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Crashes Related to Type and Location of Driveway Access

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Disclaimer

Metric Conversion

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

This study examines how commercial driveway access location and design interact with roadway and interchange characteristics to influence vehicular, bicycle, and pedestrian safety. The final sample for analysis included: a) 192 roadway segments with 9,889 commercial driveways and 10,596 driveway-related crashes; and b) 69 interchanges with 832 commercial driveways and 853 driveway-related crashes in the vicinity of the interchanges. Several analytical methods were used to assess the safety effects of driveway type and location on crash type and severity, including summary statistics and statistical analysis, generalized linear modeling techniques, and exploratory case studies. Results indicated that both non-traversable medians and TWLTLs decrease the overall crash frequency at commercial driveways along corridors compared to undivided or painted medians. Exclusive right-turn lanes at commercial driveways were found to reduce the average number of driveway-related crashes near interchanges by 49.7% compared to shared right-turn lanes, and by 64.0% compared to no right-turn lanes. Shared right-turn lanes also significantly reduced the probability of severe injury and fatality crashes by 35.3% at commercial driveways along corridors. Both sufficient driveway throat length and driveway channelization were found to improve commercial driveway safety. Unsignalized or signalized commercial driveways located less than 500 ft from the end of the interchange ramp taper increased the potential for severe injury crashes by 261%. Conventional bike lanes appeared to induce pedestrian/bicycle crashes at or near commercial driveway locations, possibly due to the potential for motor vehicles to encroach into the bike lane and/or overlook bicyclists when crossing bike lanes to enter or exit commercial driveways. Conventional bike lanes were also found to significantly increase the risk of minor injury crashes at commercial driveways near interchanges. Therefore, when a bike lane is needed on a major roadway, buffered bike lanes or other types of physical barriers should be used when feasible, as well as bike lane paint at driveway locations to further alert motorists of the presence of bicyclists. Case study analysis further revealed that a variety of conflicts and crashes occur when aligning high-volume commercial driveways at full median openings without signal control. Crash clusters were also observed at driveways in the functional area of signalized intersections and interchanges. A contributing factor identified in crash reports was a tendency for “good Samaritans” to allow drivers entering or exiting driveways on multilane roadways to blindly cross one or more lanes of queueing traffic. Suggestions are offered for consideration by FDOT and other agencies relative to commercial driveway access policy, permitting and mitigation to improve roadway and interchange area safety.

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Executive Summary

An important objective of access management is to limit traffic conflicts that could result in vehicular, bicycle, and pedestrian crashes. Commercial driveways and side streets connecting to major roadways are a key source of these conflicts. While medians can reduce left-turn conflicts from driveway traffic, separating conflict areas through improved access spacing reduces the exposure of all system users to traffic conflicts. In the areas surrounding highway interchanges, commercial driveways pose unique safety challenges. The combination of high traffic volumes, unfamiliar drivers, and turning and weaving movements in interchange areas can lead to numerous conflicts and safety problems when commercial driveways on the crossroads are not carefully managed.

Despite the safety issues associated with driveways, relatively few studies have explored the issue. Even fewer have examined how driveway type and location may influence crash frequency and severity. This comprehensive study was undertaken to advance the body of knowledge on this topic. It examines how commercial driveway access location and design interact with roadway and interchange characteristics to influence vehicular, bicycle, and pedestrian safety. The findings are translated into guidance for transportation agencies responsible for access management.

Methodology

Several analytical methods were used in this study to assess the safety effects of driveway type and location on crash type and severity in relation to roadway and interchange characteristics. They include summary statistics and statistical analysis, generalized linear modeling techniques, and exploratory case studies. These methods have been proven effective in previous studies (Williamson and Zhou, 2014; Chen et al., 2018; Dixon et al., 2016).

The analysis was divided into qualitative and quantitative assessments. The qualitative assessment encompasses descriptive statistics of crashes, severity levels, and crash, traffic, and geometric attributes. Significance tests were conducted through ANOVA. Where the ANOVA analysis revealed that some of the tested means were different, a paired t-test was performed to further identify which pair(s) of two sample means differed. For this study, this process tested for differences in the crash rates associated with each contributing factor tested (e.g., driveway type, driveway location, median opening type, interchange type, traffic volume, posted speed limit, land use context, presence of pedestrian or bicycle facility). The p-value ($p=0.05$) was used to determine if the difference is significant between the two compared groups with a 95% confidence level.

The quantitative analysis involved statistical analysis and generalized linear modeling considering frequency (e.g., negative binomial) and severity (e.g., multinomial logit) of crashes at corridors and interchange areas. A non-negative binomial regression model was employed to investigate the influence of roadway, driveway, and traffic characteristics on driveway-related crash distributions. The multinomial logit model (MNL) was used to examine crash severity outcomes at commercial driveways and the contributing factors relative to roadway features, traffic conditions, driveway characteristics, and other crash-related variables.

Candidate driveway sites for further data collection and analysis were selected through a screening process shown in Figure E-1. The final sample for analysis included: a) 192 roadway segments with 9,889 driveways and 10,596 commercial driveway-related crashes for corridors; and b) 69 interchange sites with 832 driveways and 853 crashes in the vicinity of the interchanges for interchange areas.

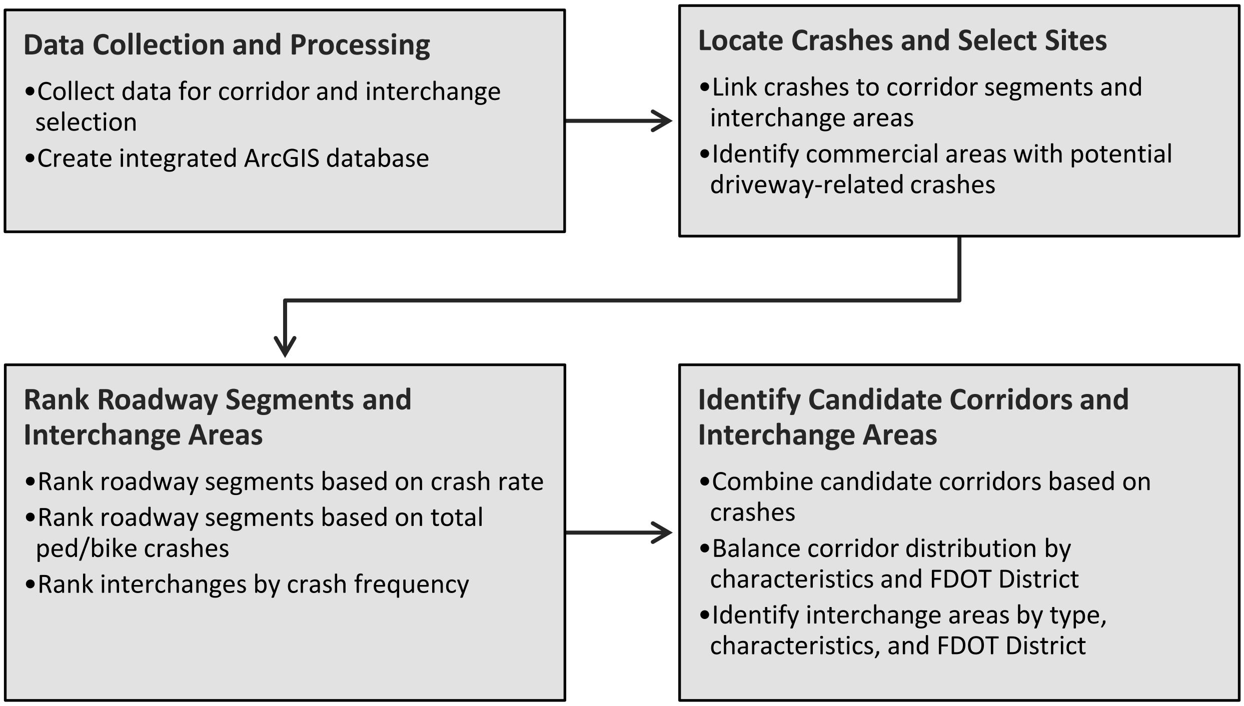

Figure E-1. Conceptual process for site screening and identification.

Crash Frequency Analysis Findings

Tables E1-E3 summarize the findings on crash frequency for variables found to have a significant influence on commercial driveway-related crashes along corridors and interchanges; however, not all values within each category were significant in explaining crash risk. The percentage values indicate the positive or negative influence of each categorical value on crash frequency compared only to the base category (identified by asterisk). From a statistical perspective, the percentage values are meaningful only in comparison to the base category and should not be compared across categories within that variable. For example, the crash risk for commercial driveways on three-lane roadways was 118% higher than on one-lane roadways, but one should not presume it was 53% higher than on two-lane roadways.

