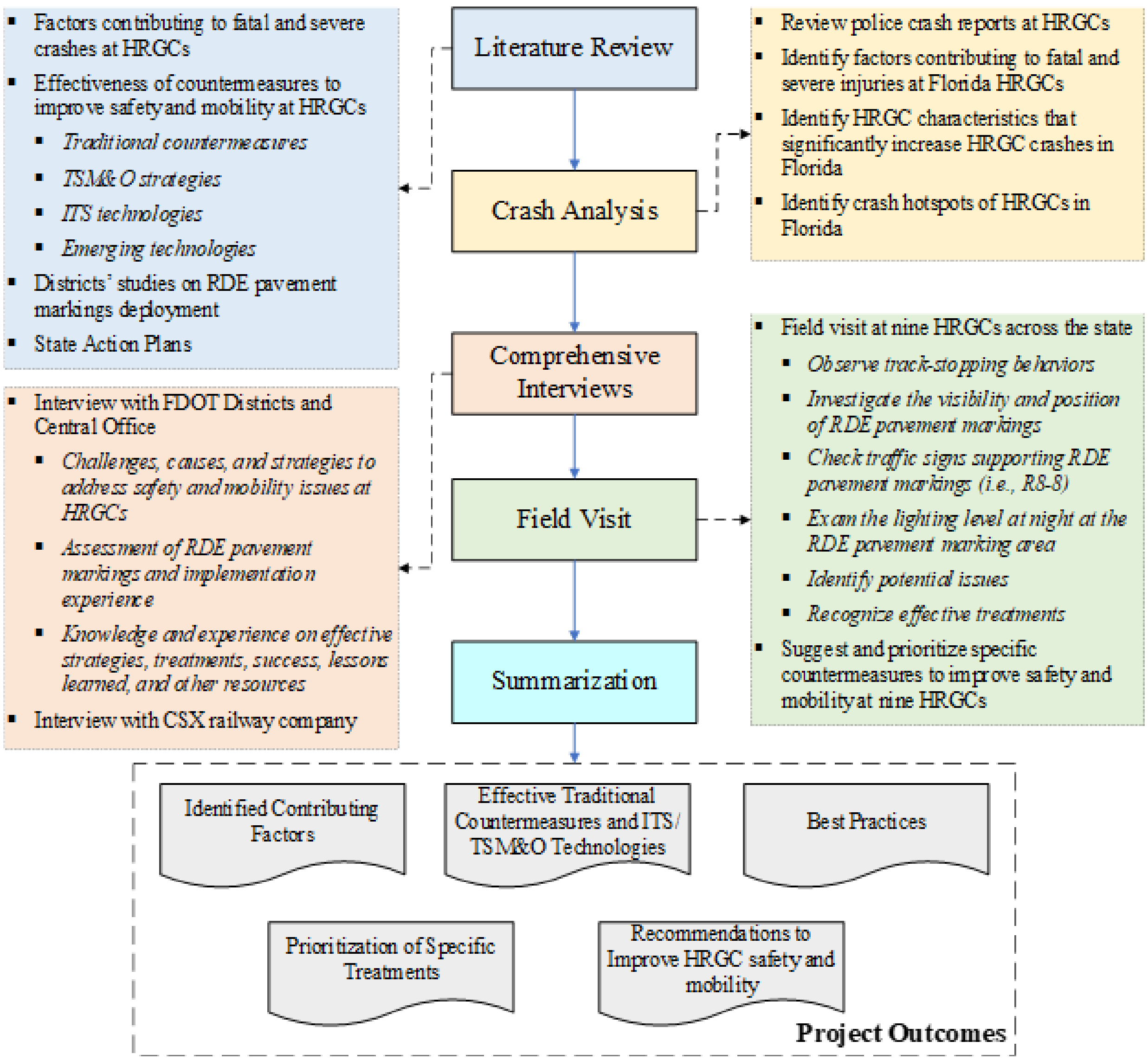
The goal of this research effort was to identify, evaluate, and recommend TSM&O strategies, traditional countermeasures, and ITS technologies to improve safety and mobility at HRGCs in Florida. The specific objectives include:

- Understand safety issues and factors contributing to fatalities and serious crashes at HRGCs.
- Assess the implementation of RDE pavement markings and associated signs at State-owned HRGCs in Florida.
- Investigate the effectiveness of various traditional countermeasures, TSM&O strategies, and ITS technologies to improve safety and mobility at HRGCs.
- Examine and provide a list of HRGCs needed for special treatments and recommend treatments.

- Provide best practices, analysis results, research findings, and recommendations to FDOT to effectively improve safety and mobility at HRGCs in Florida.

Methodology

The research team conducted the following tasks to achieve the research objectives, as shown in the figure below. The major tasks include a literature review, crash analysis, comprehensive interviews, and field visits. By summarizing the research findings from the four tasks, the research team was able to produce project outcomes, including identified contributing factors, effective traditional countermeasures, effective ITS and TSM&O technologies, best practices, prioritized specific treatments, and recommendations to improve safety and mobility at Florida HRGCs.



Research Approaches and Project Outcomes

Major Findings

The major research findings are presented below:

Contributing Factors

HRGC crashes, which occur when a vehicle, pedestrian, or bicyclist collides with a train at a level grade crossing, can result from a combination of factors. These factors generally involve a mix of human factors, infrastructure design, and operational issues. To prevent HRGC crashes or mitigate crash risks, it is necessary to learn the key contributing factors, as summarized in the table below.

Contributing Factors to Crash Risks at HRGCs in Florida

Category	Factors
Human Factor	**Failure to obey traffic control devices**: Drivers, bicyclists, and pedestrians may ignore warning signals, signs, gates, and barriers at crossings.
	High-risk appetite: Risky drivers, bicyclists, and pedestrians may attempt to beat approaching trains by crossing the tracks even when a train is visible or audible, especially when they are in a hurry.
	Distraction: Use of mobile phones, in-vehicle entertainment systems, eating, walking, or bicycling with earbuds on, or other distractions can divert the attention of road users from warning traffic control devices.
	Impairment: Alcohol or drug impairment can impair the judgment and reaction time of a road user.
Train Characteristics	**Train speed:** High-speed trains may result in reduced reaction time for both road users and train operators.
	Visibility and audibility: Poor lighting or a quiet zone can make it harder for road users to see and perceive an approaching train.
Rail Crossing Characteristics and Roadway Conditions	**Skewed or crossing sight distance problem:** Both skewed HRGCs or crossings with sight distance problems can reduce road users' ability to see an approaching train.
	Crossing with multiple tracks: It increases the chance of drivers stopping on tracks during traffic queue backup from downstream signalized intersections.
	Short distance between a crossing and downstream intersection or freeway on-ramps: Drivers could potentially mistake the opening of HRGCs as the road or freeway on-ramp they desire to turn on and make incorrect turns onto the railroad tracks.
	Grade crossing surface conditions: Uneven, rough, or deteriorated surfaces at grade crossings can cause discomfort and potential hazards for vehicles, especially at higher speeds.
Environmental Conditions	**Environmental factors:** Weather, season, temperature, and time of day, could affect the visibility of roadways and reaction time of drivers, and drivers may not be able to clearly identify the turning point to make correct turns.

Effective Traditional Treatments

Traditional treatments include various active and passive treatments, such as geometry treatments, pavement markings, signage, flashing lights, and rail control devices. Even though there are a variety of traditional treatments that improve the safety and mobility at HRGCs, there is no one-size-fits-all solution. The application of traditional treatments depends on specific scenarios and locations. The commonly used traditional treatments are summarized in the table below.

Traditional Treatments to Improve Safety and Mobility at HRGCs in Florida

Treatment	Key Points
RDE Pavement Markings	• The treatment overall decreases the dangerous stopping behaviors at HRGCs. • Various factors may influence its performance: - *RDE color and shape may mislead some road users.* - *Installation of RDE pavement markings at unnecessary locations could decrease the effectiveness of RDE.* - *Skewed crossings make it difficult for drivers to notice tracks.* - *Need to educate the public on awareness of RDE pavement markings.* - *Need maintenance on RDE pavement markings after installation is required.* - *Residents near crossings are desensitized to the dangers of the HRGCs.* - *Too many implementations of RDE pavement markings might compromise the significance of the treatment.*
Signing and Pavement Markings	• Remove potentially confusing traffic signs just upstream of HRGCs, such as “Right Lane Must Turn Right” sign. • Remove potentially confusing pavement markings just upstream of HRGCs, such as right-turn arrow pavement marking. • Change right-turn arrow pavement markings to straight-arrow pavement markings with guidance information on right-turn lane(s) before HRGCs. • Install Qwick Kurb to shorten an opening of railroad crossings to avoid intended U-turns. • Conform to MUTCD guidelines to foster uniformity and promote safe and efficient traffic operations.
Four-quadrant Gates	• Install four-quadrant gates on roadways without medians to seal the road and prevent people from going around the gates. • Four-quadrant gates should be installed at HRGCs satisfying the following criteria: - *quiet zones,* - *the public continues to ignore the flashing lights and gates,* - *in close proximity to a side street or driveway.* • The effectiveness of four-quadrant gates depends on location. • High maintenance cost is a challenge.

Traditional Treatments to Improve Safety and Mobility at HRGCs in Florida (Continued)

Treatment	Key Points
Delineators	• Delineators guide traffic flow and ensure that vehicles approach the crossing at the correct angle and refrain from stopping or parking on the tracks. • Delineators are effective in preventing wrong turns on tracks. • Avoid any red color on a delineator to prevent train engineers from incorrectly stopping when they see red. • It is good to install delineators anytime an intersection, side street or a freeway on-ramp comes within about 100-200 feet of a grade crossing. • Delineators are frequently hit; the roadway agency is constantly having to work with the railroad agency to maintain the delineators.
Fencing	• Fences are commonly installed alongside railway tracks to discourage unauthorized entry and trespassing onto the tracks or railroad right-of-way. • Fencing can be a good option at certain locations. • Fencing can prevent pedestrians from entering the railroad right-of-way but can also trap pedestrians within the right-of-way. • Zigzag fences can help prevent pedestrians and cyclists from crossing without looking. The Zigzag fence will force them to look in both directions. • It is difficult to use public funding to install fences on railroad (private) properties.
Geometry Treatment	• Geometry treatments pertain to altering a roadway or intersection's physical configuration or design and make it feasible to tackle prevailing issues and potentially even close off troublesome road sections, thereby enhancing safety and traffic flow at HRGCs.
Education	• Education increases awareness among motorists, pedestrians, and the general public regarding the hazards associated with such crossings and the appropriate steps to undertake when approaching or crossing them. • Educational endeavors may include various activities such as public awareness campaigns, specialized training programs for drivers, dissemination of informative materials, and engagement with the community.
Enforcement	• Promote active enforcement of traffic laws related to HRGCs and railroad right-of-way. • Partner with state and local law enforcement agencies, including the Florida Highway Patrol, sheriffs, and police chiefs to help enforce rail safety laws. • Develop a program to train local law enforcement and local governments on implementing effective and responsive strategies using technologies to enforce traffic laws related to HRGCs and railroad right of way. • Identify funding opportunities for local law enforcement and community stakeholders to respond to trespassing issues at HRGCs. • Apply technologies to support law enforcement at HRGCs.

Effective ITS and TSM&O Technologies

Several Intelligent Transportation Systems (ITS) applications and Transportation Systems Management and Operations (TSM&O) strategies exist to enhance safety and mobility at HRGCs. These countermeasures comprise innovative technologies, including advanced traffic signal strategies, advanced sensors, information dissemination mechanisms, and artificial intelligence (AI)-driven vehicle/pedestrian detection systems. The primary ITS interventions identified through the literature review and the interviews are outlined below.

ITS and TSM&O Treatments to Improve Safety and Mobility at HRGCs in Florida

Treatment	Key Points
Preemption and Pre-preemption	• Preemption is used to apply a special traffic signal phase sequence and timing to allow motorists to move away from the track prior to the arrival of the train and to restrict movements towards the track. • Pre-preemption is a preemption which can be implemented before or after a regular preemption to clear potential long traffic queues formed either before or after regular rail traffic signal preemption. • Preemption has been widely implemented at crossings within 200 feet of a traffic signal. • Pre-preemption needs to start 1-2 minutes before the arrival of the trains at a HRGC from railroad companies or roadside train detectors for a successful implementation.
Advanced Sensor Technologies	• Automated vehicle detection systems that incorporate both cameras and sensors. • Wireless detectors that can detect trains, compute their speeds, and provide an estimate of their length. • Automated violation warning systems to warn road users. • Automated violation data collection, verification by law enforcement, and issue of citations to violators after the verification to significantly reduce violations. • Advanced detection sensors to identify queues that form as a train passes a rail crossing. • Advanced train detection systems to detect and estimate the train arrival time at an HRGC for implementing traffic signal pre-preemption 1-2 minutes before the arrival of the trains to reduce traffic queue near the HRGC and nearby signalized intersections.
Other Advanced Technologies	• **Dynamic message signs (DMS)** that convey warning messages to road users based on the information provided by advanced detection systems on vehicles, pedestrians, and trains, heightening their awareness of trains and encouraging safer behaviors. • **Mobile applications** that integrate notifications into popular mobile mapping applications such as Google Maps and Waze. These notifications would serve to alert the general public about the potential presence of approaching trains at specific HRGCs. • **Positive Train Control (PTC) systems** installed on trains that can help monitor train movements, speed, and status, and automatically take actions to prevent collisions, and can be integrated with grade crossing equipment, allowing for the preemption of traffic signals and activation of warning devices when a train is approaching.

Best Practices

The best practices presented in the reviewed ten State Action Plans (SAPs) include:

- Identifying high-risk situations, such as Amtrak – passenger railroad service – and school bus operations to increase publicity and awareness,
- Emphasizing grade crossing closures and separation strategies,
- Considering pedestrian-pathway-rail crossings, and
- Using Railroad-Highway Crossing Inventory (RHCI) and Safety Index Tool to support programs and conduct analysis for identifying crossings with higher risk and safety challenges.

It should be noted that states are eagerly anticipating the implementation of advanced technology solutions to proactively prevent crashes and minimize delays within critical areas or their proximity. This proactive approach considers the safety and mobility measures already in place.

The success stories and lessons learned from the best practices are summarized below.

Successful Stories in Practices for Improving Safety and Mobility at HRGCs

Case	Key Points
Implementation of Delineators and Pavement Arrows in Newark, Delaware	• This initiative involved a combination of strategies, including pavement markings, guiding arrows for motorists to proceed directly through the crossing, and the deployment of flexible bollards. • Pavement markings and arrows were employed to guide motorists through the crossing in a straight path. • Flexible bollards were strategically positioned to enhance safety. • Delineators were also placed on the shoulder in this location to minimize the likelihood of collisions.
Florida's Statewide Traffic and Railroad Initiative Using Dynamic Envelopes (STRIDE)	• FDOT Central Office launched Florida Operation STRIDE to keep motorists out of danger zones near railroad crossings using RDEs. • Most FDOT Districts agreed on the effectiveness of the RDE treatment. • FDOT Central Office documented a 15% decrease in incidents where drivers became stranded on tracks or encroached upon them.
Replacing Misleading Pavement Markings to Prevent Incorrect Turns at HRGCs in Florida	• A pilot project was conducted at eight study sites in Florida to evaluate low-cost countermeasures. • Elimination of potentially misleading pavement markings and signs before railroad crossings. • Implementation of straight arrow pavement markings with guidance information before railroad crossings. • The treatment effectively prevents incorrect turns onto railroad tracks, and the effectiveness is more significant at night.

Successful Stories in Practices for Improving Safety and Mobility at HRGCs (Continued)

Case	Key Points
Other success stories	• Cooperation with a railroad company on two signal safety projects in Avon Park. • Successful collaboration between FDOT and the railroad companies on "Low-Cost Programs" where FDOT provides equipment if the railroad provides the labor. • Education in multiple languages was found to be a successful strategy in Be Rail Smart. • The High Visibility Enforcement Grants in the City of Hollywood (District 4) were found to improve driving behaviors. • The FRA Section 130 Federal Signal Safety Funding program was found to be successful.

Lessons Learned in Practices for Improving Safety and Mobility at HRGCs

Case	Key Points
Engineering solutions are not enough to address HRGC safety and mobility issues	• Most treatments at HRGCs in Florida focused on engineering solutions with limited educational efforts and enforcement likely due to insufficient funding and workforce for education and enforcement. • More education efforts are needed to increase awareness among motorists, pedestrians, and the general public regarding the hazards associated with HRGCs, along with the appropriate steps to undertake when approaching or crossing HRGCs. • Law enforcement warnings and citations for HRGC violations should follow and sustain to build safety culture at HRGCs as well as other transportation roadway facilities.
RDE may not be necessary at all HRGCs	• While establishing safe stopping areas for a HRGC is imperative, the implementation of dynamic envelopes might not always be feasible or needed. • Implementation suggestions: frequent violations were observed at HRGCs located at urban or urban arterials with multiple rail tracks when the traffic queue was backed up from the nearby downstream signalized intersections. • Determining the appropriate RDE design for a grade crossing mandates consideration of various factors, including road configuration, traffic flow patterns, and the available physical space.
Google or satellite imagery may not provide a comprehensive understanding	• These tools may not encompass all facets of the crossing, omitting crucial factors like nearby structures, vegetation, or the actual visibility angles accessible to drivers. • Conducting an on-site diagnostic review of a HRGCs with safety or mobility issues is indispensable to ensure a precise and thorough evaluation.

Lessons Learned in Practices for Improving Safety and Mobility at HRGCs (Continued)

Case	Key Points
Recurring diagnostic review of each crossing with high priority is crucial	• Regular and recurring diagnostic reviews are imperative to continuously monitor the condition of the crossings, account for alterations in traffic flows or infrastructure, and identify potential hazards. • By employing this proactive approach, ongoing safety can be maintained, and potential risks can be promptly addressed.
Other Lessons	• Close communication and collaboration with railroad companies is crucial. • In areas where the crossing is skewed, reflective delineators, in addition to the RDE, should be installed to better let drivers know the roadway location. • The visibility of R8-8 signs (Do Not Stop on Tracks) is a potential issue. The countermeasures to increase the detectability of R8-8 signs by drivers include attaching flashing beacons/lights to the signs, avoiding other signs blocking the sign, installing R8-8 signs on medians on multilane roads, and trimming tree branches.

Special Treatments

Through document review, field visit, and interview with FDOT districts, the research team identified the major safety and mobility issues at nine study sites. This study developed recommendations of special treatments to address the identified issues at the study sites, including a priority order of locations that should receive countermeasures and the type of countermeasures. The recommended specific treatments are outlined below.

Recommended Specific Treatments at Selected Study Sites

Countermeasures	Sites	Factors
Provide education and outreach programs to teach drivers to understand and comply with RDE pavement markings. Conduct law enforcement to reduce blockages of HRFGCs	• Site 1: US-41@SR-55, Bradenton, D1 • Site 3: SR-389 @ N East Ave, Panama City, D3 • Site 4: SR7-7 @ SR-10, Panama City, D3 • Site 5: W Cypress Creek @ N Andrews Ave, Fort Lauderdale, D4 • Site 6: Sheridan St @ N Dixie Hwy, Hollywood, D4 • Site 8: SR-922 @ NE 14th Ave, North Miami, D6 • Site 9: Busch Blvd@ Nebraska Ave, Tampa, D7	• These sites are observed to have incorrect stopping behaviors on rail tracks (Zone 3) in field visiting, or • An increased stopping rate at Zone 3 in districts' before-after studies. • Site 9 has significant stopping behaviors in Zones 3 and 4 on the exclusive right-turn lane.

Recommended Specific Treatments at Selected Study Sites (Continued)

Countermeasures	Sites	Factors
Relocate R8-8 Sign ("DO NOT STOP ON TRACKS")	• Site 1: US-41@SR-55, Bradenton, D1 • Site 8: SR-922 @ NE 14th Ave, North Miami, D6 • Site 9: Busch Blvd@ Nebraska Ave, Tampa, D7	• R8-8 Signs are blocked by other signs. • Relocating R8-8 signs is a low-cost countermeasure.
Add R8-8 sign at median	• Site 1: US-41@SR-55, Bradenton, D1	• Low-cost countermeasure
Attach RFB/LED lights to R8-8	• Site 1: US-41@SR-55, Bradenton, D1 • Site 3: SR-389 @ N East Ave, Panama City, D3 • Site 4: SR-77 @ SR-10, Panama City, D3 • Site 8: SR-922 @ NE 14th Ave, North Miami, D6 • Site 9: Busch Blvd@ Nebraska Ave, Tampa, D7	• Increase visibility of R8-8 to drivers. • These sites have significant incorrect stopping behaviors after the implementation of RDE pavement markings.
Replace right arrows with straight arrows and add guidance text information prior to the crossing	• US-17 @ Timuquana Rd., Jacksonville, D2 • Site 3: SR-389 @ N East Ave, Panama City, D3 • Site 4: SR-77 @ SR-10, Panama City, D3	• Prevent incorrect turns onto tracks. • A low-cost countermeasure.
Move Stop Bar of the downstream intersection back before the crossing	• US-17 @ Timuquana Rd., Jacksonville, D2	• No sufficient space between the stop bar of downstream intersection and rail tracks. • A low-cost countermeasure.

Recommendations

According to the research findings and results, Florida HRGCs experience four major safety and mobility challenges: (1) vehicles frequently stopped on tracks, (2) wrong turns onto railroad tracks, (3) motorist driving behaviors to "beat" a train or go around lowered gates, and (4) pedestrian trespassing behaviors at and near HRGC locations. To address the challenges, the following primary recommendations are provided:

Future Deployment of RDE Pavement Marking

The following recommendations are suggested to improve the effectiveness of RDE pavement markings in future deployment.

- A state-wide follow-up study should be conducted to address the long-term effectiveness of RDE pavement markings and identify the scenarios that RDE pavement markings are effective.
- Selectively deploy RDEs at HRGCs with the effective scenarios.
- Conduct more railroad safety education outreach to the public and to the law enforcement at those HRGCs with frequent violations.
- Apply technologies to provide automated violation warnings at HRGCs, and support law enforcement for issuing warnings and citations to violators.
- Conduct a pilot study to investigate the effectiveness of RDE Pavement Marking with Yellow Background to increase the visibility of rail crossings at multiple sites, especially at skewed HRGCs.

Strategies and Engineering Treatments to Improve Safety and Mobility at HRGCs

The recommended traditional engineering treatments to improve safety and mobility at HRGCs include:

- Installing four-quadrant gates if HRGCs are close to a side street or driveway, without a median to create a gap, within quiet zones, or the public continues to ignore the flashing lights and gates.
- Installing delineators if HRGCs have visibility issues, with large drop-offs, a side street within about 100-200 feet of the HRGC, or skewed design.
- Removing channelized right turn lane within an HRGC if it closes to the downstream signalized intersection with Right-Turn-On-Red operations.
- Eliminating or reducing a sudden drop of pavement of roadway edge at railroad tracks.
- Converting a signalized intersection near an HRGC to a roundabout if the HRGC has frequent queue backup onto tracks. A pilot study is needed.
- Enhancing crossings' condition and smoothing surface at HRGCs to make it safer and prevent vehicles from getting stuck on the railroad tracks.
- Replacing turning arrow markings on exclusive turning lanes before HRGCs with straight arrow pavement markings with guidance information including route and its direction.
- Moving the stop bar at the downstream signalized intersection of an HRGC to the location before the HRGC if the space between tracks and the downstream stop bar is too short to contain a vehicle safely.
- Removing potentially misleading traffic signs “RIGHT LANE MUST TURN RIGHT” before HRGCs and relocating “DO NOT STOP ON TRACKS” signs and “NO TRESPASSING” signs if blocked by other signs and making them conspicuous to the drivers and pedestrians.

- Adding flashing beacon or LED lights to increase the visibility of R8-8 signs ("DO NOT STOP ON TRACKS").
- Adding pedestrian gate and fencing at HRGCs with frequent pedestrian trespassing activities.

The recommended ITS and TSM&O applications to improve safety and mobility at HRGCs are summarized below:

- Implementing traffic signal pre-preemption at a HRGC close to a downstream signalized intersection with frequent traffic congestions, queues, or blockage before or after a regular preemption.
- Installing dynamic message signs to provide real-time information to drivers about train movements and the status of the crossing at HRGCs on major arterials with heavy traffic or high crash risk.
- Provide early warnings via audible and visual alerts at HRGCs on major arterials with heavy traffic or high crash risk.
- Implementing video surveillance systems to detect potential safety hazards at HRGCs with high incident risk and frequent pedestrian trespassing activities.
- Implementing automated violation warning systems to detect and provide warning to violators (drivers or pedestrians) automatically via alarms and/or signals at HRGCs with frequent violations of vehicle or pedestrian crossing tracks.
- Implementing incident management systems to quickly respond to crashes or other incidents at HRGCs, reducing the risk of secondary incidents and improving overall safety.

The recommended emerging technologies to improve safety and mobility at HRGCs are summarized below:

- FDOT districts have a limited implementation of emerging technologies at HRGCs. It is recommended by district rail representatives that FDOT Central Office continues to take the lead on emerging technology pilot testing or pilot deployment, and FDOT districts will support and test novel technologies.
- Railroad companies evaluated more emerging technologies. For example, Brightline has implemented a violation warning system pilot project at Northeast 141st Street and Biscayne Blvd., where they have installed cameras and sent warnings to people who went around the gates or stopped on the tracks. These warnings were sent via mail, but they cannot send any fines.
- Pilot testing of CV technology and AI-based detection and inspection technologies are underway. Most research projects are sponsored by the FRA.

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List of Abbreviations and Acronyms

AI	Artificial intelligence
CUTR	Center for Urban Transportation Research
AV	Automated vehicle
CV	Connected Vehicle
EPDO	Equivalent property damage only
FAST	Fixing America's Surface Transportation
FDOT	Florida Department of Transportation
FIU	Florida International University
FRA	Federal Railroad Administration
GIS	Geographic Information System
GPS	Global Positioning System
HRGC	Highway-Rail Grade Crossing
i-CATSS	Intelligent Crossing Assessment and Traffic Sharing System
IIJ	Infrastructure investment and jobs
ITS	Intelligent Transportation Systems
IVAA	In-vehicle auditory alert
LED	Light-Emitting diode
MUTCD	Manual on Uniform Traffic Control Devices
PDO	Property Damage Only
RCVW	Rail crossing violation warning
RDE	Rail dynamic envelope
RSIA08	Rail Safety Improvement Act of 2008
SAPs	State action plan
STRIDE	Statewide Traffic and Railroad Initiative Using Dynamic Envelopes
TSM&O	Transportation Systems Management and Operations
USF	University of South Florida

1 Introduction

This chapter briefly introduces the overview of the project, including project background, research objectives, and report organization.

1.1 Background

The 4,500 at-grade highway-rail grade crossings (HRGCs) in Florida are experiencing over 350 crashes and over a dozen fatal and serious injury crashes every year based on the data from Signal Four Analytics. HRGCs are conflict areas for trains and railroad users and present a major safety concern in Florida. The at-grade HRGCs not only affect safety, but have a significant impact on traffic operations. Data from the Federal Railroad Administration (FRA) showed an increase in HRGC crashes in Florida between 2015 and 2019. According to that data, in 2018 and 2019, the average annual number of fatalities was 17, injuries were 35, and property damage only (PDO) crashes were 65. Vehicles stopping in rail dynamic envelope (RDE) zones constituted 47% of train-vehicle crashes at HRGCs. These locations also cause increased delays, queue spillbacks at adjacent intersections, and adverse environmental impacts. The Florida Department of Transportation (FDOT) is committed to the safety and mobility of all roadway users.

Several strategies were explored by FDOT to improve safety and mobility related to railroad grade crossings, including signage, pavement markings, quadrant gates, and traffic signal preemptions and pre-preemptions, several of which have been implemented by various FDOT Districts. To improve the safety performance of HRGCs and prevent train-vehicle fatalities and injuries at these locations, the FDOT Central Office launched Florida Operation STRIDE (Statewide Traffic and Railroad Initiative using Dynamic Envelopes) in 2019. This initiative is FDOT’s commitment and action to improve the safety and mobility at HRGCs in Florida and comprises engineering treatment of RDE pavement markings and signs at state-owned highway rail-grade crossings in Florida to help keep motorists out of danger zones near railroad crossings. Preliminary results showed an overall reduction in vehicles stopped in dangerous RDE zones.

There are excellent opportunities for FDOT to improve safety and reduce congestion near and at HRGCs to save lives, reduce injuries, and lower vehicle delays in Florida. FDOT has invested significant resources and efforts via STRIDE to implement RDE pavement markings and associated signs at state-owned HRGCs. A detailed research project is needed to assess the overall implementation results from STRIDE. The research project can assist FDOT in identifying implementation issues, success stories, best practices, and lessons learned from current deployments to improve and support future deployments. For example, an earlier study in FDOT District 7 recommended that avoiding right-turn channelization within RDE areas can reduce the chance of drivers stopping in an RDE zone. Improving nighttime visibility of RDE pavement markings to motorists can increase the chance of drivers stopping in a safe zone and reduce stopping in dangerous zones.

The effectiveness and benefits of various traditional countermeasures, transportation systems management and operations (TSM&O) strategies, and Intelligent Transportation Systems (ITS) technologies to improve safety and mobility at HRGCs need to be studied to further explore new and promising active and passive technologies to mitigate fatalities and injuries at HRGCs.

1.2 Research Objectives

The goal of this research effort is to identify, evaluate, and recommend TSM&O strategies, traditional countermeasures, and ITS technologies to improve safety and mobility at HRGCs in Florida. The specific objectives include:

- Understand safety issues and factors contributing to fatalities and serious crashes at HRGCs.
- Assess the implementation of RDE pavement markings and associated signs at State-owned HRGCs in Florida.
- Investigate the effectiveness of various traditional countermeasures, TSM&O strategies, and ITS technologies to improve safety and mobility at HRGCs.
- Examine and provide a list of HRGCs needed for special treatments and recommend treatments.
- Provide best practices, analysis results, research findings, and recommendations to FDOT to effectively improve safety and mobility at HRGCs in Florida.

1.3 Report Organization

Chapter 1 introduces the project background and research objectives; Chapter 2 summarizes the literature review results, including highway rail at-grade crossing control devices, state action plans, contributing factors to HRGC safety and mobility, and treatments to improve HRGC safety and mobility; followed by Chapter 3 that describes the review of Rail Dynamic Envelopment (RDE) pavement markings in Florida. Chapter 4 presents the results of HRGC safety assessment in Florida, including crash analyses and document review. The interviews with stakeholders and field visits are summarized in Chapters 5 and 6, respectively. Chapter 7 documents major research findings and provides recommendations to FDOT to address safety and mobility issues at HRGCs in Florida.

2 Literature Review

This chapter summarizes the literature review results, including highway rail at-grade crossing control devices, state action plans, contributing factors to HRGC safety and mobility, and treatments to improve HRGC safety and mobility.

2.1 Highway Rail Grade Crossing Control Devices

From a safety standpoint, the main concern of HRGC crashes is their severity. Traffic control devices, passive and active, help improve safety at HRGCs by reducing the frequency and severity of traffic crashes.

2.1.1 Passive Devices

Passive signs are the most common method of control. While railroad crossings provide different levels of passive warnings, including stop signs and four-quadrant gates, the most common low-cost passive control methods include signs and markings (*1*). These options could be used at upstream and critical zones (i.e., close or at railroad crossing areas). Based on rail and road users' traffic flow and safety needs during the day and night, other devices may be installed at HRGCs. These include object markers, delineation devices, speed reduction devices, vehicle-activated strobe lights, sidewalk gates, and bollards (as medians and side barriers) (*2*).

2.1.1.1 Signs

Figure 2-1 shows examples of passive warning and guide signs at HRGCs that could be used on low-volume roads. Advance warning signs (w10-1), grade crossing (crossbuck) signs (R15-1), stop signs (R1-1), and yield signs (R1-2) are the most commonly used signs at railroad crossings. Guide signs could include street name signs or interstate signs. Direction signs also could be utilized as advance warning signs since they let road users know that there is a railroad track downstream.

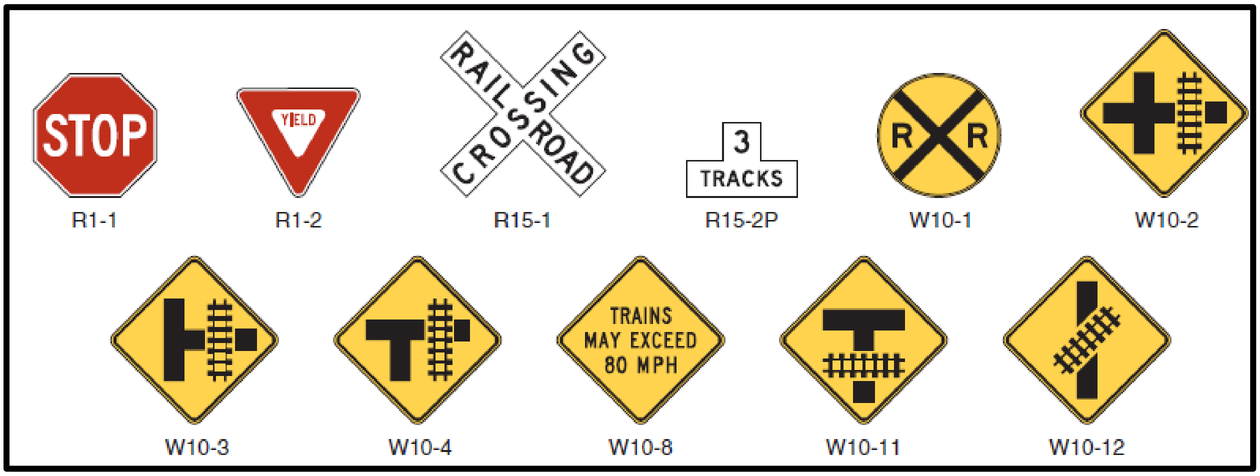


Figure 2-1. HRGC Signs and Plaques for Low-Volume Roads (*3*)

2.1.1.2 Pavement Marking

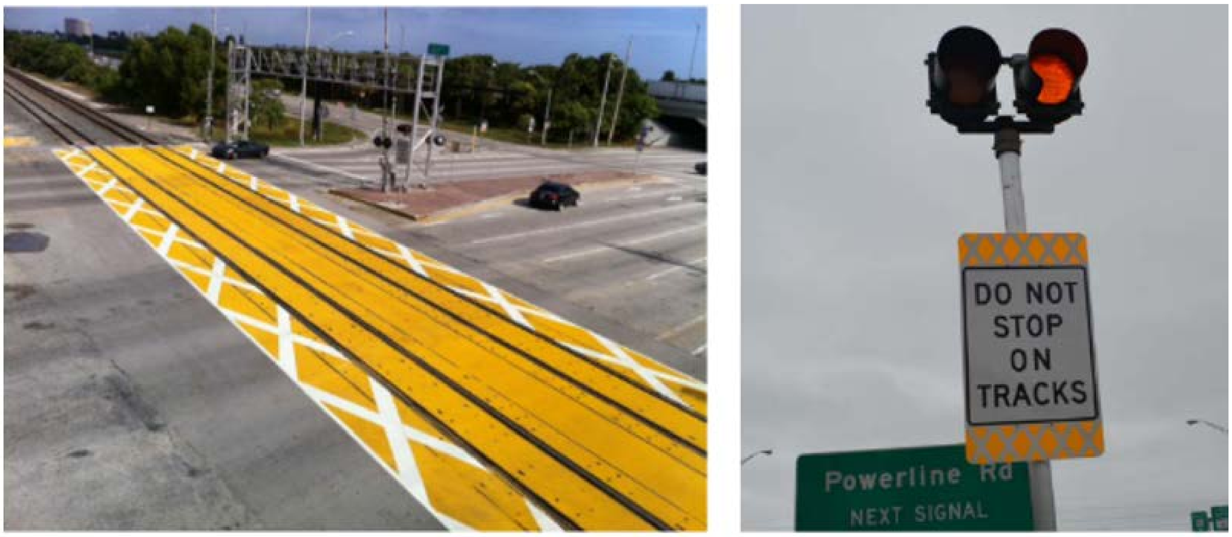
As shown in Figure 2-2, pavement markings provide advance indications and aim to prevent confusion so that the number of improper turns can be effectively diminished at HRGC tracks. Pavement markings aim to: (a) convey to drivers where to place their vehicles, (b) inform drivers about upcoming situations, and (c) specify where passing is allowed (*4*).

Figure 2-2. Pavement Marking Upstream of a Railroad Crossing
(Source: Google Maps)

2.1.1.3 Rail Dynamic Envelope (RDE)

Figure 2-3 illustrates an example of an RDE zone and its modified signage. The RDE is a section near railroad crossings that aims to keep motorists out of the danger zone. The total distance for the RDE is a minimum of 10 feet on either side of the railroad (*5*). RDEs are considered to be effective in improving safety and mobility at HRGCs. More specifically, preventing right-turn channelization within RDE areas can reduce the likelihood of drivers stopping in RDE zones. Also, improving the nighttime visibility of RDE markings could result in fewer vehicle stoppings in unsafe zones. While the results revealed that RDE markings and revised signage might help improve safe behavior, they did not reduce the number of vehicles stuck inside the gates during activation (*6*). Seemingly, regulatory and warning signs at RDE zones may be insufficient; thus, other tools, such as flashing lights/bells and in-vehicle auditory warnings, could be implemented to increase safety near HRGC roadway intersections with a history of crashes (*7*).

The marked "No Stop" areas are constructed to: (a) positively impact driver behavior, (b) decrease the number of vehicles entering the crossing and stopping too close or on the tracks, (c) reduce the number of incidents and injuries at rail crossings (*8*). Moreover, the effectiveness of flashing beacons and light-emitting diode (LED) edge-lit signs were evaluated in the STRIDE project. These measures were initially implemented at 14 railroad crossings across the state, with an additional 32 crossings planned (*8*).



(a) RDE on Yellow Pavement Marking **(b) Modified Signage**

Figure 2-3. Rail Dynamic Envelope (*6*)

New passive designs, such as ecological interface crossing for rural roads, have demonstrated satisfactory results (*9*). For instance, the proposed design crossing scenario – a combination of signing, marking, and signal light modification – influenced participants positively. They drove cautiously in the simulated environment compared to a standard crossing scenario. Photo enforcement signage has been studied recently and has also shown a positive impact (*10*). Another example is the full-matrix color LED changeable message signs with 20 mm pixels that have demonstrated a reduction in driver violations (*11*).

2.1.2 Active Devices

2.1.2.1 Gates

Active grade crossings constitute active warning and control devices, including bells, flashing lights, and gates (*12*). Active traffic control systems inform road users of the approach or presence of trains at grade crossings. These systems include four-quadrant gate systems, automatic gates, flashing-light signals, actuated blank-out, variable message signs, and traffic control signals. An example of an active HRGC with flashing-light signals and a four-quadrant gate is shown in Figure 2-4.

Figure 2-4. An Active Quadrant Gate
(Source: Google Maps)

2.1.2.2 Traffic Control Signals

Traffic control signals are defined as any highway traffic signal by which traffic is alternately directed to stop and permitted to proceed (*13*). They reduce the frequency and severity of certain types of crashes, especially right-angle collisions. The existing preemption method for traffic signals at intersections positioned near HRGCs is known as the standard preemption. This phasing gives priority to clearing vehicles off the railroad tracks as quickly as possible before a train arrives at HRGCs. However, pre-preemption phasing, as illustrated in Figure 2-5, is a particular signal phase of the standard preemption. This phasing provides extra green time to clear congested vehicle traffic at the rail crossing intersection before the train's arrival.

An FDOT project (*14*) applied pre-preemption in a simulation-based research study. The goal was to prevent train-vehicle crashes and decrease travel time delays. Based on the report, applying a series of VISSIM-based simulation models before and after the coordinated pre-preemption phases resulted in a reduction in average delay, stops, and queue length on the arterials near HRGCs. Recently, researchers have introduced a new preemption phasing for signalized intersections near HRGCs in Nebraska with dual tracks, known as Advanced Transition Preemption (*15*). This new phasing has demonstrated favorable safety and operational outcomes. Despite the positive performance of the traditional traffic signal timing and its engineered phasing, modern non-track-circuit-based technologies are cost-effective active warning devices that can be deployed at HRGCs (*16*).

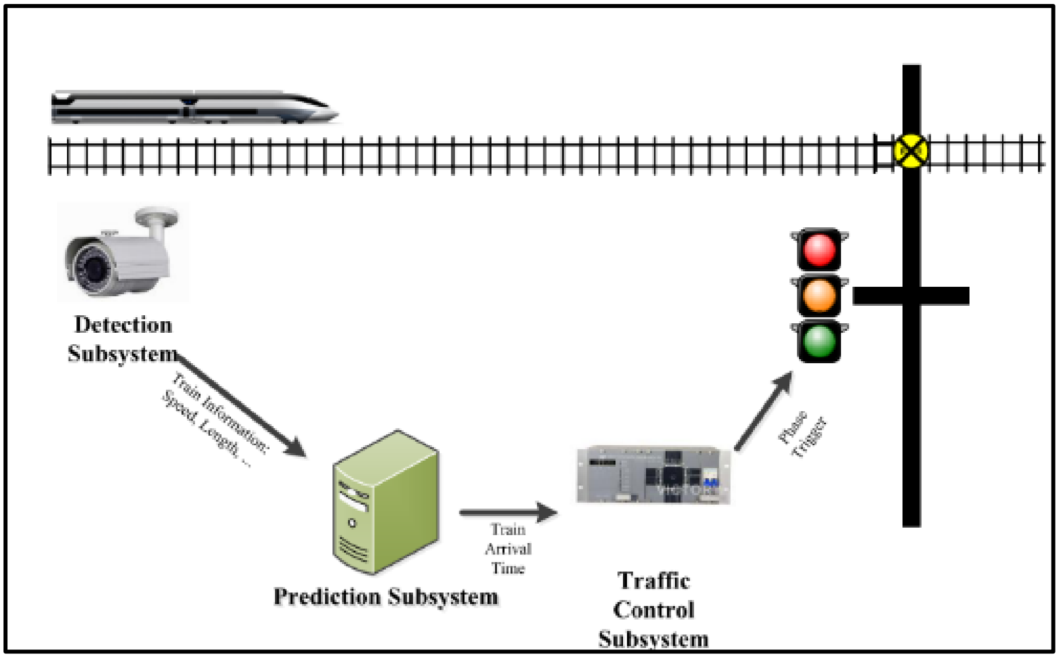


Figure 2-5. Schematic Description of the Pre-Preemption Phasing System (*17*)

2.1.2.3 Quiet Zones

Quiet zones are supplementary safety measures that could be adopted along with traffic control devices. A quiet zone is an area at least one-half mile in length. It contains one or more consecutive public HRGCs. Quiet zones are aimed at silencing train horns in populated regions while guaranteeing the safety of highway-railway users (i.e., motorists, pedestrians, and passengers). Previous study (*18*) assessed 333 quiet zones between 2012 and 2018 to understand the impact of crashes because of trespassing. The findings indicated that the fatalities due to trespassing in quiet zones increased. Thus, it seems these zones cause safety issues that need to be addressed (*19*).

2.2 State Action Plan

2.2.1 Top Ten States

Railroad crossing state action plans (SAPs) were initiated in 1994. A state action plan is an essential component of the grade crossing program management procedure (*20*). Improvement of SAPs was primarily required by Section 202 of the Rail Safety Improvement Act of 2008 (RSIA08), Public Law 110- 432, Division A, for the ten states identified with the highest number of HRGC collisions over a particular five-year period. As shown in Figure 2-6, California is ranked the highest, with 171 fatal crashes in the last five years. In November 2021, the Infrastructure Investment and Jobs (IIJ) Act was signed into law – known as Bipartisan Infrastructure Law. This act is the largest investment in US infrastructure history. A section of this act focuses on enhancing railroad safety. This act is aligned with the Fixing America's Surface Transportation (FAST) Act that mandated all 50 states and the District of Columbia to develop and implement HRGC SAPs.

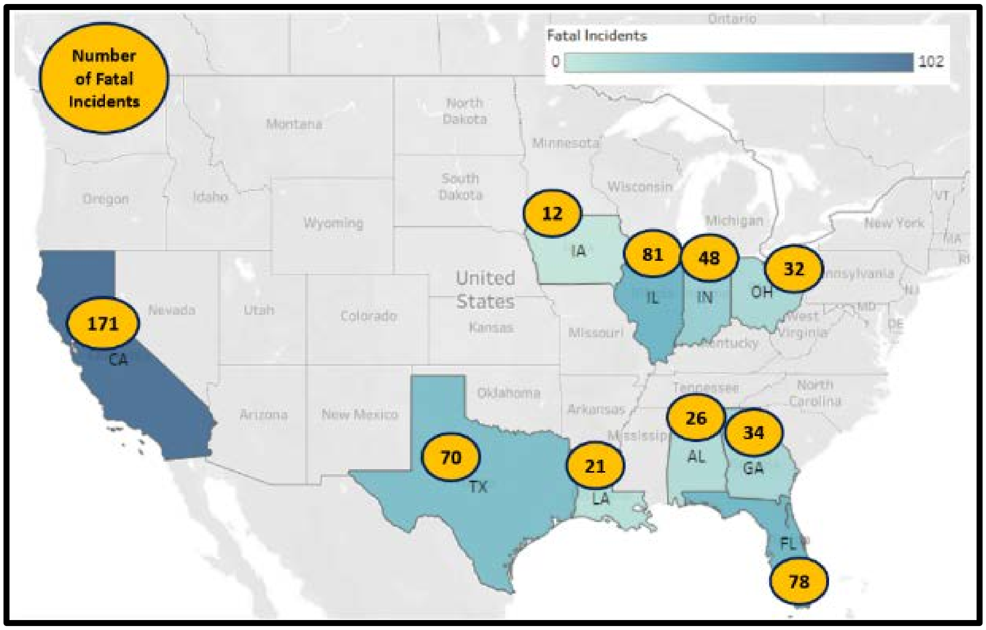


Figure 2-6. Top Ten States with HRGC Crashes
(Source: FRA Database)

2.2.2 State-of-the-Practice

The Texas SAP classified the railroad crossing safety improvement into two categories (*21*): (a) evaluation and engineering; and (b) education and enforcement. Georgia SAP emphasized data analysis since it is essential for assessing and checking progress (*22*). For instance, in the Ohio SAP (*23*), although the high-risk crossings were detected using the US DOT Accident Prediction Formula Index, statistical analysis of HRGC crash data was missing until 2010. Nevertheless, the California SAP included a crash data analysis based on crash crossing data between 2006 and 2011 (*24*). The results showed that incidents mainly included pedestrians with suicidal notes. A few HRGC crashes could therefore potentially be categorized as intentional suicides, not due to a lack of safety treatments at the crossing.

Since emergency responders and law enforcement are the first responders after a crash occurs, training them is an important step in reducing secondary crashes and impacts. The FRA (2021b) has developed a video-based training program to train the first responders. The video covers relevant and invaluable material law enforcement needs in response to a call concerning the railroad immediately, effectively, and safely.

Since the early 1970s, FDOT has been active in scientifically addressing HRGC safety risks (*25*). Similar to Louisiana (*26*), Florida's statistical analysis based on the data from 2000 to 2010 revealed that most incidents occurred at public crossings (*20*). Interestingly, HRGC crashes were found to have occurred at locations with active warning controls. However, the specific treatments of FDOT include signal timing modification or grade crossing closure/separation (*20*).

The best practices presented in the reviewed ten safety action plans include:

- Identifying high-risk situations, such as Amtrak – passenger railroad service – and school bus operations to increase publicity and awareness (*22*);
- Emphasizing grade crossing closures and separation strategies (*22, 25, 27, 28*); and
- Considering pedestrian-pathway-rail crossings (*28*).

Note that the states are looking forward to applying advanced technology to avoid incidents and delays at or close to critical zones considering the existing safety and mobility treatments.

2.2.3 Recent Studies and Practices

2.2.3.1 Safety

The car-following theory or a dilemma zone could be applied to decrease crashes at active HRGC locations (*29–31*). The dilemma zone is the road segment where more than 10% and less than 90% of the drivers would choose to stop. It is reported that the dilemma zone could cause motorist entrapment between the rail crossing gates (*31*).

A study was conducted at a congested active level crossing close to Melbourne, Australia (*29*). This study focused on analyzing the non-compliance driver behavior at activated HRGCs. Video analysis discovered that much of the non-compliance was involuntary. Also, it is linked to a dilemma zone with inadequate warning time for drivers to stop safely. Advanced warning or appropriate grace periods need to be considered to help the driver decide to safely stop the vehicle at the HRGCs.

2.2.3.2 Mobility

Congestion and queuing cause delays. To address these issues, railroad crossing projects conducted by Caltrans and Illinois DOTs are pertinent since they focused on freight movement (*32*), and travel time optimization (*33*), respectively. Previous study (*32*) evaluated the relationship between freight bottlenecks and freight impact areas. A freight bottleneck is a location where freight traffic is hampered. The emphasis of freight bottleneck research is to reduce freight delays. Freight impact areas are locations where truck traffic congestion imposes delays on traffic flow. In Illinois, dynamic traffic assignment was used to simulate how travelers utilize real-time information on traffic conditions to prevent lengthy delays caused by gate-down events that exceed 10 minutes (*33*).

The latest delay reduction technology that Caltrans has developed is an Intelligent Crossing Assessment and Traffic Sharing System (i-CATSS) that can detect and predict highway-rail blockages at grade crossings. This technology can provide first responders with real-time information on traffic conditions at crossings (*34*). Furthermore, a multi-objective mathematical model could be used as a decision-making tool to identify locations for installing LED signs (*18*). This model aims to minimize the overall hazard severity and the overall traffic delay at the studied HRGCs. Other tools that have been recently used for the challenging grade separation decision could be considered by using the benefit-cost method (*35*). This decision is crucial because emission reduction, crash avoidance, and travel time optimization have positive impacts on the

HRGC surrounding areas. Evidently, the importance of mobility effects on certain types of road users, including non-motorized traffic, school buses, emergency vehicles, and trucks, especially those transporting hazardous materials, have not been considered (*36*).

2.3 Factors Contributing to Fatalities and Serious Injuries

2.3.1 Human Factors

Human factors are one of the main factors contributing to HRGC crashes. FDOT has conducted three pilot projects using the before-after methodology in 2013, 2017, and 2019. The studies focused on incorrect turns at HRGCs and how they can prevent driver hesitation and distraction while making a turning maneuver (*4*, *37*, *38*). Note that incorrect turns onto railroad tracks due to human violation may happen on a railway close to an intersection or a freeway on-ramp or off-ramp (*37*, *38*).

Traffic violations by motorists have been one of the major concerns of FDOT in the last two decades (*6*, *39*). Several researchers have concluded that incorrect pavement markings and signs upstream of the railroad crossings can cause traffic violations (*4*, *14*, *37*, *38*, *40*, *41*). An FDOT study (*37*) recommended the following three countermeasures to address improper human violations and avoid wrong turns in the vicinity of HRGCs:

- Removing potentially confusing pavement markings and signs,
- Applying straight arrow pavement markings with guidance information, and
- Installing Qwick Kurb to avoid intended U-turns.

These findings were confirmed by another FDOT report prepared by (*38*). Motorist violations are another issue of incorrect turns at railroad crossings (*6*). Video recordings were used to evaluate the effectiveness of adding dynamic envelope marking and modified signage within critical zones. The videos were recorded in May 2012 for two 14-day periods (both directions of one crossing) at the Commercial Boulevard grade crossing in Ft. Lauderdale, Florida. The video was recorded for 224 hours – 112 before and after marking installation. It was reported that horizontal gate violations, where a motorist drives around or through the fully descended gate, were the most dangerous.

2.3.2 Train and Vehicle Characteristics

Vehicle and train characteristics often contribute to HRGC crashes. Previous study (*42*) developed an optimization model to assess the potential hazard values of the HRGCs in Florida. In this model, the following parameters were considered: average daily traffic volume, average daily train volume, train speed, and crash history. A specific Florida index was developed to diminish the hazard severity based on a priority index. The authors recommended that *the Modified Texas Priority Index Formula* (or "*the Florida Priority Index Formula*") be applied to rank the HRGCs in the State of Florida for safety improvements.

The Acoustic Warning Device could be used as the locomotive horn (*43*). A Global Positioning System (GPS) was adopted to manipulate the arrangement of directional loudspeakers. Loudspeakers are designed on the locomotive so that sound is sent forward when the horn is initially sounded 0.25 mile from a grade crossing. Other loudspeakers are sounded approaching a crossing to direct sound more to the wayside. This approach diminishes wayside noise and maintains horn detectability.

2.3.3 Railroad Infrastructure

Illinois, Indiana, Iowa, Georgia, Michigan, and West Virginia have successfully developed standard grade crossing management practices (*44*). Crossing attributes, such as crossing surface type, affect safety at HRGCs (*31*). A smooth structure of the crossing surface is vital for many reasons, including expanding lifespan, maintaining cost control, and minimizing the number of stuck/stalled vehicles (*44*). It is common to observe large numbers of crossings with unpaved (all-granular) track beds that deteriorate rapidly compared to the paved track bed, as shown in Figure 2-7. One of the issues that stem from unpaved rail and road intersections is stuck/stalled vehicles. Meanwhile, standard highway-rail grade crossing attributes such as a flat surface are essential to avoid stalling of vehicles across railroad tracks.

(a) Asphalt **(b) Concrete**

Figure 2-7. Paved Crossing Track Beds and Surfaces (*44*)

2.3.4 Environmental Conditions

Environmental factors, including weather, season, temperature, and time of day, significantly affect HRGC crashes. FDOT project (*4*) studied driver hesitation and confusion to recommend countermeasures at eleven sites during the day and night. Four pragmatic safety countermeasures were proposed to improve safety issues. The main daytime treatments were recommended as advanced direction signage and striping to enhance upstream and downstream safety. Specifically for the critical zone, treatments such as striping or dynamic envelope pavement markings, pavement gate markings, bollards, and illumination were recommended. A nighttime treatment such as standard lighting could avoid vehicle-train crashes. This prevents incorrect turns at night.

In another report by TxDOT, positive safety effects of wet-weather pavement markings for nighttime crashes (especially wet-night crashes) were reported (*45*).

2.4 Treatment and Technologies

As previously mentioned, the RSIA08 act was passed by Congress to enhance railroad safety. Among its requirements, the most notable was the mandate requiring positive train control technology to be set up on most of the U.S. railroad network. Other technology-related actions, such as a new smartphone application to raise awareness at railroad crossings and emergency notification systems, have also been implemented by FRA. Some potential pioneering technologies include positive train control, drones, machine learning algorithms, machine visioning, and underground fiber-optic. Waze application could also be used to assess and improve driver safety at and near HRGCs (*43*). Drones have been evaluated for the efficacy of applying photogrammetry software to perform line-of-sight analyses of selected grade crossings (*46*). Researchers have chosen crossings with no active warning devices and stop signs for this study since they presumed drivers would stop upon seeing a train approach. This study intended to establish if conditions permitted adequate time to stop as a result of the visual obstacles that exist.