Table E-1. Crash Frequency at Commercial Driveways along Corridors (All Crashes)

Variables	Categories	Statistically Significant**	Crash Frequency	Notes
Number of Lanes on Connecting Street	One Lane*			
	Two Lanes	Yes	+65.2%	Number of lanes is a surrogate for roadway AADT. More lanes indicate increased lane-changing behavior and potential for traffic conflicts.
	Three Lanes	Yes	+118.0%	
	Four Lanes or More	Yes	+192.9%	
Speed Limit on Connecting Street	35 mph or lower*			
	40-45 mph	Yes	−15.2%	Higher speed limits usually indicate higher levels of access control, whereas lower speed limits generally indicate higher access densities and more complex traffic.
	50 mph or Higher	Yes	−44.9%	
Driveway Design Features	Curb Flare*			
	Flush Radial	Yes	+39.8%	Flared curbed driveways generally have low driveway traffic; flush or curb radial designs are more common at higher traffic driveways as they allow for efficient ingress and egress; however, they can also increase crash risk.
	Curb Radial	Yes	+24.7%	
	Wide-open Access	Yes	−37.4%	
Driveway Number of Lanes (including both directions if available)	One Lane*			
	Two Lanes	Yes	+26.5%	Driveway number of lanes is a surrogate measure for driveway volume. Multi-lane or wide-open driveways can experience more complex traffic movements with increased potential for conflicts.
	Three Lanes	Yes	+179.1%	
	Four Lanes or More or Wide-open Access	Yes	+57.5%	
Median Type	Undivided or Painted Median*			
	Non-traversable Median	Yes	−19.9%	Both non-traversable medians (NTM) and continuous Two-Way Left-Turn Lanes (TWLTL) reduce crash risk compared to undivided roadways. NTMs tend to serve higher-volume roads and have different levels of conflict depending on median opening spacing, location, and type.
	TWLTL	Yes	−24.7%	TWLTLs provide space for vehicles to maneuver and stop as they turn or merge into traffic without blocking through lanes but allow more conflicts than NTMs.
Connecting Street 5-year Average AADT	AADT<10,000*			
	10,000<AADT≤20,000	No	N/A	The average number of crashes tended to increase for all AADT categories, but only one category is found statistically significant.
	20,000<AADT≤30,000	No	N/A	
	30,000<AADT≤40,000	Yes	+258.1%	
	40,000<AADT≤50,000	No	N/A	
	50,000<AADT≤60,000	No	N/A	
	60,000<AADT≤70,000	No	N/A	

*Indicates base category for analysis of each variable.
**Significant at 95% confidence level

Table E-2. Pedestrian/Bicycle Crash Frequency at Commercial Driveways along Corridors

Variable	Values and Base Category	Statistically Significant**	Crash Frequency (±%)?	Note
Number of Lanes on Connecting Street	**One Lane***			
	Two Lanes	No	N/A	The variable is significant in explaining crash frequency; however, none of the categorical values are statistically significant relative to the base category. More lanes entail longer crossing times and greater exposure of pedestrians or bicyclists to through-traffic conflicts.
	Three Lanes	No	N/A	
	Four Lanes or More	No	N/A	
Driveway Design Feature	**Curb Flare***			
	Flush Radial	Yes	−52.0%	Radial return designs are generally used on high-volume driveways, which have higher crash potential. On flush shoulder roadways, FDOT prefers sidewalk placement outside the clear zone or five feet beyond the shoulder pavement to provide adequate protection for pedestrians or bicyclists.
	Curb Radial	Yes	+35.2%	
	Wide Open Access	No	N/A	
Median Opening Type	**No Physical Median***			
	No Opening	Yes	−21.3%	Physical medians (both no opening and directional opening) provide buffer space for pedestrians and cyclists to wait to cross, reducing collision risk with through traffic. No median opening or a directional median opening limits vehicular turning movements thereby also reducing driveway conflicts.
	Directional Opening	Yes	−36.9%	
	Full Opening	No	N/A	
Traffic Control Device	**No Control***			
	Sign Control	Yes	+52.2%	Driveways with sign or traffic signal controls tend to have higher traffic volume and more complex traffic than locations with no traffic controls, and therefore experience higher crash frequencies.
	Traffic Signal Control	Yes	+137.9%	
Painted Bike Lane	**No Bike Lane***			
	No Paint	Yes	+39.7%	Conventional bike lanes without paint do not necessarily provide protection. Motor vehicles must cross bike lanes to enter or exit driveways, leading to conflicts with bicyclists in the bike lane.
	Painted	No	N/A	

* Indicates base category for analysis of each variable.
** Significant at 95% confidence level.

Table E-3. Crash Frequency at Commercial Driveways near Interchanges

Variable and Base Category	Values and Base Category	Statistically Significant**	Crash Frequency***	Note
Number of Lanes on Connecting Street	**One Lane***			
	Two Lanes	No	N/A	Number of lanes is a surrogate for roadway AADT. More lanes indicate increased lane changing behavior and potential conflict points.
	Three Lanes	Yes	+87.8%	
	Four Lanes or More	Yes	+113.5%	
Right-turn Lane Type	**Exclusive Right-turn Lanes***			
	Shared/Continuous Right-Turn Lane	Yes	+99.1%	Shared right-turn lanes or locations with no right-turn lane serve more than one driveway site, leading to lower driver expectancy as to where turns will occur and a higher potential for conflicts and rear-end collisions.
	No Right-turn Lane	Yes	+177.9%	
Driveway Design Feature	**Curb Flare***			
	Flush Radial	No	N/A	Both flare and curb radial design tend to increase crash frequency but only curb radial design had a significant influence. Flush or curb radial are more used at higher traffic driveways, and large radius or flare allows for quick and more efficient ingress and egress but increases crash risk.
	Curb Radial	Yes	+93.9%	
	Wide Open Access	No	N/A	
Driveway Number of Lanes (including both directions if available)	**One Lane***			
	Two Lanes	No	N/A	Driveway number of lanes may be a surrogate for driveway volume; Driveways with multiple lanes or wide-open access can experience more complex traffic movements with increased potential for conflicts.
	Three Lanes	Yes	+148.8%	
	Four Lanes or More or Wide-open Access	Yes	+133.8%	
Traffic Control Device	**No Control***			
	Sign Control	Yes	+34.8%	Locations with sign control tend to have higher traffic volume and more complex traffic than locations with no traffic controls, and therefore still experience higher crash frequencies.
	Traffic Signal Control	No	N/A	
Bike Lane Type	**No Bike Lane***			
	Conventional Bike Lane	Yes	−26.8%	Other bike lane types were also found to decrease crash frequency but not significantly. Therefore, presence of a bike lane at commercial driveways near interchanges helps to reduce crash frequency, regardless of bike lane type.
	Other Bike Lane Types	No	N/A	

Table E-3, continued

Variable and Base Category	Values and Base Category	Statistically Significant**	Crash Frequency***	Note
Connecting Street 5-year Average AADT	**AADT⩽10,000***			
	10,000<AADT⩽ 20,000	Yes	−46.1%	It is possible that fewer driveways were permitted in the interchange influence area as the AADT increased on connecting streets, thereby reducing the average number of driveway-related crashes.
	20,000<AADT⩽ 30,000	Yes	−61.9%	
	30,000<AADT⩽ 40,000	Yes	−54.9%	
	40,000<AADT⩽ 50,000	Yes	−56.3%	
	50,000<AADT⩽ 60,000	Yes	−58.2%	

* Indicates base category for analysis of each variable.
** Significant at 95% confidence level.
*** Motor vehicles only.

Crash Severity Analysis Findings

Table E-4 summarizes findings on vehicle crash severity at commercial driveways along corridors for variables and categorical values found to have a statistically significant influence on crash severity at a 95% confidence level in MNL modeling. Column 2 shows the significant categorical value with the crash severity level shown in parentheses. Column 3 shows the percentage increase (+) or decrease (−) in the potential for that injury severity level for the variable condition, compared with the absence of that condition.

Three crash severity levels were used in the analysis: no Injury (NI, base category), minor injury (MI), and severe injury (SI). The sum of the probability for all three crash severity levels is equal to 1, so increasing the probability of one severity level will decrease the probability of another, or the other two, crash severity levels. For example, an unpaved shoulder was found to be significant in explaining minor injury (MI) crashes at commercial driveways and compared to other types of shoulders, its presence increased minor injury (MI) risk by 16.4%. Conditions that influence pedestrian/bicycle crash severity at commercial driveways along corridors are shown in Table E-5, and those that influence motor vehicle crash severity at commercial driveways in the vicinity of interchanges are shown in Table E-6.

Table E-4. Crash Severity at Commercial Driveways along Corridors

Crash Variable	Significant Categorical Value (Severity Level)*	Quantitative Influence (on Specific Severity Level)	Note
Type of Shoulder	Unpaved Shoulder (MI)	+16.4% (MI)	Vehicular traffic near interchanges is often relatively high speed and turning at driveways may lead to hitting or running over the curb, causing minor injury collisions.
	Curb (MI, SI)	+33.6% (MI) +79.3% (SI)	
Weather Condition	Cloudy (MI)	+12.1% (MI)	Drivers may be more cautious and drive at relatively slower speeds in inclement weather, thereby reducing the potential for severe crashes.
	Rain (SI)	−59.3% (SI)	
Lighting Condition	Daylight (SI)	−29.8% (SI)	Daylight or sufficient lighting conditions ensure good visibility and reduce crash severity.

Table E-4, continued

Crash Variable	Significant Categorical Value (Severity Level)*	Quantitative Influence (on Specific Severity Level)	Note
Speed Limit on Connecting Street	35 mph or Lower (MI, SI)	−27.5% (MI) −69.9% (SI)	Lower speed limits create less kinetic energy upon collision thereby reducing impact on the body.
	40-45 mph (MI, SI)	−18.1% (MI) −43.6% (SI)	
Right-turn Lane Type	Shared/Continuous Right-Turn Lane (SI)	−35.3% (SI)	Drivers tend to travel at lower speeds on shared right-turn lanes while attempting to locate their target driveway.
Driveway Design Feature	Flush Radial (MI)	+20.5% (MI)	Flush radial design is generally used to allow efficient (higher-speed) turning movements. Curb flare design generally indicates lower driveway traffic and curb delineation at driveway sites forces drivers to slow down.
	Curb Flare (MI, SI)	−15.6% (MI) −43.0% (SI)	
Driveway Traffic Operations	Full Traffic Movements (MI)	+17.3% (MI)	Full traffic movement driveways increase the potential risk of minor injuries. Left-in/left-out only driveways have fewer potential conflicts than full movement driveways.
	Left-in/Left-out (MI)	−34.5% (MI)	
Driveway Channelization	With Channelization (SI)	−19.8% (SI)	This result verifies the protective effects of driveway channelization by separating opposing traffic flows and preventing encroachment.
Bike Lane Type	No Exclusive Bike Lane (MI)	−23.6% (MI)	A conventional bike lane reduces minor injury crashes, but absence of a bike lane also has this effect, perhaps due to sidewalk use. Severe injury crashes are not reduced as vehicles in the adjacent through lane may still easily encroach into the bike lane and a conventional bike lane across a driveway entrance may also increase rear-end or angle-collision risk, thereby inducing more injuries.
	Conventional Bike Lane (MI)	−20.6% (MI)	
Driveway Throat Length	Short Driveway Throat Length (MI, SI)	+4.7% (MI) +60.5% (SI)	This result verifies the safety importance of sufficient driveway throat length.
Median Opening Type	No Opening (SI)	−44.5% (SI)	No openings in the physical median prevent left-turn movements, thereby significantly reducing the potential for severe injuries.
Connecting Street AADT at the Crash Year	60,000<AADT≤70,000 (MI)	+17.0% (MI)	Only this AADT categorical value was statistically significant in explaining crash severity outcomes.

* Variable that is significant in explaining the potential of the specific injury severity level listed in the parenthesis.
** Percentage value of influence in increasing (+) or decreasing (−) the risk of specific crash severity level in the parenthesis.

Table E-5. Pedestrian/Bicycle Crash Severity at Commercial Driveways along Corridors

Crash Variable	Significant Categorical Value (Severity Level) *	Quantitative Influence (on Specific Severity Level)**	Note
Type of Shoulder	Paved Shoulder (MI, SI)	−2.0% (MI) −37.6% (SI)	Paved shoulders should be considered near commercial driveways in areas with high pedestrian/bicycle activity.
Alcohol or Drug Involvement	Alcohol or Drug Involved (SI)	+208.95% (SI)	Although not specific to access management, this verifies the serious adverse impact of substance use on traffic safety.
Driveway Number of Lanes	Two Lanes (MI, SI)	−1.4% (MI) +162.2% (SI)	Multiple driveway lanes suggest more complex traffic conditions, relatively higher vehicle speeds, and more pedestrian/bicycle exposure, therefore producing severe injury outcomes.
	Four Lanes or More OR Wide-open Access (SI)	+231.5% (SI)	
Bike Lane Type	No Bike Lane (MI)	−8.8% (MI)	If no bike lane is available, bicyclists likely will travel on the sidewalk where they are less exposed to mainstream traffic. Where bicyclists travel next to the travel lane when no bike lane is available, they are more likely to incur severe injuries or fatalities in a crash, due to increased exposure to traffic.
Driveway Throat Length	Short Driveway Throat Length (SI)	+46.4% (SI)	Sufficient driveway throat length at commercial driveways is important to pedestrian and bicycle safety along corridors.
Connecting Street AADT at Crash Year	50,000<AADT≤60,000 (MI)	+15.5% (MI)	Only this AADT categorical value was statistically significant in explaining crash severity outcomes.

* Variable that is significant in explaining the potential of specific injury severity level listed in the parenthesis.
** Percentage value of influence in increasing (+) or decreasing (−) the risk of specific crash severity level in the parenthesis.

Table E-6. Motor Vehicle Crash Severity at Commercial Driveways near Interchanges

Crash Variable	Significant Categorical Value (Severity Level Explained)*	Quantitative Influence (on Specific Severity Level)**	Note
Alcohol or Drug Involvement	Alcohol or Drug Involved (MI)	+170.9% (MI)	This verifies the serious adverse impact of substance use on traffic safety.
Lighting Condition	Dawn/Dusk (MI)	+74.6% (MI)	Sufficient lighting ensures good visibility and improves traffic safety, while dawn and dusk are often associated with fatigue or drowsiness.
Speed Limit on Connecting Street	50 mph or Higher (MI)	+101.3% (MI)	Speed limit is an indicator of traffic operating speed; higher speed limits suggest a greater impact upon vehicle collision.
Driveway Number of Lanes	One Lane (SI)	+180.6% (SI)	It is more difficult for drivers to identify one-lane driveways due to their narrow width, and sudden maneuvers upon entry (or potential for lack of compliance on site) may increase severe injury crashes. Warning or guidance signs may be needed.
Bike Lane Type	Conventional Bike Lane (MI)	+24.3% (MI)	Conventional bike lanes do not provide a physical barrier or buffer to sufficiently reduce exposure to nearby traffic, and therefore increase the injury risk to bicyclists.
Distance From Taper End to Unsignalized or Signalized IDriveway	(0, 500 ft) (SI)	+261.0% (SI)	It is important to avoid commercial driveways in the interchange influence area due to the potential for conflicts with interchange traffic and insufficient distances for vehicles to slow down before diverging from or merging with through traffic.

* Variable that is significant in explaining the potential of specific injury severity level listed in the parenthesis.

** Percentage value of influence in increasing (+) or decreasing (−) the risk of specific crash severity level in the parenthesis.

Case Study Findings

Safety issues were observed with allowing commercial driveway access in the functional area of roadway intersections, despite the use of mitigating techniques such as nontraversable medians and directional median openings. For example:

- Lengthy queues at signalized intersections disrupted driveway operations and reduced visibility of vehicles crossing through lanes to enter and exit these connections where a median opening was present.
- Queueing vehicles were observed to be allowing driveway traffic to cross through lanes at median openings or near signalized intersections, resulting in crashes in one of the through lanes, sometimes involving more than one vehicle, as vehicles proceed into or out of the driveway.

Aligning higher volume commercial driveways at full median openings was observed to result in a variety of conflicts and crashes. For example:

- The location of the median opening in relation to the shopping center driveways in the Largo case study resulted in numerous conflicts between through moving vehicles and those attempting to enter or exit the driveways from/to the full median opening. Among these is the potential for head-on collisions when multiple vehicles are attempting to exit the adjacent driveways and maneuver into the median opening simultaneously. In addition, the number of potential movements and conflicts contributed to bicycle/pedestrian crashes at this location as pedestrians or bicyclists attempted to cross these driveways.

Drivers looking left at oncoming traffic while attempting to exit commercial driveways do not notice bicyclists crossing the driveway, resulting in bicycle-involved crashes. Additional educational measures and signage could help to mitigate this issue as would painted bike lanes and other measures to make it more apparent that bicyclists may be present.

Closely-spaced commercial driveways that experience similar peak periods require special attention to ensure that adequate space is provided on-site for circulation and queueing. It is important to avoid approval of driveways near an intersection where a commercial drive-through establishment creates a potential for long queues that may spill back onto roadways and create safety issues. Where such driveways are placed near signalized intersections, additional measures are needed to ensure that interparcel cross access is provided to increase corner clearance and/or allow left-turn access at the signal.

- In the Tallahassee case example, the short spacing distances between the driveways, the volumes associated with the land uses, and their proximity to a signalized roadway intersection resulted in multiple conflicts and crashes.
- Lengthy queues at the coffee shop interfered with through traffic movement and disrupted nearby driveway operations, even as conflicts and crashes were observed between through vehicles and those exiting the fast-food restaurant, attempting to access the left turn lane at the nearby intersection.

Commercial driveway access near interchange ramps creates clear safety issues. For example,

- As shown in the West Hallandale Beach Boulevard example, rear-end collisions are a common safety problem at these locations. Vehicles exiting these driveways may suddenly stop to yield to through traffic or to traffic accessing the entrance ramp for the express lane. In some instances, drivers back up to remove themselves from the roadway and back into the vehicle behind them.
- The Scenic Highway at I-10 interchange case study illustrates the safety impacts of closely-spaced access points in proximity to interchange ramps. The combination of left-turn conflicts and crashes prior to the median installation, as well as the tendency for queueing vehicles waiting to access the interchange to obscure visibility while "good Samaritans" also allowed vehicles exiting right out of the commercial plaza driveway to enter the left-turn lanes for the interchange ramp resulted in numerous crashes. The median installation clearly mitigated many, but not all, of these safety issues.

Additional discussion of study findings and limitations, and recommended considerations in policy and practice are provided in Sections 7.2-7.4.

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1. Introduction

An important objective of access management is to limit traffic conflicts that could result in vehicular, bicycle, and pedestrian crashes. Commercial driveways and side streets connecting to major roadways are a key source of these conflicts. While medians can reduce left-turn conflicts from driveway traffic, separating conflict areas through improved access spacing reduces the exposure of all system users to traffic conflicts. In the areas surrounding highway interchanges, commercial driveways also pose unique safety challenges. The combination of high traffic volumes, unfamiliar drivers, and turning and weaving movements in interchange areas can lead to numerous conflicts and safety problems when commercial driveways on the crossroads are not carefully managed.

Despite the safety issues associated with driveways, relatively few studies have explored the issue. Even fewer have examined how driveway type and location may influence crash frequency and severity. This comprehensive study was undertaken to advance the body of knowledge on this topic. It examines how commercial driveway access location and design interact with roadway and interchange characteristics to influence vehicular, bicycle, and pedestrian safety. The findings are translated into guidance for transportation agencies responsible for access management.

2. Literature Review

For insight into analysis methods and findings related to driveway safety, an extensive literature review was conducted as a foundation for the study. Table 1 describes the methods and findings from a cross-section of the driveway and interchange area safety studies reviewed in this report. The following sections review selected findings related to access density, driveway type and volume, driveway location (corner clearance), interchange functional area, medians and left-turn restrictions, driveway and intersection offsets, and driveway design.