2.4.1 Treatments

2.4.1.1 Humps and Rumble Strips

Traffic calming measures, such as humps and rumble strips, are effective in improving driver braking behavior to reduce their speed when approaching an intersection or a railroad crossing (*47–51*). Nonetheless, previous railroad crossing driving simulation studies have shown that active crossings have a greater positive impact on driver behavior compared to passive crossings (*51*). Rumble strips or in-vehicle auditory warning devices can increase safety at HRGCs (*49*). However, the possibility of installing rumble strips in quiet zones should be reviewed because of the exterior noise of the strips (*52*).

2.4.1.2 Guardrails and Crash Cushions

Guardrails and crash cushions could be installed to reduce the severity of crashes involving errant motor vehicles after striking a railroad mast arm or stop sign. However, crash rates were found to be higher at crossings with guardrails or barriers in Iowa (*53*). Also, adding 4 feet of lateral space between the signal support and the edge of the traveled way (from a 6-foot to 10-foot offset) would reduce the likelihood of a vehicular strike and therefore the need for a guardrail.

2.4.1.3 Crossing Closure and Separation

Closure of a crossing gives the highest level of crossing safety compared to other options since the point of intersection between the highway and railroad is removed. The major advantage of crossing closure is the reduction in specific collision types and delays, as well as decreased maintenance costs. Despite the safety benefits, decisions about whether a crossing should be removed or merely enhanced depend on safety, operational factors, and cost factors (*1*, *54*).

To address some of these concerns and predict crashes at HRGCs considering the quiet zones, NDOT has developed a Poisson regression model for HRGC crash prediction (*55*). The main goal was to improve safety at urban gated crossings that are not specified for quiet zones even though they are in the quiet zone regions. Another technical report (*56*) developed prediction models at two levels, microscopic and macroscopic. The microscopic model resulted in a data-driven dynamic tree that helps to visualize crash trends at a single crossing or a group of crossings. The macroscopic analysis was conducted to develop new crash prediction models for crossings with gates, flashing lights, and crossbucks.

Human behaviors and their violations at HRGCs have been the main focus of previous studies. However, little research has been conducted to assess the influence of traffic flows on the performance of HRGCs (*31*). For example, the mobility of road users could be impacted when a train blocks a highway-rail grade crossing. Since the cost of diminished mobility surpasses safety costs (*36*), a grade separation decision must be considered when the following criteria exceed quantitative thresholds. To this end, the mobility-based review of HRGCs identified six classifications for these thresholds, including train volume and speed; road traffic volume, speed, and delay; and cross exposure (*36*). Note that the parameter *cross exposure* is calculated by multiplying road traffic volume and the average daily rail movements at a crossing.

2.4.2 Technologies

2.4.2.1 Warnings and Alerts

Warning countermeasures include auditory or visual alerts. Previous study (*57*) conducted a driving simulator study and concluded that in-vehicle audio and visual warning alerts have the potential to improve drivers' risk perception abilities and safety at grade crossings. In addition, if an obstacle appears at a railroad crossing, the notification subsystem allows quick data transfer to all vehicles and uses the automatic braking system. The proposed warning system is intelligent, which is reflected in the ability to detect the presence of vehicles at the railroad crossing, as well as estimate the time each vehicle has been on the move, which makes it possible to detect a vehicle that may be stopped due to a malfunction or other reason that does not allow further movement (*58*).

2.4.2.2 Automatic Systems

In-vehicle and in-train warning technologies are two important train-avoidance technologies. In-vehicle audio warnings could improve drivers' visual and behavioral performance. For instance, eye-tracking systems have been utilized to detect the movement of human eyes in a simulated environment (*59*). Results showed that the improved design of signs and the audio warning could prime drivers' expectations of the grade crossing in advance. This is because drivers could drive at a lower speed, perceive signs in a timely manner, and conduct an earlier visual search for the train.

In-train technologies are part of automatic train operations. For example, train obstacle detection significantly improves the safety of automatic train operations (*60*). Without this capability, smart train braking systems such as positive train control (PTC) are ineffective. In this regard, image processing and deep learning algorithms could be utilized as sophisticated AI tools for detecting upcoming obstacles, including drivers and bicyclists.

2.4.2.3 Rail Crossing Violation Warning (RCVW) Application

Automated vehicles (AV) need to interact with rail and road intersections. One way to enhance AV interaction with railroad crossing is through Connected Vehicle (CV) technology. This technology and other approaches were considered in a technical report by US DOT (*61*). One solution to avoid train-vehicle crashes is using Rail Crossing Violation Warning (RCVW), as shown in Figure 2-8. RCVW is an application that gives the driver a warning to stop when the vehicle is projected to traverse a rail crossing occupied by a locomotive. Researchers designed and developed the RCVW system at Battelle in Columbus, Ohio, from September 2018 to July 2021. The system demonstrated the potential for leveraging real-time CV concepts to enhance and transform rail crossing safety (*62*).

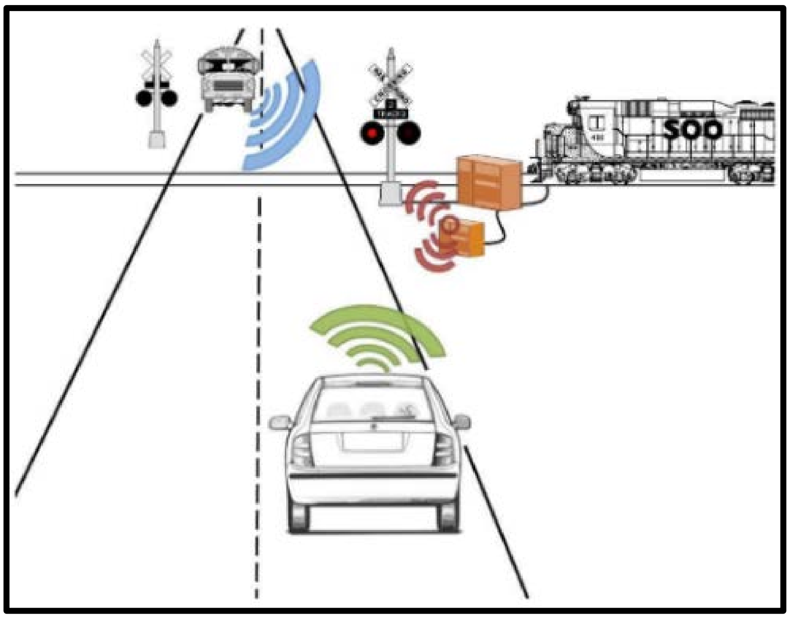


Figure 2-8. RCVW Application Concept

2.4.2.4 Emerging Developments

Artificial intelligence is a subcategory of automation. The most recent research and development efforts are trying to make the railroad crossing system safer by minimizing human violations. Researchers have been using on-edge technologies such as drones, machine learning algorithms, underground fiber optic, in-vehicle, and in-train warning systems, human eye-tracking systems, and automated braking systems (positive train control).

Human violations in the railway engineering field are more important than in other fields since train-vehicle crashes are devastating (*63*). AI systems have the potential to detect human violations. The most recent US DOT railway crossing automation project focuses on AI software applications, as shown in Figure 2-9. This software automates the detection of grade crossing violations and trespass activities from static camera video feeds (*64*). The main purpose of this project was to develop a deep learning-based computer vision tool for automating the detection of grade crossing violations and railroad right-of-way trespass activities from static camera video feeds.

Figure 2-9. Example of an Automated Video Processing at an HRGC (*64*)

2.4.3 Gaps in the US DOT Practices

In February 2022, FRA published a technical report that reviewed the pertinent documents, standards, research, and design of in-vehicle auditory alerts (IVAAs), specifically for highway-rail grade crossings (*65*). Based on this literature review, there is a research gap in IVAAs. Specifically, new auditory alerts need to be designed, tested, and validated for HRGCs. The following sections discuss the gaps in the US DOT practices from safety and mobility perspectives.

2.4.3.1 Safety

Concerning safety, it is evident there are existing gaps in studying the behavior of vulnerable users (e.g., scooters and bicyclists) as well as the impact of rail and road infrastructure on crashes and delays at railroad crossings. Among all rail-related fatalities and injuries, 94% of them occur at railroad crossings or due to trespassing (*66*). The fatalities caused by trespassing after implementing quiet zones, based on the observed data, have increased. As a potential solution, anti-trespass guard panels installed on a railroad right-of-way could physically make it difficult for pedestrians to violate the regulations of trespassing on a railroad right-of-way (*67*). The goal of these guard panels was to reduce the number of pedestrians that trespass onto the railroad right-of-way. The results showed that the number of trespassing pedestrians decreased by about 40% after installation.

2.4.3.2 Mobility

Operational attributes such as delay have been studied extensively. Based on the most recent mobility-based review paper (*36*), there is a need for further research on the application of queuing theory (using GradeDec.Net) or microsimulation tools, such as VISSIM (*15*, *17*), to quantify the crossing blockage delay. However, real-time data collection and analysis are needed to validate the accuracy of simulation results. It is worth mentioning that this delay reduction leads to cost reduction for road users. Delays at blocked crossings could be estimated using two techniques of site-specific field measurements and average gate downtime (*36*). In addition, the queuing theory could be a tool to determine the delay experienced by vehicles expected to slow down and stopped vehicles. Besides delay, other characteristics, including level of service, queue characteristics, and capacity, need to be investigated (*31*).

In summary, this review analysis offers essential guidance for transportation organizations in employing AI-based technologies, including novel human behavior (e.g., machine learning algorithms and machine visioning), train brake systems (e.g., positive train control), alert systems (e.g., in-vehicle auditory alerts), and rail monitoring (e.g., machine visioning). This analysis will also assist agencies in applying new data collection and analysis methods, such as deep learning approaches for the upcoming safety and operational action plans. Certainly, the findings stated in this report can provide valuable information that could be used by traffic designers and public facility decision-makers.

3 Review and Evaluation of RDE Implementations in Florida

This chapter describes FDOT deployments of RDE pavement markings at HRGCs in Florida and presents the evaluation results from the research team on RDE implementations via the analysis of before-after studies conducted by each FDOT District. Researchers further conducted quantitative analysis to assess the stopping behaviors of the drivers in the most dangerous zone (Zone 3) at HRGCs and identify the factors that affect the stopping rates in Zone 3.

3.1 Florida Operation STRIDE (Statewide Traffic and Railroad Initiative Using Dynamic Envelopes)

FDOT's $60 million STRIDE directive focuses on upgrading more than 4,000 state-owned HRGCs in Florida. The enhancements include signs, crossing arms, and dynamic envelopes that boost the clearance for trains, reducing the incidences of vehicles getting too close to the tracks. Figure 3-1 shows the positioning of the RDE and its signage, as well as other pertinent striping based on FDOT design standards.

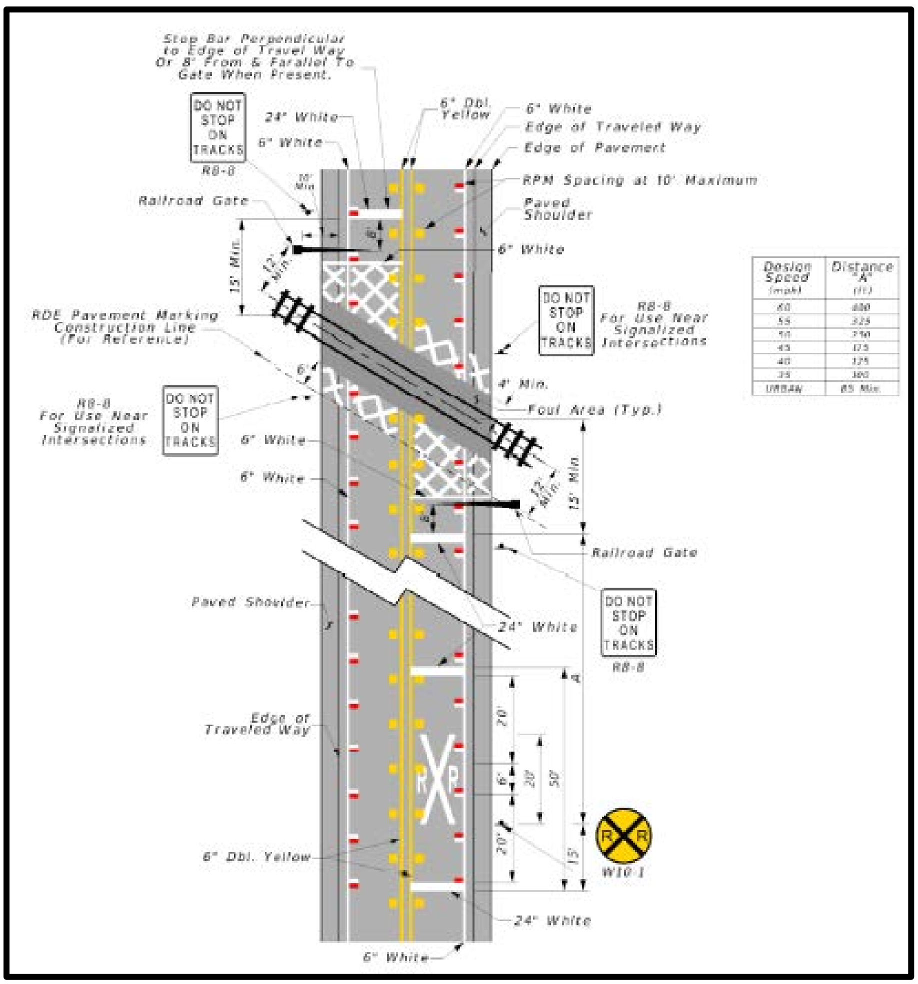


Figure 3-1. RDE Positioning and Signage for a Railroad Crossing at Two-Lane Roadway
(Source: FDOT Reference Number 509-070-1, Design Bulletin OODB21-02)

FDOT has systematically installed RDE pavement markings and associated signs at state-owned HRGCs. The Department has conducted safety evaluation studies to assess the effectiveness of RDEs. For example, an earlier study in FDOT District 7 recommended that avoiding right-turn channelization within RDE areas can reduce the chance of drivers stopping in an RDE zone. Improving the nighttime visibility of RDE pavement markings to motorists can increase the chance of drivers stopping in a safe zone and reduce stopping in critical zones. Furthermore, initial traffic data showed that RDEs decreased the number of stopped vehicles that were on or were too close to the tracks by at least 15% (*68*).

The RDE installations were applied to the crossings on the state roads and rails belonging to 17 rail companies. To conduct a detailed evaluation, the locations of RDE installations and the before and after study reports were downloaded by the research team from the FDOT eTraffic application (*69*). The before and after study report from District 7 was acquired from the authors (*70*). A total of 98 out of 620 HRGCs with RDE implementations had a corresponding report, including 11 with 'before only' or 'after only' studies. The final number of RDE installations for the analyses was 87. The list of the crossings with the before and after reports is presented in Table 3-1. The detailed HRGCs on the list is available in Appendix A.

Table 3-1. HRGCs with Installed RDEs and Before and After Studies in Florida

Railroad Company	Number of Crossings with RDE Installations	Number of Crossings with Before and After Study Report
Alabama & Gulf Coast (AGR)	4	0
AN Railway (AN)	6	0
Bay Line Railroad (BAYL)	12	5
Brightline	7	1
CSX Transportation (CSX)	172	34
Florida Central Railroad (FCEN)	11	3
First Coast Railroad (FCRD)	1	0
Florida East Coast (FEC)	76	20
Florida Gulf and Atlantic Railroad (FGA)	20	4
Florida Midland Railroad (FMRR)	4	0
Florida Northern Railroad (FNOR)	14	1
Georgia and Florida Railway (GFRR)	5	0
Norfolk Southern (NS)	7	2
South Central Florida Express (SCXF)	24	0
Seminole Gulf Railway (SGLR)	13	1
South Florida Rail Corridor (SFRC)	127	14
SunRail	117	2
Total:	620	87

To evaluate the safety effectiveness of RDE pavement markings, FRA (*71*) established four zones, safe, moderately dangerous, very dangerous, and moderately dangerous, that differ in danger severity the drivers are exposed to while stopping. The zones are presented in Table 3-2 and Figure 3-2.

Table 3-2. Levels of Danger in the RDE Zones

Zone	Distance from Rail track	Danger Level
1	Twenty (20) feet behind the stop bar and the gate arm	**Safe:** Motorist stopping behind the stop bar and gate.
2	Downstream of the stop bar but upstream of the track foul zone	**Moderately dangerous**: Motorists stopping in Zone 2 would be stuck inside of a descended gate but not struck by a train.
3	On the tracks or in the foul zone	**Very dangerous**: Dynamic Envelope Zone, in this zone, a train and vehicle would collide.
4	Twenty (20) feet immediately downstream of the tracks and outside of the track foul zone	**Moderately dangerous**: Motorists stopping in Zone 4 would not be struck by a train.

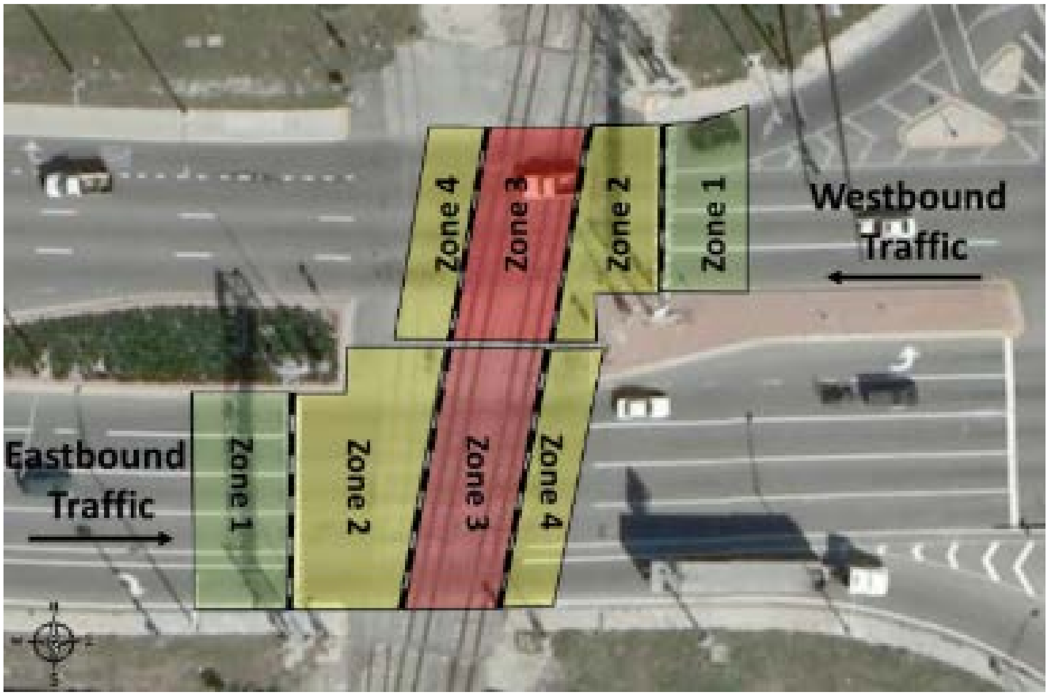


Figure 3-2. Visualization of Danger Level Zones in the RDE (*72*)

3.2 Before-After Study of RDE Implementation in Florida

3.2.1 District One

District One conducted a four-day before (pre-install of RDE) and after (post-install of RDE) data collection (video recording) and evaluation (data description). The purpose was to evaluate the effectiveness of the pavement markings placed within the dynamic envelope. Note that the location also had additional pavement markings to positively influence driver behavior and reduce the number of vehicles that come to a stop within the dynamic envelope. Figure 3-3 illustrates an implemented RDE in District One.

Figure 3-3. Example of RDE Implementation in FDOT District 1 (U.S. 41/301 @ 13th Avenue E)

The data collection before RDE installation was conducted in July and August 2020 for eight (8) hours per day (from 7:30 to 9:30 a.m., 11:00 a.m. to 1:00 p.m., 4:00 to 6:00 p.m., and 10:00 p.m. to 12:00 a.m.). The after-RDE installation data collection was conducted in March, April, May, June, and August 2021. In an attempt to capture a diverse driver mix, one of the four days of data collection was collected over a weekend day (Saturday or Sunday).

The results indicate that the total volumes were higher during the data collection efforts after the installation of the RDE pavement markings. The pre-installation driver behavior showed that 100% of the drivers stopped in Zone 1 in both directions. After the installation, 100% of the drivers were found to have stopped in Zone 1 in both directions.

Vehicle action was noted as a lane change, reverse, U-turn, or no action (waiting for traffic to clear) and was only recorded after a vehicle had stopped in Zones 2, 3, or 4. No vehicles stopped in any other zones during the pre-installation and post-installation data collection; therefore, no vehicle action in other zones was observed.

Any violation at the railroad crossing performed by a motorist was also recorded. Violations were categorized as either descending or horizontal. Descending violations are moderately dangerous and occur when a motorist passes underneath the gates after they have initiated their descent but are not yet horizontal. A horizontal violation is the most dangerous and occurs when a motorist drives around or through the fully descended gate.

3.2.2 District Two

District Two performed a four-day before (pre-install of RDE) and after (post-install of RDE) data collection (video recording). The purpose of the study was to evaluate the effectiveness of the pavement markings placed within the dynamic envelope. Note that the location also had additional pavement markings to positively influence driver behavior and reduce the number of vehicles that come to a stop within the dynamic envelope. Figure 3-4 illustrates an implemented RDE in District Two.

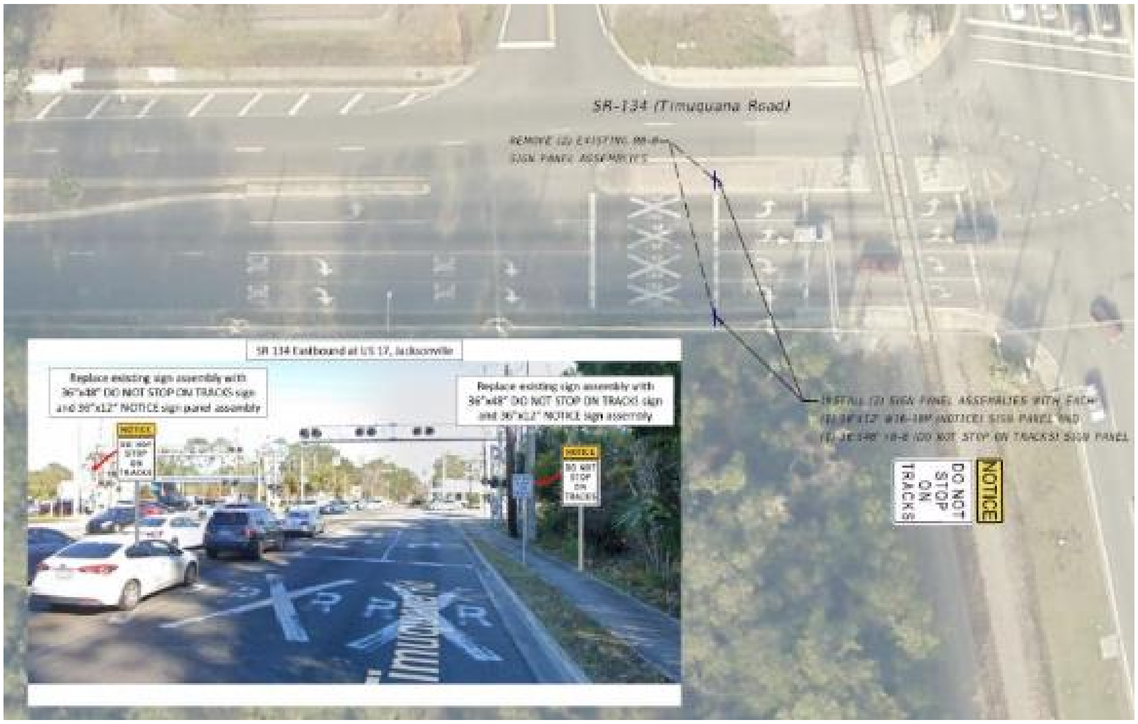


Figure 3-4. Example of RDE Implementation in FDOT District 2 (US-17/SR-15 @ SR-134)

For data collection, four-day traffic data were collected covering weekday and weekend day traffic conditions. Eight-hour counts were collected during these days (from 7:30 a.m. to 9:30 a.m., 11:00 a.m. to 1:00 p.m., 4:00 p.m. to 6:00 p.m., and 10:00 p.m. to 12:00 a.m.). The recorded traffic data were analyzed for traffic volumes by individual travel lanes and motorist stopping behavior in various assigned zones.

The findings revealed that the average bi-directional traffic volume mostly increased. On the other hand, motorists' behavior for stopping in the critical zone (Zone 3) decreased. Almost all motorists' action after being stopped was mostly reported as no action (i.e., waiting for traffic to clear). Last but not least, descending, and horizontal gate violations mostly increased although the descending violation was noticeable compared to horizontal gate violations.

3.2.3 District Three

District Three conducted a four-day before (pre-install of RDE) and after (post-install of RDE) data collection (video recording) and evaluation (data presentation). The purpose of the study was to evaluate the effectiveness of the pavement markings placed within the dynamic envelope. Note that the location also had additional pavement markings to positively influence driver behavior and reduce the number of vehicles that come to a stop within the dynamic envelope. Figure 3-5 illustrates an implemented RDE in District Three.

Figure 3-5. Example of RDE Implementation in FDOT District 3 (SR-4 @ SR-95 [US-29] in Escambia County)

For data collection, four-day traffic data were collected covering weekday and weekend day traffic conditions. Eight-hour counts were collected during these days (from 7:30 a.m. to 9:30 a.m., 11:00 a.m. to 1:00 p.m., 4:00 p.m. to 6:00 p.m., and 10:00 p.m. to 12:00 a.m.). The recorded traffic data were analyzed for traffic volumes by individual travel lanes and motorist stopping behavior in various assigned zones.

The findings revealed that the average bi-directional traffic volume and stopped motorists in the critical zone (Zone 3) mostly increased after RDE installation. Almost all motorists' action after being stopped was mostly reported as no action (i.e., waiting for traffic to clear) after RDE installation. It should be mentioned that descending and horizontal gate violations were negligible for most case studies after RDE installation. However, horizontal gate violations in one case (SR-95 [US 29] and Becks Lake Road/Muscogee Road in Escambia County) increased drastically since 1,133 dangerous horizontal violations were observed.

3.2.4 District Four

District Four conducted a four-day before (pre-install of RDE) and after (post-install of RDE) data collection (video recording) and evaluation (data analysis). After the installation of the RDE pavement markings, the same evaluation criteria and data collection methodology was applied to each crossing. The purpose of the after-implementation study was to evaluate the effectiveness of the pavement markings placed within the RDE. Additional pavement marking within the RDE may positively influence driver behavior and reduce the number of vehicles that come to a stop within the RDE. Figure 3-6 represents an example of field installation of RDEs.

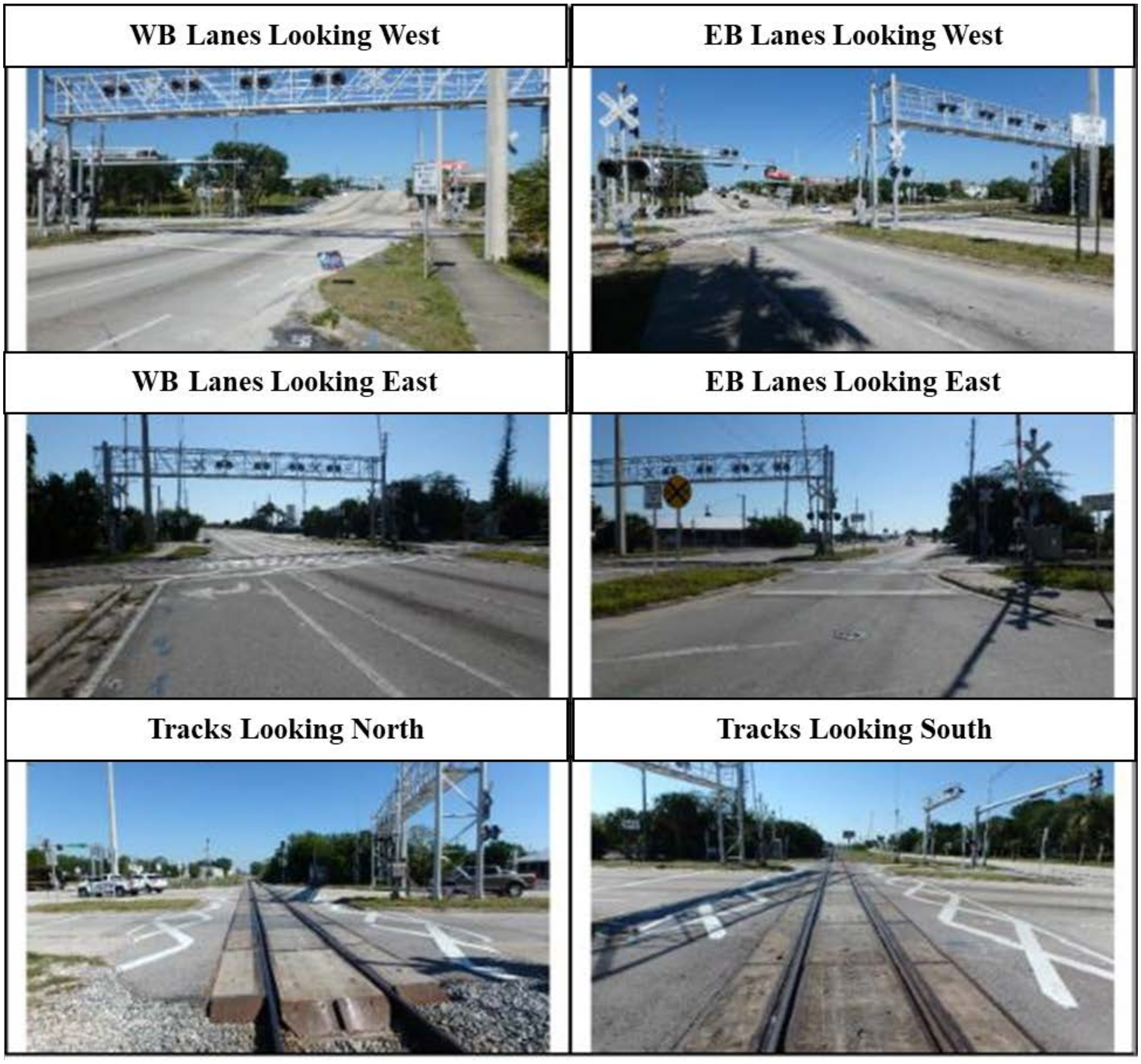


Figure 3-6. Example of RDE Implementation in FDOT District 4 (A1A @ N. Causeway Drive)

For data collection, traffic data were collected for four (4) days before and after the installation of RDE pavement markings for eight (8) hours per day (from 7:30 a.m. to 9:30 a.m., 11:00 a.m. to 1:00 p.m., 4:00 p.m. to 6:00 p.m., and 10:00 p.m. to 12:00 a.m.). In an attempt to capture a diverse driver mix, one of the four days of data collection was collected over a weekend day (Saturday or Sunday).

The findings disclosed that the average bi-directional traffic volume varied for different railroad crossings. Considering the driver's stopping behavior, stopped motorists in the critical zone (Zone 3) increased in most cases, although there were some cases with a reduction. Interestingly, almost all motorists' action after being stopped was no action (i.e., waiting for traffic to clear), regardless of pre- or post-installation of RDEs. However, some drivers did act and chose to reverse, change lanes, or make U-turns. These maneuvers occurred in Zones 2 and 4 (moderately dangerous zones). Regarding the gate violations, there were no events for post-installation vehicles stopping beyond the gate while active.

3.2.5 District Five

District Five conducted a four-day before (pre-install of RDE) and after (post-install of RDE) data collection (video recording) and evaluation (statistical analysis). The before data collection was conducted in July and August 2020. The after-data collection was conducted in December 2020 and in February, March, April, and May 2021. The purpose of this project was to evaluate the effectiveness of the installed RDE on driver stopping behavior in the critical zone. More specifically, the impact of RDEs on reducing the number of vehicles that stop within the dynamic envelop zone was studied.

For data collection, four-day traffic data were collected covering weekday and weekend day traffic conditions. Eight-hour counts were collected during these days from 7:30 a.m. to 9:30 a.m., 11:00 a.m. to 1:00 p.m., 4:00 p.m. to 6:00 p.m., and 10:00 p.m. to 12:00 a.m. covering peak traffic conditions and off-peak nighttime conditions. The recorded traffic data were analyzed for traffic volumes by individual travel lanes and motorist stopping behavior in various assigned zones. Figure 3-7 illustrates the positioning of the cameras.

Figure 3-7. Positioning of the Cameras at an HRGC to Collect Driver's Stopping Behaviors

The results showed a positive impact of the RDE pavement markings on the driver's behavior to stop their vehicles. The statistical analysis of the before and after driver-stopping behavior using a chi-square test showed significant differences between the traffic data population. This demonstrates the effectiveness of the RDE pavement markings in enhancing rail crossing safety. In conclusion, the FDOT series of studies on 14 RDE locations showed that the number and percentage of vehicles stopping in critical zones diminished with the implementation of RDE markings.

3.2.6 District Six

There are more than 80 highway-rail grade crossings in Miami-Dade County, where RDEs have been employed. District Six also conducted a before (pre-install of RDE) and after (post-install of RDE) data collection and analysis. The Department further refined its version of the RDE and developed standards shown in Figure 3-8, which guide the current installation of the pavement markings.

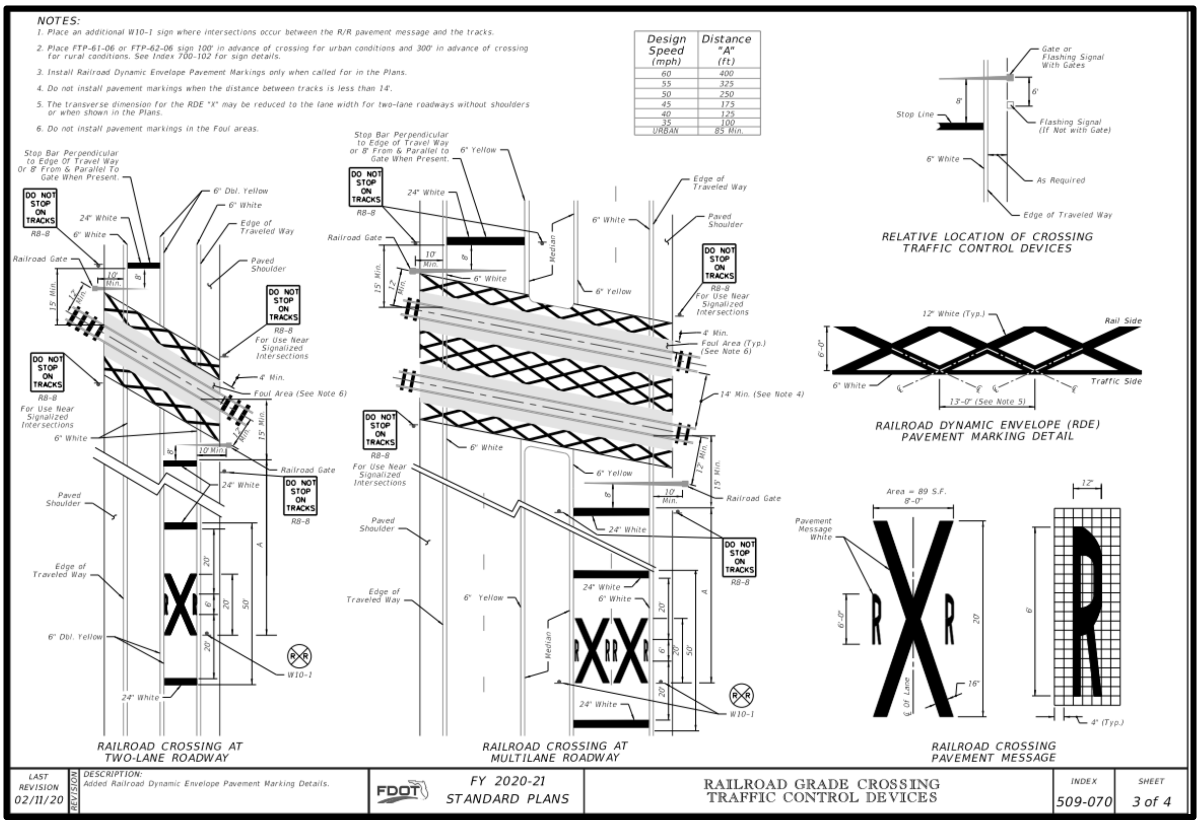


Figure 3-8. FDOT RDE Design Standards for HRGCs

(Source: FDOT Index 509-070)

The analysis was based on four days of data collected before and after the RDE installation. For data collection, the team coded driver stopping behavior at this crossing before and after the RDE implementation for eight hours per day (from 7:30 a.m.– 9:30 a.m.; 11 a.m.– 1 p.m.; 4 p.m.– 6 p.m.; and 10 p.m. to 12 a.m.), including at least one weekend day.

Findings indicate that despite the implementation of the dynamic envelope pavement markings, the number of vehicles that took action and moved away from the most dangerous area or Zone 3 did not change significantly. Finally, the number of vehicles that incurred gate violations stayed the same. After the installation of the Dynamic Envelope, two vehicles stopped beyond the gates during an activation.

3.2.7 District Seven

The primary goal of the before-after study conducted by Wang et al. (2021) was to evaluate the effectiveness of RDE pavement markings in improving safety-related stopping behaviors at grade crossings in FDOT District 7. More specifically, Wang et al. (2021) performed the following tasks:

- Collected sample data before and after implementing RDE pavement markings for different site attributes such as traffic, geometry, and environment.
- Compared stopping behaviors in critical zones at grade crossings before and after implementation of RDEs.
- Quantified the effectiveness of RDE pavement markings in improving safety-related stopping behaviors at grade crossings.

Six study sites that included various scenarios of functional classification, Annual Average Daily Traffic (AADT), speed limit, and lane configuration were selected in Hillsborough County for the before-after study. All study sites were adjacent to a signalized intersection and had the risk of improper stopping behaviors in dynamic envelope zones. Video cameras were set up at each study site to record driving behaviors at grade crossings. Field video was recorded at each study site for two days both before and after the RDE implementation. Each day, video recording covered eight hours, including morning, noon, afternoon, and night; in total, 32-hour videos were collected for each site. Similar to other districts, the research team reviewed before and after videos to retrieve stopping behaviors in four pre-defined zones at each site. Avoidance and violation behaviors were also examined.

Statistical analyses were conducted to compare retrieved behavior rates before and after the implementation. Chi-square or Fisher's Exact tests were used based on sample size to examine the significance of treatment impacts on driving behaviors. The before-after comparison results of stopping behavior showed that RDE pavement markings can significantly improve safety-related stopping behaviors at grade crossings. The following are the key findings from this study:

- The treatment tends to increase safe stopping behaviors (stopping in Zone 1 – prior to stop bar) by 20%, on average.

- The treatment tends to decrease the most dangerous stopping behaviors (stopping in Zone 3 – dynamic envelope area) by 8%, on average.

- The treatment tends to decrease moderately-dangerous stopping behaviors by 7% (stopping in Zone 2 – between the stop bar and dynamic envelope area) and 5% (stopping in Zone 4 – after the dynamic envelope area).

- Descending arm violation events (motorists go through when a cross gate arm is descending) decreased from 3 (before) to 2 (after) if including Site 3, or from 2 (before) to 1 (after) if excluding Site 3.

Several factors may influence the effectiveness of RDE pavement markings:

- The effectiveness of RDE pavement markings varies by site characteristics (geometry, traffic volume, and traffic control).
- Right-turn channelization within RDE areas may encourage motorists to stop in dangerous zones (on or near RDE areas), consequently reducing the effectiveness of the treatment. Traffic signs (R8-8) blocked by obstacles may reduce the performance of RDE pavement markings.
- Good lighting conditions result in more significant effects of RDE pavement markings compared to poor lighting conditions.
- RDE pavement markings have the most significant effects on right-turn movements, followed by left-turn and through movements.

Wang et al. (2021) provided the following recommendations for implementing RDE pavement markings in Florida:

- Extend the implementation of dynamic envelope pavement markings plus traffic signs ("Do Not Stop On Tracks") to all at-grade crossings in FDOT District 7 and other districts.
- Maintain sufficient street lighting levels at highway-rail crossings to increase the visibility of dynamic envelope pavement markings to motorists at night.
- Avoid right-turn channelization within dynamic envelope areas at crossings/ intersections with "turn on red" operations.
- Relocate R8-8 traffic signs ("Do Not Stop On Tracks") if overlapping with other signs.

3.2.8 Summary of RDE Before-After Studies in Florida

The research team reviewed and analyzed the before-after studies conducted by each of seven FDOT districts. The overall evaluation results on statewide deployments of RDE are positive. Based on the average of the before-after study results from seven FDOT districts, with a total of 73 study sites, the RDE treatment increased safe stopping behaviors (stopping in Zone 1 – prior to stop bar) by 20%, decreased moderately-dangerous stopping behaviors (stopping in Zone 2 – between the stop bar and dynamic envelope area) by 3%, decreased the most dangerous stopping behaviors (stopping in Zone 3 – dynamic envelope area) by 5%, and decreased moderately-dangerous stopping behaviors (stopping in Zone 4 – after the dynamic envelope area) by 8%.

Table 3-3 summarizes the results of the RDE before-after studies conducted by the FDOT districts. The table is organized by district, locations, methodology, results/conclusions, and comments.

Table 3-3. Before and After Study of Railroad Dynamic Envelopes Performed by FDOT

District	Locations	Methodology	Results / Conclusions	Comments
1	14 (out of 60) RDE locations with the reports.	Video recording: 8 hours per day over 4 days, including a weekend day (Saturday or Sunday).	• The RDE treatment tends to increase safe stopping behaviors in Zone 1 (prior to stop bar), by 37%, on average. • Stopped motorists in the critical zone (Zone 3) and Zones 2 (between the stop bar and dynamic envelope area) and 4 (stopping in Zone 4 – after the dynamic envelope area) were zero for all sites. • A few descending violations (only for 2 reports) were observed.	
2	12 (out of 76) RDE locations with the reports.	Video recording: 8 hours per day over 4 days, including Saturday.	• The RDE treatment tends to increase safe stopping behaviors (stopping in Zone 1 – prior to stop bar) by 14%, on average. • The treatment tends to decrease the most dangerous stopping behaviors (stopping in Zone 3 – dynamic envelope area) by 9%, on average. • The treatment tends to decrease moderately-dangerous stopping behaviors by 4% (stopping in Zone 2 – between the stop bar and dynamic envelope area) and 1% (stopping in Zone 4 – after the dynamic envelope area). • Gate violations were mostly zero for most cases. However, there were a few cases where it increased slightly.	One location had an unusual increase in descending gate violations[1] by about 88%.
3	10 (out of 43) RDE locations with the reports.	Video recording: 8 hours per day over 4 days, including Saturday. Noteworthy, Miovision video data collection units were used.	• The RDE treatment tends to increase safe stopping behaviors (stopping in Zone 1 – prior to stop bar) by 24%, on average. • The treatment tends to decrease the most dangerous stopping behaviors (stopping in Zone 3 – dynamic envelope area) by 1%, on average. • The treatment tends to increase moderately-dangerous stopping behaviors by 5% (stopping in Zone 2 – between the stop bar and dynamic envelope area) and decrease 29% for stopping in Zone 4 (after the dynamic envelope area). • Descending and horizontal gate violations were negligible for most sites.	Horizontal violations in one case increased drastically since 1,133 dangerous horizontal violations were reported[2].

[1] Location: SR 111/Edgewood Avenue – Crossing No. 621275X – CSX (Duval County)
[2] Location: State Road 95 (US 29) and Becks Lake Road / Muscogee Road in Escambia County

Table 3-3. Before and After Study of Railroad Dynamic Envelopes Performed by FDOT (Continued)

District	Locations	Methodology	Results / Conclusions	Comments
4	16 (out of 126) RDE locations with the reports.	Video recording: 8 hours per day over 4 days, including Saturday.	• The RDE treatment tends to increase safe stopping behaviors (stopping in Zone 1 – prior to stop bar) by 25%, on average. • The treatment tends to decrease the most dangerous stopping behaviors (stopping in Zone 3 – dynamic envelope area) by 6%, on average. • The treatment tends to decrease moderately-dangerous stopping behaviors by 9% (stopping in Zone 2 – between the stop bar and dynamic envelope area) and 10% (stopping in Zone 4 – after the dynamic envelope area). • Almost no gate violations were observed at crossings.	A few drivers chose to reverse, change lanes, or make a U-turn. They happened in Zones 2 and 4.
5	13 (out of 172) RDE locations with the reports.	Video recording: 8 hours per day over 4 days, including Saturday.	• The RDE treatment tends to increase safe stopping behaviors (stopping in Zone 1 – prior to stop bar) by 16%, on average. • The treatment tends to decrease the most dangerous stopping behaviors (stopping in Zone 3 – dynamic envelope area) by 3%, on average. • The treatment tends to decrease moderately-dangerous stopping behaviors by 6% (stopping in Zone 2 – between the stop bar and dynamic envelope area) and 7% (stopping in Zone 4 – after the dynamic envelope area). • There were almost no violations for post-installation vehicles stopping beyond the gate while active.	There was one case[3] that the traffic volume significantly decreased (-48%). In another case, stopped vehicles decreased by about 40%[4].

[3] Location: SR-959 / NW 57th Avenue
[4] Location: SR-886 / Port Boulevard

Table 3-3. Before and After Study of Railroad Dynamic Envelopes Performed by FDOT (Continued)

District	Locations	Methodology	Results / Conclusions	Comments
6	22 (out of 89) RDE locations with the reports.	Video recording: 8 hours per day over 4 days, including Saturday.	• The RDE treatment tends to increase safe stopping behaviors (stopping in Zone 1 – prior to stop bar) by 7%, on average. • The treatment tends to decrease the most dangerous stopping behaviors (stopping in Zone 3 – dynamic envelope area) by 4%, on average. • The treatment tends to increase moderately-dangerous stopping behaviors by 1% (stopping in Zone 2 – between the stop bar and dynamic envelope area) and decrease 4% (stopping in Zone 4 – after the dynamic envelope area). • Negligible gate violations were observed.	There were a few gate violations (e.g., Grade Crossing ID# 628334W[5] and Grade Crossing ID# 272596P[6]).
7	6 (out of 54) with a report, not on the eTraffic data source.	Video recording: 8 hours per day over 4 days, including morning, noon, afternoon, and night.	• The RDE treatment tends to increase safe stopping behaviors (stopping in Zone 1 – prior to stop bar) by 20%, on average. • The treatment tends to decrease the most dangerous stopping behaviors (stopping in Zone 3 – dynamic envelope area) by 8%, on average. • The treatment tends to decrease moderately-dangerous stopping behaviors by 7% (stopping in Zone 2 – between the stop bar and dynamic envelope area) and 5% (stopping in Zone 4 – after the dynamic envelope area). • Descending arm violation events (motorists go through when a cross gate arm is descending) decreased from 3 (before) to 2 (after) if including Site 3[7], or from 2 (before) to 1 (after) if excluding Site 3.	The results were extracted from the report entitled: "*Rail Dynamic Envelope (RDE) Pavement Markings Before-After Study in FDOT District 7*" with the report number BDV25-762-21.

Note: The "*Before and After*" reports are not available for every RDE site. There are 87 (out of 620) RDE locations with before and after study reports on the FDOT *eTraffic* data source for districts 1 to 6. (*70*) Conducted a before and after study at six sites in District 7 and these results are not available on the FDOT *eTraffic* data source.

[5] Location: SR-916 / NW 135th Street
[6] Location: NE 203rd Street / Ives Dairy Road
[7] Location: E Busch Blvd at N Nebraska Ave (NB)

3.3 Analysis of Stopping Behaviors in Zone 3

The research team closely analyzed the stopping behaviors of the drivers in the most dangerous zone (Zone 3) using RDE before-after study data to identify potentially contributing factors for developing mitigation strategies. The seven crossings from District 1 had zero stoppings in each zone; therefore, the analysis was based on the data from 80 RDE sites obtained from FDOT districts' before and after studies.

Figure 3-9 presents locations of HRGCs with positive, negative, or no change in the vehicle stoppings in Zone 3 after the RDE implementation. It could be found that after the implementation of RDE, the Zone 3 stopping behaviors were reduced in 31 locations, remained the same in 18 (the change in stopping behaviors was less than 1%), and increased in 31 crossings.

Figure 3-9. Impacts of FDOT STRIDE Program on Zone 3 Stopping Behaviors in Florida

Table 3-4 presents the summary statistics of HRGCs characteristics by different factors. The odds ratio (OR) is calculated using the formula below:

$$OR = \frac{Increased\ \%}{Decreased\ \%} \quad (1)$$

Table 3-4. Characteristics of HRGCs with RDE implementation

HRGC Characteristic	Stoppings in Zone 3 After RDE Implementations						
	Increased Dangerous Stops		No Change		Decreased Dangerous Stops		Odd Ratio (Increased % ÷ Decreased %)
	Num. of Sites	%	Num. of Sites	%	Num. of Sites	%	
Number of Tracks							
1	15	48.4	10	55.6	19	61.3	0.8
≥2	16	51.6	8	44.4	12	38.7	1.3
90 Degree Crossing							
No	20	64.5	8	44.4	14	45.2	1.4
Yes	11	35.5	10	55.6	17	54.8	0.6
Traffic Control System Nearby							
No	8	25.8	11	61.1	7	22.6	1.1
Yes	23	74.2	7	38.9	24	77.4	1.0
Railroad Crossing Gates							
Four-quadrant gate	10	32.3	9	50.0	7	22.6	1.43
None	0	0.0	0	0.0	1	3.2	0
Two-quadrant gate	21	67.7	9	50.0	23	74.2	0.91
Number of Lanes							
2	4	12.9	7	38.9	8	25.8	0.5
3 and more	27	87.1	11	61.1	23	74.2	1.2
Total							
	31	100.0	18	100.0	31	100.0	80

The OR represents the relative risk of increased stopping rates in Zone 3 with the RDE implementation. If OR > 1, the associated factor is more likely to experience an increased stopping rate in Zone 3; if OR < 1, the associated factor is more likely to experience a decreased stopping rate in Zone 3.

The analysis shows the impacts of the factors on the stopping rates in Zone 3 as presented below:

- **Number of tracks**—The OR for HRGCs with multiple tracks (≥ 2) is 1.3 that indicates multiple tracks are more likely to experience an increase in the Zone 3 stopping rates. The single-track HRGCs tend to decrease the Zone 3 stopping rate (OR = 0.8).
- ***Angle between roadway and tracks***—The OR for a screw angle (not 90 degree) experiences a higher likelihood of Zone 3 stopping rates (OR = 1.4). A right angle is more likely to decrease the Zone 3 stopping rate (OR = 0.8).
- ***Whether the HRGC is located within 200 feet of an intersection or midblock location that is controlled by a traffic control signal (TCS)***—With and without traffic controls near HRGCs may not have a significant influence on Zone 3 stopping rates since their ORs are close to 1.

- ***Type of railroad crossing gate*****—**The OR for four-quadrant gates is 1.43. Four-quadrant gates are usually associated with high traffic and long queues, consequently, this gate type is more likely to experience an increased Zone 3 stopping rates. Two-quadrant gates and no gates tend to connect to a decreased Zone 3 stopping rate (ORs = 0.91 and 0, respectively).
- ***Number of lanes*****—**HRGCs with multiple lanes (≥3) are more likely to experience an increased Zone 3 stopping rate (OR = 1.2). Two-lane HRGCs tend to experience a decreased Zone 2 stopping rate (OR = 0.5).

Based on the review of districts' RDE studies, the stopping rate in Zone 3 is influenced by the following characteristics:

- ***Non-right-angle Crossing***: When a railroad crossing is at an obtuse or acute angle, it can affect drivers' perception of the crossing and increase their caution. The non-perpendicular alignment may result in reduced visibility of approaching trains or create a perceived risk of collision, leading drivers to stop more frequently. The unique geometry of these crossings may contribute to the increased stopping behavior observed in Zone 3.
- ***Railroad Parallel to Road****:* In some cases, the railroad runs parallel to the roadway and intersects with another roadway. These crossings can pose risks if proper safety measures are not in place, such as warning signs, lights, gates, and audible signals. Lack of visibility or inadequate warning systems can increase the potential for crashes between vehicles and trains. In many cases, the intersecting road is at an acute or obtuse angle which increases the complexity of the HRGC geometry.
- ***Driveway Density****:* Driveways located close to the HRGC can reduce sight distances for drivers approaching the railroad crossing. Reduced sight distance means drivers have less time to react to the presence of a train and may choose to stop as a precautionary measure. The density of driveways on a roadway crossing the railroad might increase the stopping behavior in Zone 3.
- ***Traffic Congestion***: In areas where parallel railroads and roads exist, traffic congestion can be a problem, primarily if the crossings are heavily used or poorly designed. Increased traffic volumes, particularly during peak hours, can lead to delays, longer crossing times, and frustration for drivers.
- ***Driver Distraction***: Parallel railroads and roads in proximity may draw drivers' attention away from the road. Spectacular or unusual train movements, noise, or the mere presence of trains can cause distractions, potentially leading to crashes if drivers lose focus on the road ahead.
- ***Train Speed***: The speed of trains passing parallel to a road can affect safety. Higher-speed trains may require longer distances to stop in case of an emergency, potentially increasing the risk at crossings. Additionally, curves or obstructions along the railway line may limit driver and train operators' visibility, leading to potential hazards.

4 Review and Analysis of HRGC Safety Performance in Florida

This chapter covers (1) the analysis of contributing factors to fatal and serious injury crashes at HRGCs in Florida based on 5 years of crash data, (2) identification of HRGC crash hot spots in Florida and top 12 hot spot locations in each FDOT District, and (3) safety evaluation of HRGCs based on crash data, existing treatments, geometrics, and traffic conditions. The safety evaluation provides valuable insights for the development of mitigation strategies and countermeasures.

4.1 Analysis of Contributing Factors in Florida

This section presents the crash data analysis conducted as part of this research effort. It starts by discussing the data collection efforts that were undertaken to collect the HRGC crash information. It then presents the descriptive statistics of HRGC crashes in Florida. A comprehensive and intensive effort was made to review the police reports of HRGC crashes. Police reports of the crashes that occurred at HRGC locations in Florida from 2017-2021 were extracted and reviewed. The rationale behind the review was to confirm the relationship of the crash to the railroad crossing and gather the information that is not available in the crash summary database. The following sub-sections provide additional information.