Table 1. Summary of Driveway Safety Study Methods and Findings

Author(s)	Study Background	Analysis Methods	Findings
Amjadi, 2018	Investigated safety effects of limited corner clearance on the mainline at four-leg, signalized intersections in the State of California and the City of Charlotte, North Carolina.	Ratio of average crash frequency for sites with and without mainline driveways within 50 ft of intersection. Multiple variable regression to develop statistical relationships between variables. Generalized linear modeling techniques to develop crash prediction models. Specified a log-linear relationship using a negative binomial error structure. Economic analysis was performed using B/C ratios.	Limited clearance on receiving corners (i.e., driveway(s) within 50 ft of the signalized intersection) was associated with increases for all crash types. For approach corners with limited corner clearance (i.e., driveways within 50 ft of one or both approach corners), statistically significant decreases in total, fatal and injury, and rear-end crashes compared to no driveways within 50 ft of both approach corners.
Avelar et al., 2013	Developed alternative safety performance functions to evaluate safety impacts of various driveway configurations on rural and urban arterial highways in Oregon.	Negative binomial regression models to develop SPFs that evaluate safety impacts of various driveway configurations on urban and rural arterials.	Industrial and commercial driveways are more strongly associated with crash occurrence than other types of driveways. For a given number of driveways, more crashes are expected when driveways are isolated and fewer crashes when they are clustered.
Chen et al., 2018	Investigated the relationship between access density and crash rate on major arterials in New Mexico.	A K-mean cluster analysis to classify road segments into different groups. A negative binomial regression model to identify significant factors contributing to driveway-related crashes.	Access density, public access ratio, and commercial access ratio have the most significant impact on crash rate. The number of access points on arterial segments should be limited or reduced where existing access density is greater than 29 pts=km (47 pts=mi).

Table 1, continued

Author(s)	Study Background	Analysis Methods	Findings
Dixon et al., 2022	Assessed access management techniques for crossroads in the vicinity of interchanges, including diamond, single-point urban interchange (SPUI), partial cloverleaf (PARCLO), diverging diamond interchange (DDI), and roundabout terminal treatments in multiple states.	Micro-simulation models were developed using VISSIM to assess the operational performance of crossroads in the vicinity of interchanges. Statistical analysis using ANCOVA was used to analyze the relationship between speed and site-specific variables at each interchange configuration.	Pedestrian and bicycle crashes frequently occurred at driveways located between the terminal intersection and the next signalized intersection away from the interchange The first access point near the terminal intersection most significantly influenced safety
Eisele & Frawley, 2005	Investigated the operational and safety impact of raised medians and driveway consolidation on arterial roadways in Texas and Oklahoma	Compared crash data and traffic volumes for study corridors before and after the installation of access management techniques. Included corridors with and without raised medians and varying access point densities. Micro-simulation with VISSIM was used for operational analysis.	Consolidating driveways reduces the number of conflict points along the corridor. However, even when the number of driveways increases, the installation of a raised median still results in a decrease in the number of conflict points.
Flintsch et al., 2020	Studied the implications of both access spacing and access volume on crash risk on 8 corridors in Virginia.	New Linear Referencing System to enable correlations between databases. Satellite imagery and ITE trip Generation Manual used to estimate access volume. Poisson and negative binomial (NB) mixed regression models to evaluate effects of access spacing and volume on crash risk.	Both spacing and access volume significantly impact crash risk at or near access points. Access volume is positively associated with crash risk upstream and downstream from access points. Crash rates increased by 4% to 10% for every 457 per day increase in driveway volume. Access spacing was negatively associated with crash risk (4%–7% decrease in crash rate for every 100-foot increase in spacing).

Table 1, continued

Author(s)	Study Background	Analysis Methods	Findings
Gorthy, 2017	Compared safety impacts of full access driveways and right-in, right-out driveways with and without a physical median. Focused specifically on commercial driveways on major corridors in South Carolina	A negative binomial regression model was used to identify roadway and driveway characteristics that contribute to driveway-related crashes.	RIRO driveways produce much lower crash rates than full-access driveways. Crash rates for RIRO driveways without a restrictive median are higher than isolated RIRO driveways with these treatments. Bollards improved compliance without negatively affecting business patronage.
Kwigizile et al., 2014	Investigated the impact of corner clearance and other variables on the number of crashes occurring at signalized urban intersections in Las Vegas and North Las Vegas.	Compared Poisson model, Negative Binomial model, Zero-Inflated Poisson model, and Zero-Inflated Negative Binomial model. The Zero-Inflated Negative Binomial model was selected as the most appropriate to model crash counts for this study.	Corner clearance design has a significant impact on safety when compared to other geometric features. Increased length of corner clearance decreases crash frequency. Factors increasing crash frequency were commercial land use, traffic volume on minor street close to major street volume, higher traffic on minor approach, increase in left-turn and through lanes, and number of corner driveways.
Minh et al., 2014	Evaluated the safety performance of minimum driveway spacing policies of 13 states, including Florida, and the correlation between the safety performance of driveway spacing policies and adjacent roadway variables.	Used micro-simulation (VISSIM) to establish vehicle trajectories under different conditions and driveway spacings. Used SSAM to evaluate conflicts based on the trajectories to investigate the safety performance of different driveway spacing policies.	Posted speed limit and traffic volume are the primary impact factors for driveway safety. Significant safety differences were found across the different driveway spacing policies.
Torbic et al., 2021	Compared the safety performance functions (SPFs) of crossroad ramp terminals for single-point diamond interchanges and tight diamond interchanges in various states.	Negative binomial regression models were used to develop safety performance functions (SPFs) for crossroad ramp terminals of single-point diamond interchanges and tight diamond interchanges. The SPFs were used to predict the average crash frequency at these locations.	As ramp and crossroad AADT increase, crash frequency increases. Under high volume conditions, the single-point diamond interchange crossroad ramp terminal models show higher PDO crash frequency than respective tight diamond interchange models.

Table 1, continued

Author(s)	Study Background	Analysis Methods	Findings
Williamson & Zhou, 2014	Developed method to assess impact of commercial with drive-thru, commercial, industrial-institutional, and residential driveways on four-lane urban arterials with TWLTLs. in Illinois.	Statistical analysis using ANOVA and the paired t-test were used to analyze the effects of various driveway types and density on roadway safety.	Drive-thru driveways had largest impact on roadway safety, residential driveways had the least safety impact. Developed equivalence factors for improved measurement of safety impacts of driveway density on urban 5 lane arterials
Williamson, Zhou, & Fries, 2018	Quantified safety impact of driveway types on urban & suburban roadways in 18 Illinois cities on 2-lane undivided, 2-lane TWLTL, 4-lane undivided, and 4-lane TWLTL roads for commercial, commercial with drive-through, industrial-institutional, and residential driveways.	Regression modeling using the Poisson distribution to produce SPFs that predict the expected number of crashes by severity for four roadway types common in urban areas. Used the SPFs to develop CMFs for urban areas including the crash types of angle, turning, sideswipe, pedestrian/bicycle, fixed object, and rear-end.	Developed 39 crash prediction models for three minor driveway types on four different types of roadways, as well as 162 crash modification factors. Two additional models predicted safety impacts of commercial drive-throughs.
Xu et al., 2013	Evaluated relationship between number of driveways and adjacent land uses, median types, and median openings to determine impacts on safety on divided arterials in Las Vegas region.	Simultaneous equation models with a panel data structure for mid-block segments. Random coefficient simultaneous equation models were proposed to address heterogeneity issues.	Significant factors influencing crash rates on mid-block segments were length of segments, driveway density, and median opening density. Commercial land use type also influenced midblock segment safety.

2.1 Driveway Density and Spacing

Studies of roadway safety have long documented the effects of access density on the safety performance of roadways (Williams et al., 2014). These studies demonstrate a clear relationship between crashes and driveway density on major roadways and indicate that both crash rates and crash probability increase as access (driveway and median opening) density increases (Gluck et al., 1990, Eisele and Frawley, 2005, Schultz et al. 2006, Chen et al., 2018; Xu et al., 2013). In the largest national study to date, Gluck et al., (1999) provided relative crash rates for unsignalized access densities (Table 2), although the specific relationship varies due to differences in road geometry (lane width, presence or absence of turn lanes and medians), operating speeds, and driveway and intersection traffic volumes.

Table 2. Relative Crash Rates for Unsignalized Access Spacing

Unsignalized Access Points Per Mile[a]	Average Spacing[b] (feet)	Relative Crash Rate
10	1056	1.0
20	528	1.4
30	352	1.8
40	264	2.1
50	211	2.4
60	176	3.0
70	151	3.5

[a] Total access connections on both sides of the roadway
[b] Average spacing between access connections on the same side of the roadway

Source: Gluck et al.,1999

Several factors contribute to the causal relationship between driveway density and crashes. As explained by Avelar et al. (2013):

> Driveway-related crashes are typically the result of conflicts between vehicles, either because of conflicting turning movements at the access point or speed differentials and queued vehicles upstream of the access point. These conflict points exist regardless of driveway density, but when the spacing between driveways is very short, the conflict areas of the two driveways may interact with one another.

Flintsch et al., (2020) evaluated access volume in relation to spacing on eight corridors in Virginia and found a negative association between downstream spacing and crash rate; for every 100-foot increase in downstream spacing, the crash rate decreased by 7% for partial movement access (e.g., right in/out only) and by 5% for full movement access. Upstream spacing was not found to be a significant predictor of crash risk for either type of driveway.

Minh et al., 2014 studied the impact of minimum driveway spacing policies on safety performance using traffic micro-simulation and automated conflict analysis. They found significant differences in the safety impacts of the different driveway spacing policies. Based on these findings, they recommend that traffic volume and speed be used as the primary criteria for minimum driveway spacing. Minh et al. (2014) describe FDOT spacing guidelines as less conservative than other states. Williams et al., (2018) suggested eliminating FDOT Access Class 7 as it allows close driveway spacings that can adversely impact safety, operations, and livability of major roadway corridors.

2.2 Driveway Type and Volume

Unlike access density, findings on the implications of driveway type or volume are more limited. Flintsch et al. (2020) found a significant positive association between access volume and crash risk - on average, crash rates increased by 4% to 10% for every 457 per day increase in driveway volume. In a national study of crash modification factors (CMFs) for access management, VHB et al. (2020) identified few CMFs related to driveway characteristics, with some CMFs at the intersection and site level, but none at the corridor level; safety performance functions (SPFs) were identified for driveway design elements at the site level, but none at the intersection or corridor level and none that account for driveway volumes or median design.

Williamson et al. (2018) analyzed the safety effects of different driveway types on different types of roadways to develop crash prediction models and crash modification factors for 162 possible driveway combinations. A functional area of 250 feet upstream and downstream of each driveway was used to isolate the safety effect of individual driveways by type. Each driveway type (e.g., commercial, industrial, residential) was evaluated based on a " what if " scenario that upgraded or downgraded the driveway to a different type. The results suggest the relative increase or decrease in crashes that can be expected from converting a driveway to another type, as well as converting a roadway to another type (e.g., two-lane undivided, two-lane with a two-way left turn lane (TWLTL), four-lane undivided, and four-lane with TWLTL). Four-lane divided roadways and signalized driveways were not considered.

Several studies identify commercial driveways or land use intensity as a factor in roadway safety. Generally, higher percentages of intensive land use, such as commercial and industrial/institutional, are associated with more crashes (Flintsch et al., 2020;Williamson et al., 2018; Williamson and Zhou, 2014; Avelar et al., 2013; Schultz et al., 2010, Gluck et al., 1999). This is especially true for commercial land use, as commercial driveways tend to generate more traffic than other driveway types (Williamson et al., 2018; Chen et al., 2018). Williamson and Zhou (2014) estimated average crash rates by driveway type, with drive-through establishments having 36% higher average crash rates than other types of commercial driveways (see Table 3). Chen et al., (2018) found that access density, public access ratio, and commercial access ratio had the most significant impact on crash rates. Schultz et al. (2010) also found that arterial corridors with commercial land use tended to have higher crash rates and severity.

Table 3. Average Crash Rates by Driveway Type

Driveway Type	Crash Rate
Drive-thru	4.081
Commercial	2.837
Industrial-institutional	1.563
Residential	0.613

Source: Williamson & Zhou, 2014

2.3 Driveway Corner Clearance

Inadequate separation of commercial driveways from intersections, interchange ramps (see Interchange Functional Area), and other access points has been shown to create unsafe roadway conditions (Dixon et al., 2022; Williams et al., 2014; FHWA, 2010; Gluck et al., 1990). Kwigizile et al. (2014) found that compared to other geometric features, corner clearance design had a significant impact on safety – increased length of corner clearance decreased crash frequency. Factors that contributed to crash frequency near intersections were commercial land use, traffic volume on the minor street close to that of the major street, higher traffic on the minor approach, increase in number of left-turn lanes and through lanes (with the number of through lanes having the highest impact on the number of crashes) and the number of corner clearances (Kwigizile et al., 2014). Amjadi (2018) found statistically significant (90% level) increases in all crash types on receiving corners with driveways within 50 ft of signalized intersections (see Figure 1); however, approach corners with limited corner clearances appeared to have statistically significant reductions in total, fatal and injury, and rear-end crashes.

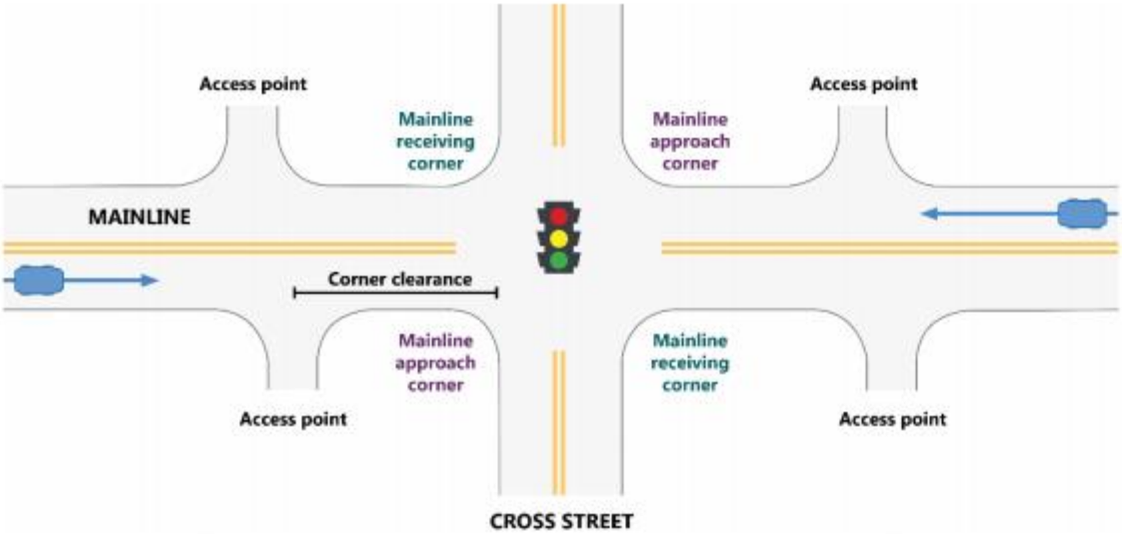


Figure 1. Schematic of corner clearance study sites.

Source: Amjadi, 2015

2.4 Driveway and Intersection Offsets

Improper driveway alignment creates additional safety concerns on undivided roadways or a roadway with a TWLTL (FHWA, 2010; Stover, 2008). When driveways on opposite sides of a roadway are not adequately offset, drivers wishing to access the opposing driveway may attempt a "jog" maneuver, rather than separate left-turn and right-turn maneuvers, as shown in Figure 2 (Stover, 2008). Driveways located within approximately 150 feet of a median opening can also lead to a number of conflicts that can adversely affect safety performance (see Figure 3) (Dixon et al., 2020).

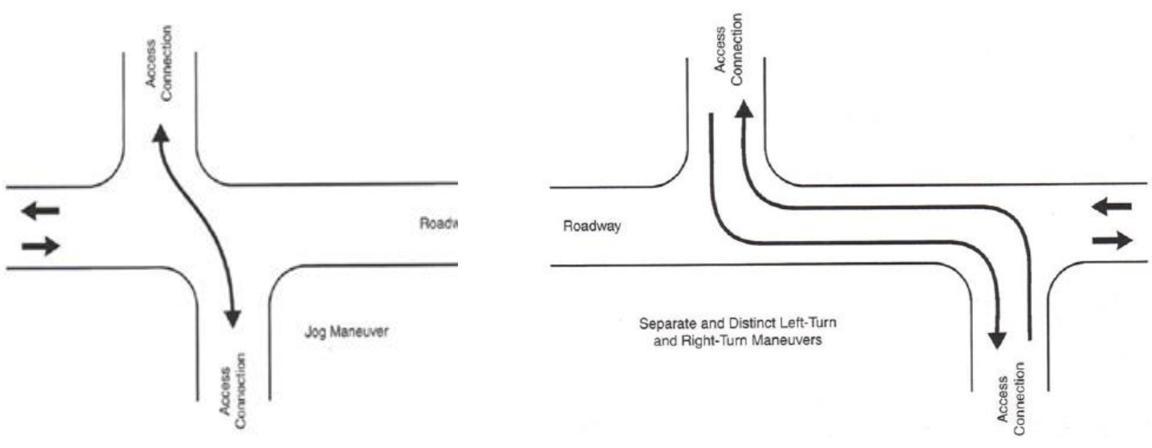


Figure 2. Schematic of a jog maneuver and separate left and right turns.

Source: Stover, 2008

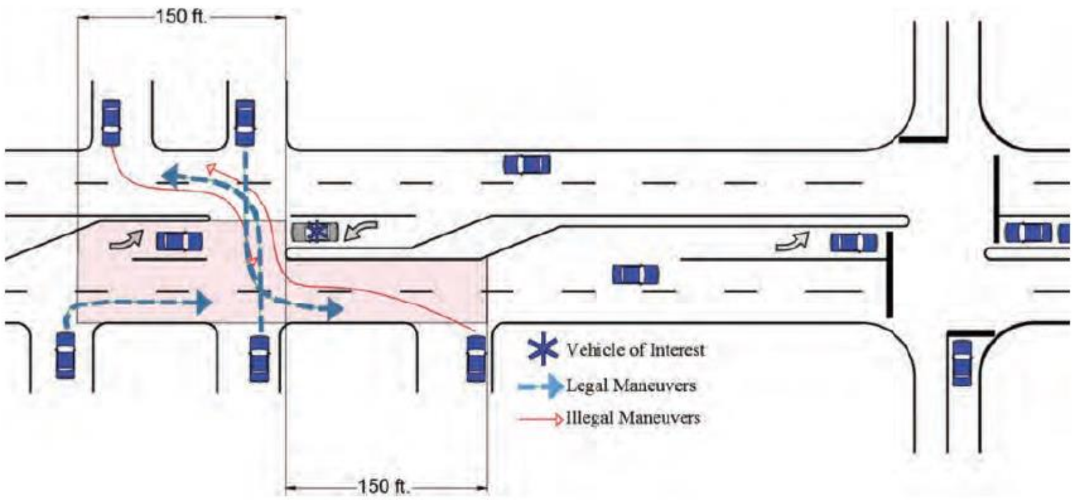


Figure 3. Defining a conflicting driveway.

Source: Dixon et al., 2020

Improper alignment of access points can be resolved as shown Figure 4. Where realignment is not possible, median changes can reduce the number of conflict points as shown in Figure 5.