4.1.1 Police Reports Review of HRGC Crashes

The analysis was based on available crash data for the years 2017-2021. The crash data were retrieved from Signal Four Analytics database. The variable “Rail Crossings” among the Emphasis Areas was used to filter and identify HRGC crashes. For the period 2017-2021, a total of 2,092 crashes were identified as potential HRGC crashes, as summarized in Table 4-1.

Table 4-1. Descriptive Statistics of HRGC Crashes by Year

Year	Potential HRGC Crashes	Actual HRGC Crashes *	Not HRGC Crashes
2017	425	348	77
2018	470	364	106
2019	436	349	87
2020	363	302	61
2021	398	327	71
Total	**2,092**	**1,690**	**402**

** After police report*

As can be observed in Table 4-1, 1,690 (80.8%) of 2,092 crashes are actual HRGC crashes, while 402 (19.2%) are not HRGC crashes. In addition to confirming whether the crashes occurred at HRGC locations, the police reports were manually reviewed to collect the following information:

- Whether or not the crash occurred at HRGC critical zone
- The major cause or contributing factor of the crash
- The at-fault vehicle or road user
- HRGC safety infrastructure such as traffic signs, signals, pavement markings, gates, surveillance, and others

- Any other information documented in narratives and crash illustration

Generally, this information is not available in the crash summary records and is essential to deducing patterns. For example, in Figure 4-1, being a semi-trailer with a fuel tank in tow, V2 stopped before the railroad (track) as required. V1, on the other hand, failed to safely stop or change lanes in response to V2 and ended up colliding with V2. The crash database correctly assigns this as "careless driving" but does not tell the sequences of events, such as "stopped at the track" or "left lane change was unsuccessful." In addition, the manual review revealed that the HRGC location is equipped with a crossbuck sign, flashing-light signals and automatic gates, a railroad dynamic envelope, and railroad crossing advance warning signs.

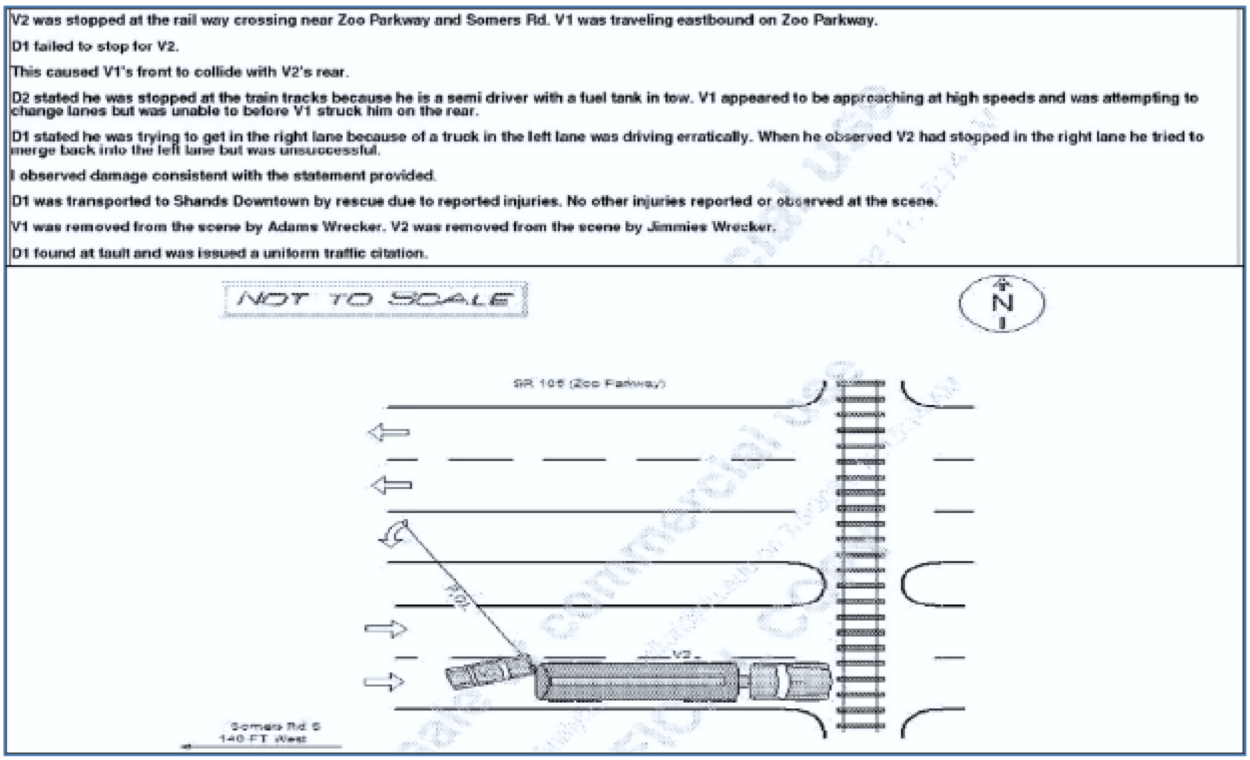


Figure 4-1. Police Report Sample on Narrative and Illustration of a HRGC Crash

Following the manual police report review, the actual HRGC crashes were further analyzed. The following sub-sections present the descriptive statistics of HRGC crashes by various variables such as crash severity, day of the week, time of the day, and first harmful event.

4.1.1.1 Crash Severity

Figure 4-2 provides the distribution of HRGC crashes by crash severity. Table 4-1 and Table 4-2 provides the HRGC crash statistics by year and crash severity. On average, about 4.4% of all HRGC crashes resulted in fatalities or serious injuries. The majority resulted in property damage only (76.4%) or injury (19.1%).

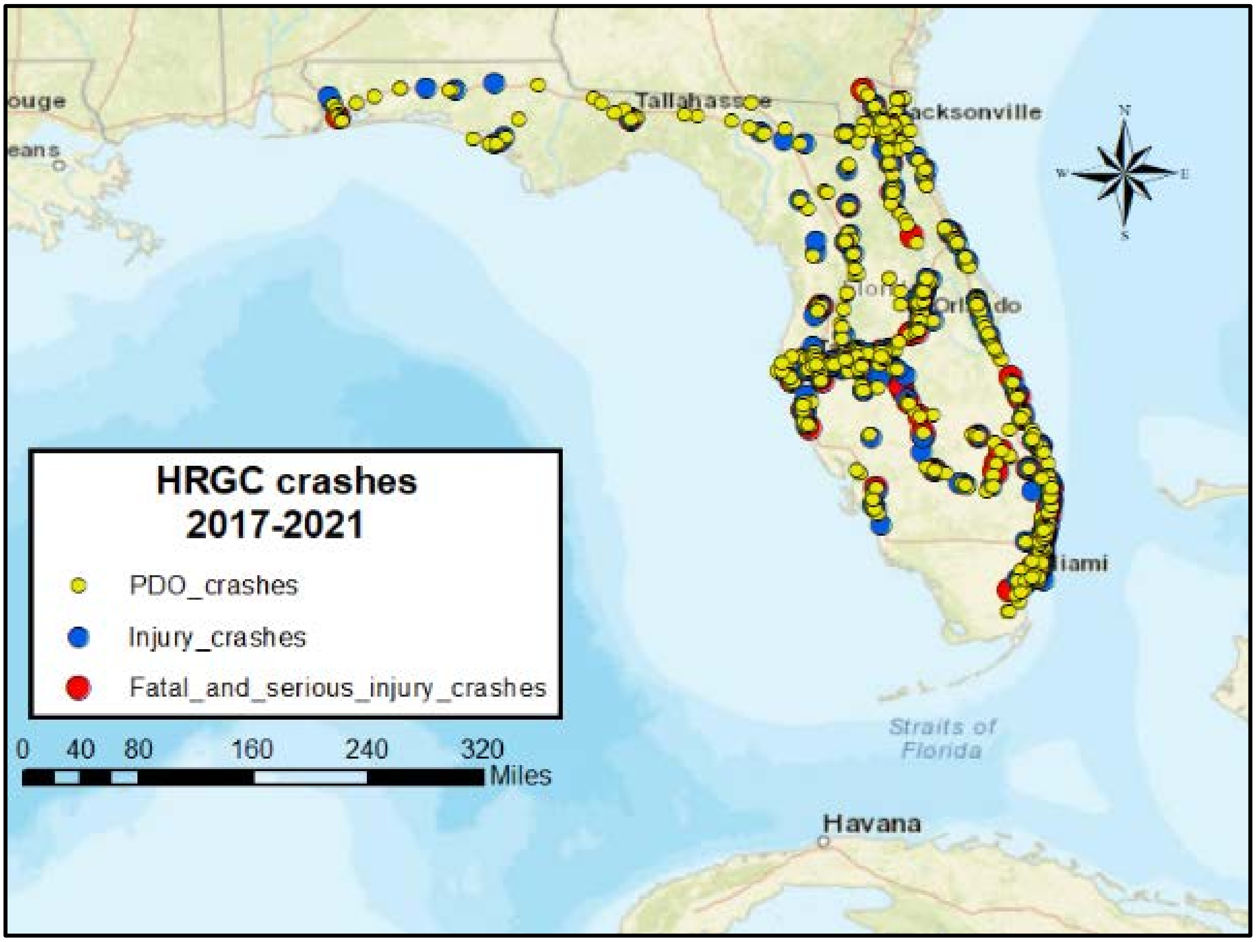


Figure 4-2. Spatial Distribution of HRGC Crashes in Florida by Severity (2017-2021)

Table 4-2. HRGC Crash Statistics by Year and Crash Severity

Year	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
2017	25	1.5%	68	4.0%	255	15.1%	348	20.6%
2018	13	0.8%	71	4.2%	280	16.6%	364	21.5%
2019	11	0.7%	57	3.4%	281	16.6%	349	20.7%
2020	10	0.6%	61	3.6%	231	13.7%	302	17.9%
2021	16	0.9%	66	3.9%	245	14.5%	327	19.3%
Total	**75**	**4.4%**	**323**	**19.1%**	**1,292**	**76.4%**	**1,690**	**100.0%**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

4.1.1.2 Temporal Characteristics

Table 4-3 provides HRGC crashes by day of the week. The highest proportion of fatal and serious injury HRGC crashes (0.9%) occurred on Thursdays, followed by Tuesdays and Fridays.

Interestingly, the smallest proportion of fatal and serious injury HRGC crashes (0.4%) occurred on Monday and Saturday.

Table 4-3. HRGC Crash Statistics by Day of Week and Crash Severity

Day of Week	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Monday	7	0.4%	53	3.1%	221	13.1%	281	16.6%
Tuesday	14	0.8%	53	3.1%	202	12.0%	269	15.9%
Wednesday	9	0.5%	55	3.3%	212	12.5%	276	16.3%
Thursday	16	0.9%	63	3.7%	225	13.3%	304	18.0%
Friday	13	0.8%	42	2.5%	228	13.5%	283	16.7%
Saturday	7	0.4%	36	2.1%	118	7.0%	161	9.5%
Sunday	9	0.5%	21	1.2%	86	5.1%	116	6.9%
Total	**75**	**4.4%**	**323**	**19.1%**	**1,292**	**76.4%**	**1,690**	**100.0%**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Table 4-4 and Figure 4-3 show the distribution of the crashes by different time periods. About three-quarters (74.8%) of crashes occurred between 6:00 am and 6:30 pm. Nearly half (44.9%) of crashes occurred during peak hours, i.e., morning peak, 6:00 am to 10:00 am, and evening peak, 3:30 pm to 6:30 pm. Specifically, 24.4% of crashes occurred during the morning peak, while 20.5% occurred during the evening peak. The highest proportion of crashes occurred during the daytime off-peak 10 am – 3:30 pm (29.9%).

Table 4-4. HRGC Crash Statistics by Time of Day and Crash Severity

Time of Day	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Morning peak 6 am – 10 am	20	0.7%	67	4.0%	335	19.8%	413	24.4%
Daytime off-peak 10 am – 3:30 pm	10	1.2%	103	6.1%	383	22.7%	506	29.9%
Evening peak 3:30 pm – 6:30 pm	11	0.6%	64	3.8%	273	16.2%	347	20.5%
Nighttime off-peak 6:30 pm – 6 am	34	2.0%	89	5.3%	301	17.8%	424	25.1%
Total	**75**	**4.4%**	**323**	**19.1%**	**1,292**	**76.4%**	**1,690**	**100.0%**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

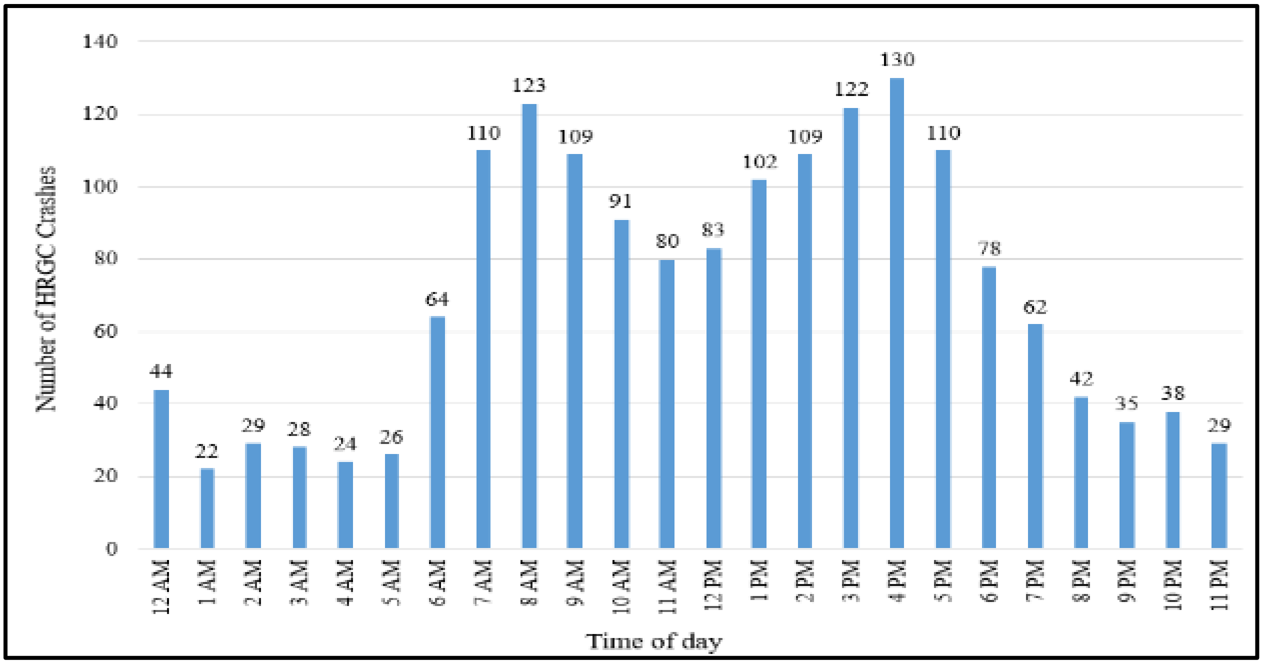


Figure 4-3. Distribution of HRGC Crashes by Different Time Periods

4.1.1.3 First Harmful Event

Table 4-5 provides the HRGC crash statistics by first harmful event and crash severity. Most fatal and severe injury HRGC crashes involved a collision between motor vehicles in transport (63.3%). About 9.4% of crashes involved railway vehicles (i.e., train or train engine). Other first harmful events included collision with fixed objects, collision with non-fixed objects, and others, as presented in Table 4-5.

Table 4-5. HRGC Crash Statistics by First Harmful Event

First Harmful Event	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Motor vehicle	25	1.5%	210	12.4%	835	49.4%	1070	63.3%
Railway vehicle	30	1.8%	35	2.1%	94	5.6%	159	9.4%
Roadside object	12	0.7%	57	3.4%	275	16.3%	344	20.4%
Non-fixed objects or pedestrian	8	0.5%	21	1.2%	88	5.2%	117	6.9%
Total	**75**	**4.4%**	**323**	**19.1%**	**1,292**	**76.4%**	**1,690**	**100.0%**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

4.1.1.4 Impact Type

The impact type of HRGC crashes (1,690 out of 2,092) are presented in Table 4-6. A majority of HRGC crashes were rear-end collisions (47.4%), followed by off-road and angle collisions. Noticeably, off-road crashes had the highest fatal and serious injury crashes (2.4%), followed by angle crashes.

Table 4-6. HRGC Crash Statistics by Impact Type

Impact Type	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Angle or Sideswipe	20	1.2%	56	3.3%	200	11.8%	276	16.3%
Head On	2	0.1%	9	0.5%	15	0.9%	26	1.5%
Off-road or Rollover	39	2.3%	97	5.7%	451	26.7%	587	34.7%
Rear End	14	0.8%	161	9.5%	626	37.0%	801	47.4%
Total	**75**	**4.4%**	**323**	**19.1%**	**1,292**	**76.4%**	**1,690**	**100.0%**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

4.1.1.5 Driver Characteristics

Table 4-7 presents drivers' contributing factors to a crash for HRGC crashes (1,690 out of 2,092). This variable identifies the driver's action(s) that may have contributed to the traffic crash. The results in Table 4-7 reveal that careless or aggressive driving contributed the most to the HRGC crashes by about 55.5%. Other contributing factors included drivers' actions such as swerving or avoiding due to wind, slippery surface, a motor vehicle, object, or non-motorist in the roadway. Besides, there were instances when drivers did not directly contribute to the crashes, such as vehicles being struck by thrown or falling objects, fire, or explosion.

Table 4-7. HRGC Crash Statistics by Driver's Contributing Factor

Driver's Contributing Factor	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
No contributing factor	4	0.2%	51	3.0%	271	16.0%	326	19.3%
Careless or aggressive driving	40	2.4%	188	11.1%	710	42.0%	938	55.5%
Disregarded signs or signals or markings	13	0.8%	28	1.7%	74	4.4%	115	6.8%
Other contributing factor	18	1.1%	56	3.3%	237	14.0%	311	18.4%
Total	**75**	**4.4%**	**323**	**19.1%**	**1,292**	**76.4%**	**1,690**	**100.0%**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

4.1.2 Factors Contributing to Fatal and Serious Injury Crashes at HRGCs in Florida

4.1.2.1 Multinomial Logistic Model

The multinomial logistic (MNL) model was developed to identify factors influencing the injury severity of HRGC crashes. It is worth mentioning that the injury severity is often reported on a KABCO scale, namely fatal (K), incapacitated injury (A), non-incapacitated injury (B), possible injury (C), or property damage only (PDO). To obtain statistically reliable estimates, this research used three injury severity categories by combining fatal (K) and incapacitated injury (A) (i.e., K+A); non-incapacitated injury (B) and possible injury (C) (i.e., B+C); and finally, PDO. An individual crash injury severity among the given severities was predicted if the crash severity likelihood function was maximum for that particular severity. Each crash severity likelihood function, which is a dimensionless measure of the likelihood of a crash, was considered a deterministic component and an error/random component. While the deterministic part is assumed to contain variables that can be measured, the random part corresponds to the unaccounted factors that impact injury severity. The deterministic part of the crash severity likelihood is designated as a linear function of the driver, roadway, vehicle, and weather characteristics, as shown in Equation 1 as shown below.

$$V_j = ASC_j + \sum_{k=1}^{K} b_{k,j} X_k \tag{1}$$

where,

V_j = systematic component of crash severity likelihood for severity *j*,
ASC_j = alternative specific constant for crash severity *j*,
$b_{k,j}$ = the regression coefficient for crash severity *j* and variable *k*, *k* =1, ..., K,
X_{ki} = independent variable *k*, and
K = a total number of independent variables included in the model.

The logit model was derived assuming that the error components are extreme value (or Gumbel) distributed (McFadden, 1981). The probability for each crash severity is given by Equation 2.

$$P_j = \frac{e^{V_j}}{\sum_{j=1}^{J} e^{V_j}} \tag{2}$$

where,

P_j = probability of the occurrence of crash severity *j*, and
J = total number of crash severities to be modeled.

The adjusted probability for each severity category is estimated using Equations 3 - 5, as shown:

$$P_{K+A} = \frac{e^{V_{K+A}}}{1 + e^{V_{K+A}} + e^{V_{B+C}} + e^{V_O}} \tag{3}$$

$$P_{B+C} = \frac{e^{V_{B+C}}}{1 + e^{V_{K+A}} + e^{V_{B+C}} + e^{V_O}} \tag{4}$$

$$P_O = 1 - (P_{K+A} + P_{B+C}) \tag{5}$$

4.1.2.2 Data Description

Table 4-8 presents the descriptive statistics of explanatory variables from the 1,609 valid data points. Most of these variables are self-explanatory. Crash contributing factors and the first harmful event are further explained in Table 4-9.

Table 4-8. Descriptive Statistics of HRGC Crashes

Variable	Factor	Count	%
HRGC intersection	Upstream	949	56.2%
	Critical zone	635	37.6%
	Downstream	106	6.2%
Time of day	Morning peak (6 am – 10am)	413	24.4%
	Daytime off-peak (10 am – 3:30 pm)	506	29.9%
	Evening peak (3:30 pm – 6:30 pm)	347	20.5%
	Nighttime off-peak (6:30 pm – 6 am)	424	25.2%
Day of the week	Weekday (Monday – Friday)	1413	83.6%
	Weekend (Saturday – Sunday)	277	16.4
Alcohol involvement	No	1,622	96.0%
	Yes	68	4.0%
Crash contributing factor	No contributing factor	326	19.3%
	Careless or aggressive driving	938	55.5%
	Disregarded traffic signs, signals, or pavement markings	115	6.8%
	Other contributing action	311	18.4%
First harmful event	Motor vehicle	1,070	63.3%
	Railway vehicle	159	9.4%
	Roadside object	344	20.4%
	Non-fixed objects or pedestrian	117	6.9%
Crash type	Angle or Sideswipe	276	16.3%
	Head On	26	1.5%
	Rear End	801	47.4%
	Off-road or Rollover	587	34.8%
Posted speed limit	15 – 35 mph	688	40.7%
	40 – 45 mph	578	34.2%
	> 45 mph	269	15.9%
	Unknown	155	9.2%
Total number of lanes	≤ 3 lanes	664	39.3%
	4 lanes	637	13.8%
	≥ 5 lanes	234	19.0%
	Unknown	155	9.2%
Weather condition	Clear	1,308	77.4%
	Adverse	382	22.6%
Lighting condition	Daylight	1,221	77.2%
	Dark – lighted	244	14.4%
	Dark – not lighted	225	13.4%
Traffic way	One-way traffic way	69	4.1%
	Two-way, divided	896	53.0%
	Two-way, not divided	639	37.8%
	Two-way, not divided, with TWLTL	86	5.1%

Table 4-9. Description of Crash Contributing Factor and First Harmful Event Variables

Variable	Description	Factor	Explanation
Crash contributing factor	This variable identifies the actions by the driver that may have contributed to the traffic crash	No contributing factor	Struck by thrown or falling object, fire, or explosion,
		Careless or aggressive driving	Following too closely, improper turns, improper backing, improper passing, failing to keep in a proper lane, failing to yield right-of-way, overcorrecting or oversteering, wrong side, or wrong way, running off the roadway
		Disregarded traffic signs, signals, or pavement markings	Disregarded traffic signs, disregarded pavement markings, exceeded posted speed limit, ran stop, drove too fast for conditions, ran a red light, stopped on track
		Other contributing action	Swerving or avoiding due to wind, slippery surface, a motor vehicle, object, or non-motorist in the roadway
First harmful event	This variable identifies the first injury or damage-causing event that characterizes the traffic crash type	Non-fixed objects or pedestrian	Pedestrian, pedal cycle, thrown or falling object, other non-fixed objects
		Motor vehicle	Parked or in transport motor vehicle
		Railway vehicle	Train, train engine
		Roadside object	Ditch, embankment, traffic barrier, curb, support poles, track, tree, roadway median, guard arm, guardrail, other fixed objects

4.1.2.3 Model Results

Table 4-10 presents the multinomial logistic model results. The model treats the PDO as the base category. Variables in boldface are significant at a 90% confidence level. The following factors were found to significantly increase the likelihood of fatal and serious injury crashes at HRGC locations:

- HRGC critical zones,
- alcohol involvement,
- disregarding traffic signs, signals, or pavement markings,
- other contributing factors, such as swerving or avoiding,
- crashes involving railway vehicles, and
- speed of 40 mph or more.

Table 4-10. Multinomial Logistic Model Results

Variable	Factor	Severity	Estimate	Std. Error	z-value	Pr (>|z|)	Relative Risk Ratio
Intercept		K+A	**-1.9358**	**0.8712**	**-2.2220**	**0.0263**	**0.1443**
		B+C	**-1.5139**	**0.5846**	**-2.5895**	**0.0096**	**0.2201**
HRGC intersection	Upstream		*Base*				
	Critical zone	K+A	**0.1402**	**0.5182**	**2.2705**	**0.0467**	**1.1505**
		B+C	**-0.7267**	**0.2698**	**-2.6930**	**0.0071**	**0.4835**
	Downstream	K+A	0.4391	0.6221	0.7058	0.4803	1.5513
		B+C	0.2860	0.3076	0.9297	0.3525	1.3310
Time of day	Nighttime off peak		*Base*				
	Daytime off peak	K+A	**-0.7241**	**0.4050**	**-1.7878**	**0.0738**	**0.4848**
		B+C	-0.1830	0.2231	-0.8203	0.4120	0.8328
	Evening peak	K+A	**-0.9886**	**0.5042**	**-1.9606**	**0.0499**	**0.3721**
		B+C	-0.1307	0.2408	-0.5426	0.5874	0.8775
	Morning peak	K+A	-0.5313	0.4392	-1.2098	0.2264	0.5878
		B+C	-0.2160	0.2394	-0.9025	0.3668	0.8057
Alcohol involvement	No		*Base*				
	Yes	K+A	**1.0862**	**0.5750**	**1.8888**	**0.0589**	**2.9629**
		B+C	0.6094	0.4031	1.5117	0.1306	1.8393
Crash contributing factor	No contributing factor		*Base*				
	Careless or aggressive driving	K+A	0.9075	0.5717	1.5875	0.1124	2.4781
		B+C	0.2168	0.2275	0.9527	0.3407	1.2421
	Disregarded traffic signs, signals, or pavement markings	K+A	**1.2078**	**0.6865**	**1.7592**	**0.0785**	**3.3460**
		B+C	0.5029	0.3369	1.4929	0.1355	1.6535
	Other contributing action	K+A	**1.5084**	**0.6276**	**2.4036**	**0.0162**	**4.5196**
		B+C	**0.5592**	**0.2947**	**1.8977**	**0.0577**	**1.7493**
First harmful event	Non-fixed object or pedestrian		*Base*				
	Motor vehicle	K+A	**-2.2722**	**0.6800**	**-3.3417**	**0.0008**	**0.1031**
		B+C	-0.0639	0.5344	-0.1195	0.9049	0.9381
	Railway vehicle	K+A	**0.3079**	**0.6650**	**1.8630**	**0.0643**	**1.3606**
		B+C	0.6575	0.5957	1.1036	0.2698	1.9299
	Roadside object	K+A	**-1.7685**	**0.6393**	**-2.7665**	**0.0057**	**0.1706**
		B+C	0.3986	0.5395	0.7388	0.4600	1.4897
Posted speed limit	15 – 35 mph		*Base*				
	40 – 45 mph	K+A	**0.7941**	**0.3819**	**2.0797**	**0.0376**	**2.2125**
		B+C	**0.3410**	**0.1795**	**1.8994**	**0.0575**	**1.4064**
	> 45 mph	K+A	**2.8862**	**0.4671**	**6.1787**	**0.0000**	**17.9256**
		B+C	**1.1761**	**0.2939**	**4.0017**	**0.0001**	**3.2417**
Total number of lanes	≤ 3 lanes		*Base*				
	4 lanes	K+A	-0.3753	0.3711	-1.0112	0.3119	0.6871
		B+C	0.0687	0.1892	0.3628	0.7167	1.0711
	≥ 5 lanes	K+A	**-1.1579**	**0.5937**	**-1.9504**	**0.0511**	**0.3141**
		B+C	-0.2117	0.2354	-0.8992	0.3686	0.8092

4.2 Identification of Hotspots in Florida

This section focuses on identifying the HRGC crash hotspots in Florida. The analysis was based on five years of HRGC crashes for the period 2017-2021. Geographic Information System (GIS)-based spatial clustering analysis was used to identify the top HGRC crash hotspots in each FDOT District.

4.2.1 Highway Railroad Grade Crossing Crash Data

Five years of HRGC crash data (2017-2021) was used in the analysis. As discussed earlier, a total of 2,092 potential HRGC crashes were retrieved from the Signal Four Analytics database. Of these crashes, 287 (13.7%) had no coordinates, meaning they could not be spatially plotted. The remaining 1,805 (86.3%) crashes were further studied. Figure 4-4 shows the spatial distribution of HRGC crashes. Note that the purple lines in the figure are state roads. HRGC crashes are not evenly distributed across Florida but are clustered more in urban areas, particularly in South Florida (from West Palm Beach to Miami), Tampa Bay and Orlando regions, and Jacksonville area experienced a moderate density of HRGC crashes.

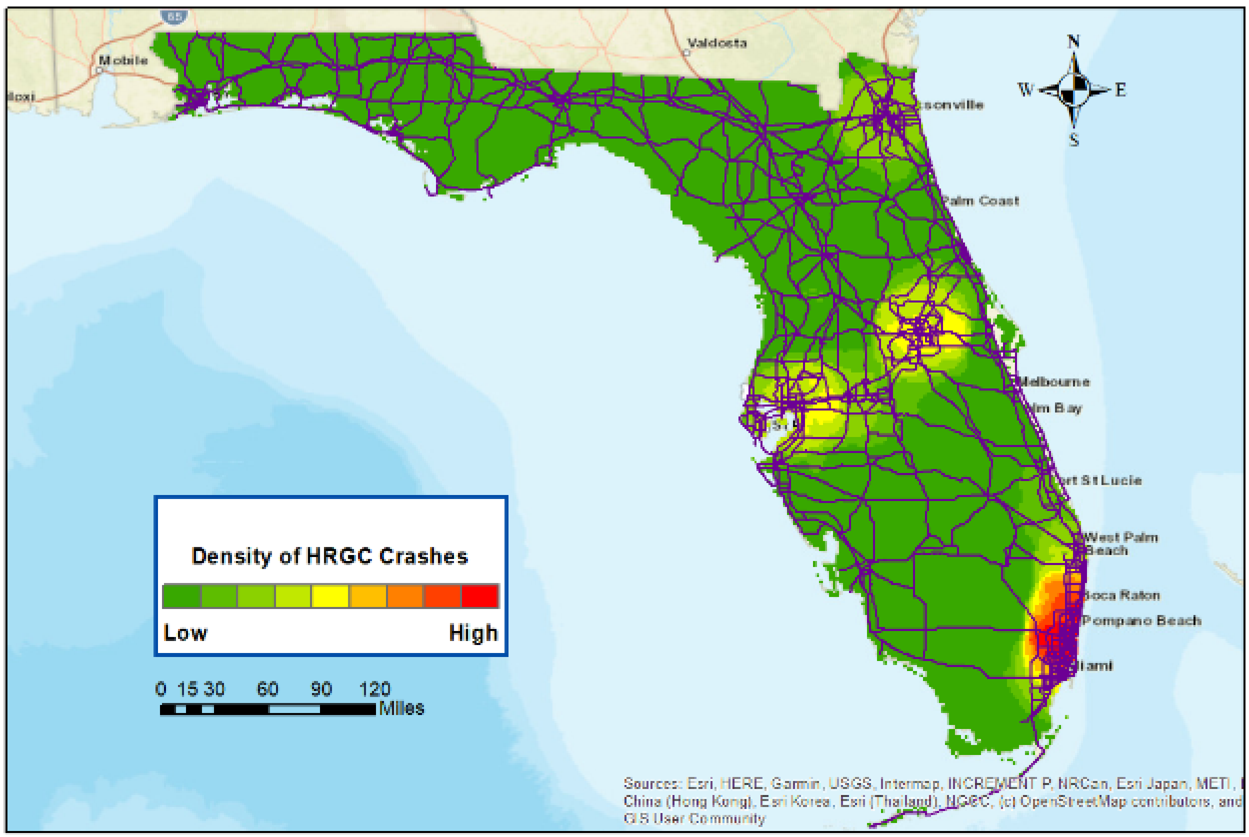


Figure 4-4. Spatial Distribution of HRGC Crashes in Florida by Density

4.2.2 Analysis Framework to Identify Crash Hotspots

A GIS-based spatial clustering analysis was used to identify HRGC crash hotspots. Figure 4-5 illustrates the concept, where the *X*- and *Y*-axis represent the spatial terrain of the region. The *Z*-

axis represents the number of HRGC crashes. This approach creates a service area (along the road network) for each HRGC crash and then merges the overlapping service areas. Depending on the density of the HRGC crashes, each overlapping service area will cover a varying number of HRGC crashes. The merged service areas are then ranked based on the total number of HRGC crashes identified within these areas and their equivalent property damage only (EPDO) scores. The following steps constitute the framework adopted to identify the HRGC crash hotspots in each FDOT District:

1. Develop the Network Dataset
2. Identify Service Area for Each Crash
3. Merge Overlapping Service Area
4. Identify Candidate Hotspots

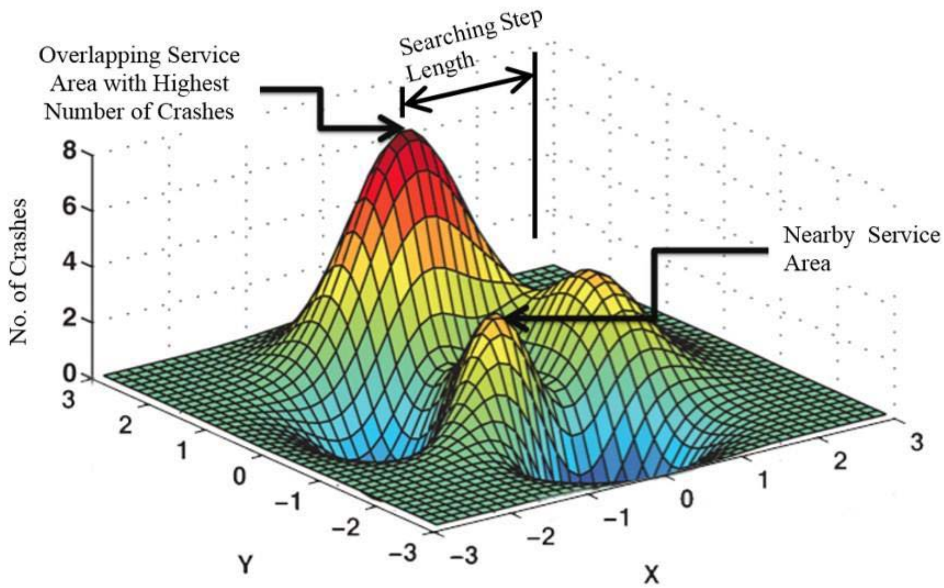


Figure 4-5. GIS-based Concept to Identify HRGC Crash Hotspots

Step 1: Develop Network Dataset

The network dataset was developed based on the 2022 Florida GIS Basemap Routes extracted from the FDOT shapefiles. The Basemap Routes Network included 17,747 records covering Florida's road network. The dataset was developed using the *Network Dataset* function in GIS.

Step 2: Identify the Service Area for Each Crash

The HRGC crash service area was identified based on a default radius. The *radius of the HRGC crash service area* helps determine the total number of HRGC crashes that occurred within the core area. The radius will affect the number of crashes within the overlapping service area. The larger the radius, the higher the number of crashes, and the larger the service area. Since the HRGC crashes are not evenly distributed across Florida, setting the appropriate values for all districts was highly crucial. If the values are too big, the hotspot region will cover an extensive area (downtown), and if the values are too small, the hotspot region will be too small, especially in rural areas. The radius of 0.25 miles was selected and used in this analysis based on a trial-and-error method.

Step 3: Merge Overlapping Service Areas

Once the service areas for each HRGC crash were identified, the next step was to merge the overlapping service areas and determine the total number of HRGC crashes that occurred within the core area. Once the overlapping service areas were merged, the next step was to check if the number of crashes within the overlapping service area was appropriate for additional network-space analysis.

Step 4: Identify Candidate Hotspots

This step focuses on selecting HRGC crash hotspots within each FDOT District based on the number of crashes and the EPDO weighting method. The EPDO weighting method was used to calculate the EPDO score of candidate crash hotspots based on injury weighting. Note that the EPDO score considers the severity breakdown of crashes, providing greater weight to fatal and injury crashes over PDO crashes. Table 4-11 provides the EPDO weighting scores for different injury severity levels based on the comprehensive crash cost. Fatal crashes were assigned an EPDO weight of 1,414.29. This was calculated as the ratio of fatal crash cost to the PDO crash cost. Similarly, other injury types were assigned an EPDO weight as presented in the table. Finally, the PDO crashes were assigned a weight of 1.0.

Table 4-11. EPDO Weighting Scores for Different Injury Severity Levels

Crash Severity	Comprehensive Crash Cost	EPDO Factor / Weight
Fatal (K)	$ 10,890,000.00	1,414.29
Incapacitating / Serious Injury (A)	$ 888,030.00	115.33
Non-incapacitating / Minor Injury (B)	$ 180,180.00	23.40
Possible Injury (C)	$ 103,950.00	13.50
Property Damage Only (O)	$ 7,700.00	1.00

Source: FDOT Safety Office[8]

4.2.3 HRGC Crash Hotspots

Table 4-12 lists the top 12 HRGC crash hotspots in each FDOT District based on the EPDO scores and Figure 4-6 through Figure 4-12 map the top 10 HRGC hotspots in each District.

[8] Florida Department of Transportation State Safety Office's Crash Analysis Reporting (CAR) System, analysis years 2015 through 2019. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/fdm/2023/2023-fdm-complete.pdf?

Table 4-12. Top HRGC Crash Hotspots in Each FDOT District

District	Rank	Service Area #	Search Radius of a Service Area (mi)	Total Crashes	K - Fatal	A – Serious Injury	B - Minor Injury	C - Possible Injury	O - PDO	EPDO Score
1	1	243	0.42	5	1	0	0	1	3	1430.79
1	2	268	0.31	3	1	0	0	1	1	1428.79
1	3	295	0.32	3	1	0	0	0	2	1416.29
1	4	476	0.39	2	1	0	0	0	1	1415.29
1	5	327	0.30	1	1	0	0	0	0	1414.29
1	6	331	0.31	1	1	0	0	0	0	1414.29
1	7	460	0.48	4	0	2	0	1	1	245.16
1	8	400	0.36	5	0	1	1	1	2	154.23
1	9	306	0.35	5	0	1	0	2	2	144.33
1	10	485	0.31	2	0	1	1	0	0	138.73
1	11	452	0.35	3	0	1	0	1	1	129.83
1	12	312	0.34	3	0	1	0	0	2	117.33
2	1	810	0.31	2	1	0	0	0	1	1415.29
2	2	649	0.31	1	1	0	0	0	0	1414.29
2	3	678	0.30	1	1	0	0	0	0	1414.29
2	4	697	0.31	1	1	0	0	0	0	1414.29
2	5	655	0.38	4	0	1	1	0	2	140.73
2	6	788	0.34	5	0	1	0	1	3	131.83
2	7	713	0.35	4	0	0	1	2	1	51.40
2	8	690	0.31	2	0	0	2	0	0	46.80
2	9	751	0.34	5	0	0	1	1	3	39.90
2	10	661	0.31	3	0	0	1	1	1	37.90
2	11	715	0.42	3	0	0	1	1	1	37.90
2	12	772	0.33	2	0	0	1	1	0	36.90
3	1	776	0.31	4	0	1	0	1	2	130.83
3	2	794	0.36	3	0	1	0	1	1	129.83
3	3	705	0.31	1	0	0	1	0	0	23.40
3	4	787	0.34	1	0	0	1	0	0	23.40
3	5	811	0.31	1	0	0	1	0	0	23.40
3	6	813	0.31	1	0	0	1	0	0	23.40
3	7	819	0.31	1	0	0	1	0	0	23.40
3	8	711	0.39	3	0	0	0	1	2	15.50
3	9	703	0.31	1	0	0	0	1	0	13.50
3	10	729	0.25	1	0	0	0	1	0	13.50
3	11	793	0.31	1	0	0	0	1	0	13.50
3	12	815	0.31	1	0	0	0	1	0	13.50
4	1	214	0.89	26	2	0	0	1	23	2865.07
4	2	244	0.44	5	1	1	1	0	2	1555.01
4	3	257	0.41	6	1	0	3	1	1	1498.99
4	4	133	0.62	22	1	0	2	1	18	1492.59
4	5	99	0.54	10	1	0	2	1	6	1480.59
4	6	134	0.37	6	1	0	1	0	4	1441.69
4	7	130	0.37	13	1	0	0	1	11	1438.79
4	8	93	0.46	6	1	0	0	1	4	1431.79
4	9	116	0.65	5	1	0	0	1	3	1430.79
4	10	125	0.41	4	1	0	0	0	3	1417.29
4	11	163	0.31	4	1	0	0	0	3	1417.29
4	12	208	0.33	3	1	0	0	0	2	1416.29

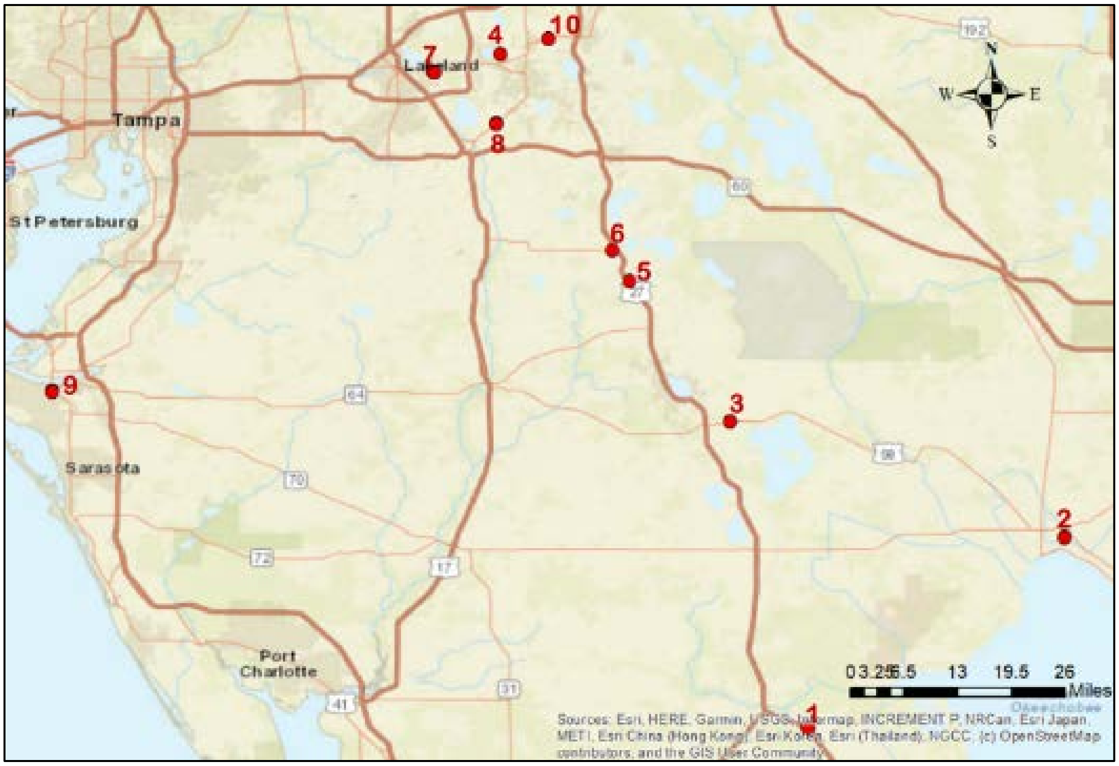


Figure 4-6. Top 10 HRGC Crash Hotspots of FDOT District 1

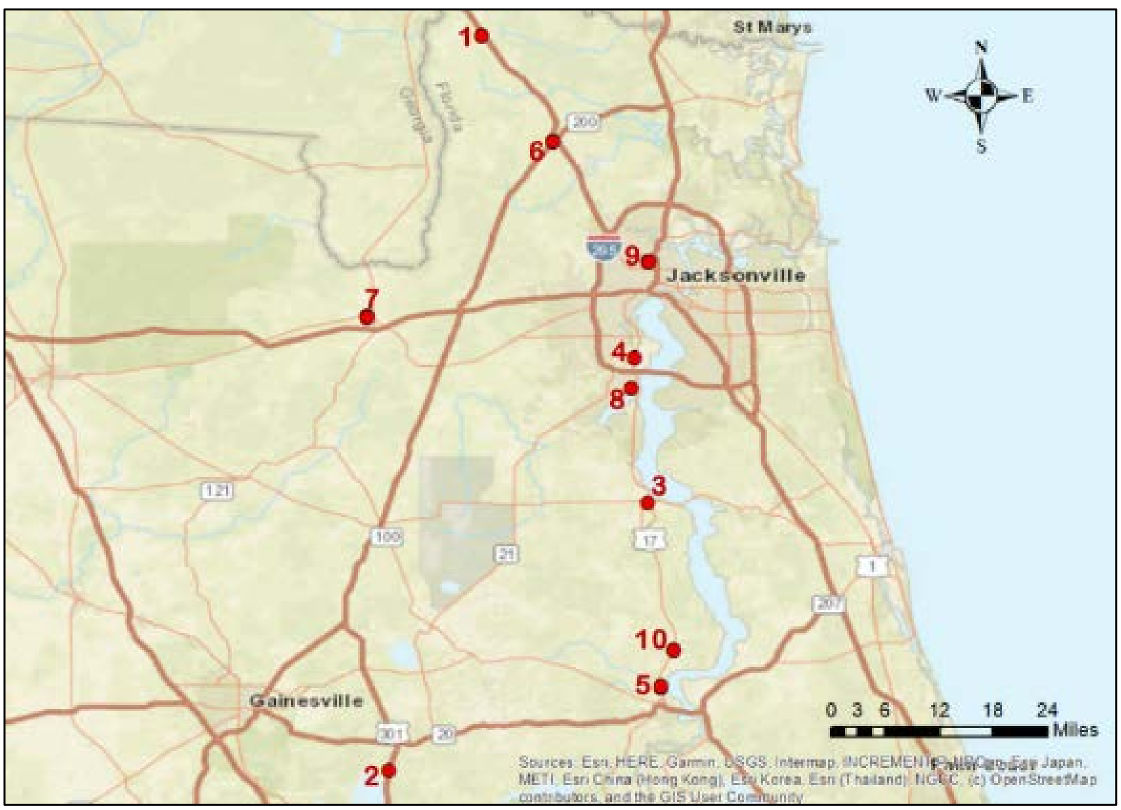


Figure 4-7. Top 10 HRGC Crash Hotspots of FDOT District 2

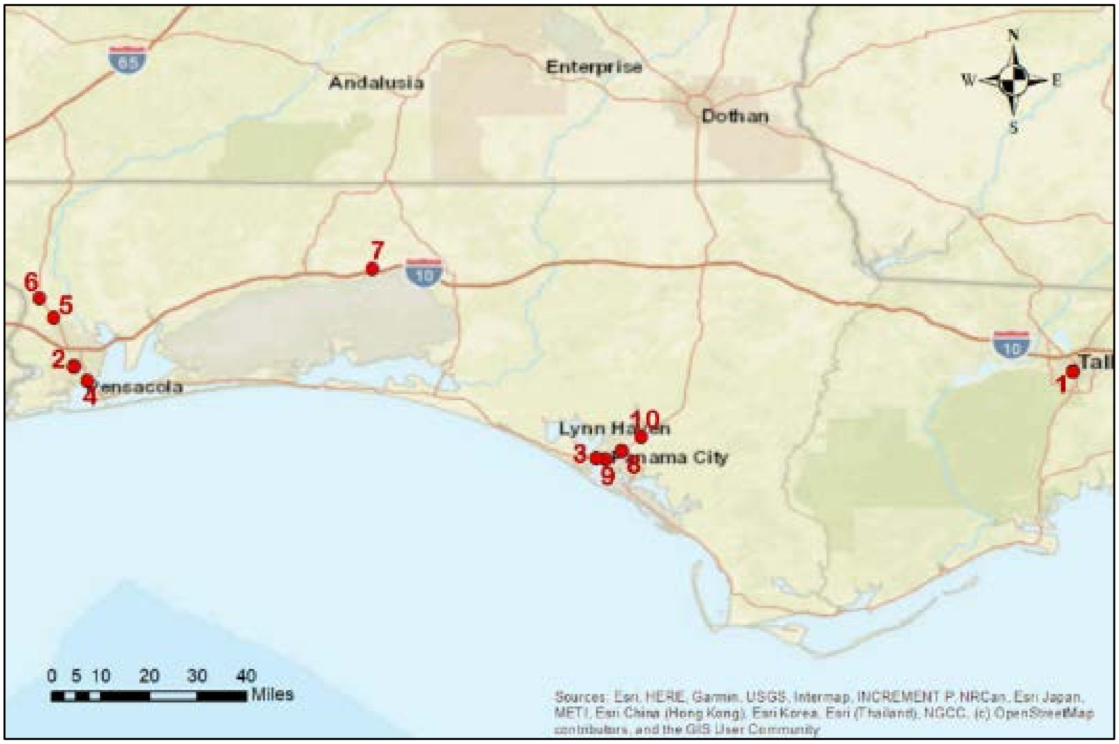


Figure 4-8. Top 10 HRGC Crash Hotspots of FDOT District 3

Figure 4-9. Top 10 HRGC Crash Hotspots of FDOT District 4

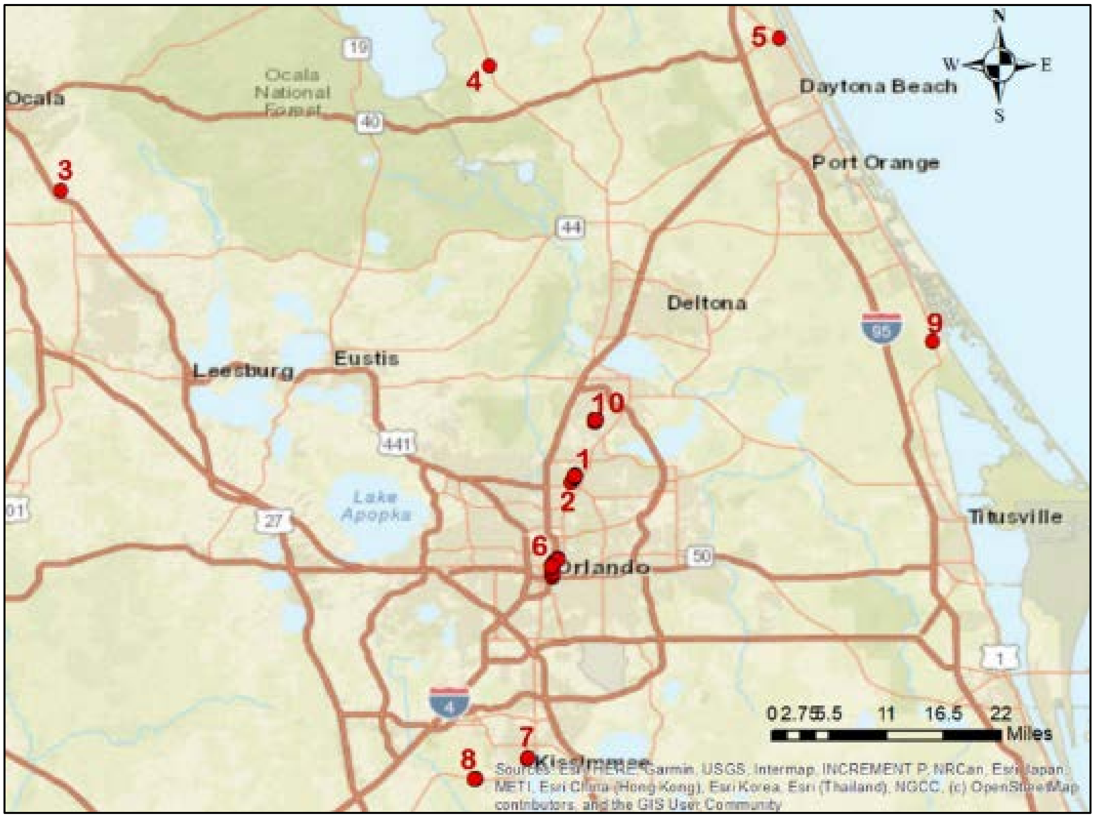


Figure 4-10. Top 10 HRGC Crash Hotspots of FDOT District 5

Figure 4-11. Top 10 HRGC Crash Hotspots of FDOT District 6

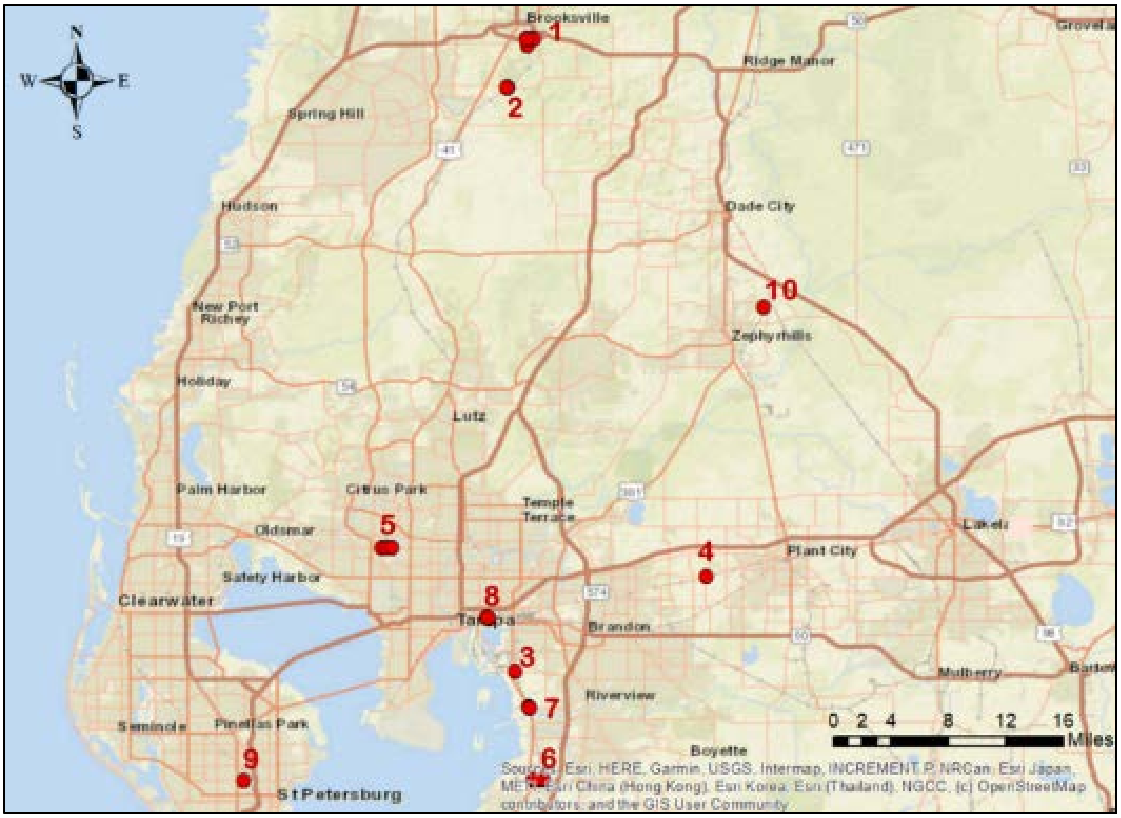


Figure 4-12. Top 10 HRGC Crash Hotspots of FDOT District 7

4.3 Review of Existing Treatments, Geometries, and Traffic Conditions

This section focuses on reviewing the existing treatments, geometrics, and traffic conditions of the identified HRGCs locations. The review also identifies issues to be addressed and provides a list of HRGCs that need special treatments to improve safety.