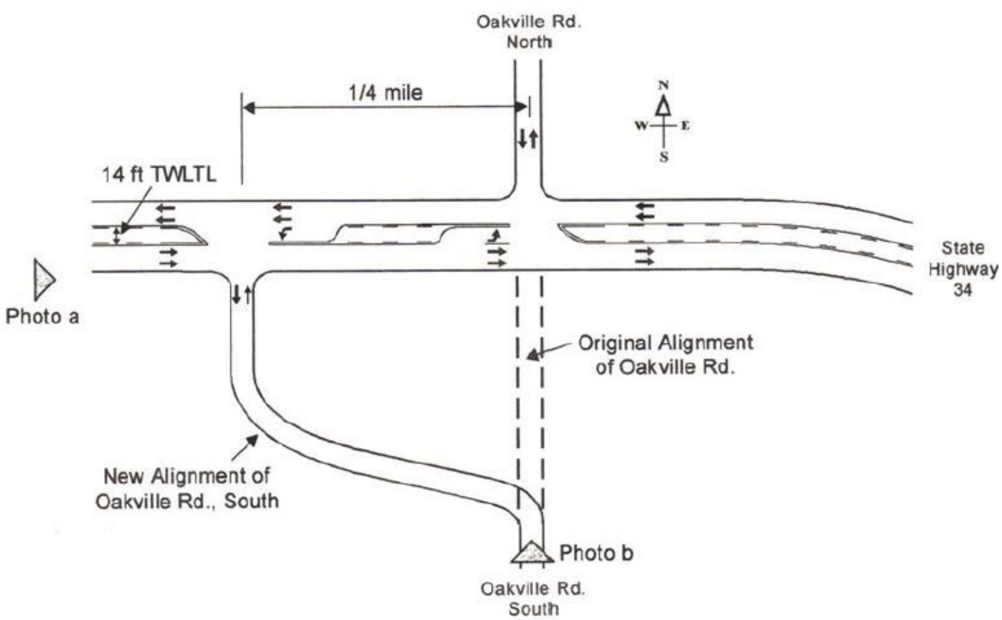
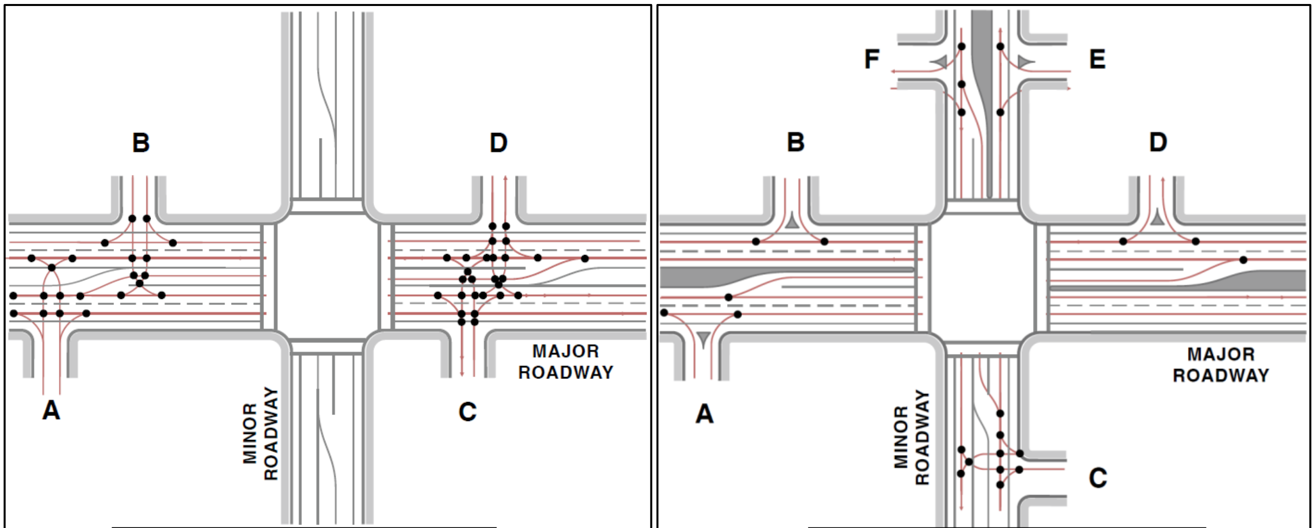


Figure 4. Schematic illustration of relocated minor roadway.

Source: Stover, 2008



Typical Access Scenario

Preferred Access Scenario

Figure 5. Offsets and conflict points before and after the installation of a raised median.

Source: FHWA, 2010

2.5 Driveway Design

Driveway design features shown to affect pedestrian, bicycle and motor vehicle safety are provided in .

Table 4. Driveway throat length, for example, is the distance between the outer edge of the connecting roadway to the first point on the driveway where traffic conflicts can occur (Dixon et al., 2016, p. 137). Inadequate throat length can lead to conflicts at the site entrance that can result in queues backing into the roadway, exposing queued vehicles to crashes and interference with pedestrians and cyclists crossing the driveway. A 25-foot minimum throat length is recommended (i.e., storage for about two cars), with more depending on site, driveway, roadway, and user characteristics. Driveways with wide turning radii may adversely impact bicycle/pedestrian safety by promoting high-speed entry and exit.

Table 4. Driveway Design Considerations That Affect Safety

Design Objectives	Design Issues
Cross section	Number of lanes Lane widths Presence of a median Driveway edges
Horizontal alignment	Connection transition Intersection angle between the roadway and the driveway Driveway alignment Presence of channelizing islands Throat length Length for weaving in multilane driveways
Vertical alignment	Vertical discontinuities Grade change Americans with Disabilities Act (ADA) conformity
One-way operation	Connection point for ingress or egress Separation of ingress and egress movements Right-turn entry into the site and right-turn egress
Other	Stopping sight distance Driveway visibility for motorists, bicyclists, and pedestrians

Adapted from Dixon et al., 2016

2.6 Bicycle and Pedestrian Safety

Where bike lanes and sidewalks traverse a driveway, bicyclist and pedestrian safety depends on visibility, driver expectations, and, for bicyclists, skill level (Williams et al., 2014). A common safety problem at driveways is the tendency for drivers turning right out of a driveway to monitor oncoming traffic on the left without looking for bicyclists and pedestrians to their right. Crashes involving bicyclists and pedestrians become less common when bicyclist and pedestrian travel patterns are consistent with motorists' expectations (National Academies of Sciences, Engineering, and Medicine, 2021). For example, separated bike lanes with a one-way configuration can reduce these conflicts.

Lack of visibility at driveways (Figure 6) and the tendency for vehicles to encroach on sidewalks as they exit driveways (Figure 7) can also create serious hazards for pedestrians and cyclists. A landscaped buffer between the curb and sidewalk can enhance pedestrian visibility for entering and exiting vehicles (Dixon et al., 2009) and provide space for a vehicle turning into the driveway to stop before the sidewalk and safely wait for pedestrian activity without extending into the active travel lane (Gattis et al., 2010). Where sidewalks intersect with a driveway, ADA compliant sidewalk cross-slopes must be integrated with the driveway vertical slope to help define the pedestrian space and improve accessibility.

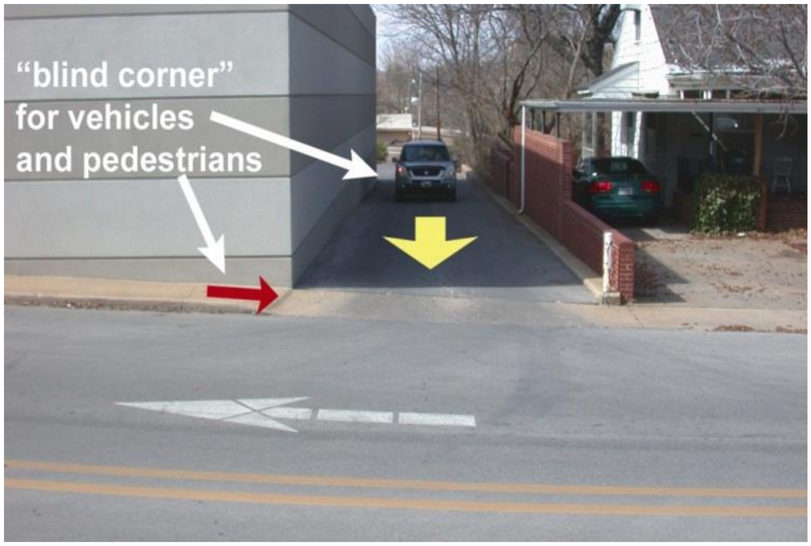


Figure 6. Limited pedestrian sight distance at driveways.

Source: Gattis et al., 2010. (Photo by J. Gattis)

Figure 7. Exiting vehicle encroaching on active sidewalk.

Source: Williams et al., 2014. (Photo by P. Demosthenes)

Separating pedestrian access from vehicular access in site design reduces pedestrian/vehicular conflicts for improved safety (Figure 8). Changes to standard site plans may be proposed during access permitting and development review to achieve this result.

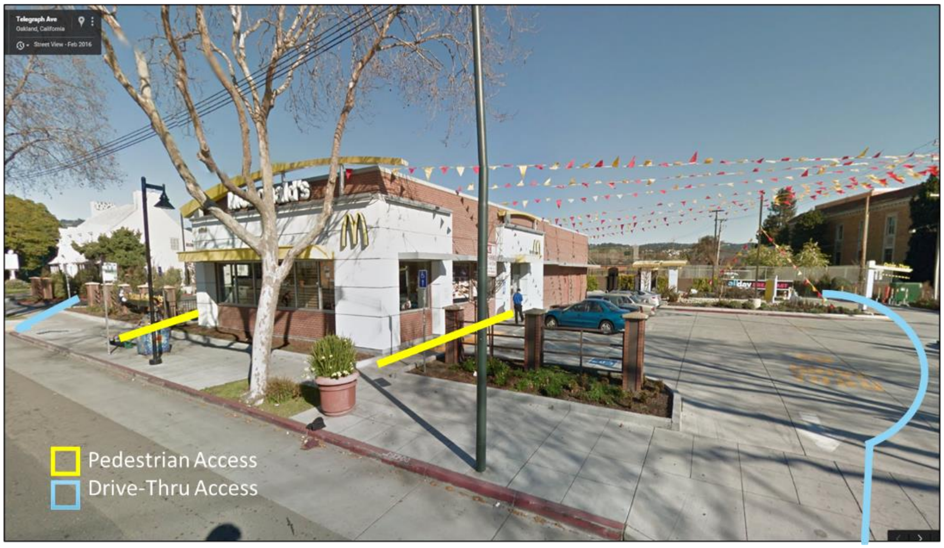


Figure 8. Improving pedestrian safety through separation of driveway and pedestrian access.

Source: FDOT (Google image, Berkeley, CA)

2.7 Medians and Left-turn Restrictions

Techniques that reduce or eliminate left turns into or out of driveways are particularly beneficial to safety as left turns are associated with more serious injury and fatality crashes. The relative percentage of crashes associated with left turns into and out of driveways is shown in Figure 9 (FHWA, 2010). Left-turn restrictions can be accomplished with driveway design techniques, but most effectively with raised medians. Right-in, right-out-only driveways reduce conflicts, but the effectiveness of this driveway type in crash reduction depends on driver compliance or the addition of a raised median (Gorthy, 2017; Butorac et al, 2018).

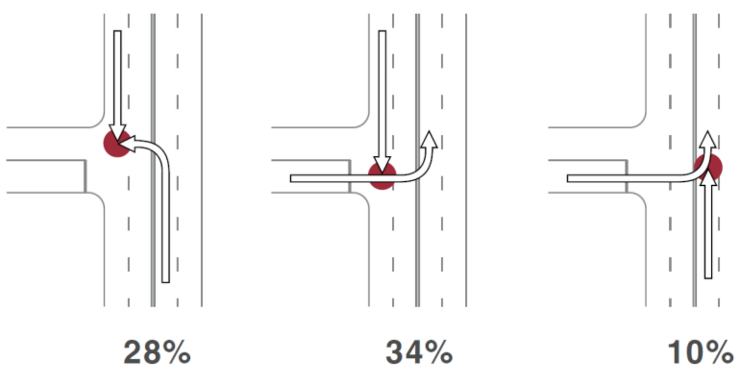


Figure 9. Crash frequencies associated with driveway left-turn movements.

Source: FHWA, 2010

Several studies have found that replacing continuous two-way left-turn lanes (TWLTLs) with nontraversable medians improves overall safety (Alluri et al., 2012; Eisele and Frawley, 2005; Gluck et al., 1999). Eisele and Frawley (2005) found that nontraversable medians improve safety on roadways with high driveway density. Alluri et al., (2012) identified a 30% reduction in total crash rate after median conversion. The safety improvement from nontraversable medians has been attributed to reduced conflict points (see Figure 10), resulting in lower crash rates than undivided roadways or roadways with a TWLTL (Gluck et al., 1999).

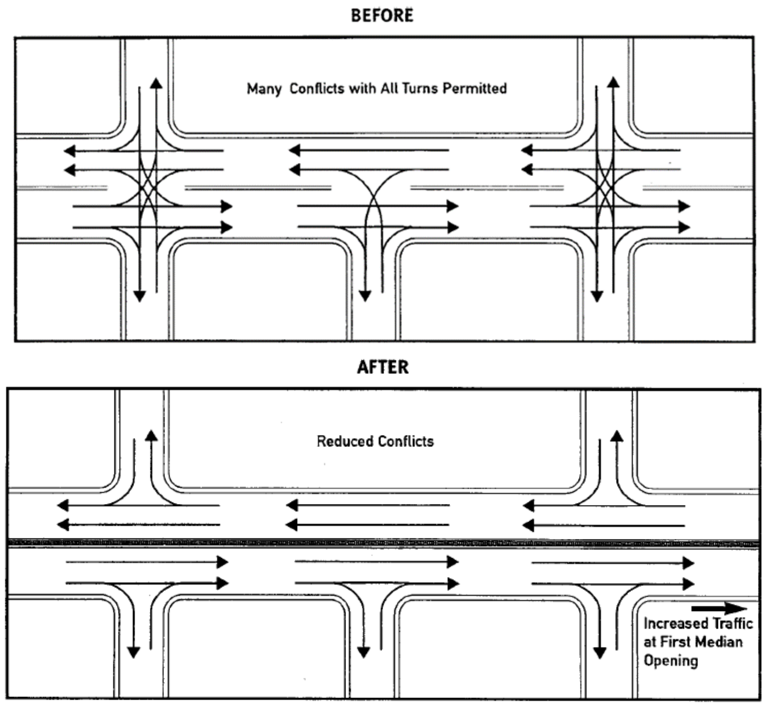


Figure 10. Conflict points before and after the installation of a nontraversable median

Source: Gluck et al., 1999

2.8 Interchange Functional Area

Driveway access in the functional area of highway interchanges has unique safety implications. Areas of particular concern near an interchange terminal are (Williams et al., 2014):

- The first driveway after an interchange off-ramp terminal,
- The first unsignalized crossroad intersection after an interchange off-ramp terminal,
- The first median opening after an interchange off-ramp terminal, and
- The first signalized crossroad intersection after an interchange off-ramp terminal or the closest access drive.

Torbic et al. (2021) compared the SPFs of crossroad ramp terminals for single-point diamond interchanges and tight diamond interchanges. In this study, ramp terminal-related crashes were divided into two categories: crashes occurring on the crossroad within the ramp terminal boundary (100 feet from the curb return of the ramp connection) and crashes occurring on a ramp. For single-point diamond interchanges, free-flow right turns were found to improve safety. For tight diamond interchanges, the average annual daily traffic (AADT) for the crossroads and ramps were found to have the most significant impact on safety.

Dixon et al. (2022) assessed the effects of various factors on several interchange types and their associated crossroad access points. Interchange types in this study included diamond interchanges, single-point urban interchange (SPUI), partial cloverleaf (PARCLO), diverging diamond interchange (DDI), and a roundabout terminal treatment configuration. Figure 11 shows conflict points near the first downstream driveway of an interchange terminal. This schematic illustrates a driveway near a PARCLO located 54 feet from the intersection, the next left turn is approximately 174 feet from the intersection (Dixon et al., 2022). Figure 12 shows conflict points near the first upstream driveway of an interchange terminal. The schematic shows conflicts between the first upstream driveway and queue spillback from either the left through lane, a TWLTL, or turn bay.

Dixon et al. (2022) found that bicycle and pedestrian crashes near interchanges were most common at driveways located between the terminal intersection and the nearest signalized intersection. An example of this type of conflict is shown in Figure 11 and Figure 12. Crashes at crossroad ramp terminals involving bicyclists and pedestrians are more likely to result in fatalities and injuries, rather than property damage only (Torbic et al., 2020).

Overall safety-related findings from this study include the following (Dixon et al., 2022):

- Rear end and angle crashes were the most common crash type identified during this analysis
- Most crashes were possible injury or property damage only
- Pedestrian and bicycle crashes frequently occurred at driveways located between the terminal intersection and the next signalized intersection away from the interchange
- The first access point near the terminal intersection most significantly influenced safety
- Raised medians adjacent to queues that form upstream of a signalized terminal intersection provide added safety benefits
- Intersection traffic control treatments and physical roadway channelization limit erratic maneuvers by drivers intending to turn left at the next intersection

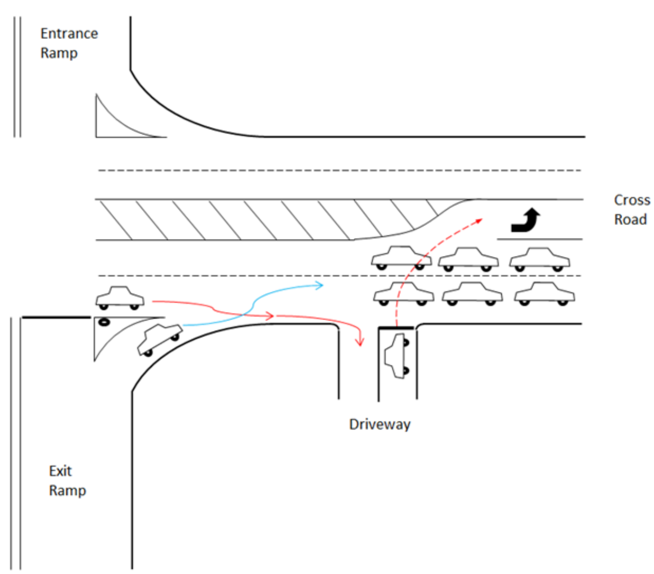


Figure 11. Potential conflicts at the first downstream driveway.

Source: Dixon et al., 2022

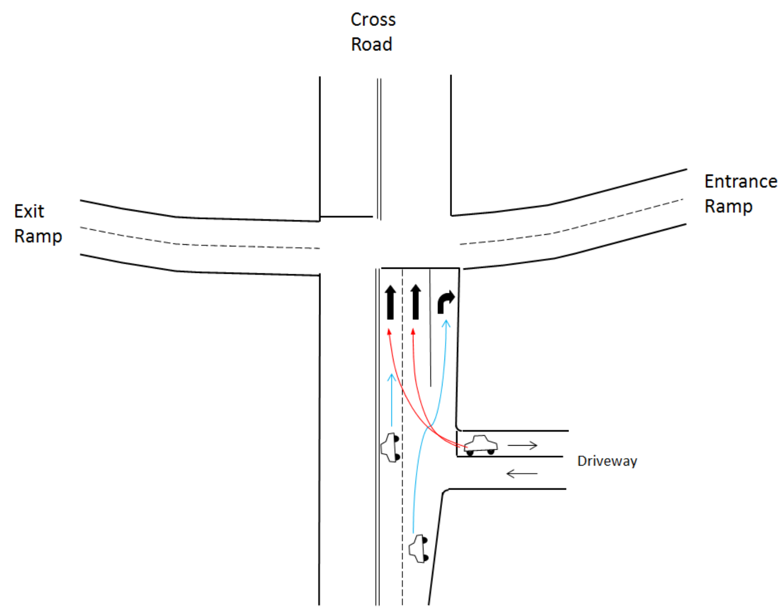


Figure 12. Potential conflicts at the first upstream driveway.

Source: Dixon et al., 2022

Median type also affects the operational function of roadways in the vicinity of interchanges. According to Dixon et al. (2022) roadways with raised medians have higher average travel speeds for vehicles traveling toward the interchange when compared to roadways with a TWLTL.