4.3.1 Highway Railroad Grade Crossing Data

The HRGC locations data was collected from the FDOT shapefiles as of 2022. The shapefile had 1,949 potential HRGC locations. Figure 4-13 shows the spatial distribution of HRGCs. Note that the purple lines in the figure are state roads. HRGCs are widely but not evenly distributed across Florida. There are clusters in urban areas, particularly in Tampa Bay, South Florida (from West Palm Beach to Miami) regions, Orlando, and Jacksonville areas.

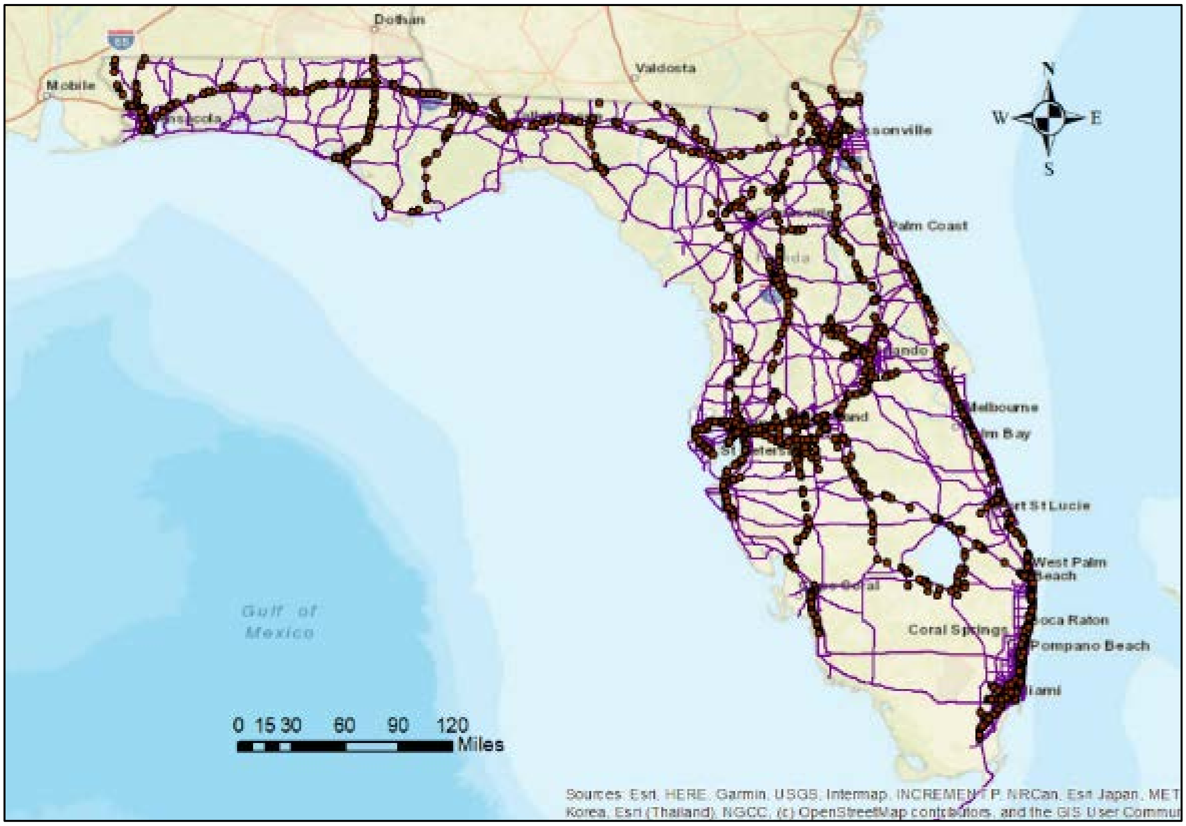


Figure 4-13. Spatial Distribution of HRGC Locations across Florida

4.3.2 Review of Existing Treatments at HRGCs

Similar to the police report review process, the review of HRGCs was conducted via an in-house web tool that streamlines the review process. Figure 4-14 presents an example of how the HRGC locations were reviewed. Using the web-based application, each HRGC location was viewed in Google Maps to answer a set of questions. The review was particularly intended to gather existing treatments and geometrics concerning HRGC locations. Additional geometric variables such as number of lanes, median type, and posted speed limit were later extracted using ArcGIS application. Traffic conditions are reported in terms of the AADT, which was also extracted using ArcGIS.

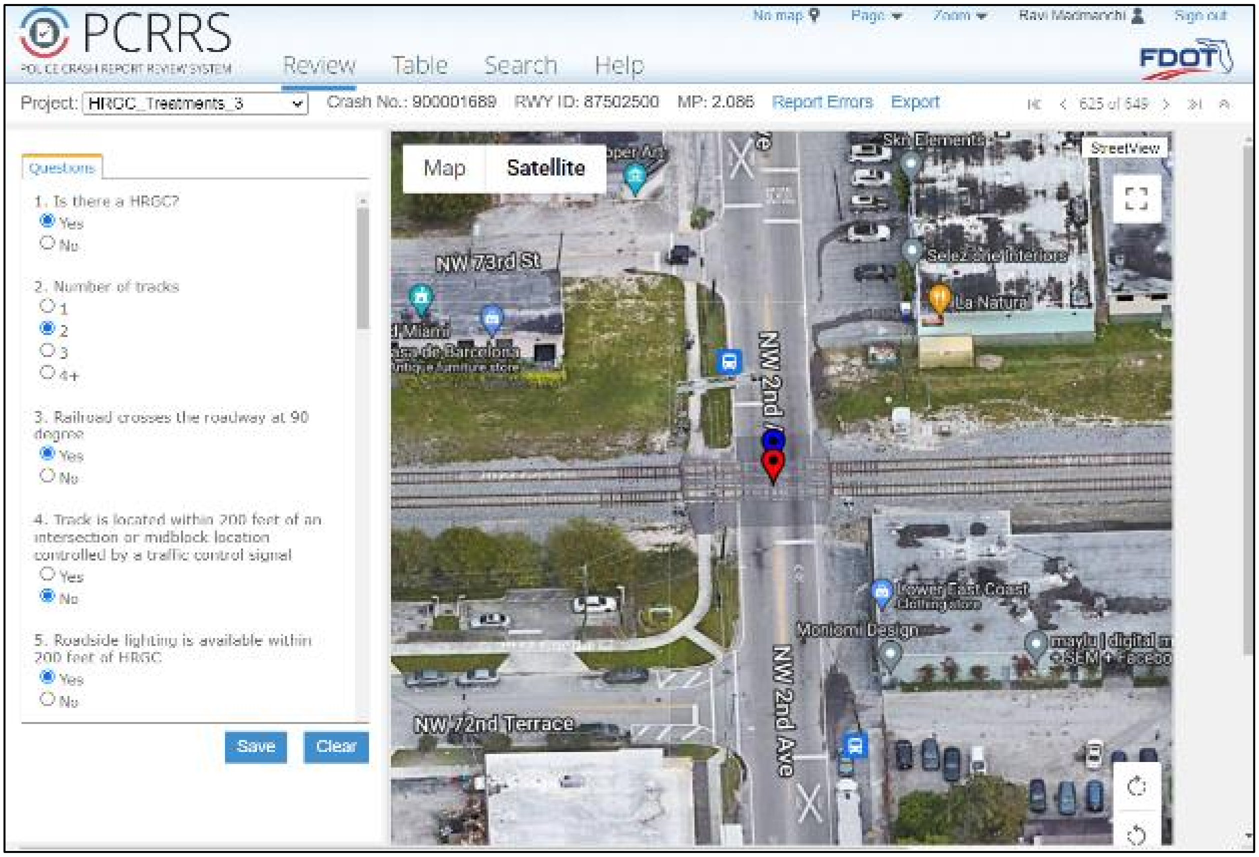


Figure 4-14. Excerpt of HRGC Review

Table 4-13 presents the review questions, together with the type of questions, description, and a set of attribute values. All questions are intended to gather information about the existing treatments and geometrics. Since the review was done using Google Maps, it was important that the street view date is included.

Table 4-13. Information Collected for Each HRGC Location in Florida

Question	Description	Attribute Values
HRGC	Presence or absence of a Highway-Railroad Grade Crossing at given coordinates	Presence (Yes); Absence (No)
Number of Tracks	Number of tracks that crosses the roadway at a Highway-Railroad Grade Crossing location	Number (Integer)
HRGC_Angle_90	Whether the angle between the track(s) and the roadway at the Highway-Railroad Grade Crossing location is 90 degrees	Is 90 degrees (Yes); Is not (No)

Table 4-13. Information Collected for Each HRGC Location in Florida (Continued)

Question	Description	Attribute Values
Traffic control signal nearby	Whether the HRGC is located within 200 feet of an intersection or a midblock location that is controlled by a traffic control signal (TCS)	Presence (Yes); Absence (No)
Lighting	Presence of roadside lighting facilities within 200 feet of a Highway-Railroad Grade Crossing	Presence (Yes); Absence (No)
Pavement markings *(Check all that apply)*	Pavement markings within 100 feet of a Highway-Railroad Grade Crossing	Lane markings; X-Shape and R-R markings; Stop line; Yield line; Railroad Dynamic Envelope (RDE); Lane-use/Arrow; NO PASSING zone markings; Centerline markings; Other; None
Traffic signs *(Check all that apply)*	Traffic signs within the advance warning sign locations of a Highway-Railroad Grade Crossing	Crossbuck sign (R15-1), Supplemental number of tracks (R15-2P) plaque, Supplemental STOP sign, Supplemental YIELD sign, DO NOT STOP ON TRACKS sign (R8-8), Flashing DO NOT STOP ON TRACKS sign, Grade Crossing Advance Warning Sign (W10 Series), Emergency Notification Sign (I-13), TRACKS OUT OF SERVICE Sign (R8-9), Other, None
Traffic control signals *(Check all that apply)*	Traffic control signal(s) at a Highway-Railroad Grade Crossing	Flashing-light signals, Flashing-light signals & Automatic gates, Automated wayside horn, Traffic control signals, Pedestrian, and bicycle signals, Other, None
Railroad crossing gates *(Check all that apply)*	Type of a railroad-grade crossing gate at a Highway-Railroad Grade Crossing	Four-quadrant gate; Two-quadrant gate; Pedestrian automatic gate; Other; None
Pedestrian facilities *(Check all that apply)*	Pedestrian crossing facilities within 100 feet of a Highway-Railroad Grade Crossing	Pedestrian sidewalk, Pedestrian crosswalk, Pedestrian sign(s), Other, None
Additional safety measures *(Check all that apply)*	Traffic safety measures/devices within 100 feet of a Highway-Railroad Grade Crossing	Guards (e.g., anti-trespass panels); Guardrails; Speed reduction devices (e.g., hump, rumble strips); Object markers; Delineation devices (e.g., bollards, tubular markers); Crash cushions; Bells, Other; None
Street view image date	Google Maps Street view image date if present	mm/yyyy

4.3.2.1 HRGC Geometrics

The review revealed that 1,910 of 1,949 (i.e., 98.0%) were actual HRGCs. A total of 39 locations (i.e., 2.0%) were not considered HRGCs, a few being grade separated, some having railroad tracks removed, and the rest do not have any rail grade crossing. Of 1,910 HRGCs, nearly three-quarters have one railroad track crossing the roadway, as presented in Figure 4-15. The figure further shows that about a quarter of HRGCs have two railroad tracks, and a few (i.e., 3.4%) have three or more railroad tracks.

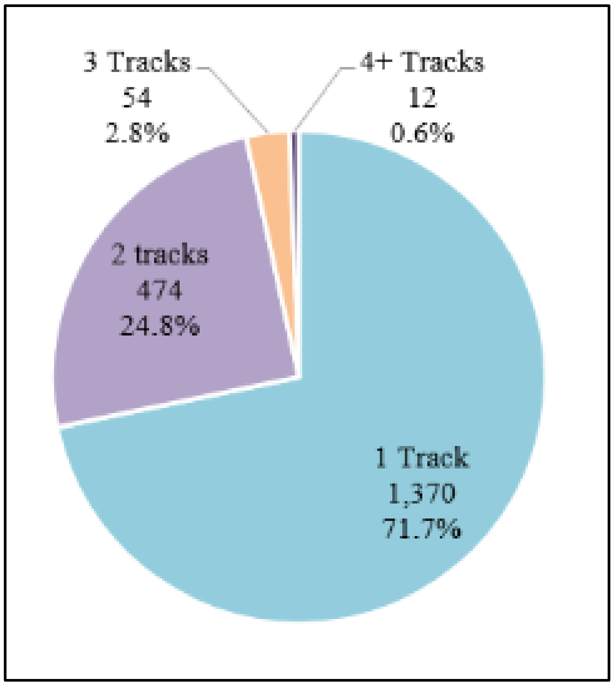


Figure 4-15. Number of Railroad Tracks at HRGCs

Figure 4-16 presents additional geometrics and roadside lighting availability. Most of the HRGCs are skewed (i.e., 59.9%), and a majority are equipped with roadside lighting within 200 ft (i.e., 65.2%). There are about 391 of 1,910 (i.e., 20.5%) of HRGCs that are located within 200 ft of an intersection or midblock location controlled by a traffic control signal. The Manual on Uniform Traffic Control Devices (MUTCD) specifies that if a highway-rail grade crossing is equipped with a flashing-light signal system and is located within 200 ft of an intersection or midblock location controlled by a traffic control signal, the traffic control signal should be provided with preemption. This recommendation improves operation efficiency and reduces the possibility of vehicles stopping within the track zone.

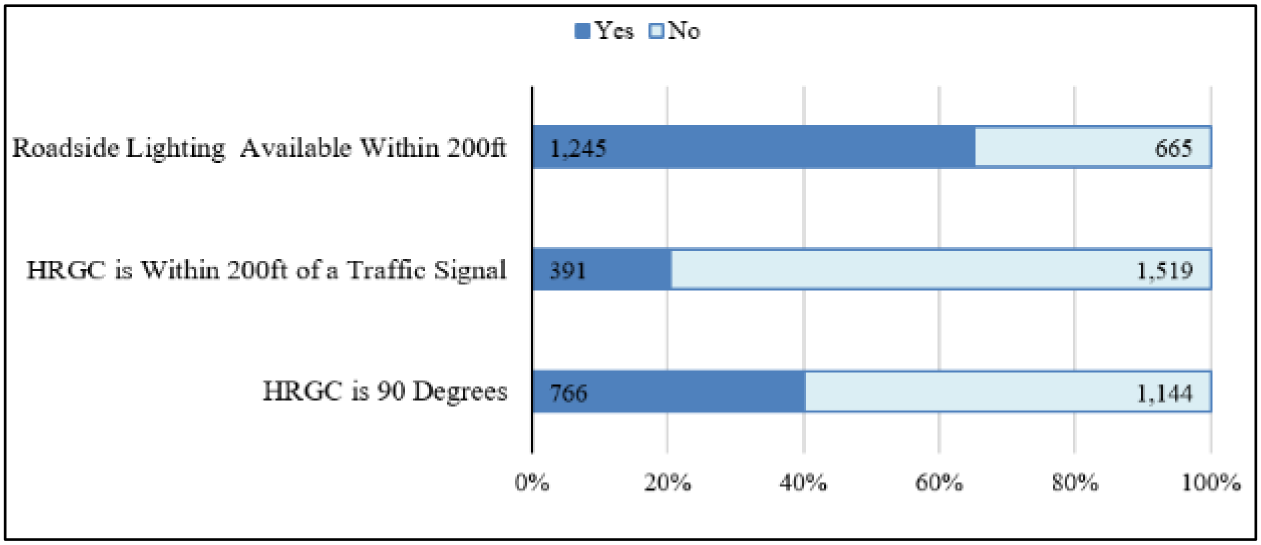


Figure 4-16. Roadside Lighting Availability, HRGC Angle, and Presence of Traffic Control Signal

4.3.2.2 Pavement Markings at Grade Crossings

The MUTCD requires that on paved roadways, pavement markings in advance of a grade crossing shall consist of an X, the letters RR, a no-passing zone marking (on two-lane, two-way highways with center line markings), and certain transverse lines, as shown in Figure 4-17. A stop line is especially installed to indicate the point behind which highway vehicles are or might be required to stop at grade crossings of paved roadways that are equipped with active control devices such as flashing-light signals, gates, or traffic control signals. Given the importance, the review was intended to gather all the information pertaining to pavement markings. In addition to documenting the existing pavement markings, the review also included lane use markings that are installed on an as-needed basis and railroad dynamic envelope (RDE) markings which are optional as per the MUTCD standards.

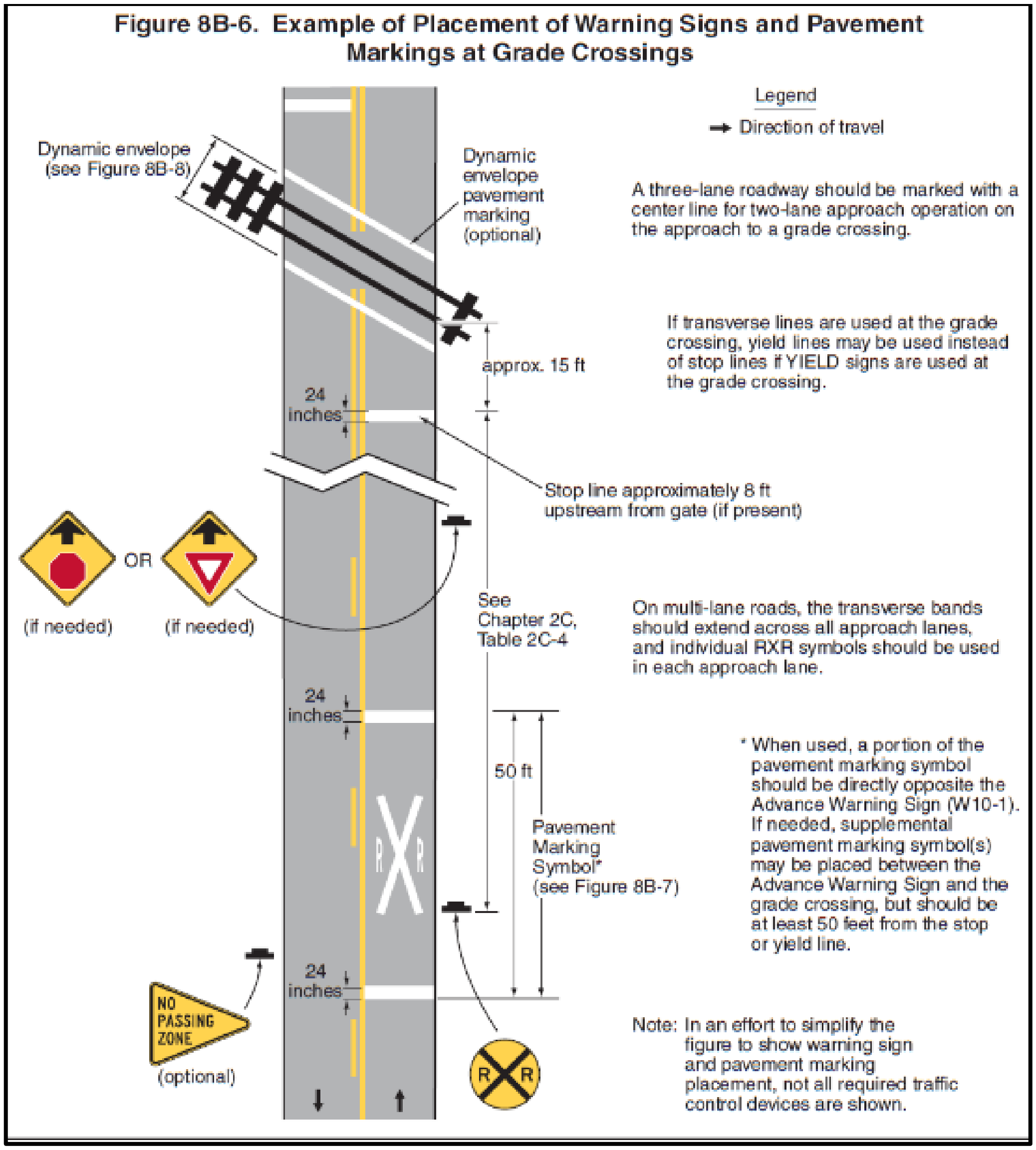


Figure 4-17. Excerpt of HRGC Pavement Markings
(MUTCD, 2009)

As can be inferred from Figure 4-18, the review revealed that lane markings, X and the letters RR, and STOP line markings exist in at least 93.2% of HRGCs. Despite being optional, the RDE markings were found at approximately a quarter of HRGCs. The goal of these additional markings is to reduce the number of vehicles that come to a stop within the dynamic envelope, a violation of most applicable State highway traffic laws, thus reducing the possibility that a vehicle is present on the tracks when a train approaches. Research indicates that the addition of the dynamic envelope pavement markings reduces the number of vehicles that stop within the dynamic envelope zone and increases the number of vehicles that stop properly and safely behind the stop line (*6*). Only 66 (i.e., 3.5%) HRGCs do not have grade crossing-related pavement markings.

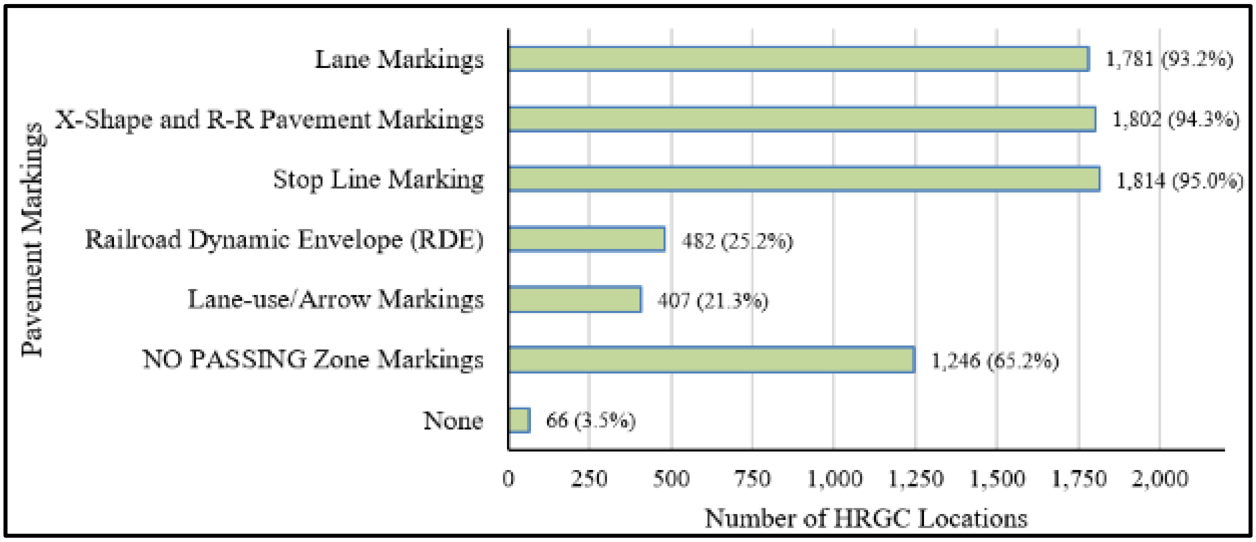


Figure 4-18. Pavement Marking Types in the Vicinity of HRGCs

4.3.2.3 Traffic Signs at Grade Crossings

Most HRGCs are controlled by various traffic signs, as shown in Figure 4-19. These traffic control devices direct attention to the location of a grade crossing and advise road users to stop before the grade crossing as necessary to yield to any rail traffic occupying or approaching and in proximity to the grade crossing. As can be inferred from Figure 4-19, crossbuck, advance warning, and emergency notification signs were installed in at least 93.6% of HRGCs. As expected, the supplemental Number of Tracks (R15-2P) plaque was found at 536 (i.e., 28.1%) HRGCs, a 99.2% of 540 HRGCs with multiple tracks. Only 4.2% and 3.2% had Crossbuck Assemblies with YIELD or STOP signs, respectively. A DO NOT STOP ON TRACKS (R8-8) sign is installed at 26.6% of HRGCs.

It is worth mentioning that a DO NOT STOP ON TRACKS (R8-8) sign is only installed whenever an engineering study determines that the potential for highway vehicles to stop on the tracks at a grade crossing is significant. Only 7 (i.e., 0.4%) HRGCs do not have grade crossing-related traffic control signs.

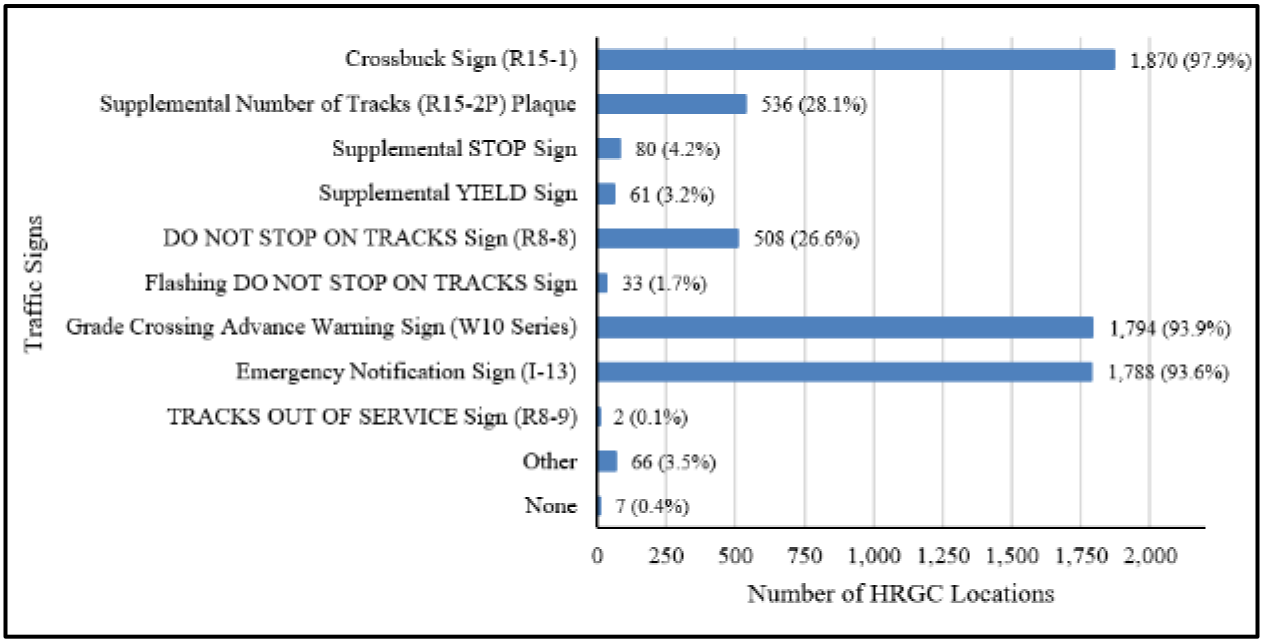


Figure 4-19. Traffic Sign Types in the Vicinity of HRGCs

At some HRGCs (i.e., 3.5%), additional signs accompanied crossbuck assemblies or advance warning signs. Such signs included:

- STOP HERE ON RED (R10-6, R10-6a),
- STOP HERE WHEN FLASHING (R10-8, R10-8a),
- DO NOT DRIVE ON TRACKS (R15-6a),
- LOOK (R15-8), and
- LANE USE SIGNS.

Figure 4-20 presents the grade crossing advance warning signs and plaques (W10 Series) that are installed at HRGCs. A single sign or a combination of signs is usually installed at each approach in advance of an HRGC. These signs advise road users of grade crossing presence well in advance so that they yield or act appropriately to any rail traffic occupying or approaching and in proximity to the grade crossing. The review revealed that W10-1 is the most frequently used sign featuring at more than 1,772 of 1,910 (i.e., 92.8%) HRGCs. W10-2, W10-3, and W10-4 are also common, especially on a parallel railway if the distance from the edge of the track to the edge of the parallel roadway is less than 100 feet. Together, W10-2, W10-3, and W10-4 are installed at 207 of 1,910 (i.e., 10.8%) of HRGCs.

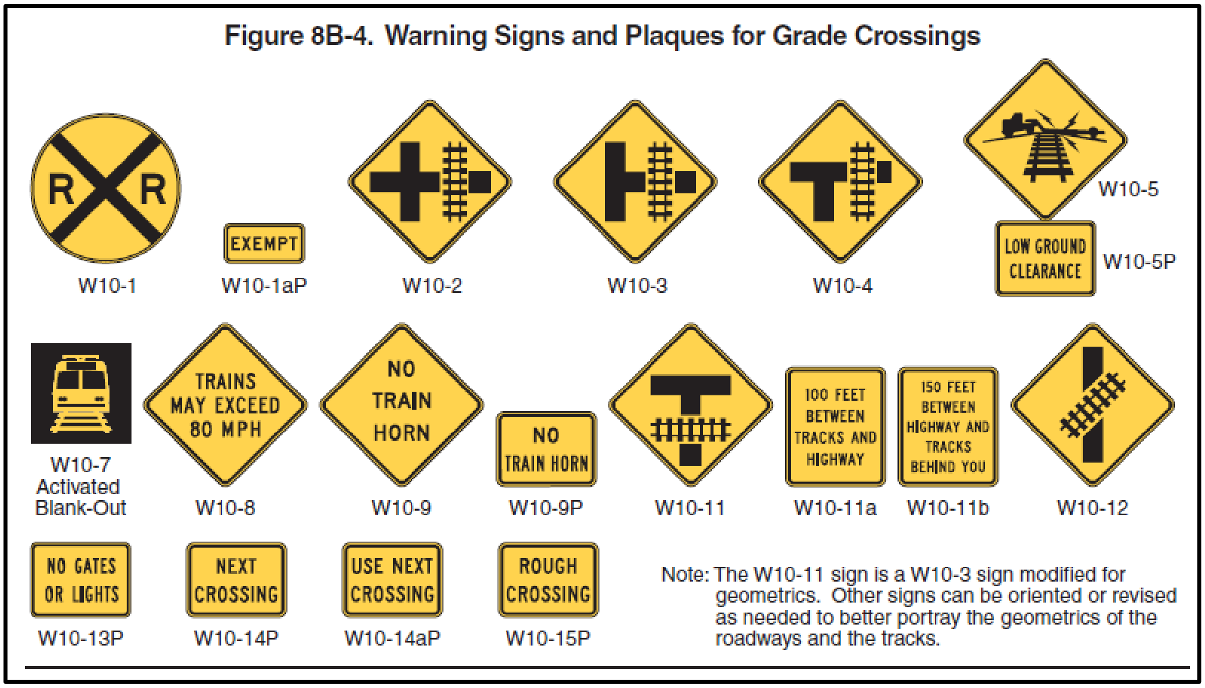


Figure 4-20. Excerpt of Advance Warning Signs and Plaques for HRGCs
(MUTCD 2009)

4.3.2.4 Active Traffic Control Systems at Grade Crossings

Active traffic control systems inform road users of the approach or presence of rail traffic at grade crossings. These systems include four-quadrant gate systems, automatic gates, flashing-light signals, traffic control signals, actuated blank-out, and variable message signs, and other active traffic control devices. This effort reviewed flashing light signals, flashing light signals in combination with automatic gates, traffic control signals, pedestrian signals, and gate types, as presented in Table 4-14 and Table 4-15. The review revealed that most HRGCs have flashing-light signals together with automatic gates (i.e., 85.8%). Traffic control signals are sometimes used instead of flashing-light signals to control road users at HRGCs, especially at or very close to an intersection. Traffic control signals account for about 3.3% of HRGCs. There are also about 5.5% of HRGCs that are not equipped with active traffic control systems, as shown in Table 4-14. Regarding railroad gates, a majority of HRGCs are controlled by two-quadrant gates, followed by pedestrian gates and four-quadrant gates.

Table 4-14. Active Traffic Control Systems at HRGCs

Active traffic control	Count	Percent
Flashing-Light Signals	130	6.8%
Flashing-Light Signals & Automatic Gates	1,638	85.8%
Traffic Control Signals	63	3.3%
Pedestrian and Bicycle Signals	81	4.2%
None	106	5.5%
Total	**1,910**	**100%**

Table 4-15. Railroad Crossing Gates at HRGCs

Railroad crossing gates	Count	Percent
Four-quadrant Gate	205	10.7%
Two-quadrant Gate	1,426	74.7%
Pedestrian automatic Gate	384	20.1%
None	250	13.1%
Total	**1,910**	**100%**

4.3.2.5 Pedestrian Facilities and Additional Safety Measures at Grade Crossings

In addition to traffic signs, pavement markings, and active traffic control systems related to grade crossing, there are pedestrian crossing facilities and other safety measures, as summarized in Table 4-16 and Figure 4-21, respectively. These devices inform road users of the approach or presence of rail traffic at grade crossings and provide safe facilities for pedestrians. The pedestrian facilities that are widely deployed at or near grade crossings are sidewalks, crosswalks, and signs to alert drivers about pedestrian presence. However, nearly half of the HRGCs do not have pedestrian crossing facilities.

Table 4-16. Pedestrian Crossing Facilities at HRGCs

Pedestrian facilities	Count	Percent
Pedestrian Sidewalk	983	51.5%
Pedestrian Crosswalk	123	6.4%
Pedestrian Sign(s)	80	4.2%
None	884	46.3%
Total	**1,910**	**100%**

It is not surprising that additional safety measures at grade crossings are only included in less than half of HRGCs. For example, object markers are installed to mark the presence of a fixed object adjacent to the roadway. In essence, guards, guardrails, speed reduction devices, crash cushions, and other measures in Figure 4-21 are only installed whenever an engineering study determines the need.

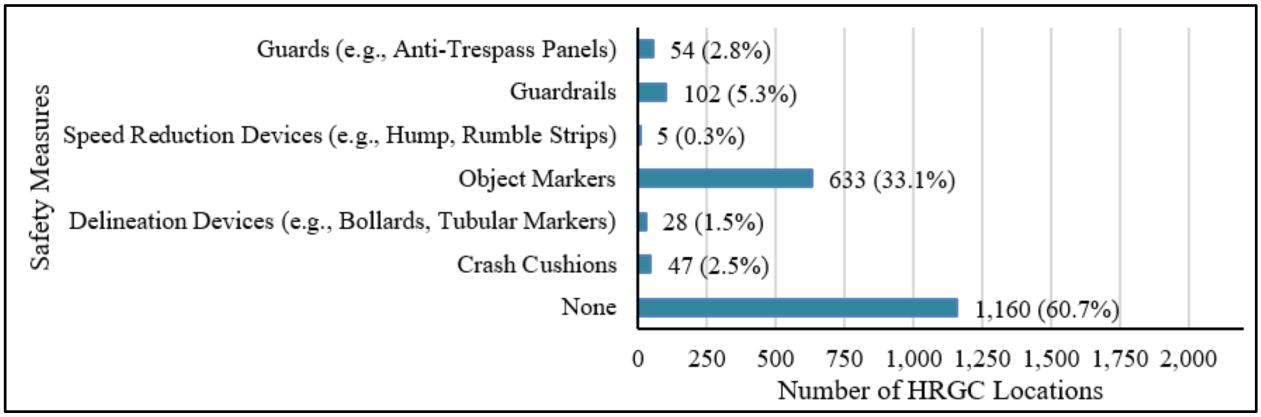


Figure 4-21. Safety Measures at HRGCs

4.3.3 Safety Evaluation

In addition to reviewing the existing treatment at HRGCs, the safety evaluation of HRGCs was conducted by analyzing crashes, geometrics, and traffic conditions at HRGCs. The results in Table 4-17 provide a wide array of statistics through which the mitigation strategies could be thoughtfully taken into consideration.

Table 4-17. Descriptive Statistics of Variables by HRGC and Crashes

Variable	Factor	Number of HRGCs	Total Crashes	Total Crashes per HRGC
Number of Tracks	1	1,370	431	0.31
	2	474	479	1.01
	3	54	39	0.72
	4+	12	9	0.75
Number of Lanes	2	1,354	419	0.31
	3	66	39	0.59
	4	392	377	0.96
	5	15	25	1.67
	6	79	94	1.19
	7	1	0	0.00
	8	3	4	1.33
Posted Speed Limit (mph)	15	2	0	0.00
	20	6	0	0.00
	25	129	25	0.19
	30	276	131	0.47
	35	370	245	0.66
	40	169	142	0.84
	45	289	190	0.66
	50	39	30	0.77
	55	88	32	0.36
	60	28	14	0.50
	65	13	3	0.23
	Unknown	501	146	0.29
AADT	< 7,650	875	228	0.26
	7,650 - 18,000	481	315	0.65
	> 18,000	332	402	1.21
	Unknown	222	13	0.06
TCS	No	1,519	601	0.40
	Yes	391	357	0.91
Railroad gate	Four-quadrant gate	205	259	1.26
	Two-quadrant gate	1,427	674	0.47
	None	250	25	0.10
	Unknown	28	0	0.00
	Total	**1,910**	**958**	**0.50**

4.3.3.1 Negative Binomial Regression Model

Similar to the descriptive statistics in Table 4-17, the model results in Figure 4-18 suggest the same at a 90% confidence level. In short, crashes occur more at HRGC with high traffic volume, number of lanes between 4 and 5, multiple tracks, railroad gates, near a traffic control signal, and high-speed facilities. For example, multiple tracks were found to be associated with more crashes than a single-track HRGC. In addition, the number of crashes per HRGC was found to increase with the increase in the number of lanes from 4 to 5. Higher posted speed limits, high traffic volume, and the presence of a traffic control signal within 200 ft were found to increase the number of crashes per grade crossing.

Table 4-18 presents the Negative Binomial regression model results. This model helped to identify the variables that significantly increase crashes at HRGC locations. The predicted crash frequency can be calculated using Equation 6, as follows:

$$N_{i,s} = y \times e^{b_0 + b_{aadt}\, AADT/(1{,}000)} \times CMF_{v1} \times CMF_{v2} \times \ldots CMF_{vx} \qquad (6)$$

where,

$N_{i,s}$ = Predicted annual average crash frequency,
y = Number of years of crash data,
$AADT$ = Average Annual Daily Traffic (veh per day),
CMF_{vx} = Crash Modification Factor for variable x, e.g., number of lanes
b_o = Model intercept,
b_{vx} = Model coefficient for variable x, e.g., number of lanes

Table 4-18. Negative Binomial Model Results

Variable	Factor	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)		-3.958	0.265	-14.937	< 0.001
AADT_1000		0.033	0.005	6.650	<0.001
Number of lanes	≤ 3 lanes	Base			
	4 – 5 lanes	0.412	0.118	3.496	<0.001
	> 5 lanes	-0.421	0.241	-1.747	0.081
Number of tracks	1	Base			
	2+	0.918	0.109	8.385	<0.001
Railroad gate	None	Base			
	Four-quadrant gate	0.863	0.299	2.890	0.004
	Two-quadrant gate	0.672	0.267	2.521	0.012
TCS_Nearby	No	Base			
	Yes	0.259	0.109	2.378	0.017
Posted speed limit	15 – 35 mph	Base			
	40 – 45 mph	0.185	0.110	1.674	0.094
	> 45 mph	0.303	0.167	1.808	0.071

Similar to the descriptive statistics in Table 4-17, the model results in Figure 4-18 suggest the same at a 90% confidence level. In short, crashes occur more at HRGC with high traffic volume, number of lanes between 4 and 5, multiple tracks, railroad gates, near a traffic control signal, and high-speed facilities. For example, multiple tracks were found to be associated with more crashes than a single-track HRGC. In addition, the number of crashes per HRGC was found to increase with the increase in the number of lanes from 4 to 5. Higher posted speed limits, high traffic volume, and the presence of a traffic control signal within 200 ft were found to increase the number of crashes per grade crossing.

4.3.3.2 Engineering Countermeasures

The frequency and severity of traffic crashes could be reduced through the 4Es of traffic safety: *Engineering, Education, Enforcement, and Emergency Medical Services*. This research emphasizes the *Engineering* countermeasures.

The following *Engineering* countermeasures could be considered at the HRGC locations in Florida:

- Traffic signs
  - Crossbuck sign
  - Grade crossing advance warning signs (W10 Series)
  - Emergency Notification Sign (I-13)
  - DO NOT STOP ON TRACKS (R8-8) sign
- Pavement Markings
  - X-Shape and R-R Pavement Markings
  - Stop line
  - Railroad Dynamic Envelope
- ITS Technologies
  - Automatic gates
  - Flashing signals

Since Engineering countermeasures do not completely mitigate HRGC incidents, it is crucial to consider *Education* and *Enforcement* strategies to address some issues related to HRGC crashes. A sample of 140 crashes that occurred at a grade crossing critical zone with trains suggested that a majority of crashes were due to human error, such as attempting to pass under lowered arms of a railroad gate and stopping on tracks. While engineering countermeasures such as a DO NOT STOP ON TRACKS (R8-8) sign and a RDE would reduce the number of vehicles that stop within the dynamic envelope zone, the following education and enforcement efforts could improve safety at HRGCs:

- Conduct safety campaigns like "Always Expect a Train" to remind people to be cautious at railroad crossings.
- Educate the public regarding safety at railroad crossings through various mediums such as websites, social media, and public service announcements.
- Collaborate with organizations like Operation Lifesaver, which aims to raise national and state awareness of railroad crossing issues.

- Conduct consistent enforcement by local or state police of traffic safety laws and provide a sustained effort by the courts to impose penalties on violators to discourage and deter motorists from making poor decisions at grade crossings.
- Provide warnings and citations to drivers parking or deliberately stopping on tracks.
- Enforce driving under influence (DUI) laws.

5 Interview with Stakeholders

This chapter presents the results and findings from the interviews with representatives of each of seven FDOT districts, FDOT Central Office, and a major railroad company on HRGC-related questions. The interview results and findings provide valuable insights on (1) safety and mobility challenges, causes, and strategies to address safety and mobility issues at HRGCs in Florida, (2) assessment of FDOT STRIDE program to improve HRGC safety, and (3) experts' knowledge and experience on effective strategies, treatments, success, lessons learned, and resources to improve Florida HRGC safety and mobility.

5.1 Interviews with FDOT Districts

5.1.1 Interview Questionnaire

The questionnaire for the FDOT districts had three main themes: 1) Challenges, causes, and strategies to address safety and mobility issues at HRGCs, 2) FDOT STRIDE (Statewide Traffic and Railroad Initiative using Dynamic Envelopes) program, and 3) Knowledge and experience on effective strategies, treatments, success, lessons learned, and other resources. Each theme included specific topics that are presented in Table 5-1.

Table 5-1. Detailed Topics included in Interview Questionnaire

Challenges, Causes, and Strategies to Address Safety and Mobility issues at HRGCs	
1	Primary safety and mobility challenges in HRGC operations
2	The main causes of serious safety and mobility issues at HRGC locations
3	Implemented or planned strategies to address the identified issues
4	Needed resources to implement strategies
5	Educational outreach on HRGC safety
FDOT STRIDE Program - Railway Dynamic Envelope Pavement Markings	
6	District assessment on effectiveness of RDE implementations
7	Ineffective RDE implementations, HRGCs with RDE treatment that are of special concern, suggestions for improving RDE effectiveness
8	Examples of HRGCs with RDE implementation with safety and mobility problems for a field review to investigate and develop solutions
9	Success stories and lessons learned from the RDE implementation
Knowledge and Experience on Effective Strategies, Treatments, Success, Lessons Learned, and other Resources	
10	Effective strategies and treatments (traditional, TSM&O, ITS, and emerging technologies) to improve safety and mobility at HRGCs.
11	Successes and lessons learned from the previously implemented HRGC strategies and countermeasures (not limited to RDE)
12	Other information and resources

Through integrating feedback and comments from project managers, the interview questionnaire was finalized, as shown in Appendix B.

5.1.2 Briefs of Districts' Interviews

The invitation email was sent to all FDOT districts (including Florida's Turnpike Enterprise or FTE) and Central Office. FTE responded that Turnpike is a high speed limited access facility and does not have any HRGCs. Thus, the interviews were conducted with districts 1-7 and the Central Office, as shown in Table 5-2. The analysis of interviews is shown in the following sections.

Table 5-2. Interviews Date and Time

Agency	Interview Date and Time
District 1	04/05/2023
District 2	03/30/2023
District 3	05/01/2023
District 4	04/07/2023 and 04/24/2023
District 5	03/28/2023
District 6	04/10/2023
District 7	04/12/2023
Central Office	06/20/2023

5.1.3 Challenges, Causes, and Strategies to Address Safety and Mobility Issues at HRGCs

5.1.3.1 Safety and Mobility Challenges and Causes

Table 5-3 presents FDOT districts and the Central Office's opinions on the safety and mobility challenges in Florida. Through the interviews, the top challenges, which were identified by all districts and the Central Office, include:

- ***Trespassing***—Trespassing is one of the top challenges noted by the representatives from all districts and the Central Office. Pedestrians cross the tracks at unauthorized locations or walk along the railroad, therefore do not observe the railroad right-of-way, and often do not realize the dangers of trespassing.
- ***Drivers and Pedestrians' Awareness/Behavior***— One significant cause of incidents at highway rail grade crossings is drivers or pedestrians failing to obey the warning signals, such as crossing gates, flashing lights, and audible alarms. This can happen due to negligence, distraction, impatience, or intentionally trying to beat the train. Many motorists and pedestrians are unaware of the dangers of rail crossings. The representatives from all districts referred to this as a safety and mobility challenge.
- ***Traffic Queueing onto Railroad Tracks***—Stopping on the railroad tracks was reported by all districts, including Central Office, as a significant challenge at HRGCs. Short queuing areas near parallel roadways and rail lines can cause traffic to queue onto the railway tracks, creating potentially hazardous situations. It can be caused by insufficient queuing space or when the drivers do not pay attention to the traffic.

Table 5-3. Safety and Mobility Challenges and Causes at HRGCs across FDOT Districts

Safety and Mobility Challenges	Districts							Central Office
	1	2	3	4	5	6	7	
Trespassing	✓	✓	✓	✓	✓	✓	✓	✓
Driver Awareness/Behavior	✓	✓	✓	✓	✓	✓	✓	✓
Pedestrian Awareness/Behavior	✓	✓	✓	✓	✓	✓	✓	✓
Traffic Queueing onto Tracks (stopping on crossings)	✓	✓	✓	✓	✓	✓	✓	✓
Insufficient Funding	✓	✓	✓	✓	✓	✓	✓	
Insufficient Education on Railroad Safety	✓		✓	✓	✓		✓	
New Train Services, Increase in Train Speed and Traffic Volumes, High Populated Areas		✓		✓	✓		✓	✓
Wrong Turns onto Tracks		✓			✓	✓	✓	
HRGC Geometry	✓	✓		✓			✓	
Surface Conditions (condition of surface material, humped/crowned crossings)	✓	✓	✓					
Vandalism			✓	✓				
Signal Conditions	✓							
Sidewalks with Gaps		✓						
Sensory Overload at Crossings					✓			
Preemption Issues						✓		

The following challenges and causes were identified by some districts, but not all.

- ***Insufficient Funding***—Insufficient funding for the maintenance and improvement of grade crossings can lead to safety issues. This includes inadequate signage, malfunctioning warning devices, and lack of maintenance of crossing surfaces, which can contribute to crashes. District 1 noted the need for additional funding for active warning devices, crossing reconstructions, and grade separations. District 2 mentioned that funding is always a concern, and they frequently have more issues than they can address. District 3 commented that more funds are needed to address all the problems in the district. District 3 also mentioned that they receive the lowest amount of Section 130 funding in the state and expressed that if, for example, four-quadrant gates become a mandate, they will need more funds to implement one crossing. Districts 4 and 5 mentioned the need for more funding for educational outreach campaigns. District 6 stated more funds would allow them to accomplish more safety projects. District 7 had to cancel some projects because some costs nearly doubled the original amount due to rising costs.

- ***Insufficient Education on Railroad Crossing Safety***—Lack of awareness and education regarding proper behavior and precautions at grade crossings can contribute to crashes. Many drivers and pedestrians may not fully understand the risks involved or may be unaware of the appropriate actions to take when approaching or crossing railway tracks.

Districts 1, 3, 4, 5, and 7 discussed it as both a challenge and the cause of safety and mobility issues. District 3 mentioned the importance of railroad safety education through driver's education programs in high schools. District 4 noted that Brightline reviews video footage of incidents at gates and provides education to the households of violators. They said that they are repeatedly sending educational materials to the same households, indicating that it is the same people performing incorrect behavior at crossings. District 5 suggested more educational outreach could be performed if funding was available. District 7 suggested performing railroad safety education at grade schools and to the public.

- ***New Train Services, Increase in Train Speed and Traffic Volume, High Populated Areas*****—**Districts 2, 4, 5, and Central Office discussed that there are many new train services, speed increases, and traffic volume increases in some areas. This poses a challenge since people are not accustomed to the high-speed and high traffic volumes of trains.
- ***Wrong Turns onto Railroad Tracks*****—**People driving onto railroad tracks pose a challenge. Vehicles may make incorrect turns and end up on railroad tracks, especially at poorly marked or confusing pavement marking and signage, or if the driver's GPS provides unclear directions. This can result in collisions with trains if the driver is unable to clear the tracks in time. This cause of safety and mobility issues was indicated by districts 2, 5, 6, and 7.
- ***HRGC Geometry*****—**The crossing geometry plays a role as many of the railroads are parallel to the roads and are crossed by another road. The crossing road is often at an obtuse or acute angle where the visibility is often hindered (District 1). Additionally, there might be an intersection close to the HRGC which increases traffic congestion and queuing at grade crossings. Long queues of vehicles waiting for the train to pass increase the risk of rear-end collisions or impatient drivers trying to cross the tracks before the train arrives (District 2, 4, and 7).
- ***Road Surface Conditions at HRGCs*****—**Uneven or deteriorated road surfaces at grade crossings were indicated by districts 1, 2, and 3. They can cause discomfort and potential hazards for vehicles, especially at higher speeds. Rough surfaces may lead to loss of control, tire damage, or crashes when crossing the tracks.
- ***Vandalism*****—**Acts of vandalism, such as damaging or tampering with warning devices, can compromise the effectiveness of safety measures at grade crossings. This can lead to crashes if drivers or pedestrians are not adequately alerted to the presence of an approaching train. District 3 mentioned people shooting out lights, and District 4 recalled a site visit they were conducting with Brightline to review some recently installed ITS devices. Brightline found that three of the four devices had been vandalized.
- ***Signal Condition*****—**Railroad signal flashing light conditions are a challenge faced by District 1. This refers to not only the inventory of what is at each location, but also the condition of the equipment at crossings. Some signals are antiquated.

- ***Sidewalk with Gaps***—District 2 noted that there are gaps in sidewalks near crossings that result in pedestrians walking on uneven surfaces (the sidewalk ends before the railroad).
- ***Sensory Overload at Crossings***—District 5 discussed that at some locations, there are many signs and signals that might introduce misunderstanding for drivers.
- ***Preemption Issues***—District 6 discussed preemption issues they are facing at some locations. Challenges arise when shared infrastructure signals conflict with railroad signals. The issue is where there are multiple signalized intersections near each other. The traffic lights on the shared infrastructure would be green to allow traffic to clear the tracks, but the railroad lights would be flashing red.

5.1.3.2 Implemented or Planned Strategies to Address the Identified Issues

In interviews, FDOT districts and the Central Office provided information of their strategies (implemented and/or planned) to address the identified challenges and causes, as described below.

District 1

<u>*Implemented Strategies*</u>

- Adding or upgrading active warning devices.
- Performing diagnostic field reviews using the federal funding Section 130.

District 2

<u>*Planned Strategies*</u>

- Moving the stop bar back behind the railroad tracks at a HRGCs with a T intersection and a 10-foot queueing area. This approach aims to eliminate the right turn on red movement but will also prevent people from queueing on the tracks.
- Applying an Intersection Control Evaluation (ICE) process to HRGCs to treat them more like intersections and look for more innovative ways to lay out the intersections with crossings.
- Constructing roundabouts at railroad crossings to improve the traffic flow and reduce the likelihood of queues back on the tracks. The railroad company tentatively approved the project. The concept of the roundabout is presented in Figure 5-1.

Before Treatment After Treatment

Figure 5-1. Concept of Roundabout at HRGCs to Improve Traffic Flow and Safety

District 3

Implemented Strategies

- Resurfacing rough crossings on state roads.

Planned Strategies

- Conducting an education program (Operation Lifesaver) at schools to teach students the respect they should have for the rail and rail crossings.

District 4

Implemented Strategies

- Updating signal houses and equipment with an on-site signal safety grant from FHWA.
- Installing premium fencing, delineators, and ITS devices using a grant from Brightline.
- Collaborating with District 5 and companies to set up preemption operations at HRGCs adjacent to traffic signals along the FEC corridor.

Planned Strategies

- Working on several crossing closures and finding areas where they can potentially implement some grade separations.

District 5

Implemented Strategies

- Installing a pre-signal on the railroad cantilever to stop traffic before they get to the tracks during the high impact time.
- Installing preemption at HRGCs adjacent to a signalized intersection.

Planned Strategies

- Blank-out signs to negate turns when trains approach.
- Lidar to identify vehicles queuing across the tracks.
- Installing delineators to reduce wrong turns onto tracks, avoiding any red color on them to prevent train engineers incorrectly stopping when they see red.
- Installing pre-signals along Horatio Ave in Maitland.

District 6

Implemented Strategies

- Implemented pavement markings and delineators at skewed HRGCs.
- Installing preemption at HRGCs adjacent to a signalized intersection.

Planned Strategies

- Installing no trespassing panels (Figure 5-2) at several locations. The rail companies are still in negotiation since they are concerned that the installation of the panels would impede their ability to inspect the tracks.

Figure 5-2. Example of Rubber No-Trespassing Panels on and near Tracks

District 7

Implemented Strategies

- Upgrading railroad signal lights to LEDs with Section 130 funds.
- Adding an appropriate "DO NOT STOP ON TRACKS" sign (R8-8) at HRGCs.
- Implementing no-turn blank out signs.

- Installing track-lean preemption at most intersections adjacent to HRGCs.
- Employing queue flushing, reverse queue management, and advanced warning signs (not tied to oncoming trains, need to research).
- Implementing turnkey operations for crossing replacements and fast track contracts for emergency repairs.
- Removing abandoned RR Crossings.
- Operation Lifesaver is starting back up for educating the public.

5.1.3.3 Resources

All districts are facing limited funding available each year, which makes it challenging to conduct annual HRGC diagnoses and implement necessary treatments to address HRGC safety and mobility issues. Districts also expect to allocate funding to extend the safety treatments on state roads (e.g., RDE pavement markings) to county/city HRGCs since local agencies do not have sufficient budget. District 2 mentioned that they are expecting matching contributions to safety improvement projects from railway companies. District 5 indicated that a lot of the railroads have proprietary technology and are under the Department of Homeland Security (DHS), so they have certain restrictions to allowing transportation agencies to access their equipment for implementing new technologies. Each District has special resource demands to implement HRGC projects, as shown in Table 5-4.

Table 5-4. Resource Expectation by FDOT Districts

District	Resource Expectation
1	• Additional funding for active warning devices, crossing reconstruction, and grade separations. • Additional funding for the Annual Signal Safety project to upgrade signals. • Additional funding for small crossing surfaces in rural areas to improve the resiliency of the crossing, where the city/county is not able to do it.
2	• $1.5M each year cannot cover all needed projects. • Expect matching contribution from railway companies.
3	• Additional funding for Operation Lifesaver education program. • Additional funding for upgrading all rough crossings, not limit to state roads.
4	• Additional funding for Be Rail Smart Campaign to provide education and outreach to the public.
5	• Additional funding for installing delineators at 172 crossings along SunRail (currently has the funding for 17 crossings). • Treatments to improve the safety of pedestrians, bicyclists, and motorists. • Collaboration with rail carriers.
6	• Additional funding for Signal Safety Program (Section 130), the existing budget is $600k per year. • Additional funding for delineators, signal improvements, enhanced pavement markings, no trespassing panels. • Additional funding for Operation Lifesavers, Law Enforcement.
7	• Additional funding for the field review of potentially hazardous crossings during the annual diagnostic review for Section 130 funding. • Test and pilot countermeasures across the state rather than a single district. • Additional funding for six Section 130-funded projects (had cost overruns of nearly double).

The equipment and installation costs differ across geographic areas. The estimated cost by various countermeasures is presented in Appendix D.

5.1.3.4 Education

Despite funding limitations, districts actively engage or plan to engage in Operation Lifesaver and employ various outreach strategies to raise awareness about rail safety among the public and their partners. Continued collaboration, exploring additional funding opportunities, and conducting follow-up studies are potential avenues for further enhancing rail safety outreach in the future.

Some districts participate in multiple events and platforms to share the message of rail safety. This includes attending Metropolitan Planning Organization/Transportation PO meetings, CTST meetings, rest areas, schools, and tabling events. They also utilize social media, Mobility Week, OMD Expo, videos, billboards, and bus wraps to disseminate rail safety information. Collaboration with other offices and campaigns further expands their reach.

The input from the FDOT districts and the Central Office are presented in Table 5-5.

Table 5-5. Current Educational Outreach on HRGCs Safety

Educational Outreach	District							Central Office
	1	2	3	4	5	6	7	
Operation Lifesaver	✓	✓	✓		✓	✓	✓	
Rail Safety Week		✓			✓		✓	
Mobility Week		✓		✓				
Be Rail Smart				✓		✓		✓
Various Events				✓				
Various Media				✓				

- ***Operation Lifesaver*–** Operation Lifesaver is a national, non-profit public safety education and awareness program aimed at reducing collisions, fatalities, and injuries at HRGCs and preventing trespassing on railroad tracks. The program is implemented in multiple states across the United States. District 1 participates in Operation Lifesaver. Staff in District 2 are Operation Lifesaver-certified. Districts 3 and 7 plan to do Operation Lifesaver at the schools through the driver's education programs. The aim is to teach students the respect they should have for the rail and rail crossings. District 5 and 6 participates in Operation Lifesaver.

- ***Rail Safety Week* –** Rail Safety Week is a collaborative effort among Operation Lifesaver, Inc., state Operation Lifesaver programs, and rail safety partners across North America, including the U.S., Canada, and Mexico. District 2 participates in Rail Safety Week each year, where they distribute rail safety messages. District 5 participated in operation Lifesaver during the Rail Safety Week.

- ***Mobility Week* –** Mobility Week is an annual initiative dedicated to promoting various transportation options, encouraging sustainable travel choices, and raising awareness about the importance of transportation accessibility and mobility throughout the state. Districts 2 and 4 incorporate rail safety into Mobility week. District 4 shares information on social media.

- ***Be Rail Smart* –** The Be Rail Smart campaign was launched in 2018 by District 4 as an effort to increase rail crossing safety awareness throughout all counties within a district (Broward, Palm Beach, Martin, St. Lucie and Indian River). The campaign was embraced by District 6 and now, FDOT is expanding the Be Rail Smart throughout the state. The campaign's goals include (1) Reducing the number of incidents on or around the tracks, (2) Creating campaign champions, and (3) Establishing campaign partners. Campaign initiatives promote public education and awareness of rail safety through community outreach, agency partnerships and print and digital media advertising.

- ***Various Events* –** District 4 goes to MPO/TPO meetings, CTST meetings, rest areas, schools, and various tabling events to share the message of rail safety.

- ***Various Media* –** District 4 District uses various media, such as videos, billboards, bus wraps, and social media to share information on railroad safety.

5.1.4 FDOT STRIDE Program

Table 5-6 presents the FDOT districts' and Central Office's evaluation on the effectiveness of RDE pavement markings in improving drivers' compliance at HRGCs. Four districts stated the RDE pavement markings are overall effective, but the effectiveness varies over locations (District 6) or needs to be adjusted (district 7). Districts 2 and 3 stated that the RDE pavement markings are mildly effective and have no negative effects. District 1 stated that they did not see a significant benefit in the implementation of RDE pavement markings. This may be caused by many crossings with RDE implementation in District 1 being on rural roads and having no frequent traffic queues invading rail tracks.

Table 5-6. Districts' Evaluation on RDE Pavement Markings

Assessment	District							Central Office
	1	2	3	4	5	6	7	
Effective				✓[1]	✓	✓	✓	✓
Mildly effective		✓	✓					
Not see a benefit	✓							

[1]*District 4 stated that the RDE is effective based on feedback from the public after installation.*

The Central Office stated that the RDE pavement markings decreased the number of incidents with drivers being stuck on or fouling the tracks by 15% based on the initial data analysis. But the data also shows the effectiveness varies by Districts. FDOT Central Office is interested in knowing why the RDE pavement markings do not work in some locations.

The research team summarized the factors, as shown in Table 5-7, that may influence the effectiveness of RDE pavement markings in improving drivers' stopping compliance behaviors at HRGCs from the interviews. The major factors are provided below.

Table 5-7. Factors Influencing the Effectiveness of RDE Pavement Markings

Factors	District							Central Office
	1	2	3	4	5	6	7	
RDE color and shape misleading road users		✓			✓	✓		✓
Installing RDE pavement markings in unnecessary locations	✓	✓						✓
Skewed crossings make drivers difficult to detect tracks, especially at night				✓			✓	✓
The public awareness on RDE pavement markings					✓	✓	✓	
Maintenance responsibility after Installation				✓			✓	
Residents near crossings desensitized to the dangers of the rail			✓					
Too many implementations of RDE pavement markings		✓						

- ***RDE color and shape misleading road users***—The white color and "X" shape of RDE pavement markings make this treatment look like crosswalks and may mislead pedestrians to walk. In addition, the white RDE pavement markings may be insufficient to highlight the track area to drivers. Districts 2, 5, and 6 and the Central Office mentioned this potential issue.

- ***Installing RDE pavement markings in unnecessary locations***—Districts 1 and 2 believe that the RDE pavement markings should be effective at crossings where traffic queues frequently form back to tracks. These crossings are usually located in urban areas with high traffic volumes and adjacent to signalized intersections. If crossings are located on rural roads with low traffic or far from downstream intersections, the likelihood of stopping on tracks is low so the implementation of RDE may not show a significant benefit at these locations.

- ***Skewed crossings make drivers difficult to detect tracks***—District 4 and the Central Office mentioned skewed crossings make RDE pavement markings look like arrows that may direct drivers turn into tracks. This issue is more severe in a low-visibility environment (e.g., nighttime).

- **The public's awareness on RDE pavement markings**—District 7 mentioned that some people did not understand the purpose of RDE pavement markings without explanation. Districts 5 and 6 have a similar opinion.

- ***Maintenance responsibility after Installation***—The installation of RDE pavement markings needs the collaboration between FDOT and railway companies. However, the maintenance responsibility (e.g., repaint) belongs to FDOT. If FDOT installs the treatment on county/city roads, the maintenance is the local agencies' responsibility.

- ***Residents near crossings desensitized to the dangers of the rail***—District 3 mentioned that residents growing up near rail tracks may be somewhat desensitized to the dangers of the rail. They are more likely to overlook the message of RDE pavement markings.

- ***Too many implementations of RDE pavement markings***—District 2 stated that people may not pay attention to RDE pavement markings because they are frequently present at all crossings.

The FDOT districts and the Central Office proposed suggestions to enhance the effectiveness of RDE pavement markings in Florida, as summarized in Table 5-8. These suggestions, which aim to address the factors identified in Table 5-7, include:

- ***RDE pavement markings with yellow background***—Districts 2, 5, and 6 suggested changing the RDE color to yellow for increasing the visibility of tracks. However, the new design is not approved in the MUTCD. FDOT is talking to FHWA about an experiment of new RDE color pattern as shown in Figure 5-3.

- ***Education Program***—Districts 5, 6, and 7 suggested education programs to increase road users' awareness on the RDE pavement markings and increase their compliance with RDEs. The education program needs more funding allocation.

Table 5-8. Suggestions to enhance RDE Pavement Markings in Florida

Suggestions	District							Central Office
	1	2	3	4	5	6	7	
Implementing the RDEs in yellow to increase the visibility (need the approval by FHWA)		✓			✓	✓		✓
Education to increase public awareness on RDE pavement markings					✓	✓	✓	
Install RDE on crossings with regular queues back into tracks	✓	✓		✓				
Following-up evaluation	✓				✓			
Expand RDEs to local roads				✓				✓
Install reflective delineators at skewed crossing in addition to RDE pavement markings				✓				✓

Figure 5-3. RDE on Yellow Pavement Marking Installed in District 4

- ***Install RDE on crossings with regular queues back into tracks***—Districts 1, 2 and 4 suggested implementing RDE pavement markings at crossings in urban areas with high traffic and/or adjacent to signalized intersections. These crossings have a potential risk that vehicles stop on tracks due to traffic queues. District 2 also suggested avoiding deploying RDE pavement markings everywhere. This may get more people to pay attention to the new markings.

- ***Following-up evaluation***—Districts 1 and 5 suggested doing follow-up evaluations to further address the effectiveness of RDE pavement markings in various scenarios. This follow-up evaluation is beneficial to obtain a reliable assessment and examine the long-term performance of RDE pavement markings.

- ***Expand RDEs to local roads***—FDOT District 4 and Central Office suggested expanding the deployment of RDE pavement markings to county/city roads.

- ***Install reflective delineators***—District 4 suggested installing reflective delineators to prevent vehicle wrong turning into tracks. This treatment is more useful at skewed crossings where RDE pavement markings look like arrows and may misdirect drivers turning into tracks.

5.1.5 Knowledge and Experience on Effective Strategies, Treatments, Success, Lessons Learned, and Other Resources.

5.1.5.1 Traditional Treatments

Traditional treatments include a wide range of technical countermeasures, such as geometry treatments, pavement markings, signage, flashing lights, and rail control devices. Overall, all districts and the Central Office confirmed the effectiveness of traditional treatments in improving the safety and mobility at HRGCs. Some districts also mentioned that there is no one-size-fits-all solution. The implementation of traditional treatments depends on scenarios and locations.

The major traditional treatments discussed in the interviews are summarized below.

Four-quadrant Gates

Four-quadrant gates, also known as full-gate grade crossings or complete barrier gates, are advanced safety systems used at railroad crossings to enhance safety for motorists, pedestrians, and train operations. As shown in Figure 5-4, four-quadrant gates provide a physical barrier across all lanes in both directions, creating a safer crossing environment.

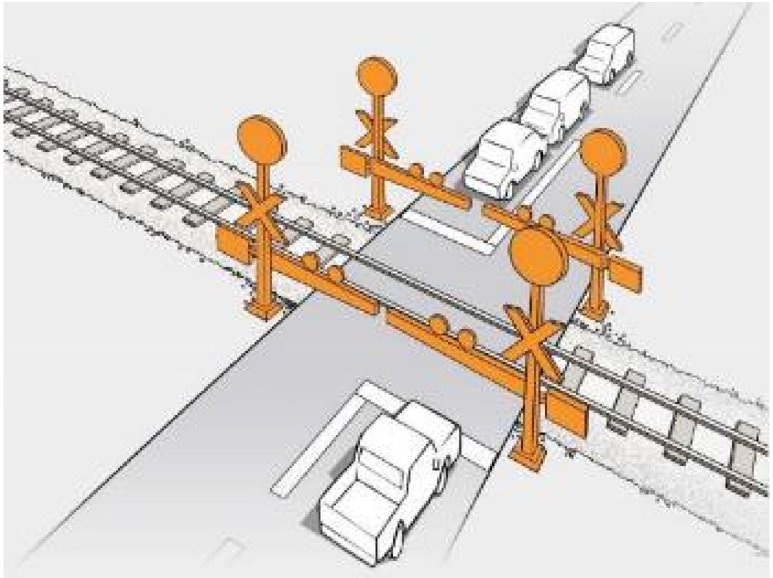


Figure 5-4. Concept of Four-quadrant Gate at an HRGC

(Source: CA.gov)

By blocking all lanes of traffic in all directions, four-quadrant gates significantly reduce the risk of motorists or pedestrians attempting to cross the tracks while a train is approaching or passing, thus preventing collisions between vehicles and trains, and reducing the chances of crashes and their associated consequences. Four-quadrant gates reduce the risk of vehicles stopping on the tracks or getting stuck between gates, leading to a smoother flow of traffic after the train passes. In addition, four-quadrant gates can be integrated with other safety systems, such as flashing lights, warning signs, and train-activated warning systems, to provide a comprehensive safety solution. However, the high installation and maintenance cost is a challenge for implementing four-quadrant gates at HRGCs.

The feedback from the districts on four-quadrant gates are summarized in Table 5-9.

Table 5-9. Summary of FDOT Districts' Comments on Four-Quadrant Gates

District	Key Points
1	• The effectiveness of four-quadrant gates depends on location. • They are good, but need to avoid the issue where a driver can feel trapped between gates.
2	• Railway companies may not support four-quadrant gates due to additional maintenance required. • District 2 would explore using roundabouts as an alternative to four-quadrant gates.
3	• The effectiveness of four-quadrant gates depends on location. • Should not be used everywhere.
4	• Install four-quadrant gates on roadways without medians to seal the road. • Four-quadrant gates may not block all vehicles traveling around the gate on a very-wide road due to the limited gate length. • Brightline is installing four quadrant gates, especially in the Indian River County areas.
5	• Should be installed at an HRGC that is in close proximity to a side street or driveway. • Should be installed at HRGCs within quiet zones.
6	• District 6 has a good number of four-quadrant gates along the Brightline corridor and the South Florida Rail corridor. • They are effective in stopping people from going around the gates.
7	• Four-quadrant gates can be effective, but also need education programs to help the public comply with the treatment. • They are good to be installed at locations where the public continues to ignore the flashing lights and gates.

Delineators

Delineators are designed to provide visual guidance and enhance visibility for motorists and pedestrians, especially during low-light conditions or adverse weather. Delineators are commonly used at railroad crossings to complement other safety measures and ensure that drivers can clearly identify the presence of the crossing, even from a distance, as shown in Figure 5-5.

Figure 5-5. Delineators next to Railroad Tracks
(Source: https://www.news4jax.com)

Delineators are typically equipped with reflective materials, making them highly visible at night or in low-light conditions. This enhanced visibility allows motorists to identify the railroad crossing well in advance and take appropriate precautions. Placing delineators before a railroad crossing serves as an advanced warning for drivers, giving them time to slow down, look for oncoming trains, and be prepared to stop if necessary. Delineators can help guide traffic, ensuring that vehicles approach the crossing at the proper angle and avoid stopping or parking on the tracks. In some cases, delineators are installed to create a designated pathway for pedestrians, indicating where it is safe to cross the tracks and helping them stay away from the active rail area. Since delineators are installed within railway properties, the responsibility of maintenance is a challenge to roadway agencies.

The feedback from districts on delineators are summarized in Table 5-10.

Table 5-10. Summary of FDOT Districts' Feedback on Delineators

District	Key Points
1	• Limited experience with delineators
2	• Delineators could be used more, but working on railroad property is difficult. • Delineators are frequently hit; the roadway agency is constantly having to work with the railroad agency to maintain the delineators. • It would be good to install delineators anytime there is a side street coming in within about 100-200 feet of a grade crossing, to help guide motorists not to drive on the tracks.
3	• Be effective in many scenarios but should be used everywhere.
4	• Brightline and Central Florida Express have installed delineators. • No incident reported after the installation. • The delineators have to be replaced periodically due to them being hit. • Need to discuss with railway companies to decide who should maintain delineators.
5	• SunRail has installed delineators at numerous crossings. • Avoid any red color on a delineator to prevent train engineers incorrectly stopping when they see red.
6	• Be effective to prevent wrong turn on tracks. • The main issue with delineators is ongoing maintenance.
7	• Like the idea of using these tubular delineators across an HRGC. • The delineators have the potential to help a lot at crossings, especially those with large drop-offs.
Central Office	• They like to see delineators in places where a raised median cannot be installed. • Brightline has a crew that travels around and replaces delineators as needed.

Fencing in Addition to Pedestrian Gate

Fences are typically installed along the railway tracks and can vary in design and materials used, as shown in Figure 5-6**.** One of the main reasons for installing fences along railroads is to deter unauthorized access and trespassing on the tracks. Fencing and integrating pedestrian gates helps prevent pedestrians from crossing the tracks at unauthorized locations, reducing the risk of crashes involving trains and people. However, the high installation cost and additional maintenance efforts are the challenge to implementing fences along a railway corridor. In addition, people may try to climb the fence and be trapped within the right-of-way of tracks.

Figure 5-6. Fencing along Railroad Tracks to Deter Trespassing
(Source: https://www.steelpalisade.net/palisadefence/railwayfence.html)

The feedback from districts on fencing is summarized in Table 5-11.

Table 5-11 Summary of FDOT Districts' Feedback on Fencing to Pedestrian Gates

District	Key Points
1	• Fencing is not always an effective deterrent to pedestrians, as people will generally still find a way over or through the fence or will just remove it.
2	• Fencing can be a good option at certain locations. • Fencing often gets cut or knocked down, and working on railroad property to repair it is difficult. • It is difficult to use public funding to install fences on railroad (private) properties.
3	• Fencing is not very often used. • Pedestrian gates are a good safety measure, but pedestrians can easily lift up fencing and go through. • A sturdier option should be explored.
4	• The railroad companies are asking for measures to channelize pedestrians at railroad crossings.
5	• Fencing can prevent pedestrians from entering the railroad right of way but can also trap pedestrians within the right of way.
6	• Looking into using more fencing to prevent people from walking along the tracks and also from dumping things on the track.
7	• With the fence, this often is not effective as people will cut, remove, or climb over it. • There is also the issue of liability to consider. • Zigzag fences (Figure 5-7) can help reduce pedestrians and cyclists from crossing without looking. The Zigzag fence will force them to look in both directions.
Central Office	• Install at the location with trespassing issues. • In addition to gates, they also use vegetation type barriers and anti-trespass mats.

Figure 5-7. Zigzag Fence at HRGCs
(Source: https://www.pressdemocrat.com)

Roundabout

District 2 proposed a roundabout design as an alternative to four-quadrant gates at HRGCs, as shown in Figure 5-8. This design aims to avoid traffic queues onto rail tracks due to traffic signal operations. District 2 is interested in conducting a pilot study to demonstrate the roundabout at Post St. @ McDuff Ave. in Jacksonville, Florida. With much discussion and collaboration, the rail company has tentatively approved this project to move forward. The evaluation of the safety effectiveness of the roundabout is unavailable yet.

Figure 5-8. Pilot Project of Roundabout at SR 228 and SR 129, District 2

5.1.5.2 TSM&O and ITS Treatments

There are many TSM&O and ITS countermeasures to improve the safety and mobility of HRGCs. These countermeasures cover various advanced technologies, such as traffic signal strategies, advanced sensors, information dissemination, and AI-powered vehicle/pedestrian detection. The major ITS treatments discussed in the interviews are given below.

Preemption and Pre-preemption

If a grade crossing is in proximity to a signalized intersection, a traffic queue from the intersection may extend back onto the rail tracks. With the interconnection with the train-activated warning systems, traffic signals can receive an advanced warning time of a train approaching and activate a “preempted” mode for cleaning vehicles on tracks before the train arrives. Pre-preemption is an enhanced preemption strategy that assigns “extra” green time to the movements blocked by a train before and after the train arrives. The pre-preemption strategy not only increases the safety of HRGCs (cleaning tracks before training comes), but also optimizes the traffic operations before, during, and after trains approach.

Preemption is an attractive solution for FDOT to solve the safety and mobility issues at HRGCs and has been implemented at multiple sites in Florida. However, the strategy (including pre-preemption) is facing several challenges in practice, such as train warning time from railway systems, preemption timing design, etc. The feedback from the districts and the Central Office is given in Table 5-12.

Table 5-12. Summary of FDOT Districts' Feedback on Preemption

District	Key Points

1	• The District has widely implemented preemption where applicable.
	• There are conflicts between traffic signal timings and ARMEA (American Railway Engineering and Maintenance-of-Way Association) guidelines for maximum rail warning time.
	  ▪ The Traffic Ops manual requires a high amount of time (sometimes up to 60s) to clear a queue.
	  ▪ The railroads have a maximum time they can use and cannot go up to 60s.
	  ▪ Long warning time (≥ 40s) may not be retrieved accurately.

2	• Preemption has been done everywhere since the 1990's. • It would be good to do a wide-scale verification that the preemption timing is still working the same as originally intended.
4	• The current preemption does not allow enough time in some cases to clear the tracks. • A previous attempt was made to conduct a pilot study to test train detectors (Island Radar technology) for providing a long train warning time. • Rail companies feel radar or other detectors aimed at their property is encroachment of their right of way.
5	• All crossings within 200 feet of a traffic signal have preemption.
6	• Preemption is working on with the traffic operations office.
7	• Preemption is an effective treatment and has been working in general. • The public needs better information about the process. • Many vehicles travel under the gate arm as it comes down or drive around the gate arm, so they do not have to wait on the train.
Central Office	• Most railroads are against preemption and pre-preemption as they do not want people knowing the location of their trains.

Advanced Sensor Technologies

Advanced sensor technologies, such as radar, lidar, and AI-powered video analytics, can be used to detect road vehicles (including pedestrian) and rail trains. The detection can provide train warning time to preemption operations or be used for road user warning/citation. Overall, FDOT Districts are interested in advanced sensor technologies, but need state-wide research/pilot studies. Some detection technologies discussed in the interviews are summarized below:

- ***District 1***—District 1 is starting to do more ITS near crossings (vehicle detection with both cameras and sensors) but not at crossings, as the railroads are somewhat cautious. The monitoring is done by Traffic Ops to detect crashes and backups.
- ***District 2***—District 2 is exploring wireless detectors that are going to be installed off of the railroad right-of-way and be able to detect trains, calculate speed, and estimate length. The new sensors will use the gathered data to eventually inform motorists when crossings will be blocked and for how long.
- ***District 4***—District 4 attempted to test Island Radar for train detection, but it did not work out due to the complications of connecting the technology to the network. The District also

discussed Vehicle Presence Detectors (VPO) that are being installed at any crossing along FEC/Brightline where the trains go over a crossing at a speed of over 79mph.

- ***District 6***— Brightline has implemented a pilot project of a violation warning system at NE 141st Street and Biscayne Blvd., where they have installed cameras and sent warnings to people who went around the gates or stopped on the tracks. These warnings were sent via mail, but they cannot send any fines.

Figure 5-9. Brightline Violation Warning System in Miami, Florida

- ***District 7*—**District 7 is interested in using advanced detection sensors at multiple locations to detect queues formed during a train passing a rail crossing. This helps the downstream signals clear the queue backups that are caused by train delays. They also discussed with CSX the need to put cameras at locations like this to issue warnings/citations to people causing the damage when tractor trailers are going through railroad crossings.

Other Technologies

FDOT districts also discussed some TSM&O and ITS technologies in interviews, as shown below:

- ***Dynamic Message Signs (DMS)*—**Districts 2, 3, and 7 are interested in putting DMS at some crossings to provide warning messages to road users to increase their awareness of trains and encourage them to engage in safer behaviors. District 7 suggests putting out safety messages during certain months or during a backup or delay. An example of the safety message is “Prepare to Stop When Flashing”

- ***Mobile Apps*—**District 7 suggested adding a notification to mobile mapping apps (e.g., Google Map, WAZE, etc.) that will inform the public of possible incoming trains at a crossing, using ITS or advanced warning systems.

- ***Emerging Technologies***—FDOT districts are interested in the next generation technologies, such as connected vehicles, AI-powered detection, and inspection, etc. However, they do not have much experience with these technologies and felt these types of initiatives should be statewide rather than only at the district-level.

5.1.5.3 Successes, Lessons Learned, and Other Resources

Table 5-13 presents the success stories and lessons learned in FDOT District rail crossing practice.

Table 5-13. Successes and Lessons-learned by FDOT Districts.

District	Key Points
1	• Cooperation with a railroad company on two adjacent signal safety projects in Avon Park. • Close communication with railroad companies.
2	• Has worked diligently to implement the low-cost and easy countermeasures (i.e., all crossings have gates). • Looking into other new ideas. • Successfully worked with the railroads on "Low-Cost Programs" where FDOT provides equipment if the railroad provides the labor.
3	• The RDE treatment does seem effective. • With regard to funding, more is always good.
4	• The District has received an on-site signal safety grant from FHWA, which will allow them to update signal houses and equipment to make it safer. They also have a grant from Brightline to install premium fencing, delineators, and ITS devices. • For CSX, once the RDE was installed on state roadways, any maintenance to the striping is FDOT's responsibility.
5	• Installing Do Not Stop on Tracks (R8-8) signs with flashing lights installed to deter drivers from stopping on tracks.
6	• Implementation of RDE, four-quadrant gates, and delineators at certain locations. • Education in multiple languages is important and a successful strategy in Be Rail Safe. • FRA gave the police in City of Hollywood (District 4) High Visibility Enforcement Grants and found improved behaviors.
7	• FRA Section 130 Federal Signal Safety Funding program is successful. • The RDE helps educate and train the traveling public to stay out of the area of fouling the track with the visual cues. • Educated people who call in concerning the preemption lights and gates. Mainly why the green light comes on to clear the traffic that may be on the tracks.

5.2 Interviews with CSX Company

This section presents interviews with representatives of the CSX company to learn their TSM&O strategies, insights, ITS applications, innovative treatments, success stories and/and lessons learned to improve safety and mobility at HRGCs in Florida. The interview questions cover the following topics: (1) challenges, causes, and strategies to address safety and mobility issues at HRGCs, and (2) knowledge and experience on effective strategies, treatments, successes, lessons learned, and other resources.

5.2.1 Overview of Company CSX in Florida

CSX Transportation, known as CSX, is a Class I (meaning it has an annual carrier operating revenue of $943,898,958 or more) freight railroad company operating in the Eastern United States and the Canadian provinces of Ontario and Quebec. The railroad operates on approximately 21,000 route miles of the racks, including about 1,627 miles in Florida and is the largest railroad company (*72*). The CSX railroad network is presented in Figure 5-10.

Figure 5-10. CSX Railroad Network in Florida

5.2.2 Challenges, Causes, and Strategies to Address Safety and Mobility Issues at HRGCs

5.2.2.1 Primary Safety and Mobility Challenges in HRGC Operations

The railroad industry in the United States has a long history, predating the development of many roadways. With the growth of the nation and increased transportation demands, roadways were constructed parallel to existing rail lines. This proximity has led to numerous crossings, each representing a potential impact on public safety.

- ***Number of crossings:*** Having a high number of crossings remains an ongoing concern, as this increases the risk of crashes involving vehicles, pedestrians, and trains. In addition, when trains become longer, they require more space to stop for crew changes and maintenance. If there are numerous crossings along the tracks, it can cause blockages when a train stops at a crossing, impeding the flow of traffic on both roadways and railways. This can lead to delays and disruptions in the transportation network.

- ***Incidents:*** Crashes, derailments, or other disruptions can have significant impacts on the fluidity of the entire railway network. With a network spanning 21,000 miles, an incident in one location can cause ripple effects that affect train operations over long distances. For example, an incident in Tampa could disrupt train services all the way from Miami to Chicago, leading to delays and logistical challenges. Incidents, including strikes or collisions, can pose a risk of derailment. When a train is involved in a collision or strikes an object at a crossing, it can cause the train to lose control and potentially derail. Derailments not only result in significant damage to the infrastructure and rolling stock but also pose a grave risk to the safety of passengers and crew members.

- ***Community Development Impacts****:* The development of communities around railway networks can introduce additional challenges. Increased pedestrian and vehicular traffic near crossings can raise safety concerns because people need to navigate these intersections safely. Moreover, the growing traffic can further exacerbate mobility issues, such as congestion and delays, requiring careful planning and coordination to ensure smooth transportation operations. The railroad industry is also impacted by community development. Large developments often lack adjacent roadways or alternate access routes, resulting in only one at-grade crossing for a community. It is important for municipalities to understand the implications of this limited access. While Tampa requires two crossings per community, other areas may not have similar stipulations. Increased community development brings in more motorists and pedestrians, which can lead to delays at railway crossings. Developers should consult with railroads during the planning phase to address potential issues. However, developers may not always remain involved once the development is complete, which can pose long-term challenges for the safety and mobility of residents. CSX has expressed a desire to be involved in the planning process whenever possible, as they can provide insights based on their experiences with other developments.

5.2.2.2 The Main Causes of Serious Safety and Mobility Issues at Your HRGC locations

According to CSX, here are the leading causes of safety issues at HRGCs:

- ***Driver Behavior***: CSX identifies driver behavior as a significant cause of incidents, including running into trains, ignoring signage, going around gates, and driving onto tracks.

- ***Trespassing Behavior***: Another cause of issues is trespassing, where individuals enter railroad property without authorization, posing risks to their safety.

- ***Low Ground Clearance Locations***: Concern arises in areas where the track has low ground clearance, as vehicles may get stuck and be at risk of being struck by a train. Additionally, the removal of stuck vehicles may potentially damage the tracks, requiring inspection afterward.

- ***Intentional Acts***: Acts such as suicide, fraud, and criminal behavior can also pose safety concerns, although they may not be specifically relevant to HRGC.

5.2.2.3 Implemented or Planned Strategies to Address the Identified Issues

CSX has implemented or planned the following strategies to address the safety and mobility issues:

- ***Non-traversable medians:*** Non-traversable medians are physical barriers placed in the center of the road to prevent vehicles from crossing over into opposing lanes or turning across traffic. This treatment can be an effective tool for preventing people from going around gates, particularly in locations with regular gates. These medians can be standalone structures or combined with delineators to create a more robust barrier. They are effective in locations where regular gates are used at railroad crossings, but they may not be suitable for locations with four quadrant gates. Four quadrant gates are typically used at higher-risk crossings and have barriers on all sides to completely block off the crossing.

- ***Delineators:*** Delineators are reflective posts or markers placed along the road to provide visual guidance and enhance visibility. The Delaware treatment example refers to a specific approach or case study related to delineator usage.

- ***Incorrect turn on railroad tracks treatment****:* To address the issue of drivers making incorrect turns onto railroad tracks, several measures can be implemented. These may include pavement markings, such as arrows, directing vehicles away from the tracks. Delineators, which are reflective markers, can also be used to guide drivers and highlight the correct path. Additionally, flexible barriers, such as bollards, can be installed to physically prevent vehicles from entering the tracks when making incorrect turns.

5.2.2.4 Educational Outreach on HRGC Safety

CSX also supports the following education programs to enhance the public awareness of HRGCs and increase their compliance with traffic rules:

- ***Operation Lifesaver****:* An organization dedicated to promoting safety at railroad crossings and preventing crashes.

- ***CSX's in-house safety outreach efforts****:* This program uses digital platforms like billboards and targeted digital ads to show their commitment to raising awareness and addressing safety concerns in problematic locations. Such initiatives can be effective in reaching a wide audience and educating people about railway safety.

- ***CSX Outreach****:* The establishment of the Incident Reduction Team by the CSX police department at three locations in Florida demonstrates their proactive approach to safety. These teams focus on outreach and education, aiming to create awareness among the public and law enforcement personnel about railroad safety. Collaborating with Brightline, another railroad operator, further enhances their efforts in outreach and education.

5.2.3 Knowledge and Experience on Effective Strategies, Treatments, Successes, Lessons Learned, and other Resources

5.2.3.1 Traditional Treatments

CSX provided their option on the traditional treatments to improve the safety and mobility of HRGCs as below:

- ***Four quadrant gates****:* Four quadrant gates can be effective in certain situations. They are typically used at railroad crossings to prevent vehicles from crossing the tracks when a train is approaching. However, they may not be suitable for all cases, as different locations and circumstances may require different treatments.

- ***Geometry treatment****:* Geometry treatment refers to modifying the physical layout or design of a roadway or intersection. This treatment is particularly important when there are multiple roads entering or exiting an area. By adjusting the geometry, it is possible to address issues and potentially close off problematic roadways to improve safety or traffic flow. CSX often conducts a review when a roadway is problematic.

- ***Pavement marking****:* Pavement marking involves the application of painted lines, symbols, and patterns on the road surface to provide guidance and information to drivers. This treatment is often considered during diagnostic reviews, where the condition and effectiveness of existing pavement markings are assessed. Proper pavement marking can enhance safety and help drivers navigate the road. CSX review the marking during the diagnostic review.

- ***Signs and flashing lights****:* When it comes to signs and flashing lights, transportation authorities typically follow the Manual on Uniform Traffic Control Devices (MUTCD). The MUTCD provides guidelines and standards for the design, installation, and maintenance of traffic control devices, including signs and signals. Adhering to these guidelines ensures consistency and helps promote safe and efficient traffic operations.

- ***Non-Traversable Medians****:* Non-traversable medians are raised barriers or physical dividers placed in the center of the road approaching the grade crossing. These medians are designed to prevent vehicles from crossing over into the opposing lanes or attempting to go around crossing gates. They help direct vehicles to approach the crossing correctly and discourage unsafe driving behaviors, thus reducing the risk of collisions with oncoming trains.

- ***Education****:* Education plays a critical role in enhancing safety at highway rail grade crossings. It involves raising awareness among drivers, pedestrians, and the general public about the risks associated with grade crossings and the proper actions to take when approaching or crossing them. Educational efforts may include public awareness campaigns, driver training programs, distribution of informational materials, and community outreach initiatives. By promoting knowledge and understanding, education can contribute to improved safety behaviors and increased compliance with crossing regulations.

5.2.3.2 TSM&O and ITS Applications

CSX also provided their opinions on TSM&O and ITS applications to improve the safety and mobility of HRGCs:

- Preemption may not always be the ideal solution in every situation. While it can be effective in many cases, there are instances where alternative solutions may be more suitable.
- CSX had not extensively explored other types of technology yet, but they expressed an interest in learning more about them. This openness to exploring alternative solutions is commendable as it allows for a more comprehensive evaluation of available options.

5.2.3.3 Emerging Technologies

According to CSX, the emerging technologies to improve the safety and mobility of HRGCs are as follows:

- ***Waze and railroad predictions***: The collaboration between Waze and partner railroads to predict train arrival times can be helpful for drivers in planning their routes. However, it is crucial to ensure that this information is used responsibly. Drivers should exercise caution and not solely rely on this information when making driving decisions. It is essential to follow traffic rules and regulations and not take unnecessary risks based solely on the predicted train arrival times.
- ***CSX's robotic dog for inspections***: The use of a robotic dog by CSX for inspecting train cars and tracks is a fascinating application of technology. Robotic inspections can enhance efficiency and safety in the transportation industry. These advancements can help identify maintenance issues and potential hazards more quickly and accurately. However, it is important to note that human oversight and expertise should still be in place to interpret and act upon the inspection results effectively.

5.2.4 Successes and Lessons Learned from the Previously Implemented HRGC Strategies and Countermeasures

5.2.4.1 Lessons Learned

There is no universal solution that applies to all locations and situations concerning railroad safety. It is necessary to conduct a separate analysis for each location to gain an understanding of driver's behavior and determine the most appropriate countermeasures to implement. The main thoughts provided by CSX include:

- ***RDE is not always the best option***: Dynamic envelopes refer to the space required for vehicles to safely stop behind the crossing when a train is approaching. While it is important to establish appropriate stopping distances, implementing dynamic envelopes is not always feasible or the most effective solution. Factors such as road layout, traffic patterns, and available space must be considered when determining the appropriate design for a grade crossing.

- ***Google or satellite imagery may not provide a comprehensive understanding***: While Google Maps or satellite imagery can be useful tools for obtaining an overview of a location, they have limitations when it comes to assessing grade crossings. These tools may not capture all aspects of the crossing, such as nearby structures, vegetation, or the actual sightlines available to drivers. Conducting an on-site diagnostic review allows for a more accurate and comprehensive assessment.

- ***Diagnostic review of each crossing is crucial***: A one-time assessment of grade crossings is not sufficient for ensuring ongoing safety. Regular diagnostic reviews are necessary to evaluate the condition of the crossing, assess any changes in traffic patterns or infrastructure, and identify potential risks. These reviews should be conducted by qualified personnel who can observe driver behavior, assess visibility, examine signage and warning systems, and address any emerging safety concerns.

5.2.4.2 Success Story

CSX observes instances of drivers mistakenly turning onto tracks. An effective treatment implemented in Newark, Delaware near Deer Park Tavern involved pavement markings, arrows to guide motorists straight through the crossing, and flexible bollards. In this location, they have used pavement markings through the crossing: arrows keep motorists moving straight through the crossing, and flexible bollards. The delineators in this location are on the shoulder, so they are not hit as often. This is something CSX has started to recommend in locations where this behavior is happening often. Figure 5-11 shows the location of the implemented treatment. Figure 5-12 and Figure 5-13 show the treatments on eastbound and westbound, respectively.

Figure 5-11. A Successful Delineator Deployment at an HRGC in Newark, Delaware

Figure 5-12. Delineators and Pavement Arrows on Eastbound at an HRGC in Newark

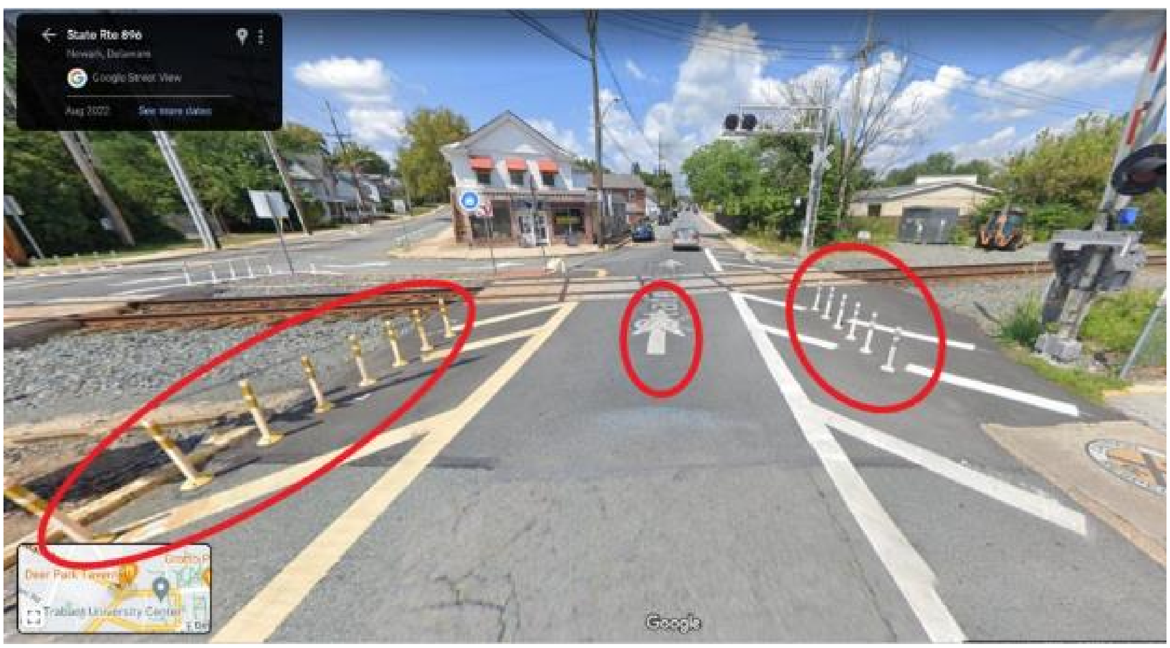


Figure 5-13. Delineators and Pavement Arrows on Westbound at an HRGC in Newark

It may be beneficial to consider using delineators with non-traversable curbing. These types of delineators are less likely to be hit by vehicles and can potentially be more effective in such locations.

5.2.5 Estimated HRGC Treatment Cost

Estimated HRGC treatment costs that are extracted from the districts, vendors, railroad companies, and the Internet are summarized in Appendix C. The estimated costs are only for reference since they can vary significantly and change with time.

6 In-field Observations

This chapter describes the field visit efforts on nine selected study sites with high priority. The field visits aimed to observe traffic operations (especially stopping behaviors) with the RDE pavement marking treatment, identify any potential issues, and recommend improvement treatments.

6.1 Site Selection

This study selected nine HRGCs for field observations. The nine HRGCs cover all FDOT districts and typical implementation scenarios of the RDE treatment. The selection criteria are:

- The HRGCs are located on a State Road with the RDE treatment.
- The HRGCs are closed to a signalized intersection in urban/suburban areas is preferred.
- The HRGCs should satisfy one or more following conditions: (1) increased Zone 3 stopping rates (stopping within track areas), (2) significant crash records, or (3) recommended by FDOT districts.

Table 6-1 lists the nine study HRGC sites and the factors for field visiting.

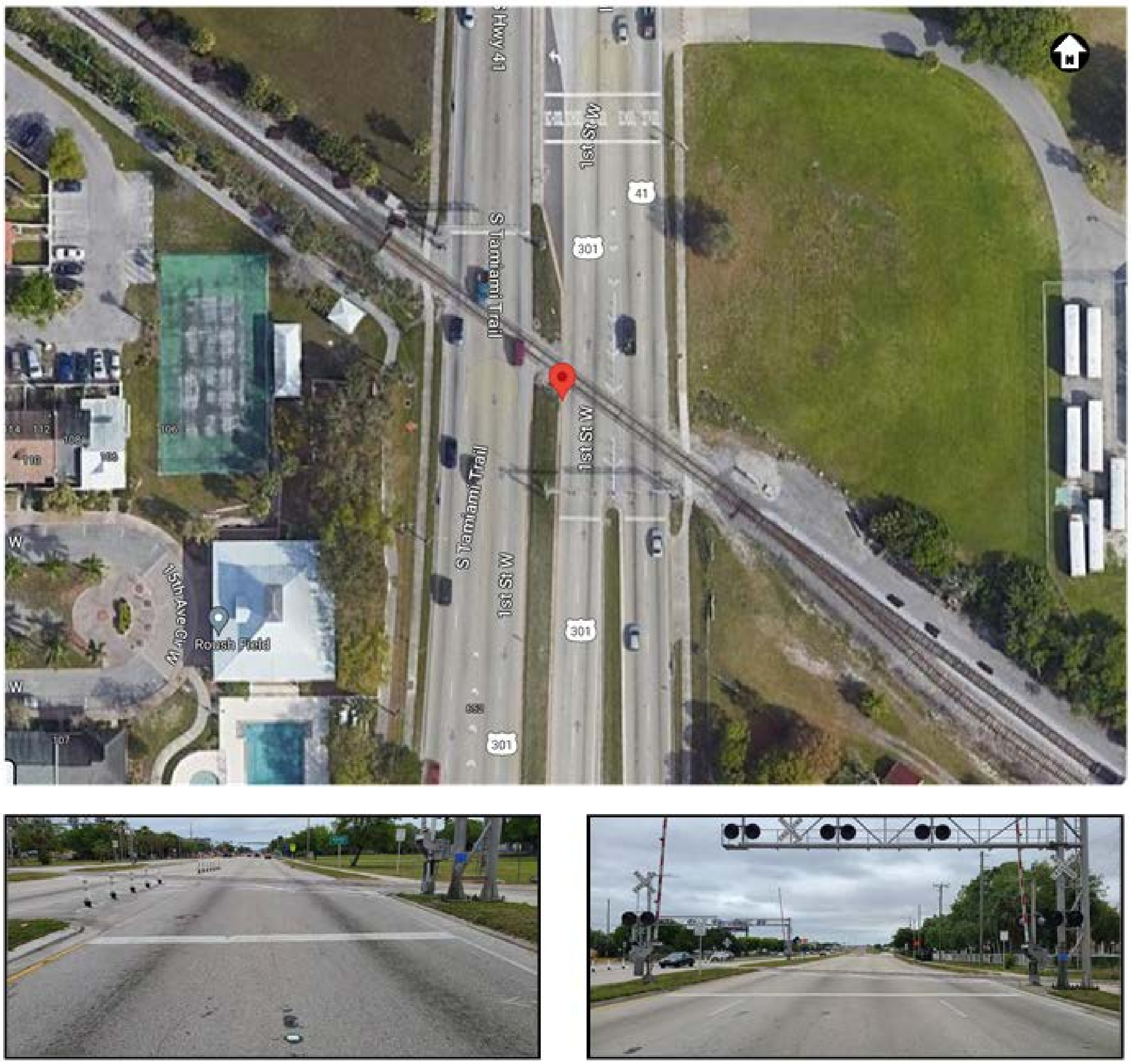
Table 6-1. List of Study Sites for Field Observations

Intersection	District	Factors for Field Visit
US41@SR55, Bradenton	District 1	• 5 crashes—1 serious injury, 1 possible injury, 1 minor injury, and 2 PDO (Property Damage Only)
US17 @ Timuquana Rd., Jacksonville	District 2	• Track stopping decreased 6% on WB after the treatment. • Track stopping increased 4.5% on EB after the treatment. • Suggested by District 2
SR389 @ N East Ave, Panama City	District 3	• Track stopping increased 11.5% after the treatment
SR77 @ SR10, Panama City		• Track stopping increased 23% after the treatment
W Cypress Creek @ N Andrews Ave, Fort Lauderdale	District 4	• 4 crashes-1 fatal and 3 PDO • Track stopping increased 4.4% on EB and 2.4% on WB
Sheridan St @ N Dixie Hwy, Hollywood		• 6 crashes: 1 fatal, 1 possible injury, 4 PDO • Track stopping increased 7.1% on EB and 1.6% on WB
US17 @ Colonial Dr, Orlando	District 5	• 6 crashes
SR922 @ NE 14th Ave, North Miami	District 6	• 2 crashes: 1 fatal, 1 PDO • Track stopping increased 15% on EB after the treatment
Busch Blvd@ Nebraska Ave, Tampa	District 7	• Track stopping increased 2% on NB after the treatment

6.2 Site 1 – US-41/301 @ 13th Avenue E, Bradenton, District 1

6.2.1 Site Characteristics

US41/301 is a divided urban arterial with 8 lanes on both sides located in Manatee County, Florida. AADTs are 67,000 vpd (SB) and 68,000 vpd (NB). The number of tracks is one. The Clear Storage Distance (CSD) measured from the RDE/gate to the downstream intersection (NB) limit line is 528 ft. An aerial view and street views and RDE Treatment at US 41 at 13th Ave, District 1 are shown in Figure 6-1.



Looking North Towards Railroad

Looking South Towards Railroad

Figure 6-1. Aerial Photograph and RDE Treatment at US-41 @ 13th Ave E, District 1

6.2.2 Before-after Study by District 1

The before-after study result at this site conducted by District 1 (Source: FDOT District 1) is shown in Table 6-2. No incorrect stopping behaviors (Zone 2, Zone 3, and Zone 4) were observed in either before or after stages.

Table 6-2. Before-After Study at US-41 @ 13th Ave E, District 1

Zone	Southbound			Northbound		
	Pre-Install	Post-Install	Change	Pre-Install	Post-Install	Change
	Stops (%)	Stops (%)	Stops (%)	Stops (%)	Stops (%)	Stops (%)
Zone 1	37 (100%)	31 (100%)	0%	49 (85.7%)	32 (88.0%)	0%
Zone 2	0 (0%)	0 (0%)	0%	0 (0%)	0 (0%)	0%
Zone 3	0 (0%)	0 (0%)	0%	0 (0%)	0 (0%)	0%
Zone 4	0 (0%)	0 (0%)	0%	0 (0%)	0 (0%)	0%
Total	37	31		49	32	

6.2.3 Field Observation by the Research Team

The research team conducted site visit on May 12, 2023.The incorrect stopping behaviors observed by the research team at this site is shown in Figure 6-2, the R8-8 sings "DO NOT STOP ON TRACKS" are shown in Figure 6-3, and nighttime visibility of RDE pavement marking is shown in Figure 6-4.

Stopping on Tracks　　Stopping on RDE Pavement Markings

Figure 6-2. Incorrect Stopping Behaviors at US-41 @ 13th Ave E, District 1

Figure 6-3. R8-8 Signs at US-41 @ 13th Ave E, District 1

Figure 6-4. The Nighttime Visibility of RDE Pavement Marking at US-41 @ 13th Ave E, District 1

6.2.4 Identified Issues and Suggested Treatments

The identified issues and suggested treatments based on field observations by the research team at Site 1 are summarized in Table 6-3. The suggested relocation and treatment of R8-8 signs at Site 1 are shown in Figure 6-5.

Table 6-3. Identified Issues and Specific Treatments at Site 1

Issue	Potential Causes	Suggested Treatments
Stops on tracks in queues	• Long queue during peak hours (Figure 6-2). • Drivers do not understand the RDE pavement markings.	• Provide education/outreach to let drivers understand the compliance behaviors with the RDE pavement markings.
Drivers ignore the information of R8-8 ("DO NOT STOP ON TRACKS")	• US41/US301 is a multi-lane arterial with bi-directional 8 lanes. • A median split the same-directional four-lane on NB (2 by 2). • Drivers on the NB inner lanes may not detect the R8-8 on roadside (Figure 6-3)	• Install an R8-8 sign on the median on NB. • Install an R8-8 sign on the median separating NB and SB. • Relocate R8-8 on roadside to make it visible to drivers. • Attach Flashing Beacons or LED Flashing Lights to the R8-8 sign to increase its visibility. • See Figure 6-5.
Low lighting level at RDE	• No street lighting at the crossing (Figure 6-4). The lighting level near the RDE pavement marking is 0.11 foot-candle.	• Install street lighting at the crossing.
No stopping behavior improvement with RDE pavement markings in District's before after study	• Drivers need to understand RDE pavement markings.	• Provide RDE educational outreach and conduct law enforcement. • Perform a follow-up study to observe the drivers' stopping behavior improvement over a long-term implementation of RDE pavement markings.

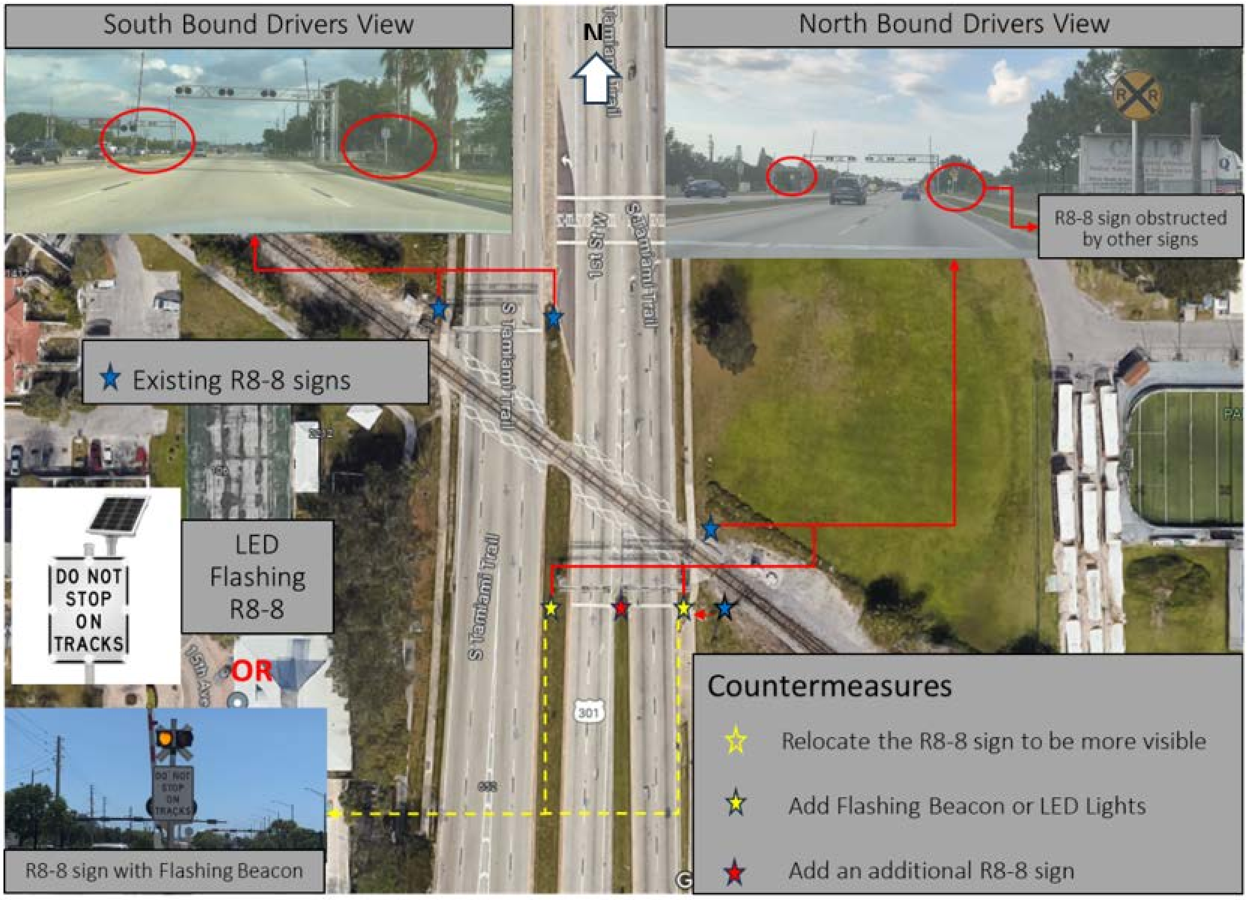


Figure 6-5. Suggested Countermeasures of R8-8 Signs at US-41/301 @ 13th Ave E, District 1

6.3 Site 2 – US-17 @ SR-134, Jacksonville, District 2

6.3.1 Site Characteristics

The crossing (US DOT # 620891) is located on SR-134 (Timuquana Rd), which is a four-lane urban minor arterial. Its AADT is 21,500 vpd. The crossing (with one track) is close to the downstream intersection (US 17 @ SR-134) with a distance of only 20 ft. Aerial Photograph and RDE Treatment at US-17 @ SR-134, District 2 in Figure 6-6.

Figure 6-6. Aerial Photograph and RDE Treatment at US-17 @ SR-134, District 2

6.3.2 Before-after Study by FDOT 2

Table 6-4 shows the before-after study result at this site conducted by District 2 (Source: FDOT District 2). It reported a decrease of 8% in stopping in Zone 3 (track area) on WB and an increase of 5% on WB after the implementation of the RDE treatment. Please note that the WB data in Table 6-4 has only one observation. It was not possible to achieve a meaningful statistical conclusion. Green in the table indicates a positive result and red shows a negative result. The cell without color indicates no impact after the RDE implementation.

Table 6-4. Before-after Study of RDE Pavement Marking at US-17 @ SR-134, District 2

Zone	Eastbound			Westbound		
	Pre-Install	Post-Install	Change	Pre-Install	Post-Install	Change
	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)
Zone 1	332 (27.6%)	351 (27.2%)	-0.4%	49 (100%)	21 (95.5%)	-4.5%
Zone 2	200 (16.6%)	267 (20.7%)	4.1%	0 (0%)	0 (0.0%)	0.0%
Zone 3	237(19.7%)	151 (11.7%)	-8.0%	0 (0%)	1 (4.5%)	4.5%
Zone 4	434 (36.1%)	523 (40.4%)	4.3%	0 (0%)	0 (0.0%)	0.0%
Total	1,203	1,292		49	22	

6.3.3 Field Observations by the Research Team

A field visit was conducted by the research team at US-17 @ SR-134, District 2 on May 20, 2023. No stops on tracks were found during the field visit. However, two stops on RDE pavement markings and one stop in Zone 2 (passing stop bar with a risk of being hit by a descending rail gate) were observed (per 8 minutes) as shown in Figure 6-7. The storage space between the stop bar and the RDE pavement markings is short (one vehicle). It results in some stopped vehicles' rear invading into the RDE pavement marking.

Stopping in Zone 2 (between Stop Bar and Tracks) — Stopping on RDE Pavement Markings

Figure 6-7. Observed Incorrect Stopping Behavior at US-17 @ SR-134, District 2

Two R8-8 signs ("DO NOT STOP ON TRACKS") are installed on the roadside and median as shown in Figure 6-8. The roadside R8-8 sign may be blocked by the vegetation. The crossing is illuminated. The nighttime lighting level near the track area (on roadside) is 0.43 fc (WB) and 0.49 fc (EB), as shown in Figure 6-9.

Figure 6-8. Observed R8-8 Signs at US-17 @ SR-134, District 2

Figure 6-9. The Nighttime Visibility of RDE Pavement Marking at US-17 @ SR-134, District 2

6.3.4 Identified Issues and Suggested Treatments

The identified issues and suggested treatments based on field observations by the research team at Site 2 are summarized in Table 6-5. The proposed countermeasures at Site 2 are shown in Figure 6-10.

Table 6-5. Identified Issues and Specific Treatments in Site 2, District 2

Issue	Potential Causes	Suggested Treatments
Stops on RDE pavement markings in Zone 4 (after the rail tracks)	• The storage space between the stop bar of the downstream intersection and the RDE pavement markings is short (one vehicle). It results in some stopped vehicles' back invading into the RDE pavement markings (Figure 6-7).	• Move the intersection stop bar before the rail tracks. • Add R10-6 Sign near the stop bar ("STOP HERE ON RED"). • See Figure 6-10.
Potential risk of incorrect turn onto tracks	• Continuous right-turn arrow pavement markings on exclusive right-turn lanes may mislead drivers.	• Replace continuous right-turn arrows with straight arrows with straight arrows + guidance information ("SOUTH HWY17"). • See Figure 6-10. • Installing delineators to guarantee that drivers can clearly identify the presence of the crossing, even from a distance.
Stops in Zone 2 (passing the stop bar before the trail tracks)	• Drivers do not understand the RDE pavement markings.	• Provide education/outreach to let drivers understand the compliance behaviors with the RDE pavement markings.
Drivers cannot see the R8-8 sign on roadside from certain angles	• Blocked by the tree branches.	• Trim tree branches.

Figure 6-10. Proposed Countermeasures at US-17 @ SR-134, District 2

6.4 Site 3 – SR-389 @ US-231, Cedar Grove, District 3

6.4.1 Site Characteristics

The research team visited two sites (Sites 3 and 4) in FDOT District 3. Site 3 – SR-389 (N East Ave) is a two-lane divided urban major collector with AADT of 19,000 vpd. It is close to the downstream intersection (SR-389 @ SR-75/US-231). A side road (Lafeyette Rd) is connected to SR-389 on the upstream of the crossing. The RDE pavement markings are installed on both sides of the tracks, as shown in

Figure 6-11. No street lighting is available at the crossing and the downstream intersection is illuminated.

6.4.2 Before-after Study by District 3

Table 6-6 shows the stopping rate in Zone 3 increased 11.5% after implementing the RDE treatment at SR-389 @ US-231, District 3. Green in the table indicates a positive result and red shows a negative result. The cell without color indicates no impact after the RDE implementation.

Table 6-6. Before-After Study at SR-389 @ US-231, District 3

Zone	Pre-Install Veh. Stops (%)	Post-Install Veh. Stops (%)	Change Veh. Stops (%)
Zone 1	252 (5.9%)	262 (9.5%)	3.6%
Zone 2	1,536 (34.1%)	1,199 (41.3%)	7.2%
Zone 3	124 (2.6%)	424 (14.1%)	11.5%
Zone 4	2,467 (57.9%)	960 (35.1%)	-22.8%
Total	4,379	2,845	

6.4.3 Field Observation by the Research Team

The field visit was conducted by the research team on May 19, 2023.The research team observed incorrect stopping behaviors at SR-389 @ US-231, District 3 as shown in Figure 6-12, including one stop on tracks and three stops on RDE pavement markings (per 8 minutes).

SR 389 (East Avenue) Looking South

R/R Crossing Looking East

Figure 6-11. Aerial Photograph and RDE Treatment at SR-389 @ US-231, District 3

Figure 6-12. Example of Incorrect Stopping Behaviors at SR-389 @ US-231, District 3

The lighting level at RDE the pavement markings and track areas are low, as shown in Figure 6-13. The foot-candle readings on the roadside near the tracks is 0.25 fc (SB) and 0.24 fc (NB).

Figure 6-13. Driver's View on RDE at Night at SR-389 @ US-231, District 3

On NB, there are continuous right arrows on the right-turn lane surface upstream of the crossing as shown in Figure 6-14. This design tends to increase drivers' confusion on selecting correct turning points (US 231 or Lafayette Rd) and the likelihood of incorrectly turning onto the rail tracks. It is suggested to replace right arrows with straight arrows and add guidance text information prior to the crossing.

Figure 6-14. Continuous Right-Turn Arrows prior to the Crossing Increasing the Risk of Incorrect Turn into Tracks at SR-389 @ US-231, District 3

6.4.4 Identified Issues and Suggested Treatments

The identified issues and suggested treatments based on field observations by the research team at Site 3 are summarized in Table 6-7. The proposed countermeasure of pavement markings at Site 3 are shown in Figure 6-15. The change of pavement marking from right-turn arrow before the railroad tracks to straight arrow with intended destination roadway information can eliminate the confusion of drivers for making incorrect turns onto railroad tracks.

Table 6-7. Identified Issues and Specific Treatments at Site 3, District 3

Issue	Potential Causes	Suggested Treatments
Stops on tracks and RDE pavement markings	• Long queue during peak hours (Figure 6-12). • Drivers do not understand the RDE pavement markings.	• Provide education/outreach to let drivers understand the compliance behaviors with the RDE pavement markings.
Low lighting level at track areas	• No lighting poles at the crossing (Figure 6-13).	• Install lighting pole at the crossing.
Potential risk of incorrect turn into tracks	• Continuous right arrows in the upstream of crossing tend to increase drivers' confusion on selecting correct turning points.	• Replace right arrows with straight arrows and add guidance text information prior to the crossing. • See Figure 6-15. • Installing delineators to guarantee that drivers can clearly identify the presence of the crossing, even from a distance.
District before-after study shows an increased stopping on tracks with the RDE pavement markings	• Drivers need to understand RDE pavement markings. • Data errors.	• Provide RDE educational outreach and conduct law enforcement • Perform a follow-up study to observe the drivers' stopping behavior improvement over a long-term implementation of RDE pavement markings.

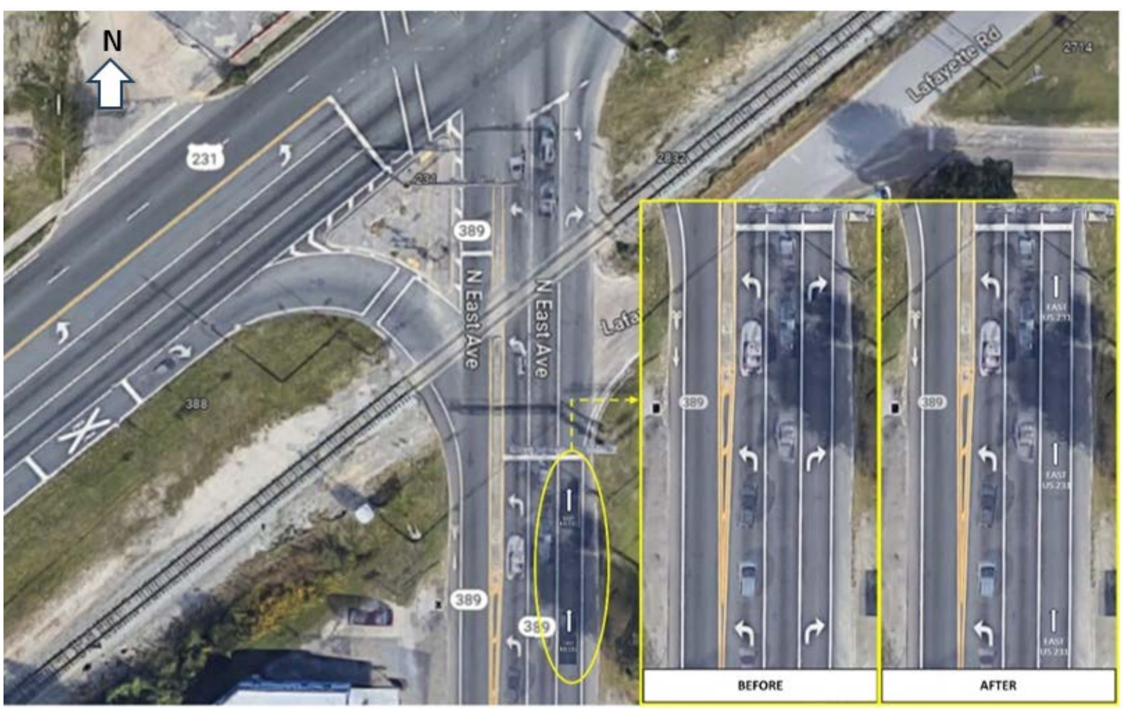


Figure 6-15. Proposed Countermeasure of Pavement Markings at SR-77 @ US-231, District 3

6.5 Site 4 – SR-77 @ US-231, Panama City, District 3

6.5.1 Site Characteristics

Site 4 - SR 77 (MLK Jr. Blvd) is a four-lane divided rural minor arterial with a posted speed limit of 45 mph and AADT of 25,500. The overhead lighting features are available at the downstream intersection (SR-77 @ US-231). The RDE pavement markings are installed on both sides of the tracks, as shown in Figure 6-16.

6.5.2 Before-after Study by District 3

Table 6-8 shows the stopping rate in Zone 3 increased 4.8% after implementing the RDE treatment at SR 77 @ US-231, District 3. Green in the table indicates a positive result and red shows a negative result. The cell without color indicates no impact after the RDE implementation. It shows the stopping behaviors at Zone 1 decreased by 2.7% and increased by 4.8% at the most dangerous Zone 3 after the implementation of RDE.

Table 6-8. Before-After Study at SR-77 @ US-231, District 3

Northbound			
Zone	**Pre-Install Veh. Stops (%)**	**Post-Install Veh. Stops (%)**	**Change Veh. Stops (%)**
Zone 1	2,517 (72.7%)	2,441 (70%)	-2.7%
Zone 2	892 (25.8%)	847 (25%)	0.8%
Zone 3	28 (0.8%)	196 (5.6%)	4.8%
Zone 4	23 (0.7%)	1 (0.0%)	0.7%
Total	3,460	3,485	

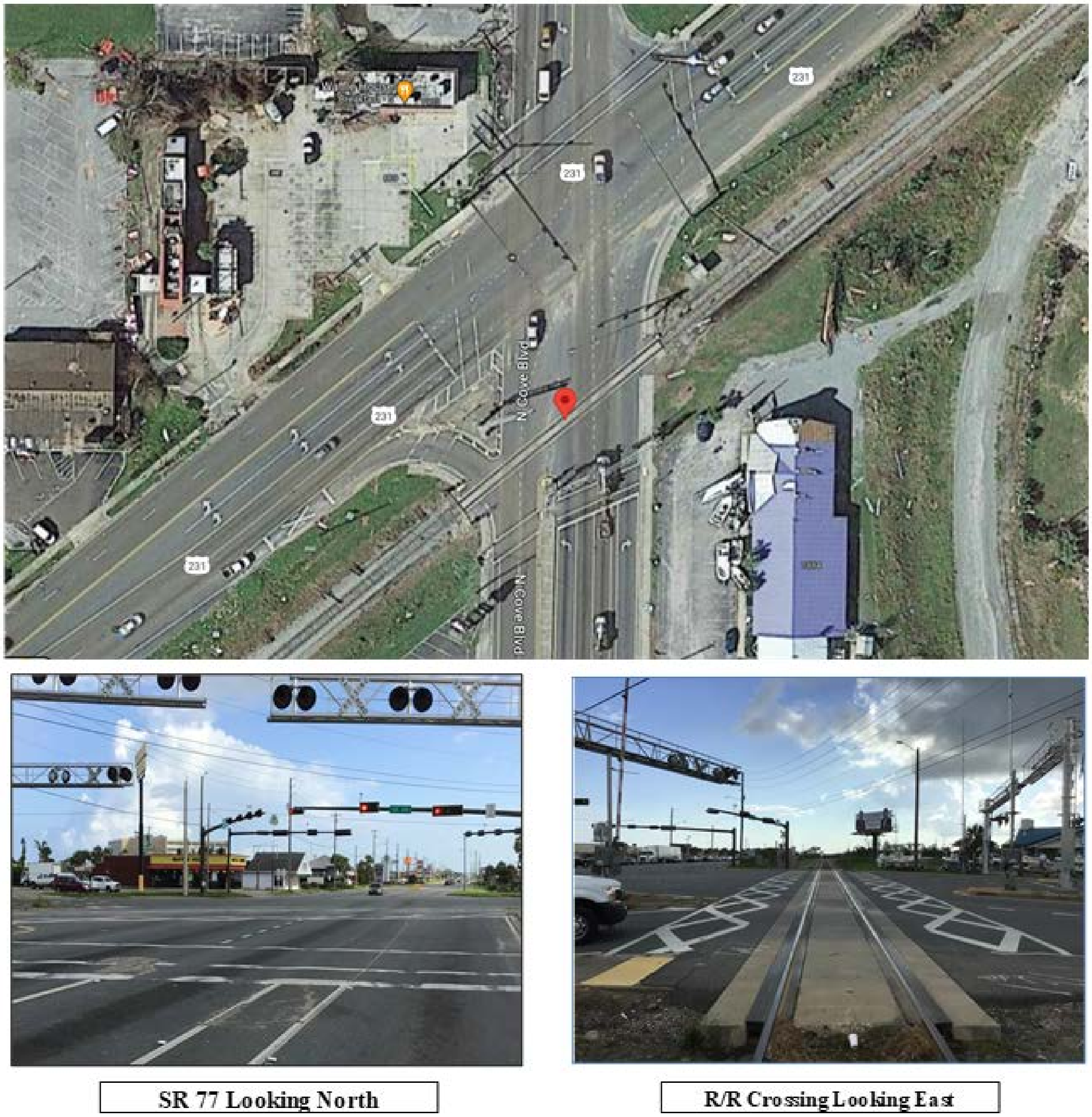


Figure 6-16. Aerial Photograph and RDE Treatment at SR 77 @ US-231, District 3

6.5.3 Field Observation by the Research Team

The field visit was conducted by the research team on May 19, 2023. No incorrect stopping behaviors were observed in the daytime or nighttime. The crossing is illuminated as shown in Figure 6-17, and its nighttime visibility is good. The roadside lighting levels adjacent to the track area are 1.19 fc (WB) and 2.48 fc (EB).

On NB, there are continuous right arrows on the right-turn lane surface upstream of the crossing as shown in Figure 6-18. This design tends to increase drivers' confusion on making correct turning points (US-231) and the likelihood of incorrectly turning onto the railroad tracks, especially at night. It is suggested to replace right arrows with straight arrows and add guidance text or roadway symbol information prior to the crossing.

Figure 6-17. Night Visibility of RDE Pavement Markings at SR-77 @ US-231, District 3

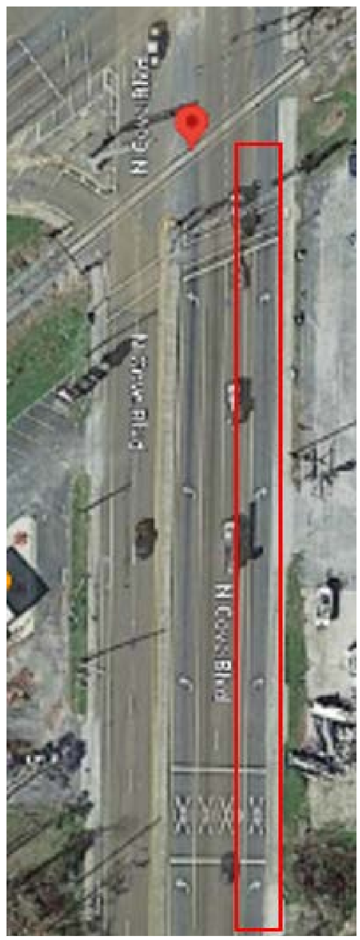


Figure 6-18. Continuous Right-Turn Arrows prior to the Crossing Increasing the Risk of Incorrect Turn into Tracks at SR-389 @ US 231, District 3

6.5.4 Identified Issues and Suggested Treatments

The identified issues and suggested treatments based on field observations by the research team at Site 4 are summarized in Table 6-9. The proposed countermeasure of pavement markings at Site 4 are shown in Figure 6-19.

Table 6-9. Identified Issues and Specific Treatments at Site 4, District 3

Issue	Potential Causes	Suggested Treatments
Potential risk of incorrect turn into tracks	• Continuous right arrows in the upstream of crossing tend to increase drivers' confusion on selecting correct turning points. • Skewed crossings make it difficult for drivers to detect rail tracks and correct turning points.	• Replace right arrows with straight arrows and add guidance text information prior to the crossing, see Figure 6-19. • Installing delineators to guarantee that drivers can clearly identify the presence of the crossing, even from a distance.
District's before-after study shows an increased stopping on tracks with the RDE pavement markings	• Drivers need to understand RDE pavement markings. • Data errors.	• Provide RDE educational outreach and conduct law enforcement. • Adding flashing beacon/LED lights to increase the visibility of R8-8 signs ("DO NOT STOP ON TRACKS"). • Perform a follow-up study to observe the drivers' stopping behavior improvement over a long-term implementation of RDE pavement markings.

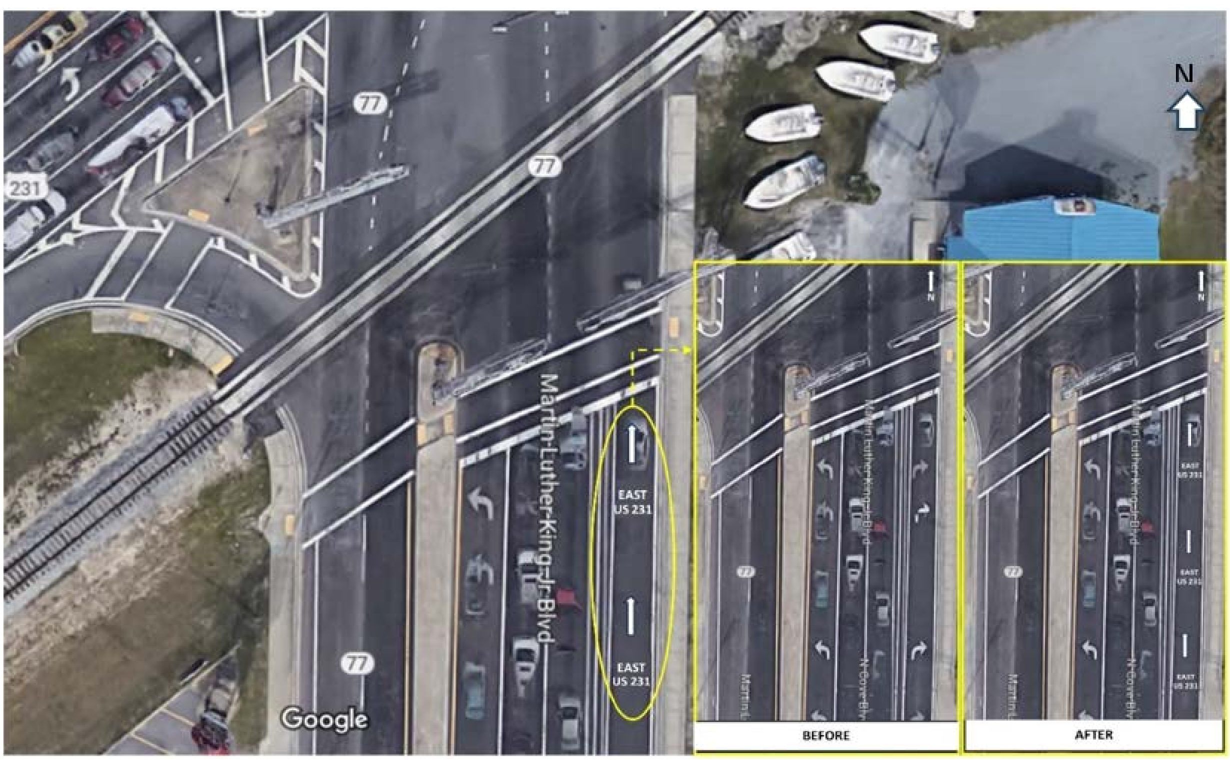


Figure 6-19. Proposed Countermeasure of Pavement Markings at SR-77 @ US-231, District 3

6.6 Site 5 – W Cypress Creek Rd @ N Andrews Ave, Fort Lauderdale, District 4

6.6.1 Site Characteristics

The research team also visited two sites (Sites 5 and 6) in FDOT District 4. Site 5 - W Cypress Creek Rd is an urban principal arterial with 8 lanes and AADT of 55,000 vpd. As shown in Figure 6-20, the distance between the rail tracks and the downstream intersection is 306 ft. The RDE pavement markings are installed on both sides of the tracks as shown in Figure 6-20. Roadway lighting is available at this site.

Figure 6-20. Aerial Photograph and RDE Treatment at W Cypress Creek Rd @ N Andrews Ave, District 4

6.6.2 Before-after Study by District 4

Table 6-10 presents the before-after study conducted by FDOT District 4 on stopping behaviors at this site. It is reported that the stopping rate at Zone 3 (track areas) is increased after the RDE treatment on EB and WB. Green in the table indicates a positive result and red shows a negative result. The cell without color indicates no impact after the RDE implementation. The stopping behaviors at the most dangerous Zone 3 slightly increased for both eastbound and westbound, by 4.4% and 2.4%, respectively. They also increased by 2.4% and 2.8% at Zone 4 for eastbound and westbound, respectively.

Table 6-10. Before-After Study at W Cypress Creek Rd @ N Andrews Ave, District 4

Zone	Eastbound			Westbound		
	Pre-Install	Post-Install	Change	Pre-Install	Post-Install	Change
	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)
Zone 1	411 (46.5%)	492 (42.5%)	-4.0%	294 (85.7%)	387 (88.0%)	2.3%
Zone 2	195 (22.1%)	224 (19.3%)	-2.8%	39 (11.4%)	17 (3.9%)	-7.5%
Zone 3	50 (5.7%)	117 (10.1%)	4.4%	4 (1.2%)	16 (3.6%)	2.4%
Zone 4	227 (25.7%)	325 (28.1%)	2.4%	6 (1.7%)	20 (4.5%)	2.8%
Total	883	1,158		343	440	

6.6.3 Field Observation by the Research Team

The field visit was conducted by the research team on May 21, 2023. When queues on WB form due to the downstream red signal, a few stops (<5) in Zone 2 (between the stop bar and the RDE pavement makings) were observed by the research team as shown in Figure 6-21, but no stops in Zone 3 were observed during a 20-minutes period during peak hours.

Figure 6-21. Stopping in Zone 2 in Queues on WB at W Cypress Creek Rd @ N Andrews Ave, District 4

FDOT District 4 installed three R8-8 signs ("DO NOT STOP ON TRACKS") on the roadside and median. The median R8-8 sign, and one roadside R8-8 sign, are equipped with flashing lights, as shown in Figure 6-22, and increase the awareness of the tracks to drivers, especially at night.

Figure 6-22. Signs with Flashing Lights on WB Median at W Cypress Creek Rd @ N Andrews Ave, District 4

The crossing is illuminated and the visibility of tracks and RDE pavement markings is good as shown in Figure 6-23.

Figure 6-23. Night Visibility of RDE Pavement Markings at W Cypress Creek Rd @ N Andrews Ave, District 4

6.6.4 Identified Issues and Suggested Treatments

The identified issues and suggested treatments based on field observations by the research team at Site 5 are summarized in Table 6-11. The proposed countermeasure of R8-8 signs with flashing beacon at Site 5 are shown in Figure 6-24.

Table 6-11. Identified Issues and Specific Treatments at Site 5, District 4

Issue	Potential Causes	Suggested Treatments
Stops in Zone 2 (passing the stop bar before the trail tracks)	• Drivers do not understand the RDE pavement markings.	• Provide education/outreach to let drivers understand the compliance behaviors with the RDE pavement markings.
District's before-after study shows an increased stopping on tracks with the RDE pavement markings	• Drivers need to understand RDE pavement markings. • Data errors.	• Adding flashing beacon/LED lights to increase the visibility of R8-8 signs ("DO NOT STOP ON TRACKS"), see Figure 6-24. • Provide RDE educational outreach and conduct law enforcement. • Perform a follow-up study to observe the drivers' stopping behavior improvement over a long-term implementation of RDE pavement markings.
Two bike fatalities by train (2012 and 2017)	• Moving over crossing. • Trespass crossings when train arrives.	• Adding flashing beacon/LED lights to increase the visibility of R8-8 signs ("DO NOT STOP ON TRACKS"). • Provide educations and outreach on awareness of the hazards associated with HRGCs. • Enforce the laws to reduce pedestrian/bike trespassing at HRGCs.
Four vehicle-train crashes (2 fatalities and 2 injuries) since 2012	• Moving over crossing or stopped on crossing.	• Check the preemption settings to ensure sufficient track clearance time. • Consider advance pre-preemption strategies to (1) provide advanced warnings to drivers, and (2) optimize traffic signal operations to clean tracks more efficiently.

Figure 6-24. Suggested Countermeasure of R8-8 Signs at W Cypress Creek Rd @ N Andrews Ave, District 4

6.7 Site 6 – SR-822 @ Dixie Hwy, Hollywood, District 4

6.7.1 Site Characteristics

Site 6 - SR 822 is an urban minor arterial with four lanes and AADT of 27,500 vpd. The crossing is located between two signalized intersections (SR 822 @ Dixie Hwy and SR 822 @ SW 4th Ave). The distance between the tracks and the intersections is around 50 ft on both sides. The RDE pavement markings are installed on both sides of the tracks. Roadway lighting is available at this site. The site layout is presented in Figure 6-25.

Figure 6-25. Aerial Photograph and RDE Treatment at SR-822 @ Dixie Hwy, District 4

6.7.2 Before-after Study by District 4

Table 6-12 presents the before-after study on stopping behaviors conducted by FDOT District 4 at this site. Green in the table indicates a positive result and red shows a negative result. The cell without color indicates no impact after the RDE implementation. It is reported that the stopping rate at Zone 3 (track areas) increased after the RDE treatment on EB and WB. A major concern was on eastbound since there was a significant reduction of safe stopping behaviors in Zone 1, and increase of dangerous stopping behaviors in Zones 2, 3, and 4.

Table 6-12. Before-After Study at SR-822 @ Dixie Hwy, District 4

Zone	Eastbound			Westbound		
	Pre-Install	Post-Install	Change	Pre-Install	Post-Install	Change
	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)
Zone 1	54 (85.7%)	50 (54.3%)	-31.4%	99 (14.5%)	58 (22.0%)	7.5%
Zone 2	4 (6.3%)	16 (17.4%)	11.1%	52 (7.6%)	19 (7.2%)	0.4%
Zone 3	1 (1.6%)	8 (8.7%)	7.7%	89 (13.1%)	41 (15.5%)	2.4%
Zone 4	4 (6.3%)	18 (19.6%)	13.3%	441 (64.8%)	146 (55.3%)	-9.5%
Total	63	92		681	264	

6.7.3 Field Observation by the Research Team

The field visit was conducted by the research team on May 21, 2023. The research team observed two stops on RDE pavement markings on EB during a 20-minutes observation period, as shown in Figure 6-26. The short distance between the two adjacent intersections (Dixie 4 Hwy and SW 4th Ave) causes vehicle queues to extend to the track area when they are facing a red signal at Dixie Hwy. It is suggested to optimize the traffic signal coordination between the two intersections to avoid the queue forming before Dixie Hwy. The nighttime visibility of the tracks and RDE pavement markings looks good, as shown in Figure 6-27.

Figure 6-26. Stopping in Zone 3 (Eastbound) at SR-822 @ Dixie Hwy, District 4

Figure 6-27. Visibility of RDE Pavement Markings at Night at SR-822 @ Dixie Hwy, District 4

6.7.4 Identified Issues and Suggested Treatments

The identified issues and suggested treatments by the research team at Site 6 are summarized in Table 6-13. The proposed countermeasures of R8-8 signs with flashing beacon and delineators at Site 5 are shown in Figure 6-28.

Table 6-13. Identified Issues and Specific Treatments at Site 6, District 4

Issue	Potential Causes	Suggested Treatments
Stops in RDE pavement markings	• The short distance between the two adjacent intersections (Dixie Hwy and SW 4th Ave) caused vehicle queues to extend to the track area (Figure 6-25). • Drivers do not understand the RDE pavement markings.	• A signal timing study is needed to optimize the traffic signal coordination between the two intersections to clean the queue before the red signal. • Provide education/outreach to let drivers understand the compliance behaviors with the RDE pavement markings.
District's before-after study shows an increased stopping on tracks with the RDE pavement markings	• Drivers need time to understand RDE pavement markings. • Data errors.	• Adding flashing beacon/LED lights to increase the visibility of R8-8 signs ("DO NOT STOP ON TRACKS"). See Figure 6-28. • Provide RDE educational outreach and conduct law enforcement. • Perform a follow-up study to observe the drivers' stopping behavior improvement over a long-term implementation of RDE pavement markings.
One pedestrian injury	• Moving over crossing and hitting by train.	• Adding pedestrian gate and fencing Reduce pedestrian/bike trespassing at HRGCs.
One vehicle-train crash in 2015	• Stalled and stuck on crossing.	• Installing delineators to guarantee that drivers can clearly identify the presence of the crossing, even from a distance.

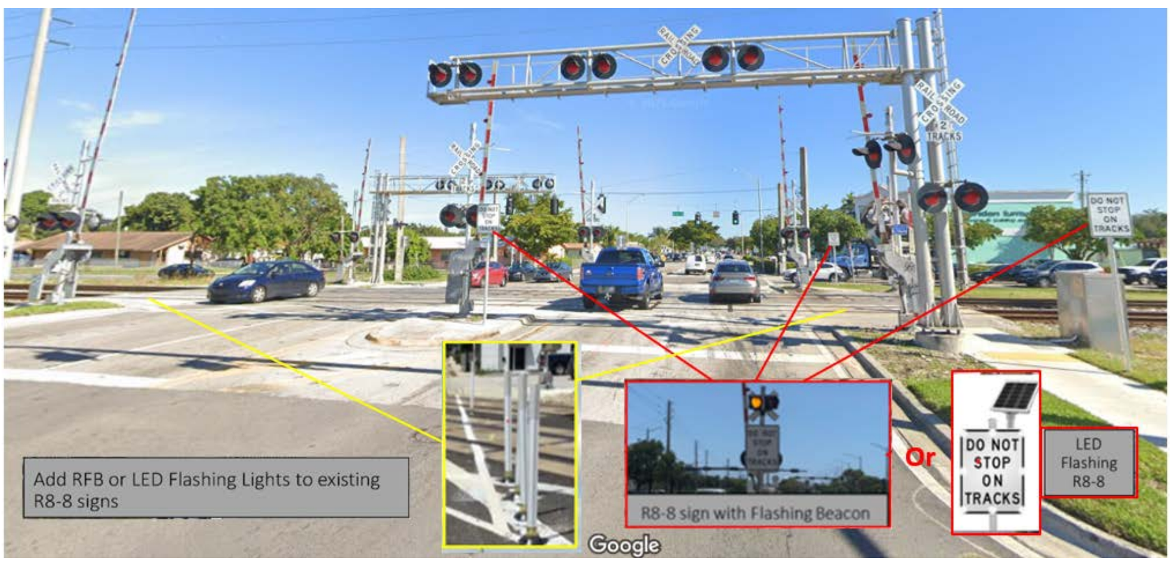


Figure 6-28. Suggested Countermeasures of R8-8 Signs and Delineators at SR-822 @ Dixie Hwy, District 4

6.8 Site 7 – W Colonial Dr @ SunRail Crossing, Orlando, District 5

6.8.1 Site Characteristics

The crossing (USDOT # 622181A) is a single track at-grade crossing located on W Colonial Dr, which is a four-lane urban principal arterial with 40 mph speed limit and AADT of 36,000. The distances from this crossing are 260 ft to Garland Ave and 520 ft to Orange Ave. As shown in Figure 6-29, the RDE pavement markings are installed on both sides of the rail tracks. Roadway illumination is available.

Figure 6-29. Aerial Photograph and RDE Treatment at W Colonial Dr @ SunRail Crossing, District 5

6.8.2 Before-after Study by District 5

From the before-after study at this site, FDOT District 5 reported a slight decrease in Zone 3 (track area) stopping rates with the RDE treatment in EB (0.3%, insignificant) and a significant reduction in WB (6.8%, significant at 95% confidence level), as shown in Table 6-14. Green in the table indicates a positive result and red shows a negative result. The cell without color indicates no impact after the RDE implementation.

Table 6-14. Before-After Study of Stopping Rate at W Colonial Dr @ SunRail Crossing, District 5

Zone	Eastbound			Westbound		
	Pre-Install	Post-Install	Change	Pre-Install	Post-Install	Change
	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)	Veh Stops (%)
Zone 1	233 (19.7%)	516 (76.2%)	56.5%	466 (18.6%)	1,636 (21.7%)	3.1%
Zone 2	745 (62.9%)	42 (6.2%)	-56.7%	1,618 (64.7%)	610 (8.1%)	-56.6%
Zone 3	65 (5.5%)	35 (5.2%)	-0.3%	191 (7.6%)	60 (0.8%)	-6.8%
Zone 4	141 (11.9%)	84 (12.4%)	0.5%	225 (9.0%)	5,227 (69.4%)	60.4%
Total	1,184	677		2,500	7,533	

6.8.3 Field Observation by the Research Team

The research team conducted a field visit on May 17, 2023. No Zone 3 (track area) stopping behaviors were observed in the field visit. As shown in Figure 6-30, during the downstream red signal, queues formed on WB, but the track area is clean.

Figure 6-30. Queue Formed during Downstream Red Signal at W Colonial Dr @ SunRail Crossing, District 5

The R8-8 Sign (“DO NOT STOP ON TRACKS”) on WB equipped with Flashing LEDs activated at a fixed time interval. The flashing sign increases drivers’ attention to the RDE area, especially during the night. The crossing is illuminated and the lighting level on roadside adjacent to track areas is 0.9 fc, as shown in Figure 6-31.

Figure 6-31. Visibility of RDE Pavement Markings at Night at W Colonial Dr @ SunRail Crossing, District 5

6.8.4 Identified Issues and Suggested Treatments

The identified issues and suggested treatments based on field observations by the research team at Site 5 are summarized in Table 6-15. The proposed countermeasure for adding lighting pole on westbound to improve lighting level for westbound at Site 7 is shown in Figure 6-32.

Table 6-15. Identified Issues and Specific Treatments at Site 7, District 5

Issue	Potential Causes	Suggested Treatments
District's before-after study shows an increased stopping rate in Zone 4 with the RDE pavement markings	• Drivers need to understand RDE pavement markings. • Data error.	• Adding flashing beacon/LED lights to increase the visibility of R8-8 signs ("DO NOT STOP ON TRACKS"). • Provide RDE educational outreach and conduct law enforcement. • Perform a follow-up study to observe the drivers' stopping behavior improvement over a long-term implementation of RDE pavement markings.
Low visibility at night on WB	• No lighting pole near crossing on WB.	• Install a lighting pole on WB to increase nighttime safety. • See Figure 6-32.

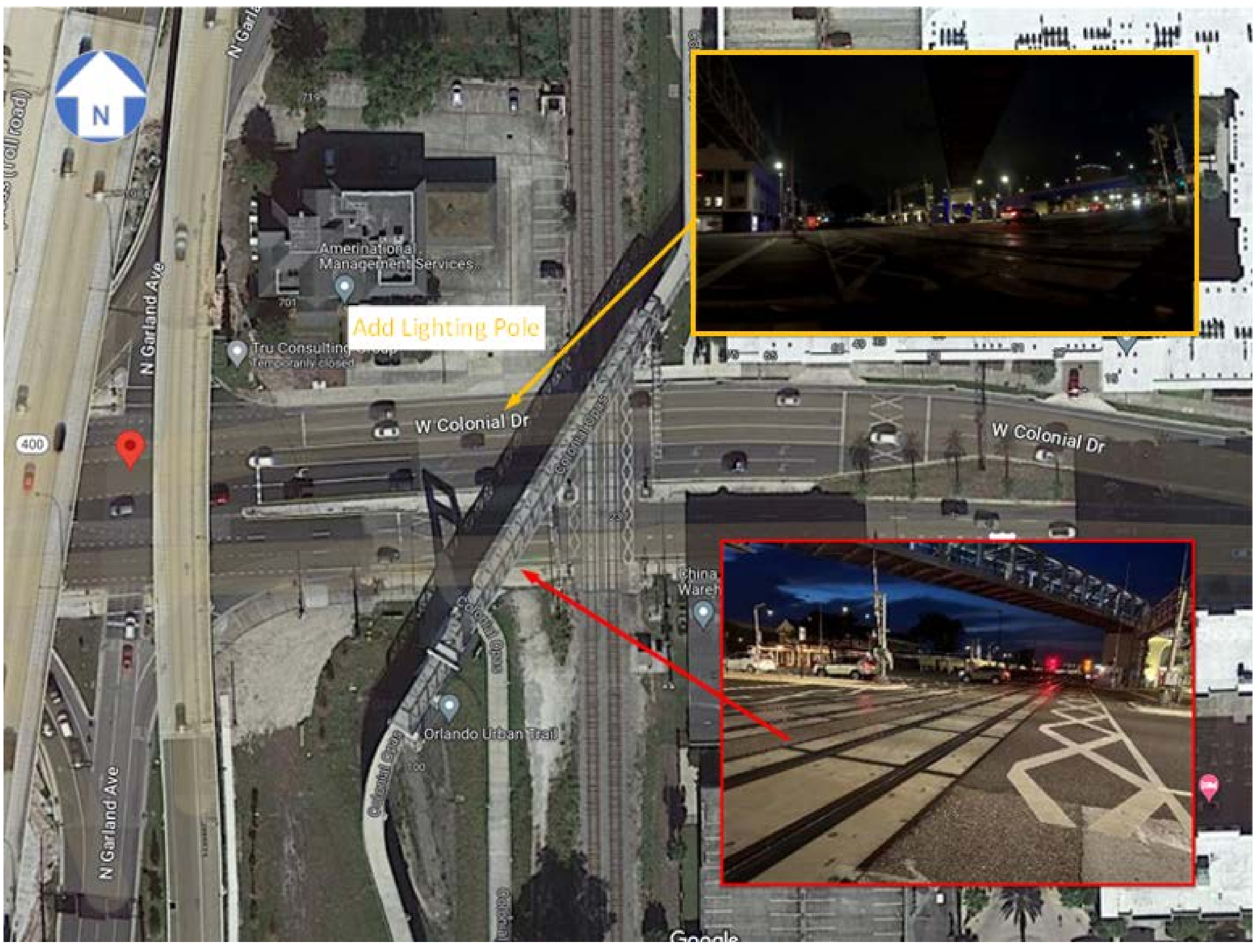


Figure 6-32. Proposed Countermeasure of Lighting Pole at W Colonial Dr @ SunRail Crossing, District 5

6.9 Site 8 – SR-922 @ NE 14th Ave, North Miami, District 6

6.9.1 Site Characteristics

SR-922 @ NE 14th Ave, North Miami is an intersection connecting a multi-lane arterial (NE 123rd St/SR 922) and a two-lane road (NE 13th PI) as shown Figure 6-33. The HRGC is located on the westbound with two tracks and RDE pavement markings on both sides. The HRGC is close to the downstream intersection (25 ft). Right-turn-on-red (RTOR) is allowed at this intersection. Street illumination is available. The speed limit on NE 123rd St is 35 mph and AADT is 33,600 vpd.

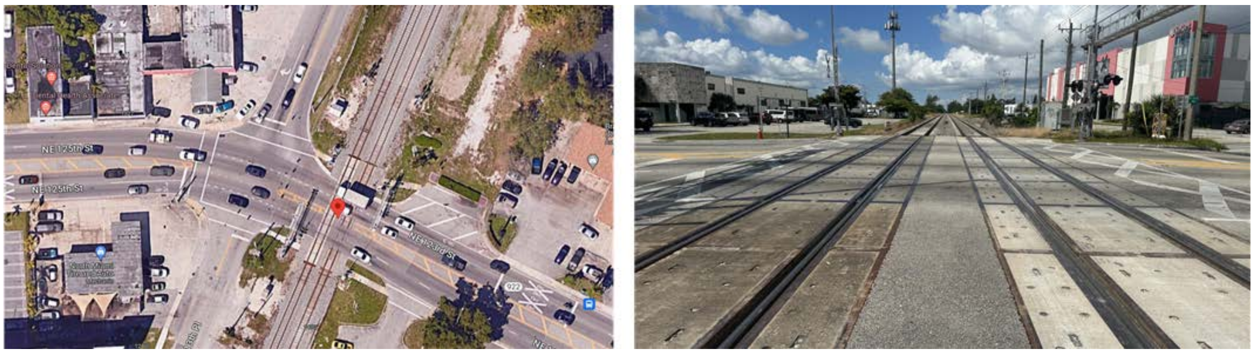


Figure 6-33. Aerial Photograph and RDE Treatment at SR-922 @ NE 14th Ave, District 6

6.9.2 Before-after Study by District 6

FDOT District 6 reported eight incidents between 1978 and 2019 at this particular crossing located on SR-922 / NE 125th Street, North Miami. Table 6-16 shows the result of a before-after study on stopping behaviors at SR-922 / NE 125th Street, North Miami. Green in the table indicates a positive result and red shows a negative result. The cell without color indicates no impact after the RDE implementation. The results are mixed with Zones 1, 2, and 4 are positive but the critical Zone 3 is negative for eastbound by an increase of 14.9% of dangerous stopping behaviors.

Table 6-16. Before After Study on Stopping Behaviors at SR-922 @ NE 14th Ave, District 6

Zone	Eastbound			Westbound		
	Pre-Install Veh. Stops (%)	Post-Install Veh. Stops (%)	Change Veh. Stops (%)	Pre-Install Veh. Stops (%)	Post-Install Veh. Stops (%)	Change Veh. Stops (%)
Zone 1	20 (50.0%)	230 (52.8%)	2.8%	896 (94.7%)	1,234 (93.5%)	-1.2%%
Zone 2	8 (20.0%)	47 (10.8%)	-9.2%%	35 (3.7%)	56 (4.2%)	0.5%
Zone 3	0 (0.0%)	65 (14.9%)	14.9%%	10 (1.1%)	15 (1.1%)	0.0%
Zone 4	12 (30.0%)	94 (21.6%)	-8.4%%	5 (0.5%)	15 (1.1%)	0.6%
Total	40	436		946	1,320	

6.9.3 Field Observation by the Research Team

A field visit was conducted on May 22, 2023. The major observations during the field visit are summarized below. No Zone 3 stopping behaviors were observed during the field visit. The R8-8 sign ("DO NOT STOP ON TRACKS") on WB is installed far from the road edge as shown in

Figure 6-34, so drivers may not see the message. It is suggested to relocate the sign to make it more visible to drivers. Roadway lighting is unavailable at the southeast corner of the intersection. The lighting level on the roadside adjacent to the track area is 0.13 fc (EB) and 0.17 (WB).

Figure 6-34. Driver's View on WB at SR-922 @ NE 14th Ave, District 6

6.9.4 Identified Issues and Suggested Treatments

The identified issues and suggested treatments based on field observations by the research team at Site 5 are summarized in Table 6-16. The suggested relocation and treatment of R8-8 signs at Site 5 are shown in Figure 6-35.

Table 6-17 Identified Issues and Specific Treatments at Site 8 in District 6

Issue	Potential Causes	Suggested Treatments
Drivers may not detect the R8-8 sign ("DO NOT STOP ON TRACKS")	• The R8-8 sign on WB is installed far from the road edge.	• Relocate the R8-8 sign to make it visible to drivers. • Attach Flashing Beacons or LED Flashing lights to R8-8 signs to increase the visibility. • See Figure 6-35.
Low lighting level on track areas	• Roadway lighting is unavailable at the southeast corner of the intersection.	• Install street lighting near the HRGC.
District's before-after study shows an increased rate of stopping on tracks with the RDE pavement markings	• Drivers need time to understand RDE pavement markings. • Data errors.	• Adding flashing beacon/LED lights to increase the visibility of R8-8 signs ("DO NOT STOP ON TRACKS"). • Provide RDE educational outreach and conduct law enforcement. • Perform a follow-up study to observe the drivers' stopping behavior improvement over a long-term implementation of RDE pavement markings.

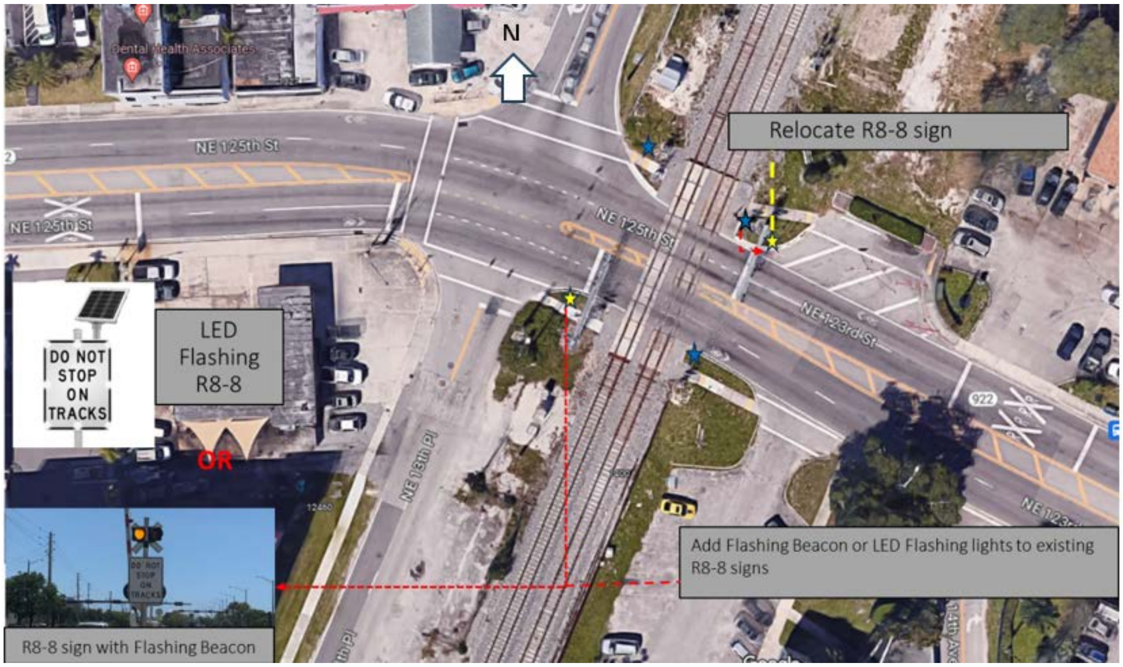


Figure 6-35. Proposed Countermeasure of R8-8 at SR-922 @ NE 14th Ave, District 6

6.10 Site 9 – E Busch Blvd @ N Nebraska Ave, Tampa, District 7

6.10.1 Site Characteristics

E Busch Blvd @ N Nebraska Ave is an intersection connecting two multi-lane arterials in the Tampa Bay area. An aerial view and street views and RDE Treatment at E Busch Blvd @ N Nebraska Ave in Tampa, District 1 are shown in Figure 6-36. The rail tracks cross the northbound with RDE pavement markings on one side of the tracks and are close to the downstream intersection as shown in Figure 6-37. Right-turn-on-red (RTOR) is allowed at this intersection. A paved right-turn channel presents at northbound.

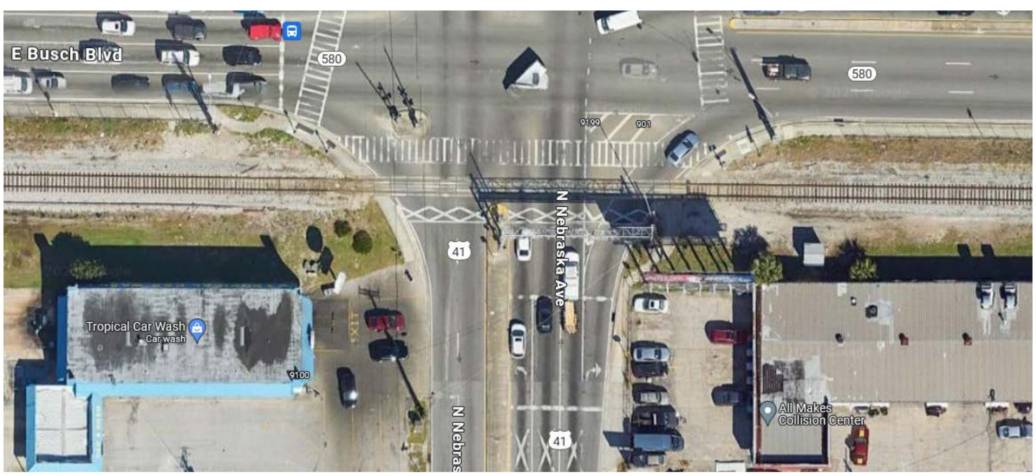


Figure 6-36. Aerial Photograph and RDE Treatment at E Busch Blvd @ N Nebraska Ave, District 7

Figure 6-37. One-side RDE Pavement Marking at E Busch Blvd @ N Nebraska Ave. District 7

This site allows the operation of turning on red, and there is right-turn channelization with paved islands within the dynamic envelope area. This design, which may induce right-turning motorists to stop at Zone 3 or Zone 4 to seek available gaps in conflicting traffic when they meet a red signal, tends to reduce the performance of RDE pavement markings to improve stopping behaviors at Zones 3 and 4.

6.10.2 Before-after Study by District 7

FDOT District 7 reported the following findings based on the results of before-after study as shown in Table 6-17. The most dangerous stopping behavior (stopping in Zone 3) rate slightly but insignificantly increased by 2.4%. The stopping behavior rate in Zone 2 (moderately dangerous) significantly decreased by 5.9%. The safe stopping behavior (stopping in Zone 1) rate did not significantly change after the implementation. The stopping behavior rate in Zone 4 (moderately dangerous) significantly increased by 3.1%.

Table 6-18. Before After Study on Stopping Behaviors at E Busch Blvd @ N Nebraska Ave, District 7

Zone	Northbound		
	Pre-Install	Post-Install	Change Veh. Stops (%)
	Veh. Stops (%)	Veh. Stops (%)	
Zone 1	731 (43.7%)	647 (44.0%)	0.3%
Zone 2	434 (26.0%)	296 (20.1%)	-5.9%%
Zone 3	411 (24.6%)	397 (27.0%)	2.4%
Zone 4	95 (5.7%)	130 (8.8%)	3.1%%
Total	1,671	1,470	

6.10.3 Field Observation by the Research Team

The research team conducted a field visit on May 13, 2023, with clear weather conditions. The major observations during the field visit are summarized below. The field review confirmed the overlap of RDE pavement markings with right-turn channelization. The track area (dynamic envelope) is close to the intersection edge along EB/WB. Right-turn-on-red vehicles are more likely to stop within track areas (Zone 3) and Zone 4 to seek available gaps in the conflicting traffic, as shown in Figure 6-37. An R8-8 Sign ("DO NOT STOP ON TRACKS") is on roadside is behind other signs. Drivers, especially on the right-turn lane, have difficulty detecting the sign when they approach the crossing. Figure 6-38 shows driver's view on the R8-8 which is behind an R10-15 "TURNING VEHICLES YIELD TO PEDESTRIANS" sign.

Figure 6-38. Drivers' View When Approaching the Crossing at E Busch Blvd @ N Nebraska Ave, District 7

In addition, the RDE pavement marking is narrow and with the same color (white) as other pavement markings. The RDE pavement marking is obstructed by the overhead structure. The visibility of the pavement markings is fair to poor for approaching drivers at night although street lighting is available at the intersection.

6.10.4 Identified Issues and Suggested Treatments

The identified issues and suggested treatments based on field observations by the research team at Site 9 are summarized in Table 6-18. The proposed treatments and relocation of R8-8 signs at Site 9 are shown in Figure 6-39.

Table 6-19. Identified Issues and Specific Treatments at Site 9, District 7

Issue	Potential Causes	Suggested Treatments
Observed stops in Zone 4 (the downstream area next to rail tracks)	• The overlap of RDE pavement markings with right-turn channelization pavement markings. • The track area is close to the intersection edge. • Right-turn-on-red vehicles are more likely to stop within track areas (Zone 3) and Zone 4 to seek available gaps in the conflicting traffic.	• Provide education/outreach to let drivers understand the compliance behaviors with the RDE pavement markings.
Drivers on outer lanes may not detect the R8-8 sign	• The R8-8 Sign ("DO NOT STOP ON TRACKS") on roadside is blocked other signs.	• Relocate R8-8 to be visible. • Attach Rapid Flash Beacons (RFB) or LED Flashing Lights to R8-8 signs to increase visibility. • See Figure 6-39.
Drivers are difficult to detect RDE pavement markings at night	• The RDE pavement marking is obstructed by the overhead structure shadows. • The lighting pattern of Bright– Dark–Bright (before-on-after RDE pavement markings) makes drivers difficult to detect the pavement markings.	• Adjust lighting pole angle to eliminate the uniformity lighting pattern.
Observed stops on tracks on the receiving direction	• Right-turn vehicles (from EB to NB) need to yield to conflicting traffic during red signals.	• Install R8-8 sign on EB. • See Figure 6-39.

Figure 6-39. Proposed Countermeasure of R8-8 at Busch Blvd @ N Nebraska Ave, District 7

6.11 Priority of Recommended Treatments

The proposed countermeasures were ranked based on effectiveness, technical maturity, and cost. A high priority was assigned to the countermeasures that are most likely to address the identified issues cost-effectively. The prioritized countermeasures are given in Table 6-19.

Table 6-20. Prioritized Countermeasures for Selected HRGCs

Countermeasures	Sites	Factors
Provide education and outreach programs to teach drivers to understand and comply with RDE pavement markings Conduct law enforcement to reduce blockages of HRFGCs	• Site 1: US41@SR55, Bradenton, D1 • Site 3: SR389 @ N East Ave, Panama City, D3 • Site 4: SR77 @ SR10, Panama City, D3 • Site 5: W Cypress Creek @ N Andrews Ave, Fort Lauderdale, D4 • Site 6: Sheridan St @ N Dixie Hwy, Hollywood, D4 • Site 8: SR922 @ NE 14th Ave, North Miami, D6 • Site 9: Busch Blvd@ Nebraska Ave, Tampa, D7	• These sites have observed incorrect stopping behaviors on rail tracks (Zone 3) in field visiting, or • An increased stopping rate at Zone 3 in districts' before-after studies. • Site 9 has significant stopping behaviors in Zones 3 and 4 on the exclusive right-turn lane.
Relocate R8-8 Sign ("DO NOT STOP ON TRACKS")	• Site 1: US41@SR55, Bradenton, D1 • Site 8: SR922 @ NE 14th Ave, North Miami • Site 9: Busch Blvd@ Nebraska Ave, Tampa, D7	• R8-8 Signs are blocked by other signs. • Relocating R8-8 signs is a low-cost countermeasure.
Add R8-8 sign at median	• Site 1: US41@SR55, Bradenton, D1	• Low-cost countermeasure
Attach RFB/LED lights to R8-8	• Site 1: US41@SR55, Bradenton, D1 • Site 3: SR389 @ N East Ave, Panama City, D3 • Site 4: SR77 @ SR10, Panama City, D3 • Site 8: SR922 @ NE 14th Ave, North Miami, D6 • Site 9: Busch Blvd@ Nebraska Ave, Tampa, D7	• Increase visibility of R8-8 to drivers. • These sites have significant incorrect stopping behaviors after the implementation of RDE pavement markings.
Replace right arrows with straight arrows and add guidance text information prior to the crossing	• US17 @ Timuquana Rd., Jacksonville, D2 • Site 3: SR389 @ N East Ave, Panama City, D3 • Site 4: SR77 @ SR10, Panama City, D3	• Prevent incorrect turns onto tracks. • A low-cost countermeasure.
Move Stop Bar of the downstream intersection back before the crossing	• US17 @ Timuquana Rd., Jacksonville, D2	• No sufficient space between the stop bar of downstream intersection and rail tracks. • A low-cost countermeasure.

7 Best Practices, Findings, and Recommendations

This chapter documents major research findings and provides recommendations to FDOT to address safety and mobility issues at HRGCs in Florida.

7.1 Research Findings

This section will include the major findings based on the literature review, interviews of each FDOT District, Central Office, and CSX, and field visits with HRGCs with high priority. The findings will be presented via two areas, with one in issues and strategies to improve safety and mobility OF HRGCs, and the other one in RDE pavement marking.

7.1.1 Issues and Strategies to Improve Safety and Mobility of HRGCs

- ***Contributing Factors to HRGC crashes:*** Human factors, train characteristics, railroad crossing characteristics and roadway conditions, and environmental conditions are the five main factors contributing to HRGC crashes. Among them, human factors contribute significantly to the HRGC-related fatalities, serious injuries, and crashes.

- ***Primary Challenges and Active FDOT Programs in Managing HRGCs:*** The primary challenges in managing HRGCs in Florida include (1) issues of driver and pedestrian trespassing behaviors at HRGCs, (2) general public unawareness of the hazards associated with HRGCs, and (3) frequent traffic queue backed up onto tracks from nearby downstream signalized intersections. In response, the FDOT has implemented and/or is in the process of executing various treatments and initiatives, including programs like rail inspection program, a rail crossing safety improvement program, a grade crossing opening/closure program, a Rail System Plan, rail capacity programs, Florida's SAP for HRGCs, and STRIDE at both the state and district levels. These efforts are aimed at mitigating these challenges. Continuous endeavors remain imperative to completely mitigate these risk factors and enhance overall HRGC safety.

- ***Funding Needs to Address HRGC-Related Issues:*** Insufficient funding is another common obstacle faced by FDOT districts. Districts require supplementary financial resources to effectively undertake improvement projects across a broader spectrum of sites, bolster educational initiatives, and extend safety treatments to county and city roads.

- ***Engineering Strategies, Countermeasures, and Technologies:*** Warning traffic signs, warning flashing lights, adequate pavement markings, REDs, two- quadrant gates, four-quadrant gates, delineators, preemption and pre-preemption mechanisms, ITS technologies, and automated violation warning system are acknowledged as impactful engineering strategies and measures for enhancing the safety and mobility of HRGCs. A successful implementation of these treatments necessitates careful consideration of various factors including site-specific conditions, maintenance strategies, and the allocation of support resources. Customizing these aspects in alignment with the unique characteristics of a HRGC with high priority is crucial for the effectiveness of these treatments.

- ***Education Strategies:*** Human factors contribute significantly to the HRGC-related fatalities, serious injuries, and crashes. Besides utilizing engineering strategies to prevent and reduce HRGC-related safety and mobility issues, transportation agencies should invest more funding and efforts in education strategies and statewide outreach activities to increase awareness among motorists, pedestrians, and the general public regarding the hazards associated with such crossings, traffic laws at HRGCs, and the appropriate steps to undertake when approaching or crossing them. The educational outreach activities include are not limited to Operation Lifesaver, Rail Safety Week, Mobility Week, Be Rail Smart, website, news channels, and social media.

- ***Law Enforcement Strategies:*** After statewide education and outreach regarding the hazards and traffic laws associated with HRGCs, FDOT can lead the effort to collaborate with FHP, local transportation agencies, and local law enforcement agencies to conduct statewide high-visibility enforcement campaigns to reduce violations of stopping at railroad tracks or blockage of HRGCs. Transportation and law enforcement agencies can work together to utilize technologies to provide automated violation warnings at HRGCs, and law enforcement officers can verify violations and issue citations to violators.

- ***FDOT District Strategies and Efforts:*** Each FDOT District has formulated unique strategies tailored to tackle safety and mobility challenges at HRGCs. These strategies include an array of approaches, such as yearly safety evaluations, HRGC improvement and enhancements, implementation of traffic control devices, improvement of traffic signs and pavement markings, enhancement of crossing surface conditions at HRGC critical zones, innovative geometry design, educational initiatives, and the integration of novel technologies. These diverse strategies collectively contribute to fostering safer and more efficient conditions at HRGCs within each district.

- ***Collaboration with Railway Companies:*** Collaboration with railway companies plays a pivotal role in the successful implementation of HRGC improvement projects. Given that the initial installation and continuous upkeep require using railroads' right-of-way, it is essential to establish effective partnerships. Optimal practice constitutes forming agreements between roadway and railway agencies at the state level, offering a broader framework for cooperation compared to district-level agreements. It is essential to involve railroad companies in land development associated with HRGCs in the early stage to obtain their inputs. The above strategic approach ensures streamlined collaboration and HRGC enhancements.

- ***Applications of Innovative Approaches and Advanced Technologies:*** FDOT Central Office and FDOT districts are actively exploring innovative interventions, including the deployment of novel treatments like roundabouts near HRGCs to prevent queue backed to railroad tracks, automated violation detection systems, pre-preemption strategies to improve safety and alleviate traffic congestion, queue management strategies, dynamic message signs, as well as emerging technologies such as Connected Vehicles (CV) and AI. To comprehensively evaluate the efficacy of these strategies, the suggestion of initiating state-wide pilot projects is put forth. These pilot initiatives and projects hold the potential to provide valuable insights into the practicality and impact of these advancements on HRGC safety and mobility.

7.1.2 Evaluation Results of Statewide RDE Pavement Marking Deployments

- The overall evaluation results on statewide deployments of RDE are positive. Based on the average of the evaluation results from seven FDOT districts with a total of 73 study sites, the RDE treatment increased safe stopping behaviors (stopping in Zone 1 – prior to stop bar) by 20%, decreased moderately-dangerous stopping behaviors (stopping in Zone 2 – between the stop bar and dynamic envelope area) by 3%, decreased the most dangerous stopping behaviors (stopping in Zone 3 – dynamic envelope area) by 5%, and decreased moderately-dangerous stopping behaviors (stopping in Zone 4 – after the dynamic envelope area) by 8%.
- RDE pavement markings are more effective at HRGCs with only one railroad track, 90 degrees between roadway and tracks, HRGC with two lanes or less in a travel direction.
- RDE pavement markings are generally less effective at HRGCs with multiple railroad tracks, angled between roadway and tracks, HRGC with multiple lanes ($\geq$3) in one travel direction.
- With and without traffic controls near HRGCs may not have a significant influence on Zone 3 stopping rates.
- Four-quadrant gates are usually associated with high traffic and long queues; consequently, this gate type is more likely to experience increased Zone 3 stopping rate. Two-quadrant gates and no gates tend to connect to a decreased Zone 3 stopping rate.
- Some districts reported that the current RDE color (white) and shape (“X”) may mislead road users. A yellow background is suggested to increase the visibility of track areas but needs approval from FHWA.
- While instances of vehicles stopping directly on tracks were infrequent during field visits, there was a notable prevalence of vehicles stopping on RDE pavement markings or passing the stop bar. In response, the suggestion is to institute active education programs targeted at drivers to bolster their adherence to RDE pavement markings followed by enforcement by issuing warnings and citations to violators. These education and enforcement initiatives hold the potential to improve driver compliance, ensuring that they respect and correctly respond to RDE markings, ultimately contributing to safer highway-rail grade crossings.
- The placement of supporting signage (R8-8) exhibits variation across different sites. A recommended approach involves repositioning these signs to optimize their visibility for drivers. Additionally, the suggestion is to enhance sign visibility, particularly during nighttime, by incorporating flashing LEDs or lights. On multi-lane arterials, installing R8-8 signs on both the median and roadside is advisable to ensure drivers can effectively

discern the critical message "DO NOT STOP ON TRACKS." This concerted effort aims to maximize driver awareness and comprehension of essential safety instructions at HRGCs.

- To gain a more precise understanding of the RDE treatment's performance, some FDOT districts proposed conducting follow-up studies in the future.

7.1.3 Contributing Factors

Highway-rail grade crossing crashes, which occur when a vehicle, pedestrian or bicyclist collides with a train at a level grade crossing, can result from a combination of factors. These factors generally involve a mix of human factors, infrastructure design, and operational issues. Many HRGC crashes are often avoidable. To prevent HRGC crashes or mitigate crash risks, it is necessary to learn the key contributing factors. The major contributing factors including human factors, train characteristics, railroad crossing characteristics, roadway conditions, and environmental conditions are summarized below.

7.1.3.1 Human Factors

Human factors are one of the main factors contributing to HRGC crashes. Most HRGC incidents are directly attributed to human behaviors. These behaviors may include, but are not limited to, the following behaviors:

- **Failure to obey traffic control devices**: Drivers, bicyclists, and pedestrians may ignore warning signals, signs, gates, and barriers at crossings.
- **High risk appetite**: Risky drivers, bicyclists, and pedestrians may attempt to beat approaching trains by crossing the tracks even when a train is visible or audible, especially in a hurry.
- **Distraction**: Use of mobile phones, in-vehicle entertainment systems, eating, walking, or bicycling with earbuds on, or other distractions can divert an attention of road users from warning traffic control devices.
- **Impairment**: Alcohol or drug impairment can impair judgment and reaction time of a road user.

Intentional violations by road users are key safety concern at HRGCs (*6*). It was stated that horizontal gate violations, where a motorist drives around or through the fully descended gate, were risky. Based on the statistical analysis conducted as part of this research effort, the following human factors were found to significantly increase the likelihood of fatal and serious injury crashes at HRGC locations including: (1) alcohol involvement, (2) disregarding traffic signs, signals, or pavement markings, (3) swerving or avoiding, and (4) vehicle speed of 40 mph or more. Therefore, driver and pedestrian education concerning rail safety must be enhanced, train safety awareness must be increased, and individuals ignoring existing traffic laws at HRGCs must be prosecuted. The use of technologies to automatically detect violation and provide warning must be explored to support law enforcement for issuing citations.

7.1.3.2 Train Characteristics

Train characteristics, such as train speed, often affect the severity of HRGC crashes. Fitzgerald et al. (2020) established an optimization model to evaluate the potential hazard values of the HRGCs in Florida. In this model, the following parameters were considered: average daily traffic volume, average daily train volume, train speed, and crash history. The authors recommended that the Modified Texas Priority Index Formula (or "the Florida Priority Index Formula") be utilized to rank the HRGCs in the State of Florida for safety enhancements. Based on the statistical analysis conducted as part of this research effort, crashes involving railway vehicles were found to have a significantly higher probability of fatalities and serious injuries. In addition, poorly lit or Quiet Zones (train horns would not be routinely sounded) can make it harder for road users to perceive an approaching train. It will be especially dangerous if road users are distracted or impaired. Therefore, a high-speed train and Quiet Zone could contribute to the severity of HRGC crashes. In summary, the following train characteristics could contribute to HRGC crashes:

- **Train speed**: High-speed trains may have less reaction time for road users and train operators.
- **Visibility and audibility**: Poorly lit or Quiet Zone can make it harder for road users to see and perceive an approaching train.

7.1.3.3 Railroad Crossing Characteristics and Roadway Conditions

A skewed HRGC or an HRGC with sight distance problems can make it harder for road users to see and perceive an approaching train. A curve, obstacle, or hill near a grade crossing could reduce road user's ability to see an upcoming train. It will become especially dangerous for road users when they ignore and violate the warning from traffic control devices at the HRGC. In summary, the roadway conditions at HRGCs that could contribute to HRGC crashes are discussed below.

Grade crossing attributes, such as crossing surface types and conditions, impact safety at HRGCs (*31*). A smooth structure of the crossing surface is critical for many reasons, including developing lifespan, preserving cost control, and decreasing the number of stuck/stalled vehicles (*44*). It is vital that standard HRGC attributes, such as a flat surface, are maintained to prevent stalling of vehicles on railroad tracks. Moreover, based on the statistical analysis conducted as part of this research effort, crossing surface conditions at HRGC critical zones (i.e., close or at railroad crossing areas) were found to significantly increase the likelihood of fatal and serious injury crashes at HRGC locations. During the agency interviews of this research project, FDOT districts 1, 2, and 3 also indicated that uneven, rough, or deteriorated surfaces at grade crossings can cause discomfort and potential hazards for vehicles, especially at higher speeds. Rough surfaces may lead to loss of control, tire damage, or crashes when crossing the tracks.

In summary, the following crossing characteristics, and roadway surface conditions at HRGCs could contribute to HRGC crashes:

- **Skewed or crossing sight distance problem:** Both skewed HRGCs or the crossings with sight distance problems can reduce road user's ability to see an upcoming train.

- **Crossing with multiple tracks:** It increases the chance of drivers to stop on tracks during traffic queue backup from downstream signalized intersections.
- **Short distance between a crossing and downstream intersection or freeway on-ramps:** Drivers could potentially mistake the opening of HRGCs as the road or freeway on-ramp they desire to turn and make incorrect turns onto the railroad tracks.
- **Grade crossing surface conditions**: Uneven, rough, or deteriorated surfaces at grade crossings can cause discomfort and potential hazards for vehicles, especially at higher speeds.

7.1.3.4 Environmental Conditions

Environmental factors, including weather, season, temperature, and time of day, significantly affect HRGC crashes. (*4*) studied driver hesitation and confusion to recommend daytime and nighttime countermeasures at eleven sites. Practical safety countermeasures were proposed. The recommended daytime treatments included advanced direction signage and striping to enhance upstream and downstream safety. Particularly for the critical zone, treatments such as striping or rail dynamic envelope (RDE) pavement markings, pavement gate markings, bollards, and illumination were recommended. Nighttime treatments such as standard lighting could prevent vehicle-train crashes.

7.1.4 Traditional Treatments

Traditional treatments include various active and passive treatments, such as geometry treatments, pavement markings, signage, flashing lights, and rail control devices. Even though there are a variety of traditional treatments that improve the safety and mobility at HRGCs, there is no one-size-fits-all solution. The application of traditional treatments depends on specific scenarios and locations. The following sections discuss some commonly used traditional countermeasures.

7.1.4.1 Rail Dynamic Envelope Pavement Markings

The rail dynamic envelope (RDE) is a section near railroad crossings that aims to keep motorists out of the danger zone. RDEs are considered to be effective in improving safety and mobility at HRGCs. More specifically, preventing right-turn channelization within RDE areas can reduce the likelihood of drivers stopping in RDE zones. Table 7-1 presents the assessment by FDOT districts and the FDOT Central Office regarding the impact of RDE pavement markings on enhancing drivers' adherence at HRGCs.

Among the districts, four districts indicated an overall positive efficacy of RDE pavement markings, although their effectiveness demonstrated variation across locations (as seen in District 6) or called for adjustments (notably in District 7). Districts 2 and 3 conveyed that RDE pavement markings exhibit a moderate level of effectiveness and pose no adverse consequences. District 1 expressed a lack of notable advantages from RDE pavement marking implementation. This disparity could be attributed to the prevalence of rural road crossings with RDE implementation in District 1, where infrequent traffic queues invade rail tracks.

Table 7-1. Districts' Evaluation on RDE Pavement Markings

Assessment	District							Central Office
	1	2	3	4	5	6	7	
Effective				✓[1]	✓	✓	✓	✓
Mildly effective		✓	✓					
Do not see a benefit	✓							

[1]District 4 stated that the RDE is effective based on feedback from the public after installation.

Based on the data, the Central Office reported a 15% reduction in incidents involving drivers being trapped on or encroaching upon tracks due to the implementation of RDE pavement markings. However, the data also highlights that the effectiveness of these markings differs across various districts.

The research team conducted a detailed evaluation based on a total of 73 before-after studies in the seven FDOT districts. The overall results show an increase in safe stopping behaviors (stopping in Zone 1 – prior to stop bar) by 20%, decreased moderately-dangerous stopping behaviors (stopping in Zone 2 – between the stop bar and dynamic envelope area) by 3%, decreased the most dangerous stopping behaviors (stopping in Zone 3 – dynamic envelope area) by 5%, and decreased moderately-dangerous stopping behaviors (stopping in Zone 4 – after the dynamic envelope area) by 8%.

The research team has also compiled a list of factors and feedback from FDOT District and Central Office interviews, which are believed to impact the effectiveness of RDE pavement markings in enhancing drivers' adherence to stopping compliance at HRGCs. The key factors are outlined below:

- ***RDE color and shape misleading road users*** — The RDE pavement markings, characterized by their white color and "X" shape, resemble crosswalks. This resemblance could potentially confuse pedestrians and lead them to believe they can walk across. Furthermore, the use of white RDE pavement markings might not be adequately effective in drawing drivers' attention to the track area. This concern was raised by districts 2, 5, and 6, as well as the Central Office.
- ***Installing RDE pavement markings at unnecessary locations*** — Districts 1 and 2 believe that RDE pavement markings would likely prove effective at crossings where traffic queues frequently extend back to the tracks. These crossings are typically situated in urban areas characterized by substantial traffic flow and proximity to signalized intersections. Conversely, crossings on rural roads with limited traffic or far from downstream intersections are less prone to instances of stopping on tracks. Consequently, implementing RDE markings at these locations might not yield substantial benefits.
- ***Skewed crossings make it difficult for drivers to notice tracks*** — District 4 and the Central Office pointed out that at skewed crossings, the appearance of RDE pavement markings

resembling arrows could potentially mislead drivers into making turns towards the tracks. This concern is exacerbated in limited visibility conditions, such as during nighttime.

- ***Public awareness of RDE pavement markings*** — District 7 observed that some individuals did not comprehend the purpose of RDE pavement markings without an explanation. This sentiment was also shared by districts 5 and 6.
- ***Maintenance responsibility after installation*** — Installing RDE pavement markings necessitates cooperation between FDOT and railway companies. However, the responsibility for maintenance tasks such as repainting rests with FDOT. In cases where FDOT installs these markings on county or city roads, the maintenance responsibility falls upon the respective local agencies.
- ***Residents near crossings are desensitized to the dangers of the HRGCs*** — District 3 indicated that individuals who have grown up near rail tracks might have developed a certain level of desensitization towards the potential hazards of railways. As a result, they could be more prone to disregarding the message conveyed by RDE pavement markings.
- ***Too many implementations of RDE pavement markings* —** District 2 mentioned that individuals might disregard the significance of RDE pavement markings because these markings are commonly found at all crossings.

The FDOT districts and the Central Office have provided a series of recommendations aimed at increasing the effectiveness of RDE pavement markings in Florida, as summarized below:

- ***Install RDE pavement markings with yellow background*** — Districts 2, 5, and 6 have proposed the idea of altering the color of RDE pavement markings to yellow in order to enhance the visibility of tracks. It is important to note that this new design is not currently approved by the Manual on Uniform Traffic Control Devices (MUTCD) (*73*). To explore this concept further, FDOT is engaged in discussions with the FHWA regarding the possibility of conducting an experimental trial involving the new RDE color pattern, as depicted in Figure 5-3.
- ***Conduct outreach activities*** — Districts 5, 6, and 7 have proposed educational initiatives aimed at increasing road users' understanding of RDE pavement markings and promoting greater adherence to these markings. Securing additional funding allocation is necessary to support the outreach efforts.
- ***Install RDE at crossings where regular queues back into tracks*** — Districts 1, 2, and 4 have proposed installing RDE pavement markings at pedestrian crossings located in urban areas with high traffic flow or adjacent to signalized intersections. These specific crossings pose a potential hazard where vehicles could inadvertently stop on the tracks due to traffic queues. In addition, District 2 has recommended avoiding the installation of RDE pavement markings at all HRGC locations. This tactic is intended to garner greater attention from road users towards the new markings.

- ***Conduct follow-up evaluation*** — Districts 1 and 5 have proposed conducting follow-up assessments to evaluate the efficacy of RDE pavement markings more comprehensively in various situations.

- ***Expand RDEs to local roads*** —District 4 and the Central Office have recommended the extension of the deployment of RDE pavement markings to include county and city roads.

- ***Install reflective delineators*** — District 4 proposed the installation of reflective delineators as a measure to prevent vehicles from making incorrect turns onto tracks. This approach proves particularly valuable at skewed crossings where RDE pavement markings look like arrows and could potentially mislead drivers into turning onto tracks.

7.1.4.2 Signing and Pavement Marking

Signing and pavement markings are the most common traditional treatments to primarily improve safety at HRGCs. Based on the findings from the FDOT research projects, (*4*) and (*74*)recommended the following three countermeasures to address improper human violations and avoid wrong turns near HRGCs:

- Removing potentially confusing traffic signs just upstream of HRGCs, such as Right Lane Must Turn Right sign.

- Removing potentially confusing pavement markings just upstream of HRGCs, such as right-turn arrow pavement marking.

- Change right-turn arrow pavement markings to straight arrow pavement markings with guidance information on right-turn lane(s) before HRGCs, and

- Installing Qwick Kurb to shorten an opening of railroad crossings to avoid intended U-turns.

To this end, CSX has shared their perspective on using signs, pavement markings, and flashing lights. They emphasized that transportation agencies commonly follow the MUTCD guidelines when it comes to signs and flashing lights. The MUTCD offers comprehensive guidelines and standards governing the design, placement, and maintenance of traffic control devices, including signs and signals. Conforming to these guidelines fosters uniformity and plays a pivotal role in promoting safe and efficient traffic operations.

CSX also discussed the use of painted lines, symbols, and patterns on the road surface to provide guidance and information to road users. Typically, this approach is examined as part of diagnostic reviews, which involves assessing the condition and efficacy of existing pavement markings. Effective pavement markings can significantly bolster safety measures and assist drivers in successfully navigating roadways. CSX, as part of their diagnostic review process, evaluates the adequacy of these markings.

7.1.4.3 Four-quadrant Gates

By obstructing all lanes of traffic in every direction, four-quadrant gates play a significant role in minimizing the risk of both motorists and pedestrians attempting to cross tracks when a train is either approaching or traversing. This robust preventive measure effectively averts collisions between trains and vehicles, subsequently minimizing the occurrence of crashes and their subsequent effects. Furthermore, four-quadrant gates mitigate the likelihood of vehicles stopping on the tracks or becoming trapped between gates, leading to a smoother traffic flow once the train has cleared. Additionally, these gates can be seamlessly integrated with other safety mechanisms, including flashing lights, warning signs, and train-activated alert systems, thus providing a comprehensive safety solution. Nevertheless, its high installation and maintenance costs often prohibit the widespread installation of four-quadrant gates at HRGCs. Four-quadrant gates on roadways with medians may not be effective if the gates cannot seal the road at the HRGC. A summary of the feedback from various districts on the topic of four-quadrant gates is consolidated in Table 7-2.

Table 7-2. Summary of FDOT Districts' Comments on Four-Quadrant Gates

District	Key Points
1	• The effectiveness of four-quadrant gates depends on location. • They are good, but need to avoid the issue where a driver can feel trapped between gates.
2	• Railway companies may not support four-quadrant gates as they require additional maintenance. • District 2 would explore using roundabouts as an alternative to four-quadrant gates.
3	• The effectiveness of four-quadrant gates depends on location. • They should not be used everywhere.
4	• Install four-quadrant gates on roadways without medians to seal the road. • Four-quadrant gates may not block all vehicles traveling around the gate on a very wide road due to the limited gate length.
5	• Four-quadrant gates should be installed at an HRGC that is in close proximity to a side street or driveway. • Four-quadrant gates should be installed at HRGCs within quiet zones.
6	• District 6 has several four-quadrant gates along the Brightline corridor and the South Florida Rail corridor. • They are effective in stopping people from going around the gates.
7	• Four-quadrant gates can be effective but also need outreach efforts to help the public comply with the treatment. • They are good to be installed at locations where the public continues to ignore the flashing lights and gates.

7.1.4.4 Delineators

Delineators are specifically designed to offer visual guidance and augment visibility for both motorists and pedestrians, particularly in situations characterized by diminished lighting or adverse weather conditions. Delineators are frequently installed at HRGCs, where they work in conjunction with other safety measures to guarantee that drivers can clearly identify the presence of the crossing, even from a distance.

Delineators are typically equipped with reflective materials, rendering them highly conspicuous during nighttime or when lighting is limited. This enhanced visibility facilitates early recognition of railroad crossings by drivers, enabling them to take suitable precautions. Strategically placing delineators ahead of a railroad crossing function as an advanced alert for drivers, affording them ample time to decelerate, scan for approaching trains, and be ready to stop if needed.

Delineators play a role in guiding traffic flow, ensuring that vehicles approach the crossing at the correct angle and refrain from stopping or parking on the tracks. On certain occasions, delineators are set up to establish a designated pedestrian pathway, indicating a secure zone for crossing the tracks and assisting pedestrians in avoiding active rail areas. It is worth noting that as delineators are positioned within railway properties, the challenge of maintenance falls upon roadway authorities. The consolidated feedback from the districts regarding delineators is presented in Table 7-3.

Table 7-3. Summary of FDOT Districts' Feedback on Delineators

District	Key Points
1	• Limited experience with deployment of delineators.
2	• Delineators could be used more, but working on railroad property is difficult. • Delineators are frequently hit; the roadway agency is constantly having to work with the railroad agency to maintain the delineators. • It is good to install delineators anytime there is a side street coming in within about 100-200 feet of a grade crossing, to help guide motorists not to drive on the tracks.
3	• Delineators are effective in many scenarios but should not be used everywhere.
4	• Brightline and Central Florida Express have installed delineators; no incidents were reported after the installation. • Delineators have to be replaced frequently as they are hit often. • Need to discuss with railway companies to decide who should maintain delineators.
5	• SunRail has installed delineators at numerous crossings. • Avoid any red color on a delineator to prevent train engineers incorrectly stopping when they see red.
6	• Delineators are effective in preventing wrong turns on tracks. • The main issue with delineators is ongoing maintenance.
7	• Open to the idea of using tubular delineators at HRGCs. • Delineators have potentials to make grade crossings with large drop-offs safer.
Central Office	• Delineators are suggested in places where a raised median cannot be installed. • Brightline has a crew that travels around and replaces delineators as needed.

7.1.4.5 Fencing

Fences are commonly installed alongside railway tracks, displaying a range of designs and materials. The primary purpose behind installing these fences is to discourage unauthorized entry and trespassing onto the tracks or railroad right of way. Incorporating fencing along with pedestrian gates serves to deter pedestrians from crossing tracks at locations not designated for such purposes, thereby minimizing the likelihood of train-pedestrian crashes. Nevertheless, the obstacle of high installation costs and subsequent maintenance demands presents challenges to the widespread implementation of these fences along railway corridors. Additionally, there is a potential concern that individuals might attempt to climb the fence and be trapped within the right-of-way of tracks. The feedback from districts on fencing is summarized in Table 7-4.

Table 7-4. Summary of FDOT Districts' Feedback on Fencing to Pedestrian Gates

District	Key Points
1	• Fencing is not always an effective deterrent to pedestrians, as people will generally still find a way over or through the fence or will just remove it.
2	• Fencing can be a good option at certain locations. • Fencing often gets cut or knocked down, and working on railroad property to repair it is difficult. • It is difficult to use public funding to install fences on railroad (private) properties.
3	• Fencing is not very often used. • Pedestrian gates are a good safety measure, but pedestrians can easily lift up fencing and go through. • A sturdier option should be explored.
4	• The railroad companies are asking for measures to channelize pedestrians at railroad crossings.
5	• Fencing can prevent pedestrians from entering the railroad right-of-way but can also trap pedestrians within the right-of-way.
6	• Looking into using more fencing to prevent people from walking along the tracks and also from dumping things on the track.
7	• With the fence, this often is not effective as people will cut, remove, or climb over it. • There is also the issue of liability to consider. • Zigzag fences can help prevent pedestrians and cyclists from crossing without looking. The Zigzag fence will force them to look in both directions.
Central Office	• Install fences at the location with trespassing issues. • In addition to pedestrian gates, they also use vegetation type barriers and anti-trespass mats.

Non-traversable medians are another method for avoiding unauthorized entry of vehicles on tracks. In definition, non-traversable medians refer to elevated barriers or physical partitions in the middle of the road as it approaches a grade crossing. These medians are strategically implemented to hinder vehicles from crossing into the lanes of oncoming traffic or going around crossing gates. Their purpose lies in guiding vehicles to approach the crossing in the intended manner and discouraging unsafe driving actions. In doing so, they effectively diminish the likelihood of crashes with trains coming from the opposite direction.

7.1.4.6 Geometry Treatment

Geometry treatments pertain to the alteration of the physical configuration or design of a roadway or intersection. These treatments become especially crucial in scenarios involving multiple road entrances or exits within an area. By adjusting the geometry, it becomes feasible to tackle prevailing issues and potentially even close off troublesome road sections, thereby enhancing both safety and traffic flow. CSX frequently engages in reviews when a roadway has problematic characteristics.

District 2 has introduced a roundabout design as a substitute for the four-quadrant gates at HRGCs, as depicted in Figure 5-8. This alternative approach is geared towards mitigating traffic backups onto rail tracks that can result from traffic signal operations. With the intention of showcasing the viability of this roundabout design, District 2 is keen on initiating a pilot study at the intersection of Post St and McDuff Ave in Jacksonville, Florida. After considerable deliberation and collaboration, the rail company has provisionally approved this project to proceed. It is important to note that, as of now, the assessment of the safety effectiveness of this roundabout design is unavailable yet.

7.1.4.7 Education

Education plays a critical role in the advancement of safety at HRGCs. This involves increasing awareness among motorists, pedestrians, and the general public regarding the hazards associated with such crossings, along with the appropriate steps to undertake when approaching or crossing them. Educational endeavors may include a range of activities, including public awareness campaigns, specialized training programs for drivers, the dissemination of informative materials, and engagement with the community. By fostering comprehension and familiarity, education can substantially contribute to the adoption of safer behaviors and heightened adherence to crossing regulations.

In the face of funding constraints, districts are actively participating in or preparing to participate in various events and platforms to communicate the importance of rail safety. These efforts comprise participation in gatherings such as Metropolitan Planning Organization/Transportation PO meetings, Community Traffic Safety Team (CTST) meetings, school events, and tabling events. In addition, they employ modern communication channels such as social media, Mobility Week, OMD Expo, videos, billboards, and bus wraps to effectively spread rail safety awareness. In general, ongoing cooperation among agencies and education organizations, the pursuit of extra funding sources, and the conducting of follow-up studies offer potential paths for advancing rail safety awareness even more effectively. The educational outreach efforts in Florida are discussed below:

- ***Operation Lifesaver* –** Operation Lifesaver is a nationwide, non-profit initiative that enhances public safety awareness and education. Its primary objective is to decrease the occurrence of crashes, fatalities, and injuries at HRGCs while also discouraging trespassing on railroad tracks.
- ***Rail Safety Week* –** Rail Safety Week is a collaborative endeavor involving Operation Lifesaver, Inc., state-level Operation Lifesaver programs, and rail safety partners throughout North America, including the United States, Canada, and Mexico.
- ***Mobility Week* –** Mobility Week constitutes a yearly campaign centered on advocating diverse transportation alternatives, fostering sustainable travel decisions, and spotlighting the significance of accessible and flexible transportation across the entire state.

- ***Be Rail Smart*** – In 2018, District 4 launched the Be Rail Smart campaign with the objective of enhancing awareness about rail crossing safety across all counties within the district. The success of this initiative led District 6 to adopt and endorse the campaign, subsequently prompting the expansion of Be Rail Smart by FDOT throughout the entire state. The campaign's primary goals involve three aspects: (1) reducing incidents occurring on or near railway tracks, (2) fostering campaign champions, and (3) forging partnerships to bolster its impact. The campaign's strategies involve leveraging community outreach, collaborating with various agencies, and employing print and digital media advertising to educate and raise awareness about rail safety among the public.

- ***Various Events*** – District 4 actively engages in multiple platforms and events, including MPO/TPO meetings, CTST meetings, school events, and a range of tabling events. These efforts are aimed at effectively conveying the message of rail safety to a diverse audience.

- ***Various Media*** – District 4 employs a variety of media channels, including videos, billboards, bus wraps, and social media, to disseminate information and raise awareness about railroad safety. CSX utilizes digital platforms, including billboards and targeted digital advertisements, to demonstrate their dedication to heightening awareness and tackling safety issues in areas of concern. Such endeavors prove effective in reaching a broad audience and educating individuals about railway safety.

7.1.4.8 Enforcement

According to the updated Florida's State Action Plans (SAPs) (FDOT 2022) (*75*) for HRGCs led by the FDOT Freight and Multimodal Operations (FMO) Office, it indicated that "A combination of driver behavior and trespassing data points to human behavior being by far the largest rail safety challenge. The data on driver behavior displays the variety of driver behaviors that lead to incidents, despite warning and protection devices at crossings." Therefore, besides engineering approaches, addressing the challenges through education and enforcement is vital to rail safety in Florida. The statewide education and outreach efforts on HRGC-related safety, laws, and regulations need to continue and expand, and law enforcement warnings and citations for HRGC violations should follow and sustain to build safety culture at HRGCs. The suggested law enforcement efforts in Florida are provided below:

- Promote active enforcement of traffic laws related to HRGCs and railroad right of way.

- Partner with state and local law enforcement agencies, including the Florida Highway Patrol, sheriffs, and police chiefs to help enforce rail safety laws.

- Develop a program to train local law-enforcement and local governments on implementing a response strategy to enforce traffic laws related to HRGCs and railroad right of way.

- Identify funding opportunities for local law-enforcement and community stakeholders to respond to trespassing issues at HRGCs.

- Apply technologies to support law enforcement at HRGCs.

7.1.5 ITS and TSM&O Treatments

Several Intelligent Transportation Systems (ITS) applications and Transportation Systems Management and Operations (TSM&O) strategies exist to enhance the safety and mobility at HRGCs. These countermeasures include innovative technologies, including advanced traffic signal strategies, advanced sensors, information dissemination mechanisms, and Artificial Intelligence (AI)-driven vehicle/pedestrian detection systems. The primary ITS interventions identified through the literature review and the interviews are outlined below.

7.1.5.1 Preemption and Pre-preemption

In cases where a grade crossing is situated near a signalized intersection, there is a potential for a queue of vehicles from the intersection to extend onto the railroad tracks. Through integration with train-activated warning systems, traffic signals can receive an advanced notification of an approaching train. A rail traffic control signal preemption is used to apply a special traffic signal phase sequence and timing to allow motorists to move away from the track prior to the arrival of the train and to restrict movements towards the track. This enables the activation of a "preempted" mode aimed at clearing vehicles from the tracks before the train's arrival. Rail traffic signal preemption is essential to HRGC safety. Conventional preemption strategies include two modes: *Simultaneous Preemption*—A traffic signal controller and railroad active warning devices receive notification of an approaching train simultaneously; and *Advance Preemption*—Traffic signal controllers receive notification of an approaching train earlier than railroad active warning devices.

MUTCD Section 8C.09 Traffic Control Signals at or Near Highway-Rail Grade Crossings provides a clear guidance for traffic signal preemption at or near HRGCs as shown below.

> *04 If a highway-rail grade crossing is equipped with a flashing-light signal system and is located within 200 feet of an intersection or midblock location controlled by a traffic control signal, the traffic control signal should be provided with preemption in accordance with Section 4D.27.*
>
> *05 Coordination with the flashing-light signal system, queue detection, or other alternatives should be considered for traffic control signals located farther than 200 feet from the highway-rail grade crossing. Factors to be considered should include traffic volumes, highway vehicle mix, highway vehicle and train approach speeds, frequency of trains, and queue lengths.*
>
> *06 The highway agency or authority with jurisdiction and the regulatory agency with statutory authority, if applicable, should jointly determine the preemption operation and the timing of traffic control signals interconnected with highway-rail grade crossings adjacent to signalized highway intersections.*

During regular preemption, all existing turning movements toward the HRGC should be prohibited during the signal preemption sequences. According to the MUTCD, a blank-out or changeable message sign and/or appropriate highway traffic signal indication or other similar type sign may be used to prohibit turning movements toward the HRGC during preemption. The R3-1a and R3-2a signs may be used for this purpose.

A more innovative approach known as "pre-preemption" can also be implemented before or after a regular preemption to clean potential long traffic queues formed either before or after regular rail traffic signal preemption. This strategy involves allocating additional green time, much longer than conventional preemption modes (simultaneous or advanced), to the traffic movements affected by the train, both prior to and following the train's passage. The pre-preemption strategy serves a dual purpose: enhancing HRGC safety by clearing the tracks before the train arrives and optimizing traffic flow before, during, and after the train approaches.

Preemption is a desirable resolution for FDOT to address the safety and mobility concerns associated with HRGCs, and its implementation has been witnessed across various locations in Florida. Nevertheless, the effectiveness of this strategy, including the concept of preemption and pre-preemption, encounters several real-world challenges. These challenges include the duration of train warnings provided by railway systems and the difficulties of preemption timing design. As such, preemption may not always be the ideal solution in every situation. While it can be effective in many cases, there are instances where alternative solutions may be more suitable. The collective input and insights from the districts and the Central Office are summarized in Table 7-5.

Table 7-5. Summary of FDOT Districts' Feedback on Preemption

District	Key Points
1	• The District has widely implemented preemption where applicable. • There are conflicts between traffic signal timings and ARMEA (American Railway Engineering and Maintenance-of-Way Association) guidelines for maximum rail warning time ▪ The Traffic Operations Manual requires a lot of time (sometimes up to 60 seconds) to clear a queue. ▪ The railroads have a maximum time they can use and cannot go up to 60 secs. ▪ Long warning time (≥ 40s) may not be regained accurately.
2	• Preemption has been done everywhere since the 1990s. • It would be good to do a wide-scale verification that the preemption timing is still working the same as originally intended.
4	• The current preemption does not allow enough time in some cases to clear the tracks. • A previous attempt was made to conduct a pilot study to test train detectors (Island Radar technology) for providing a long train warning time. • Rail companies feel radar or other detectors aimed at their property is encroachment of their right-of-way.
5	• All crossings within 200 feet of a traffic signal have preemption.
6	• Preemption is working with the traffic operations office.
7	• Preemption is an effective treatment and has been working in general. • The public needs better information about the process. • Many vehicles travel under the gate arm as it comes down or drive around the gate arm, so they do not have to wait on the train.
Central Office	• Railroad companies generally support the measures of traffic signal preemption as they contribute to overall safety and prevent HRGC crashes at crossings. A few railroad companies are concerned about preemption as they do not want people to know the location of their trains.

7.1.5.2 Advanced Sensor Technologies

Innovative sensor technologies such as radar, lidar, and AI-driven video analytics could be used to identify pedestrians, vehicles, trains, and their paths at or near HGGCs. This detection capability can serve multiple purposes, such as providing train warning times for preemption or pre-preemption procedures or facilitating road user warnings and citations for violations. The FDOT districts are notably interested in the prospects of advanced sensor technologies; however, they express the necessity for comprehensive statewide research and pilot studies. The following are some of the advanced technologies being adopted by the districts:

- Automated vehicle detection systems that incorporate both cameras and sensors.
- Wireless detectors that can detect trains, compute their speed, and provide an estimate of their length.
- Automated violation warning systems to warn road users.
- Automated violation data collection, verification by law enforcement, and issue of citations to violators after the verification to significantly reduce violations.

- Advanced detection sensors to identify queues that form as a train passes a rail crossing.
- Advanced train detection systems to detect and estimate the train arrival time at a HRGC for implementing traffic signal pre-preemption 1-2 minutes before the arrival of the trains to reduce traffic queue near the HRGC and nearby signalized intersections.

7.1.5.3 Other Advanced Technologies

The following are some of the other advanced technologies that are currently being used to improve safety and mobility at HRGCs:

- Dynamic message signs (DMS) that convey warning messages to road users based on the information provided from advanced detection systems on vehicles, pedestrians, and trains, heightening their awareness of trains and encouraging safer behaviors.
- Mobile applications that integrate notifications into popular mobile mapping applications such as Google Maps and Waze. These notifications would serve to alert the general public about the potential presence of approaching trains at specific HRGCs.
- Positive Train Control (PTC) systems installed on trains that can help monitor train movements, speed, and status, and automatically take actions to prevent collisions, and can be integrated with grade crossing equipment, allowing for the preemption of traffic signals and activation of warning devices when a train is approaching.

7.2 Best Practices

The Railroad Crossing SAPs were initiated in 1994. The need for SAP enhancement was particularly emphasized by Section 202 of the Rail Safety Improvement Act of 2008 (RSIA08), Public Law 110-432, Division A. The SAPs were an integral part of the grade crossing program management process (*20*). These plans play a crucial role in improving the management and safety of grade crossings. The Railroad Crossing SAPs are best practices for state DOTs to develop, implement, evaluate the statewide program for rail grade crossing hazard elimination, and routinely update the SAPs for further improvement and enhancement of railroad crossing safety and mobility.

In 2009, the Federal Rail Administration (FRA) mandated that the top 10 states with the most at-grade crossing collisions on average over a specific five-year period, produce a HRGC SAP. The highway-rail grade crossing incidents by state and by Florida County, 2016-2020, can be seen in Figure 7-1. FDOT developed that plan and delivered it on August 24, 2011. Concurrently, FDOT continued to implement its Statewide HRGC Safety Improvement Program, which is the principal statewide program for rail grade crossing hazard elimination. The SAP played a significant role in further strengthening the program. FDOT has developed an updated HRGC SAP in 2022 to advance the efforts of the programs and plans that helps address rail and highway network safety statewide.

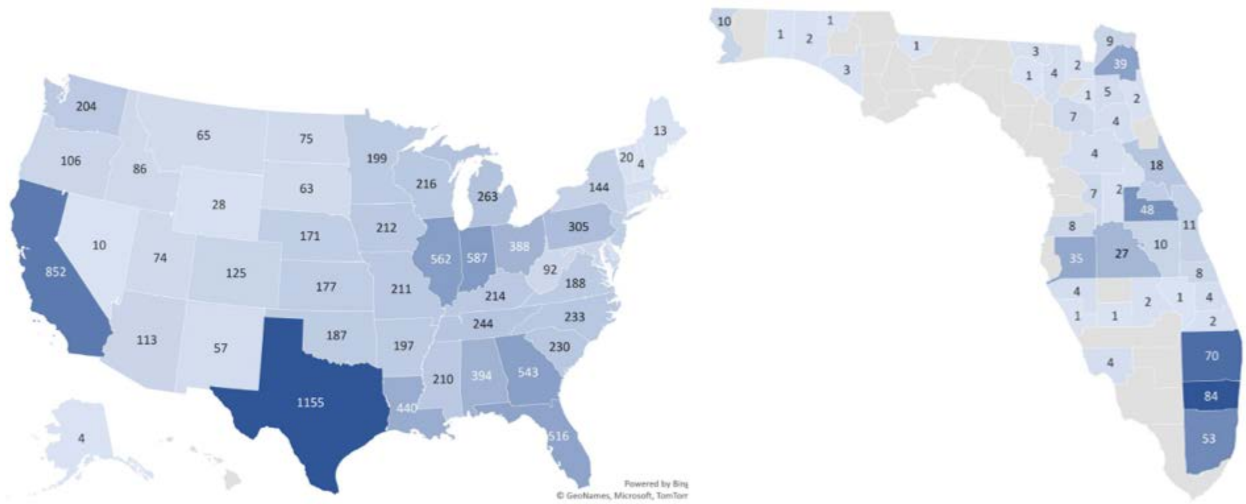


Figure 7-1. Highway-Rail Grade Crossing Incidents by State and by Florida County, 2016-2020 (*72*)

In November 2021, the Infrastructure Investment and Jobs (IIJ) Act, known as the Bipartisan Infrastructure Law, was signed into law, marking the most substantial investment in US infrastructure history. A segment of this act is dedicated to bolstering railroad safety. It is aligned with the objectives of the Fixing America's Surface Transportation (FAST) Act, which mandated all 50 states and the District of Columbia to create and implement HRGC SAPs.

7.2.1 State-of-the-Practice

The Texas SAP categorized improvements in railroad crossing safety into two distinct groups (*21*): (a) evaluation and engineering, and (b) education and enforcement. The Georgia SAP places considerable emphasis on data analysis, recognizing its crucial role in assessing progress (*22*). Similarly, the Ohio SAP (*23*) initially utilized the US DOT Accident Prediction Formula Index to identify high-risk crossings; however, comprehensive statistical analysis of HRGC crash data did not commence until 2010. However, the California SAP (Caltrans, 2014), integrates a crash data analysis spanning the period from 2006 to 2011. The analysis discovered that many incidents involved pedestrians with suicidal intentions. This revelation prompted the realization that some HRGC crashes could potentially be attributed to deliberate acts of suicide rather than lack of safety measures at the crossings.

Since emergency responders and law enforcement are typically the first responders on the crash scene, providing them with adequate training is a crucial measure in mitigating secondary crashes and their effects. Recognizing this, FRA (FRA, 2021b) introduced a video-based training program in 2021 to educate the first responders. The training video provides essential information required by law enforcement personnel when responding to incidents involving railroads. It equips them with pertinent knowledge to handle such situations promptly, efficiently, and safely.

Since the early 1970s, the FDOT has been actively engaged in systematically addressing safety risks at HRGCs (*25*). Similar to Louisiana's approach (*26*), Florida conducted a statistical analysis utilizing data from the period between 2000 and 2010. This analysis brought to light that the majority of incidents occurred at public crossings (*20*). A noteworthy observation was that HRGC crashes transpired even at locations equipped with active warning controls. FDOT's specific interventions involved modifications to signal timing or, in some cases, the decision to either close or separate the grade crossing (*20*). The updated Florida SAP (*75*) provided direction for implementing safety improvements to address the four safety challenges. Goals, objectives, and entities responsible for actions are specified to help guide implementation. FDOT started to implement dynamic envelopes at every existing FDOT roadway and state-owned land rail crossing across the state in 2019 and the launch of a statewide education initiative. Between December 2019 and September 2021, FDOT completed the installation of dynamic envelopes at 620 crossings across the state.

The best practices presented in the reviewed ten SAPs include:

- Identifying high-risk situations, such as Amtrak – passenger railroad service – and school bus operations to increase publicity and awareness (*22*).
- Emphasizing grade crossing closures and separation strategies (*22*, *25*, *27*, *28*).
- Considering pedestrian-pathway-rail crossings (*28*).
- Using Railroad-Highway Crossing Inventory (RHCI) and Safety Index Tool to support programs, conduct analysis for identifying crossings with higher risk and safety challenge (*75*).

It should be noted that states are eagerly anticipating the implementation of advanced technology solutions to proactively prevent crashes and minimize delays within critical areas or their proximity. This proactive approach considers the safety and mobility measures already in place.

7.2.2 Success Stories

This section discusses the success stories from the previously employed HRGC strategies and countermeasures.

Implementation of Delineators and Pavement Arrows in Newark, Delaware, near Deer Park Tavern

This initiative involved a combination of strategies, including pavement markings, guiding arrows for motorists to proceed directly through the crossing, and the deployment of flexible bollards. Pavement markings and arrows were employed to guide motorists through the crossing in a straight path, while the flexible bollards were strategically positioned to enhance safety. Delineators were also placed on the shoulder in this location to minimize the likelihood of collisions. This practice has garnered the recommendation of CSX, especially in areas where instances of this nature are frequent. The implementation site and the treatments applied are represented in Figure 5-11 through Figure 5-13. It is worth considering installing delineators along with non-traversable curbing, as these delineators are less prone to being struck by vehicles and may offer increased effectiveness in similar settings.

Florida's Statewide Traffic and Railroad Initiative Using Dynamic Envelopes (STRIDE)

In 2019, the FDOT Central Office launched Florida Operation STRIDE. This program aims to keep motorists out of danger zones near railroad crossings using RDEs. Almost all districts agreed on the effectiveness of RDEs. The Central Office documented a 15% decrease in incidents where drivers became stranded on tracks or encroached upon them, a result attributed to the adoption of RDE pavement markings (*68*) for statewide deployment on FDOT roadway and state-owned land rail crossings.

Replacing Misleading Pavement Markings to Prevent Incorrect Turns at HRGCs in Florida

Incorrect turns onto railroad tracks may occur if a highway-rail grade crossing is close to an intersection or a freeway on-ramp. A pilot project was conducted at eight study sites in Florida Department of Transportation districts 1, 4, and 7 to evaluate low-cost countermeasures, including elimination of potentially misleading pavement markings and signs before railroad crossings and implementation of straight arrow pavement markings with guidance information before railroad crossings. An example of the countermeasure is shown in Figure 7-2. The pilot showed that the replacement of continuous right-turn arrows with straight arrows plus guidance information on pavement can effectively prevent incorrect turns onto railroad tracks, and the effectiveness is more significant at night.

Some of the additional success stories include:

- Cooperation with a railroad company on two signal safety projects in Avon Park.
- Successful collaboration between FDOT and the railroad companies on "Low-Cost Programs" where FDOT provides equipment if the railroad provides the labor.
- Education in multiple languages was found to be a successful strategy in *Be Rail Smart*.
- The High Visibility Enforcement Grants in the City of Hollywood (District 4) were found to improve driving behaviors.
- The FRA Section 130 Federal Signal Safety Funding program was found to be successful.

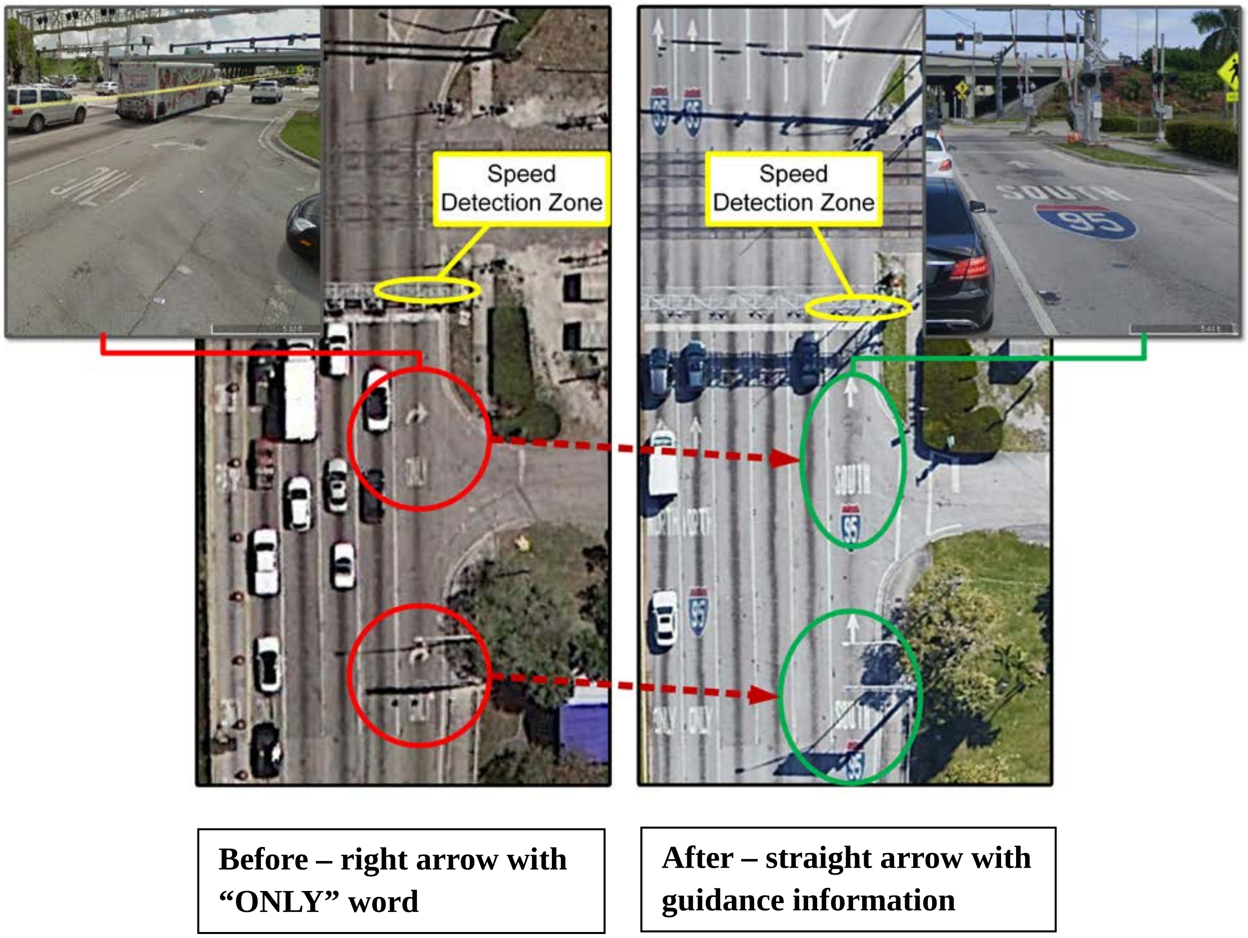


Figure 7-2. Countermeasures Implemented at W Commercial Blvd @ I-95, Oakland Park, FL

7.2.3 Lessons Learned

The experiences gained from the implementation of previous HRGC strategies and countermeasures have highlighted some valuable lessons. It is important to recognize that no one-size-fits-all solution can be universally applied to all locations and scenarios related to railroad safety. Identified HRGC strategies with proper customization based on the specific needs will be the best way to address safety and mobility issues of a HRGC. Most suitable countermeasures can be deployed. The following four lessons learned were identified based on the literature review and the interviews:

1) Engineering solutions are not enough to address HRGC safety and mobility issue
2) RDE may not be necessary at all HRGCs
3) Google or satellite imagery may not provide a comprehensive understanding
4) Recurring Diagnostic review of each crossing with high priority is crucial

The detailed description of these four major lessons learned is provided below:

- ***Engineering solutions are not enough to address HRGC safety and mobility issues:*** Most treatments at HRGCs in Florida focused on engineering solutions with limited educational efforts and enforcement likely due to insufficient funding and workforce for education and enforcement. The findings from the literature review and agency interviews in this research showed that human factors contributed significantly to HRGC-related fatalities, serious injuries, and crashes, so engineering solutions are not enough to address HRGC safety and mobility issues. More education efforts are needed to increase awareness among motorists, pedestrians, and the general public regarding the hazards associated with HRGCs, along with the appropriate steps to undertake when approaching or crossing HRGCs. Besides the efforts from engineering and education, law enforcement warnings and citations for HRGC violations should follow and sustain to build safety culture at HRGCs as well as other transportation roadway facilities. Florida transportation and law enforcement agencies can further explore and apply technologies to provide automated violation warnings and support law enforcement at HRGCs in Florida.

- ***RDE may not be necessary at all HRGCs:*** Dynamic envelopes refer to the area necessary for drivers to recognize an HRGC and stop their vehicles safely behind the stop bars of a railroad crossing when a train is approaching. While establishing safe stopping areas for a HRGC is imperative, the implementation of dynamic envelopes might not always be feasible or needed. Some FDOT districts indicated RDE deployments are not necessary for the HRGCs in rural areas without issues. Frequent violations were observed at HRGCs located at urban or urban arterials with multiple rail tracks when the traffic queue was backed up from the nearby downstream signalized intersections. Proper law enforcement or automated violation warnings and citations are suggested to enhance the deployment of RDEs. Determining the appropriate design for a grade crossing mandates consideration of various factors, including road configuration, traffic flow patterns, and the available physical space. The integration of these elements is essential to arrive at an effective and contextually appropriate solution.

- ***Google or satellite imagery may not provide a comprehensive understanding:*** Although Google Maps and satellite imagery can provide valuable insights into a location, they possess inherent limitations when it comes to evaluating grade crossings. These tools may not encompass all facets of the crossing, omitting crucial factors like nearby structures, vegetation, or the actual visibility angles accessible to drivers. Conducting an on-site diagnostic review of a HRGCs with safety or mobility issues is indispensable to ensure a precise and thorough evaluation. This approach enables a thorough and accurate assessment by accounting for physical conditions that might not be adequately represented in remote imagery.

- ***Recurring diagnostic review of each crossing with high priority is crucial:*** Conducting a singular assessment of grade crossings is inadequate for ensuring sustained safety. Regular and recurring diagnostic reviews are imperative to continuously monitor the condition of the crossings, account for alterations in traffic flows or infrastructure, and identify potential hazards. These reviews should be executed by competent individuals who possess the expertise to observe driver conduct, evaluate visibility conditions, inspect signage and warning mechanisms, and effectively address emerging safety issues. By employing this proactive approach, ongoing safety can be maintained, and potential risks can be promptly addressed.

Some of the additional lessons learned include:

- Close communication and collaboration with railroad companies is crucial.
- In areas where the crossing is skewed, reflective delineators, in addition to the RDE, should be installed to better let drivers know the roadway location.
- The visibility of R8-8 signs (Do Not Stop on Tracks) is a potential issue. The countermeasures to increase the detectability of R8-8 signs by drivers include attaching flashing beacons/lights to the signs, avoiding other signs blocking the sign, installing R8-8 signs on medians on multilane roads, and trimming tree branches.

7.3 Recommendations

According to the findings and results from Conduct Comprehensive Literature Review and Safety Evaluation of HRGCs, and Assess HRGC Strategies, Countermeasures and Technologies to Improve Traffic Safety and Mobility, the following primary recommendations are provided.

7.3.1 Primary Safety and Mobility Challenges in HRGC Operations and Their Causes

HRGCs experience four major safety and mobility challenges: (1) vehicles frequently stopped on tracks, (2) wrong turns onto railroad tracks, (3) motorist driving behaviors to “beat” a train or go around lowered gates, and (4) pedestrian trespassing behaviors at and near HRGC locations. The causes and potential countermeasures for each challenge are specified in Table 7-6.

Table 7-6. Primary Safety and Mobility Challenges, Causes, and Potential Treatments in HRGC Operations

Primary Challenges	Possible Causes	Potential Treatments
Vehicles frequently stopped on railroad tracks	Downstream signalized intersections too close to HRGCs	• Plan and design a downstream signalized intersection or freeway on-ramp away from the HRGC. • Avoid planning and constructing parallel roadways and rail lines. • If deemed adequate, move the stop bar at the downstream signalized intersection of an HRGC upstream to the location before the HRGC. • Consider removing a channelized right turn lane at downstream signalized intersections of an HRGC to discourage right-turn drivers from stopping on railroad tracks, thinking the front vehicle will move soon. • Investigate and evaluate an innovative concept such as converting a signalized intersection near an HRGC to a roundabout to avoid queue backup onto the railroad tracks. • Educate "DO NOT STOP ON TRACKS" and enforce the law.
	Backup queues onto HRGCs due to heavy traffic	• Use traffic signal preemption at signalized intersections near HRGCs where applicable. • Explore and use traffic signal pre-preemption at signalized intersections near HRGCs where applicable to clear potential heavy traffic queues before train arrival. • Consider removing a channelized right turn lane at downstream signalized intersections of an HRGC to discourage right-turning drivers stopped on railroad tracks, thinking the front vehicles will move soon. • Install queue detection systems for a needed traffic signal preemption. • Educate "DO NOT STOP ON TRACKS" and enforce the law.

Table 7-6. Primary Safety and Mobility Challenges, Causes, and Potential Treatments in HRGC Operations (Continued)

Primary Challenges	Possible Causes	Potential Treatments
	Lack of visibility of HRGCs (e.g., drivers not recognizing HRGCs)	• Use delineators at HRGCs to increase visibility to prevent wrong turns onto railroad tracks. • Use delineators, especially at skewed HRGCs. • Use Railroad Dynamic Envelope (RDE) at suitable locations where the queue frequently backs up to railroad tracks to increase visibility of HRGCs. For large HRGCs on arterials with heavy traffic, RDE deployment may not be effective. In addition, RDE may not be needed at all HRGC locations. • Install street lighting at HRGCs to increase visibility at night. • Regularly inspect HRGC flashing beacons, signage, and the visibility of pavement markings. • Relocate "DO NOT STOP ON TRACKS" R8-8 traffic signs and "NO TRESPASSING" signs according to the MUTCD at HRGCs if blocked by other signs. • Add Rapid Flashing Beacon (RFB) and LED flashing lights to R8-8 signs.
	Aggressive and inattentive driving behaviors (e.g., drivers taking their chances thinking vehicles ahead of them will move soon; not paying attention to HRGC)	• Consider removing channelized right turns at downstream signalized intersections of an HRGC to discourage right-turning drivers from stopping on railroad tracks, thinking front vehicle will move soon. • Increase funding for FDOT districts to work with Operation Lifesaver to conduct more railroad safety education to the public and students. • Educate "DO NOT STOP ON TRACKS" and enforce the law.
Incorrect turns onto railroad tracks	Potentially misleading pavement markings (e.g., right-turn arrow pavement marking before the railroad crossing)	• Remove potentially misleading pavement markings (e.g., right-turn arrow pavement markings before the railroad crossings) • Replace right-turn arrow markings on an exclusive right-turn lane before HRGCs with straight arrow pavement markings with guidance information including route and its direction (e.g., SR-60 EB, I-75 shield NB).

Table 7-6. Primary Safety and Mobility Challenges, Causes, and Potential Treatments in HRGC Operations (Continued)

Primary Challenges	Possible Causes	Potential Treatments
	Potentially misleading traffic signs (e.g., right lane must turn right sign installed before a railroad crossing)	• Remove potentially misleading traffic signs (e.g., right lane must turn right sign installed at railroad crossings).
	Rough pavement surface and sudden drop of pavement of roadway edge at railroad tracks	• Eliminate or reduce a sudden or rough drop of pavement of roadway edge at railroad tracks to prevent vehicle from getting stuck on tracks due to wrong turns onto railroad tracks.
	Informed by GPS to turn right or left when HRGCs and downstream intersections or on-ramps are remarkably close	• Install pavement markings to provide guidance information (e.g., straight arrow with route name plus direction on travel lanes). • Install traffic signs to support pavement markings.
Motorist driving behaviors to "beat" a train or go around lowered gates	Drivers do not want to wait for a train and speed through the HRGC before the gates are lowered or go around already lowered gates.	• Install four-quadrant gates at HRGCs on roadways without a median to prevent or reduce vehicles going around lowered gates. Four-quadrant gates may not be effective on a roadway with a median because the gates may not be long enough to close gaps at HRGCs. • Work with Operation Lifesaver to conduct more railroad safety education to the public and students. • Conduct educational outreach on the dangers of crossing railroad tracks. Use signage, brochures, and other materials to promote awareness and encourage safe behavior. • Increase law enforcement activities at HRGCs with frequent aggressive driving behaviors.

Table 7-6. Primary Safety and Mobility Challenges, Causes, and Potential Treatments in HRGC Operations (Continued)

Primary Challenges	Possible Causes	Potential Treatments
Pedestrian trespassing behaviors at and near HRGC locations	Pedestrians do not want to wait for train and trespass at or near HRGCs.	• Install physical barriers, such as fences and gates, to prevent pedestrians from crossing at unauthorized locations. Work with Operation Lifesaver to conduct more railroad safety education to the public and students. • Conduct educational outreach on the dangers of crossing railroad tracks. Use signage, brochures, and other materials to promote awareness and encourage safe behavior. • Increase law enforcement activities at HRGCs for crossing or pedestrian after the gate is down.

7.3.2 Future Deployment of RDE Pavement Marking

Overall, the statewide before-after studies of RDE pavement marking across Florida showed that RDEs improved safety by increasing safe stopping behaviors at Zone 1, reducing vehicle stopping behaviors at the most dangerous zone (Zone 3 - railroad tracks), and reducing moderately-dangerous stopping behaviors in Zones 2 and 4. However, the RDE deployments may not be effective at HRGCs with multiple tracks located on corridors with heavy traffic, close to downstream signalized intersections or freeway on-ramps, or necessary for rural roads with light traffic. The following recommendations are suggested to improve the effectiveness of RDE pavement markings in future deployment.

- A state-wide follow-up study should be conducted to address the long-term effectiveness of RDE pavement markings and identify the scenarios that RDE pavement markings are effective.
- Selectively deploy RDEs at HRGCs with the effective scenarios.
- Conduct more railroad safety education outreach to the public and to the law enforcement at those HRGCs with frequent violations.
- Apply technologies to provide automated violation warnings at HRGCs, and support law enforcement for issuing warnings and citations to violators.
- Conduct a pilot study to investigate the effectiveness of RDE Pavement Marking with Yellow Background to increase the visibility of rail crossings at multiple sites, especially at skewed HRGCs.

7.3.3 Strategies and Engineering Treatments to Improve Safety and Mobility at HRGCs

The recommended traditional engineering treatments to improve safety and mobility at HRGCs are summarized in Table 7-7.

Table 7-7. Recommended Traditional Engineering Treatments

Treatment	Functions and Features	Suggested Scenarios	Deployment Needs
Installing four-quadrant gates	• Prevent people from going around the gates on roadways. • Have high initial and maintain cost. • Have a potential risk of trapping.	• HRGCs close to a side street or driveway • Roadways without a median to create a gap • HRGCs within quiet zones • HRGCs where the public continues to ignore the flashing lights and gates	• Collaboration with rail companies • Education programs to help the public comply with the treatment • Enforcement to reduce violators

Table 7-7. Recommended Traditional Engineering Treatments (Continued)

Treatment	Functions and Features	Suggested Scenarios	Deployment Needs
Installing delineators	• Ensure that drivers can clearly identify the presence of the crossing, even from a distance. • Avoid any red color on a delineator.	• HRGCs with visibility issues • HRGCs with large drop-offs • A side street within about 100-200 feet of a HRGC • Skewed HRGCs	• Need periodical maintenance and damage repair
Removing channelized right turn lane within an HRGC	• Discourage right-turning drivers stopped on railroad tracks, thinking the front vehicles will move soon.	• HRGCs close to the downstream signalized intersection with Right-Turn-On-Red operations	• No special needs
Eliminating or reducing a sudden drop of pavement of roadway edge at railroad tracks	• Prevent vehicle from getting stuck on tracks due to wrong turns onto railroad tracks.	• General HRGCs	• No special needs
Converting a signalized intersection near an HRGC to a roundabout	• Avoid queue backup onto the railroad tracks.	• HRGCs with frequent queue backup onto tracks	• Need a pilot study at multiple sites
Smooth crossing surface	• Enhances the crossings' condition and surface materials at the crossings to make it safer and prevent vehicles from getting stuck on the railroad tracks.	• General HRGCs	• No special needs
Deploying RDE Pavement Markings	• Increase safe stopping behaviors and reduce vehicle stopping behaviors at the most dangerous zone (track area) and moderately dangerous zones.	• HRGCs where RDE is effective	• A follow-up study is suggested to address the effective scenarios. • Yellow background is suggested if approved

Table 7-7. Recommended Traditional Engineering Treatments (Continued)

Treatment	Functions and Features	Suggested Scenarios	Deployment Needs
Replacing turning arrow markings on exclusive turning lanes before HRGCs with straight arrow pavement markings with guidance information including route and its direction	• Give drivers a clear indicator to correct turning points. • Prevent incorrect turns onto tracks.	• HRGCs are close to downstream intersections or on-ramps. • Exclusive turning lanes	• No special needs
Moving the stop bar at the downstream signalized intersection of an HRGC to the location before the HRGC	• Prevent vehicle stopping on tracks or adjacent areas.	• HRGCs with a short distance between rail tracks and the stop bar of downstream intersections	• No special needs
Removing and relocating traffic signs	• Remove potentially misleading traffic signs “RIGHT LANE MUST TURN RIGHT’ before HRGCs. • Relocate “DO NOT STOP ON TRACKS” signs and “NO TRESPASSING” signs if blocked by other signs and make them conspicuous to the drivers and pedestrians.	• General HRGCs	• Need to follow MUTCD Standards
Adding flashing beacon/LED lights to an R8-8 sign	• Increase the visibility of R8-8 signs (“DO NOT STOP ON TRACKS”).	• General HRGCs	• No special needs
Adding pedestrian gate and fencing	• Reduce pedestrian trespassing at HRGCs.	• HRGCs with frequent pedestrian trespassing activities	• No special needs

The recommended ITS and TSM&O applications to improve safety and mobility at HRGCs are summarized in Table 7-8.

Table 7-8. Recommended ITS and TSM&O Applications

Treatment	Functions and Features	Suggested Scenarios	Deployment Needs
Implementing traffic signal preemption	• Provide a special traffic signal phase to clean vehicles from tracks before train comes. • Improve safety.	• HRGCs with nearby downstream signalized intersections	• *No special needs*
Implementing traffic signal pre-preemption	• Reduce serious traffic congestion before and after a regular preemption. • Improve safety at HRGCs.	• A nearby HRGC downstream signalized intersection with frequent traffic congestions, queues, or blockage before or after a regular preemption	• Need to know the train arrival at the HRGC 1-2 minutes in advance. • Need special traffic signal timing optimization.
Installing dynamic message signs	• Provide real-time information to drivers about train movements and the status of the crossing. • Reduce confusion at crossings by providing clear and concise messages to drivers. • Enhance driver awareness of the potential hazards associated with rail crossings. • Promote compliance with traffic laws and crossing regulations.	• HRGCs on major arterials with heavy traffic or high crash risk	• *No special needs*
Providing dynamic warning and alerts	• Provide early warnings via audible and visual alerts, using variable messaging, integrating with other systems, and lowering false alarms.	• HRGCs on major arterials with heavy traffic or high crash risk	• Need a pilot study at multiple sites.
Implementing video surveillance systems	• Monitor HRGCs and detect potential safety hazards, such as vehicles or pedestrians on the tracks.	• HRGCs with high incident risk and frequent pedestrian trespassing activities	• *No special needs*

Table 7-8. Recommended ITS and TSM&O Applications (Continued)

Treatment	Functions and Features	Suggested Scenarios	Deployment Needs
Implementing automated violation warning systems	• Detect and provide warning to violators (drivers or pedestrians) automatically via alarms, or signals or both to enhance safety and prevent accidents on railway crossings.	• HRGCs with frequent violations of vehicle or pedestrian crossing the tracks when they should not be	• Need a pilot study at multiple sites.
Implementing incident management systems	• Quickly respond to crashes or other incidents at HRGCs, reducing the risk of secondary incidents and improving overall safety.	• General HRGCs	• *No special needs*

The recommended emerging technologies to improve safety and mobility at HRGCs are summarized below:

- FDOT districts have a limited implementation of emerging technologies at HRGCs. It is recommended by district rail representatives that FDOT Central Office continues to take the lead on emerging technology pilot testing or pilot deployment, and FDOT districts will support and test novel technologies.
- Railroad companies evaluated more emerging technologies. For example, Brightline has implemented a violation warning system pilot project at Northeast 141st Street and Biscayne Blvd., where they have installed cameras and sent warnings to people who went around the gates or stopped on the tracks. These warnings were sent via mail, but they cannot send any fines.
- Pilot testing of CV technology and AI-based detection and inspection technologies are underway. Most research projects are sponsored by the FRA.

7.3.4 Resources to Implement Strategies to Address Safety and Mobility Challenges at HRGCs

FDOT districts have expressed their resource and funding limitations in effectively tackling safety and mobility issues at HRGCs within their districts. Given the constraints of annual funding allocations, it proves challenging to implement necessary strategies and countermeasures at critical HRGCs. As a result, it is advisable to initiate needs assessment meetings or surveys to identify the requirements of FDOT districts and allocate resources and funding accordingly, if such funds become available.

References

1. Ogden, B. D., & Cooper, C. (2019). *Highway-rail crossing handbook* (No. FHWA-SA-18-040). United States. Federal Highway Administration.
2. Silla, A., Dressler, A., Lehtonen, E., Virtanen, A., Mesimäki, J., & Grippenkoven, J. (2022). Potential of auxiliary strobe lights on train locomotives to improve level crossing safety. *Applied ergonomics*, *103*, 103767.
3. United States. Department of Transportation, American Traffic Safety Services Association, & Institute of Transportation Engineers. (2003). *Manual on Uniform Traffic Control Devices: For Streets and Highways*. ATSSA/ITE/AASHTO.
4. Lin, P. S., Fabregas, A., Kourtellis, A., Lall, S., & Bato, M. (2013). *Improved traffic control measures to prevent incorrect turns at highway-rail grade crossings* (No. BDK85 977-45). Florida. Dept. of Transportation.
5. STRIDE. https://www.fdot.gov/rail/programs/operation-stride.
6. Gabree, S., Chase, S., & daSilva, M. (2014, April). Effect of dynamic envelope pavement markings on vehicle driver behavior at a highway-rail grade crossing. In *ASME/IEEE Joint Rail Conference* (Vol. 45356, p. V001T06A005). American Society of Mechanical Engineers.
7. Codjoe, J., Saunders, W., Cotten, J., Mousa, S., & Ashley, G. (2020). *Evaluating the Effectiveness of Regulatory and Warning Signs on Driver Behavior near Highway/Rail Crossings* (No. FHWA/LA. 19/611). Louisiana Transportation Research Center.
8. Florida Department of Transportation (FDOT). https://www.fdot.gov/info/co/news/2021/09202021.
9. Read, G. J., Beanland, V., Stanton, N. A., Grant, E., Stevens, N., Lenné, M. G., ... & Salmon, P. M. (2021). From interfaces to infrastructure: extending ecological interface design to re-design rail level crossings. *Cognition, Technology & Work*, *23*, 3-21.
10. Ngamdung, T., & daSilva, M. P. (2019). *Effect of Photo Enforcement-Based Education on Vehicle Driver Behavior at a Highway-Rail Grade Crossing* (No. DOT/FRA/ORD-19/17). United States. Department of Transportation. Federal Railroad Administration. Office of Research, Development, and Technology.
11. Brimley, B. K., Carlson, P. J., Sunkari, S. R., & Park, E. S. (2017). *Traffic control device evaluation program: FY 2016* (No. FHWA/TX-16/9-1001-14-3). Texas A&M Transportation Institute.
12. Federal Railroad Administration (FRA). https://railroads.dot.gov/program-areas/highway-rail-grade-crossing/highway-rail-grade-crossings-overview.
13. *Manual on Uniform Traffic Control Devices* (MUTCD). https://mutcd.fhwa.dot.gov/htm/2003r1/part4/part4b.htm.
14. Lin, P. S., Fabregas, A., Kourtellis, A., Bryant, E., & Lall, S. (2014). Planning and design for prevention of incorrect turns onto highway-rail grade crossings. In *Challenges and Advances in Sustainable Transportation Systems* (pp. 358-365).
15. Chen, Y., Rilett, L. R., & Wu, Z. (2022). Advanced transition preemption strategy for signalized intersections near highway-rail grade crossings with dual tracks. *Journal of advanced transportation*, *2022*.
16. Hellman, A. D., & Poirier, P. J. (2019). *Analysis of non-track-circuit highway-rail grade crossing train detection technologies* (No. DOT/FRA/ORD-19/47). United States. Federal Railroad Administration. Office of Research, Development & Technology.

17. Lin, P. S., Wang, Z., Wang, Q., Guo, R., Sunkari, S., Songchitruksa, P., ... & Hadi, M. (2014). *Coordinated pre-preemption of traffic signals to enhance railroad grade crossing safety in urban areas and estimation of train impacts to arterial travel time delay* (No. BDK85 977-44). Florida. Dept. of Transportation.
18. Dulebenets, M. A., Pasha, J., Moses, R., Sobanjo, J., Ozguven, E. E., & Singh, P. (2021). *Improving Safety at Highway-Rail Grade Crossings in Florida While Maintaining Continuity of Passenger and Freight Flows: A Multi-Objective Approach* (No. 045780). Florida A&M University-Florida State University (FAMU-FSU). College of Engineering. Department of Civil and Environmental Engineering.
19. Qiu, S. (2022). *A Risk-Based Decision Support Framework for Railway-Highway Grade Crossing Closures* (Master's thesis, University of Waterloo).
20. Rutter, A., Morgan, C. A., Warner, J. E., & Graves, B. (2016). *Highway-railway grade crossing action plan and project prioritization noteworthy practices guide* (No. FHWA-SA-16-075). United States. Federal Highway Administration. Office of Safety Research and Development.
21. Texas Department of transportation (TxDOT). *Texas Highway Rail Grade Crossing Safety Action Plan*. 2011.
22. Georgia Department of Transportation (GDOT). *State Highway-Rail Grade Crossing Action Plan*. 2011.
23. Ohio Department of Transportation (ODOT). *Ohio Railroad Safety Improvement Plan*. 2011.
24. Caltrans: California Department of Transportation. *Rail Crossing Safety Action Plan*. 2014.
25. Florida Department of Transportation (FDOT). *Highway-Rail Grade Crossing Safety Action Plan*. 2011.
26. Strang, J. *Louisiana State Highway-Rail Grade Crossing Action Plan*. 2011.
27. Indiana Department of Transportation (InDOT). *Highway-Rail Grade Crossing Safety Action Plan*. 2014.
28. Illinois Department of Transportation (IDOT). *State of Illinois Highway-Rail Grade Crossing Safety Action Plan*. 2011.
29. Larue, G. S., & Naweed, A. (2020). Understanding why drivers cross the line at activated railway crossings. *Transportation research record*, *2674*(8), 1-11.
30. Moon, Y. J., & Coleman III, F. (2003). Dynamic dilemma zone based on driver behavior and car-following model at highway–rail intersections. *Transportation Research Part B: Methodological*, *37*(4), 323-344.
31. Vivek, A. K., Khan, T., & Mohapatra, S. S. (2021). Safety and associated parameters influencing performance of rail road grade crossings: A critical review of state of the art. *Journal of safety research*, *79*, 257-272.
32. Giuliano, G., Showalter, C., Yuan, Q., & Zhang, R. (2018). Managing the Impacts of Freight in California.
33. Kawamura, K., & Allahyari, A. (2020). *Rail-highway crossing delay study for Dolton and Riverdale* (No. NURail2020-UIC-R18). University of Illinois at Chicago. Urban Transportation Center.
34. Qian, Y., Wang, Y., Rizos, D. C., Farkas, C., & Huang, C. T. (2022). *Intelligent Crossing Assessment and Traffic Sharing System (i-CATSS)* (No. DOT/FRA/ORD-22/15). United States. Department of Transportation. Federal Railroad Administration.

35. Chandra, S., Rahmani, M., Thai, T., Mishra, V., & Camacho, J. (2021). Evaluating financing mechanisms and economic benefits to fund grade separation projects.
36. Ghaffari Dolama, M., & Regehr, J. D. (2023). Review of road user mobility impacts and criteria for prioritising highway-rail grade crossings for grade separation. *Transport reviews*, *43*(1), 131-153.
37. Lin, P. S., Wang, Z., Vasili, A., & Yang, R. (2019). Pilot Implementation for Preventing Incorrect Turns at Highway-Rail Grade Crossings.
38. Lin, P. S., Wang, Z., Vasili, A., & Schultz, D. (2017). Pilot Study for Preventing Incorrect Turns at Highway-Rail Grade Crossings.
39. Courage. *Video Based Studies of Flexible Traffic Separators at Highway*-. 2003.
40. Pei-Sung Lin, P. E., Vasili, A., Guo, R., & Yang, R. (2021). Evaluation of a Low-Cost Countermeasure to Prevent Incorrect Turns at Highway-Rail Grade Crossings. *Institute of Transportation Engineers. ITE Journal*, *91*(3), 43-48.
41. Jeng, O. J. (2005). *Human Factors Evaluation of Design Ideas for Prevention of Vehicles Entrapment on Railroad Tracks due to Improper Left Turns* (No. FHWA-NJ-2005-019). NJ Department of Transportation.
42. Dulebenets, M. A., Moses, R., Sobanjo, J. O., Ozguven, E. E., Abioye, O. F., Kavoosi, M., & Pasha, J. (2020). *Development of the optimization model for improving safety at rail crossings in Florida* (No. 042485). Florida. Department of Transportation.
43. Campbell, T., Parida, B., Ross, J. C., & America, Q. N. (2022). *Acoustical Warning Device for Locomotive Horns* (No. DOT/FRA/ORD-22/08). United States. Department of Transportation. Federal Railroad Administration.
44. Malloy, B. R., & Rose, J. G. (2014). Railway/Highway At-Grade Crossing Surface Management: An Overview.
45. Finley, M. D., Chrysler, S. T., Carlson, P., Avelar Moran, R., Pike, A. M., Park, E. S., ... & Hudson, J. G. (2018). *Traffic control device evaluation program: FY 2017* (No. FHWA/TX-18/9-1001-14-4). Texas. Dept. of Transportation. Research and Technology Implementation Office.
46. Jacobini, F. B., & Baron, W. (2021). *Line-of-Sight Analysis Using Drones And Photogrammetry [Research Results]* (No. RR 21-23). United States. Department of Transportation. Federal Railroad Administration.
47. Pilutti, T., & Ulsoy, A. G. (2003). Fuzzy-logic-based virtual rumble strip for road departure warning systems. *IEEE Transactions on intelligent transportation systems*, *4*(1), 1-12.
48. Yang, L., Zhou, H., Zhu, L., & Qu, H. (2016). Operational effects of transverse rumble strips on approaches to high-speed intersections. *Transportation research record*, *2602*(1), 78-87.
49. Tey, L. S., Wallis, G., Cloete, S., Ferreira, L., & Zhu, S. (2013). Evaluating driver behavior toward innovative warning devices at railway level crossings using a driving simulator. *Journal of Transportation Safety & Security*, *5*(2), 118-130.
50. SAMAL, S. R., Mohanty, M., & BISWAL, D. R. (2022). A review of effectiveness of speed reducing devices with focus on developing countries. *Transactions on transport sciences*, *13*(1).
51. Liu, J., Bartnik, B., Richards, S. H., & Khattak, A. J. (2016). Driver behavior at highway–rail grade crossings with passive traffic controls: A driving simulator study. *Journal of Transportation Safety & Security*, *8*(sup1), 37-55.

52. Makarla, R. (2009). *Evaluation of external noise produced by vehicles crossing over centerline rumble strips on undivided highways in Kansas* (Doctoral dissertation, Kansas State University).
53. Savolainen, P. T., Cyr, J. D., Shaw, J. W., & Day, C. M. (2020). *In-Service Evaluation of Railroad Signal and Stop Arm Pole Protection* (No. InTrans Project 17-621).
54. Preston, H., Richfield, V., & Jensen, M. (2016). *Railroad Grade Crossing Safety Project Selection* (No. MN/RC 2016-25).
55. Khattak, A., Kang, Y., & Liu, H. (2020). *Nebraska Rail Crossing Safety Research* (No. SPR-P1 (19) M091). Nebraska. Department of Transportation.
56. Mathew, J., Benekohal, R. F., & Medina, J. C. (2019). Accident Prediction Models using Macro and Micro Scale Analysis: Dynamic Tree and Zero Inflated Negative Binomial Models with Empirical Bayes Accident History Adjustment.
57. Yang, J., Yan, X., Xue, Q., & Li, X. (2022). How do signs and warning influence driving behaviors at flashing light grade crossings?. *Journal of Transportation Safety & Security*, *14*(5), 843-872.
58. Efanov, D. V., Osadchii, G. V., & Khoroshev, V. V. (2019, September). New Stage in Safety Traffic Control Technologies Development: Digital Railroad Crossing. In *2019 International Russian Automation Conference (RusAutoCon)* (pp. 1-6). IEEE.
59. Liu, R., Yan, X., Ma, S., & Xue, Q. (2022). Eye movement as a function to explore the effects of improved signs design and audio warning on drivers' behavior at STOP-sign-controlled grade crossings. *Accident Analysis & Prevention*, *172*, 106693.
60. He, D., Qiu, Y., Miao, J., Zou, Z., Li, K., Ren, C., & Shen, G. (2022). Improved Mask R-CNN for obstacle detection of rail transit. *Measurement*, *190*, 110728.
61. Neumeister, D., Polinori, A., & Sanchez-Badillo, A. (2018). *Automated Vehicles at Highway-Rail Grade Crossings* (No. DOT/FRA/ORD-18/39).
62. Withers, J., & Utterback, J. (2021). *Rail Crossing Violation Warning Application-Phase II [Research Results]* (No. RR 21-12). United States. Department of Transportation. Federal Railroad Administration.
63. Ciani, L., Guidi, G., & Patrizi, G. (2022). Human reliability in railway engineering: Literature review and bibliometric analysis of the last two decades. *Safety science*, *151*, 105755.
64. Jacobini, F. B., & Ngamdung, T. (2022). *Railroad Trespass Detection Using Deep Learning-Based Computer Vision [Research Results]* (No. RR 22-04). United States. Department of Transportation. Federal Railroad Administration.
65. Jeon, M., Lautala, P., Nadri, C., & Nelson, D. N. (2022). In-vehicle auditory alerts literature review.
66. Federal Railroad Administration (FRA). Highway-Rail Grade Crossing Safety and Trespass Prevention. https://railroads.dot.gov/highway-rail-crossing-and-trespasser-programs/railroad-crossing-safety-trespass. Accessed Oct. 20, 2022.
67. Ngamdung, T., & daSilva, M. P. (2019). *Effect of Anti-Trespass Guard Panels on Pedestrian Behavior* (No. DOT/FRA/ORD-19/23). United States. Department of Transportation. Federal Railroad Administration.
68. STRIDE. https://www.hanson-inc.com/portfolio/FDOT-Statewide-Traffic-and-Railroad-Initiative-STRIDE/193/portfolio-details.
69. Florida Department of Transportation (FDOT). Traffic Engineering and Operations: ETraffic.

https://fdot.maps.arcgis.com/apps/webappviewer/index.html?id=ed2ff4aba7bd4345a089d821fbf667e4.

70. Wang, Z., P.-S. Lin, and A. Vasili. Rail Dynamic Envelope (RDE. In *Pavement Markings Before-After Study in FDOT District 7*.
71. Federal Railroad Administration (FRA). *Effect of Dynamic Envelope Pavement Markings on Vehicle Driver Behavior at a Highway-Rail Grade Crossing*. 2014.
72. Federal Railroad Administration (FRA). https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/3627/Dynamic.
73. Florida Department of Transportation (FDOT). *Florida Rail System Plan*. 2022.
74. Federal Highway Administration (FHWA). *Manual on Uniform Traffic Control Devices*. Washington DC, 2012.
75. Lin, P. S., Wang, Z., Vasili, A., & Yang, R. (2019). Pilot Implementation for Preventing Incorrect Turns at Highway-Rail Grade Crossings.
76. Florida Department of Transportation (FDOT). Highway-Rail Grade Crossings, Florida's State Action Plan, Tallahassee 2022.

Appendix A List of HRGC with Before and After RDE Report

Table A-1. Treatment Costs of Highway Railroad At-Grade Crossing

No.	District	Location	Crossing No	County
1	1	SR 572 near US 92 (Airport Rd)	624300N - CSX	Polk
2	1	SR 60 at Phosphate Blvd (Canal)	624299G - CSX	Polk
3	1	SR 37 near Pine St (SR 35 at Florida Ave)	624163J - CSX	Polk
4	1	SR 659 at US 92 (Combee Rd)	624151P - CSX	Polk
5	1	US 92 at Fish Hatchery Rd	624138B - CSX	Polk
6	1	US 41 (301) at SR 55 (683) 13th Ave E	624712B - CSX	Manatee
7	1	SR 82 at Curtis Smith Ave	623275E - SGLR	Lee
8	2	SR 103/Lane Avenue	620619F – CSX	Duval
9	2	SR 224/Kingsley Avenue	620903X – CSX	Clay
10	2	SR 10A/Southeast Baya Drive	726310C- Norfolk Southern	Alachua
11	2	SR 20/Eastbound Off-Ramp	625010J – CSX	Alachua
12	2	SR 121/Northeast 22nd Street	625952L – CSX	Alachua
13	2	Northeast SR 26	624994U – CSX	Alachua
14	2	SR 129 (McDuff Avenue) at SR 228 (Post Street)	621216V – CSX	Duval
15	2	SR 228 (Post Street) at SR 129 (McDuff Avenue)	621215N – CSX	Duval
16	2	SR 134/Timuquana Rd West of US 17 / Roosevelt Blvd	620891F – CSX	Duval
17	2	SR 128/San Juan Ave at Roosevelt Blvd	621223F – CSX	Duval
18	2	SR 105/Heckscher Drive	620874P – CSX	Duval
19	2	SR 5/North Main Street	620858F – CSX	Duval
20	2	SR 111/Edgewood Avenue	621275X – CSX	Duval
21	2	SR 104/Busch Drive	620834S – CSX	Duval
22	2	SR10/East Duval Street	713218P - Norfolk Southern	Columbia
23	3	US 98 at E 15th St (SR 30A at SR 391) (Harrison Ave)	002775Y BAYL	Bay
24	3	SR 75 (US 231 / Harrison Ave) at SR 30A (US 98 / 15th St)	002776U - BAYL	Bay
25	3	SR 77 (MLK Jr Blvd) at SR 75 (US 231)	002778H - BAYL	Bay
26	3	SR 389 (East Ave) at SR 75 (US 231)	002783E - BAYL	Bay
27	3	SR 20 at SR 75 (US 231)	002814B - BAYL	Bay
28	3	SR 4 at SR 95 (US 29)	339630K - CSX	Escambia
29	3	SR 10 (US 90A Nine Mile Rd) at SR 95 (US 29) Southbound Ramp	339696K - CSX	Escambia
30	3	SR 79 (Waukesha St) at Pennsylvania Ave	339931 - FGA	Holmes
31	3	SR 276 (Penn Ave) at SR 10 (US 90)	339973S - FGA	Jackson

Table A-1. Treatment Costs of Highway Railroad At-Grade Crossing (Continued)

No.	District	Location	Crossing No	County
32	3	SR 77 (Main St) at SR 10 (US 90)	339945N - FGA	Washington
33	3	SR 285 at SR 10 (US 90)	339809N - FGA	Walton
34	3	US 29 (SR 95) at Becks Lake Rd/Muscogree Rd	339674K - CSX	Escambia
35	4	SR-858 / Hallandale Beach Blvd	272592M - FEC	Broward
36	4	SR-848 / Stirling Rd	6v8274P - FEC	Broward
37	4	SR-822 / Sheridan St	272577K - FEC	Broward
38	4	NW 33rd St	621538J - SFRC	Broward
39	4	Sample Rd (834)	628168G - FEC	Broward
40	4	Hammondville Rd	628171P - SFRC	Broward
41	4	Cypress Creek Rd	628183J - SFRC	Broward
42	4	6th Ave S	628146G - SRFC	Palm Beach
43	4	12th Ave S	628147N - SFRC	Palm Beach
44	4	SW 10th St	628159H - SFRC	Palm Beach
45	4	Palmetto Park Rd	628165L - SFRC	Palm Beach
46	4	A1A / N Causeway Dr	272218U - FEC	St. Lucie
47	4	A1A / Seaway Dr	272867T - FEC	St. Lucie
48	5	SR 520 at King St	272097Y - Brightline	Brevard
49	5	SR 40 W	621284W - CSX	Volusia
50	5	SR 40 / W Granada Blvd	272865E - FEC	Volusia
51	5	SR/US301 (E Noble Ave)	625293J - CSX	Sumter
52	5	CR 470	625284K - CSX	Sumter
53	5	SR 423 and Lee Rd	622393D - FCEN	Orange
54	5	US 17 (SR 50) at W Colonial Dr	622356B - FCEN	Orange
55	5	SR 35 / Baseline Rd	627223B - FNOR	Marion
56	5	SR 25 (Hames Rd)	625094G - CSX	Marion
57	5	SR 50 (Cheney Hwy)	272024S - FEC	Brevard
58	5	W South St	622192M - SunRail	Orange
59	5	SR - 526 / W Robinson ST	622344G - FCEN	Orange
60	5	US 17 (SR 50) at W Colonial Dr	622181A - SunRail	Orange
61	6	NE 203rd Street /Ives Dairy Road	272596P - FEC	Miami-Dade
62	6	SR-860 / NE 186th St	272598D - FEC	Miami-Dade
63	6	SR-826 / NE 163rd St	272604E - FEC	Miami-Dade
64	6	SR 922 NE / 125th St	272612W - FEC	Miami-Dade
65	6	SR 944 NE 54th St	272627L - FEC	Miami-Dade
66	6	SR 25 / US 27	272633P - FEC	Miami-Dade
67	6	SR 953 E 8th Ave	272736P - FEC	Miami-Dade
68	6	SR 934 / E4th Ave	272738D - FEC	Miami-Dade

Table A-1. Treatment Costs of Highway Railroad At-Grade Crossing (Continued)

No.	District	Location	Crossing No	County
69	6	SR 823 / W 4th Ave	272744G - FEC	Miami-Dade
70	6	SR 934 W 21st Street	273008H - FEC	Miami-Dade
71	6	SR 916 NW 135th Street	628334W - SFRTA	Miami-Dade
72	6	SR-959 / NW 57th Ave	628507J - SFRTA	Miami-Dade
73	6	NW 42nd Court	915143C - SFRTA	Miami-Dade
74	6	US 1 / SR 5	272654H - FEC	Miami-Dade
75	6	SR 886 Port Boulevard	272960A - FEC	Miami-Dade
76	6	SR 9 NW 27th Ave	628406X - SFRC	Miami-Dade
77	6	NW 28th Street	968422U - SFRC	Miami-Dade
78	6	SR 976 SW 40th St	631070G - CSX	Miami-Dade
79	6	SR 973 SW 87th Ave	631078L - CSX	Miami-Dade
80	6	SR 94 SW 88th St	631081U - CSX	Miami-Dade
81	6	SR-934 / NE 79th St	272621V - FEC	Miami-Dade
82	6	US 27 SR 25 NW 36th St	628377P - SFRTA	Miami-Dade
83	7	E Adamo Dr at N 39th St (SB)	624467A - CSX	Hillsborough
84	7	E Busch Blvd at N Florida Ave (NB)	626891B - CSX	Hillsborough
85	7	E Busch Blvd at N Nebraska Ave (NB)	626893P - CSX	Hillsborough
86	7	N Nebraska Ave and E Cass St (NB)	626293M - CSX	Hillsborough
87	7	W Kennedy Blvd at N Willow Ave (EB and WB)	626304X - CSX	Hillsborough

Appendix B Interview Questionnaire

B.1 FDOT Districts

Questions on Challenges, Causes, and Strategies to Address Safety and Mobility Issues at HRGCs

1. What are your district's primary safety and mobility challenges in Highway-Rail Grade Crossing (HRGC) operations?
2. What are your top five causes of serious safety and mobility issues at your HRGC locations?
3. What are the implemented or planned strategies of your agency to address the identified issues in your agency?
4. Does your agency have needed resources to implement these strategies, and what is the availability of these resources? Does your agency need any additional resources?
5. Besides the engineering approach, does your agency conduct any educational outreach on HRGC safety?

Questions about FDOT STRIDE Program – Railway Dynamic Envelope (RDE) Pavement Marking

6. What is your agency assessment on effectiveness of RDE implementations in your district?
7. Are there HRGCs with RDE implementations being ineffective? Are there HRGCs with RDE treatment that are of special concern to you? Based on your experience, what are the reasons for RDE treatments being ineffective? What are your suggestions for improving RDE effectiveness?
8. What are the top three HRGCs you suggest for the research team to conduct a field review to investigate the RDE implementation? And why?
9. Do you have success stories and lessons learned from the RDE implementation in your agency?

Questions about Knowledge and Experience on Effective Strategies, Treatments, Success, Lessons Learned, and other Resources

10. Based on your knowledge and experience, please share any effective strategies and treatments to improve safety and mobility at HRGCs in the following areas:
    - Traditional treatments (e.g., four-quadrant gates, geometry treatments, pavement markings, signage, flashing lights, etc.)
    - TSM&O and ITS applications (e.g., traffic signal preemptions, dynamic message signs, dynamic warnings and alerts, rail crossing violation warning, etc.)
    - Emerging technologies (Connected Vehicle technology, AI-based detection, and inspection, etc.)
    - Can you share any thoughts regarding the following?
        - Use of delineators to prevent turns on the tracks.
        - When is it worth it to install four quadrant gates?
            - 23% of the issue is people going around gates.
        - Add fencing in addition to ped gates,
11. Please share any successes and lessons learned from the previously implemented HRGC strategies and countermeasures (not limited to RDE) in your district.

Do you have any other information and resources to share?

B.2 Railway Company

Questions on Challenges, Causes, and Strategies to Address Safety and Mobility Issues at HRGCs

1. What are your company primary safety and mobility challenges in Highway-Rail Grade Crossing (HRGC) operations?
2. What are your top five causes of serious safety and mobility issues at your HRGC locations?
3. What are the implemented or planned strategies of your company to address the identified issues in your company?
4. Besides the engineering approach, does your company conduct any educational outreach on HRGC safety?
5. What are the top three HRGCs you suggest for the research team to conduct a field review to investigate the safety and mobility problem and develop solutions?

Questions about Knowledge and Experience on Effective Strategies, Treatments, Success, Lessons Learned, and other Resources

6. Based on your knowledge and experience, please share any effective strategies and treatments to improve safety and mobility at HRGCs in the following areas:
    - Traditional treatments (e.g., four-quadrant gates, geometry treatments, pavement markings, signage, flashing lights, etc.)
    - TSM&O and ITS applications (e.g., traffic signal preemptions, dynamic message signs, dynamic warnings and alerts, rail crossing violation warning, etc.)
    - Emerging technologies (Connected Vehicle technology, AI-based detection, and inspection, etc.)
    - Can you share any thoughts regarding the following?
        - Use of delineators to prevent turns on the tracks
        - When is it worth it to install quad gates?
            - 23% of issue is people going around gates
        - Fencing in addition to ped gates
7. Please share any successes and lessons learned from the previously implemented HRGC strategies and countermeasures.

Do you have any other information and resources to share?

Appendix C Estimated HRGC Treatment Cost

Table C-1 summarizes the treatment costs that are extracted from the districts, vendors, railroad companies, and the Internet. Table C-2 summarizes the responses from the FDOT districts 1, 2, and 7, and the FTE regarding costs estimations of HRGC treatments

Table C-1. Treatment Costs of Highway Railroad At-Grade Crossing

<table>
<tr><th>Item</th><th>Cost</th><th>Installation cost</th><th>Comment</th></tr>
<tr><td>Two-quadrant gate</td><td>$250,000 to $300,000</td><td rowspan="2">Included</td><td rowspan="2">Annual maintenance costs $4000 to 10,000/year. These values are based on a 2011 document (see the link). These values are approved by this website. Also, a 2022 document approves the four-quadrant gate price here. However, district 1 mentioned that the cost for four-quadrant gates is at least $500k.
Based on District 2, in some cases, two flashing lights & gates could be installed on a two-lane roadway for around $300,000-$350,000, while another location with the exact same roadway footprint could cost up to $1,000,000.</td></tr>
<tr><td>Four-quadrant gate</td><td>$300,000 to $500,000</td></tr>
<tr><td>Guardrail</td><td>$10 to $30</td><td>$500 to $1,500</td><td>This is the price for a linear foot. Installation cost includes the labor required to install the barrier and any additional equipment or materials needed (see the link).</td></tr>
<tr><td>Barrier delineator</td><td>$40 to $400</td><td>$80</td><td>Delineators in the form of bollards, price depends on the delineator's quality and the project's requirement. For the installation cost, see this link.</td></tr>
<tr><td>X-Shape and R-R Pavement Marking</td><td>$760</td><td>Included</td><td>Based on the distributor quote, this price is for new pavement. If the pavement is old (existing road), $178 need for a 5-gallon permanent prime.</td></tr>
<tr><td>Stop line</td><td>$718</td><td>Included</td><td>The price is for a 24" by 50' stop bar. For 12" by 50', the price is $334.</td></tr>
<tr><td>Railroad Dynamic Envelope</td><td>$1336</td><td>Included</td><td>This price is based on 6' by 25' RDE that uses 12" pavement marking rolls.</td></tr>
<tr><td>Crossbuck sign</td><td>$120</td><td>$500 to $1,500</td><td>The size is 2" by 48". The price for 5" by 48" is $129. For the installation cost, see this link. The crossbuck installation price is here.</td></tr>
<tr><td>Grade crossing advance warning signs (W10 Series)</td><td>$74</td><td>$500 to $1,500</td><td>This price is for a 30" diameter (typical signage) of W10-1. For 36" and 48" diameters, The prices are $103 and $176, respectively. For the installation cost, see this link.</td></tr>
</table>

Table C-1. Treatment Costs of Highway Railroad At-Grade Crossing (Continued)

Item	Cost Installation cost		Comment
Emergency Notification Sign (I-13)	$9	$500 to $1,500	The size is 12" by 9". The price for 15" by 9" is $11 (see the link).
DO NOT STOP ON TRACKS (R8-8) sign	$61	$500 to $1,500	This price is for 24" by 30" of the single lane (typical signage). For the installation cost, see this link.
Dynamic message sign	$8000 to $100,000	Included	For the information provided, see this link.
Stop sign	$94	$500 to $1,500	For the information provided, see this link.
Flashing light	$32000 to 250,000	Included	For the information provided, see this link and this link. District 1 mentioned that the cost is less than $300k.
Pedestrian gate	$50,000 to $300,000	Included	Costs can vary widely depending on site conditions, improvements needed, and existing infrastructure. Enhancing at-grade crossings (to connect platforms) and adding flashers and bells costs approximately $50,000 to $300,000. Creating a pedestrian overcrossing or underpass can range from $1.5 million or higher. For the information provided, see this link.
Pedestrian crossing signal	$5000	$500	For the cost, see this link. For installation costs, see this link.
Visual warning signal	$20000	Included	For the information provided, see this link.
Signal safety upgrades	$400,000 to $900,000	Included	Based on District 7, average costs for Tri-Party or Signal Safety upgrades are estimated for County/City Roads.
Signal preemption	$50k to $1M	Included	Based on District 1.
Crossing surface modifications	$200k to $500k	Included	Based on District 1.
Fencing	$50 to $85	$5 to $20	Based on the distributor quote, the price is for an 8' by 1' with welded wire mesh (Galvanized steel). Depending on the content of steel in the mesh, the price varies.
Video surveillance systems	$50,000	$5000	Depending on the camera's functionality, the server costs $3000 to $20,000. The price of the camera could also vary based on the need. A red-light camera costs $5,000 for installation and sensors (see this link).
Grade separation	$4M to $40M	Included	For the information provided, see this link and this link.
Closure	$25,000 to $100,000	Included	For the information provided, see this link.

Table C-2. District Responses Regarding Costs Estimations of HRGC Treatments

District	Cost estimation	Comment
1	To obtain more specific information, it would need to come from either a railroad company or a manufacturer of the equipment; however, below are some approximate cost ranges to consider for railroad crossing improvements: • Flashing lights and gates: most signal installations will run approximately $300k-$500k, including engineering services, materials, and labor. For flashing lights only, it would be less than $300k; however, we have not estimated that in some time, so I cannot say for sure. For four-quadrant gates, we would expect at least $500k. • Traffic signal preemptions: this varies greatly depending on what equipment is needed in the field. We have had installations for under $50k and received quotes of up to $ 1 million to install advanced preemption. These numbers would include the engineering services, materials, and labor. • Crossing surface modifications: a typical crossing surface project cost ranges between $200k to $500k, including engineering services, materials, and labor.	Geometry treatments would be very site dependent and difficult to estimate; however, Construction or Maintenance may be able to estimate an average intersection reconstruction project.
2	Unfortunately, this is going to be a very difficult question to answer. The cost of installing warning devices is highly variable with the railroads existing track structure and circuitry being the biggest driver of cost. • In some cases, we can install two flashing lights & gates on a two lane roadway for around $300,000-$350,000, while another location with the exact same roadway footprint could cost up to $1,000,000. • In urban environments the cost is generally much higher because there are often nearby upstream and downstream crossings each of which must operate on their own frequency, so they do not interfere with adjacent crossings. This requires complex circuitry installation to isolate each crossing while also having the ability to detect approaching trains a mile or more away.	

Table C-2. District Responses Regarding Costs Estimations of HRGC Treatments (Continued)

District	Cost estimation	Comment
7	It will be difficult to project Cost Range Estimates for Signal Safety projects. • Cost Rate will depend on the Work Mix, Equipment Upgrades and Size of Roadway at the Crossing. • Average Costs for Safety Upgrades on State Roads range from $500,000 to $1.3 Million. Costs have doubled in the past two years. • Average Costs for Tri-Party or Signal Safety Upgrades on County/City Roads Range from $400,000 to $900,000.	There is a sample estimate they received recently that will break down the costs of their typical Signal Safety Projects.
Florida Turnpike Enterprise	FTE does not have historical HRGC's improvement cost estimates since all crossings within the district are grade separated.	