3. Data Processing and Site Selection

Data collected to screen candidate sites and perform the analysis included:

- 2015-2019 Statewide Driveway Access Related Crash Data-GIS format (Source: FDOT State Safety Office Geographic Information System (SSOGis) Crash Query Tool)
- FDOT Roadway Characteristics Data (Source: FDOT Transportation Data Analytics)
    - Access Classification GIS Data
    - Roadway Functional Class Data
    - Roadway Median Type Data
    - FDOT Context Classification
    - 2015-2019 Traffic Volume Data (AADT)
- Florida Statewide Land Use and Cover GIS Data (Source: Florida Dept of Environmental Protection (FDEP) Geospatial Open Data)
- Interchange type (i.e., diamond, full cloverleaf, partial cloverleaf, partial diamond) (Source: FDOT Open Data Hub)
- Driveway Characteristics Data (manually obtained, process described in Section 3.1, Step 5)
    - Commercial driveways along corridors
    - Commercial driveways near interchanges (0.5 mile or first signalized intersection)

The 2015-2019 driveway-related crash data were extracted through the FDOT State Safety Office GIS (SSOGIS) Query Tool (FDOT, 2021b). According to the FDOT Crash Analysis Reporting User Manual (FDOT, 2009), a crash is considered "driveway access related" if the crash is in a driveway access or is influenced by traffic entering or exiting a driveway access. Driveway characteristics and non-motorist facility data (i.e., presence of sidewalk, crosswalk, pedestrian/bicycle signal, etc.) of the analyzed driveway sites were manually reviewed and recorded by trained student assistants, as described in Section 3. The ArcGIS data layers for roadway characteristics and traffic volumes were downloaded from the FDOT Transportation Data Portal (FDOT, 2021a). Land use data used to identify commercial areas were downloaded from the Florida Department of Environmental Protection Geospatial Open Data Hub. Interchange locations were downloaded from the FDOT Open Data Hub.

Candidate driveway sites for further data collection and analysis were selected through a screening process shown in Figure 13 and discussed in this section. Methods used to select case study sites are discussed in Section 4.3.

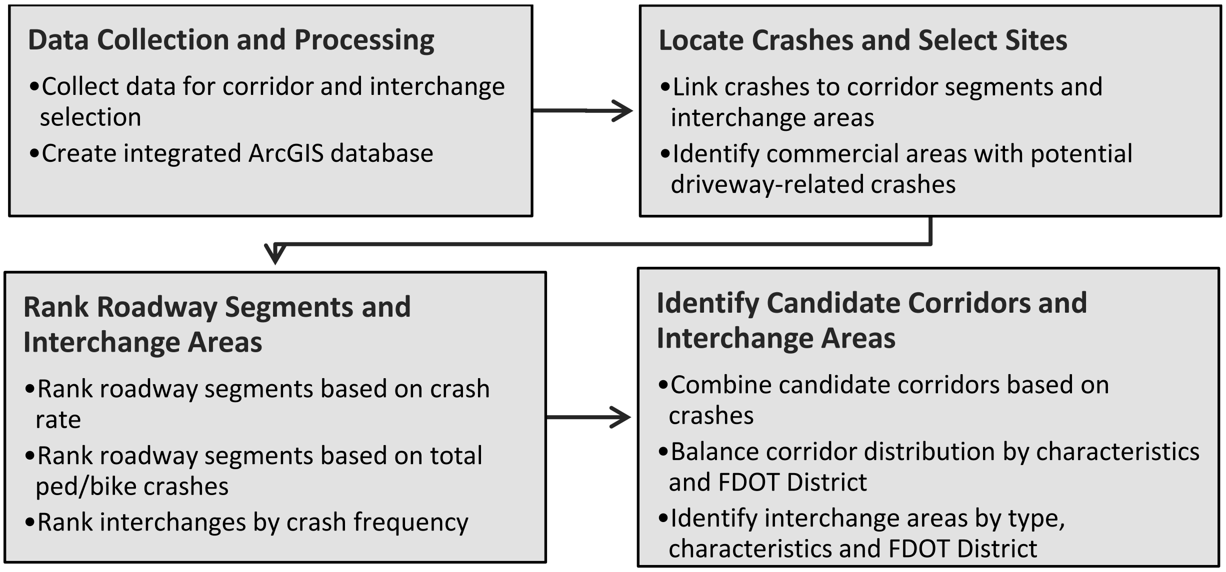


Figure 13. Conceptual process for site screening and identification.

Factors considered in initial corridor and interchange area site selection were:

- High historical vehicular crashes and/or pedestrian/bicycle crashes,
- Existing land use (presence of commercial driveways) and FDOT context classification,
- Roadway functional classification,
- Access classification,
- Median type, and
- Interchange type and driveway location and spacing from ramps.

The aforementioned data was imported into an ArcGIS environment and two integrated databases with the same geocoordinate system were created. The first was dedicated for the corridor, and the second for the interchange analyses. There were 65,583 driveway access related crashes (for all types of driveways, not only commercial driveways) in 2015-2019 statewide. Table 5 shows the breakdown of crash statistics by year and FDOT District. This data provided the initial foundation for the site screening process of commercial driveways located along corridors and in vicinity of interchanges. Figure 14 shows all the data collected and the process for candidate site identification.

Table 5. Driveway Access-related Crash Statistics by Year and FDOT District

FDOT District	2015	%	2016	%	2017	%	2018	%	2019	%
1	1198	8.9	1237	8.0	1403	9.2	1458	10.7	730	9.4
2	1511	11.2	1913	12.4	1381	9.0	1061	7.8	861	11.1
3	1472	10.9	1193	7.7	1339	8.8	1109	8.1	1071	13.8
4	2225	16.5	2919	19.0	2887	18.9	3603	26.4	1712	22.1
5	1939	14.4	2350	15.3	2214	14.5	1411	10.3	1276	16.5
6	2639	19.5	2657	17.3	2567	16.8	3087	22.6	622	8.0
7	2526	18.7	3129	20.3	3483	22.8	1909	14.0	1482	19.1
8	2.0	0.0	3.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0
Total	13,512		15,401		15,276		13,640		7754	

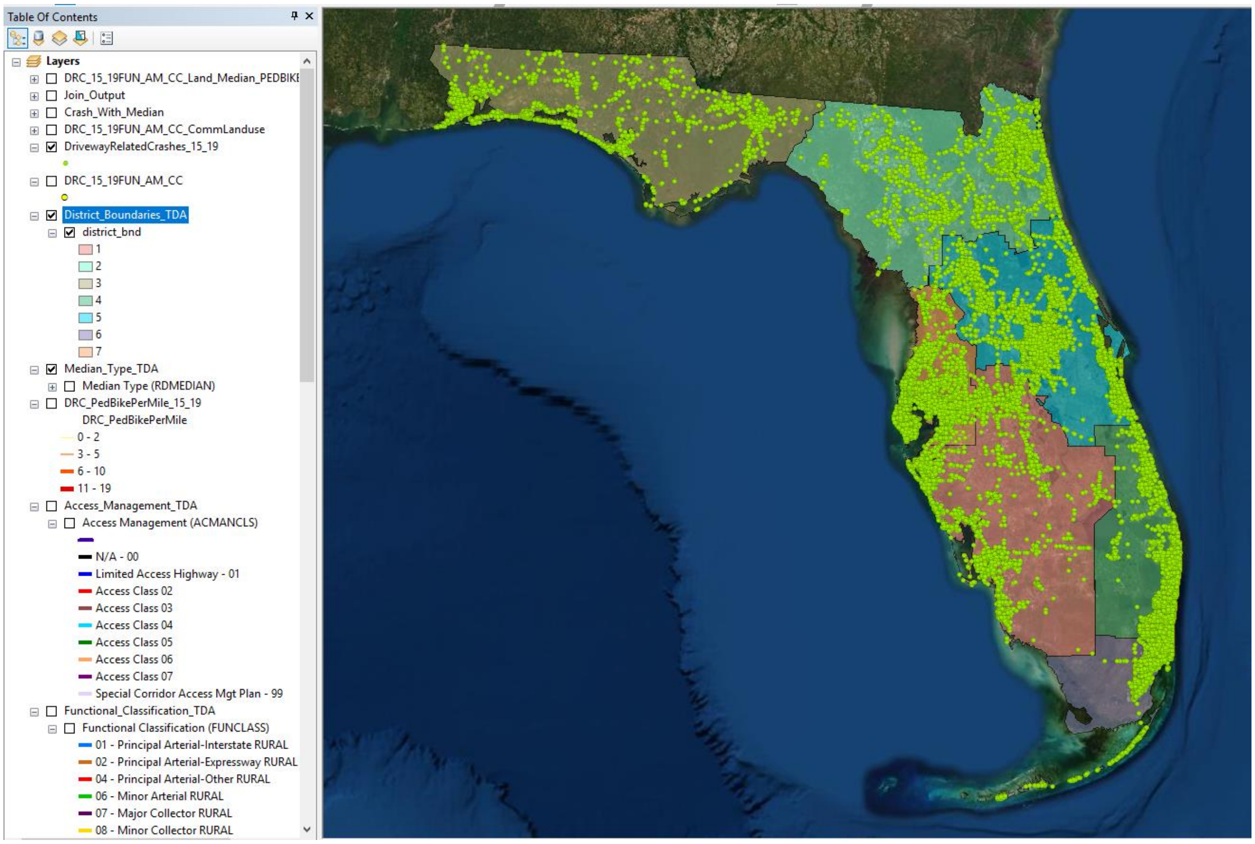


Figure 14. Data integration for candidate commercial driveway site selection.

3.1 Selection of Candidate Corridor and Driveway Sites

For the corridor study, the objective was to identify potential commercial driveway-related crashes, including pedestrian and bicycle crashes, that may be impacted by interaction with traffic entering and exiting the commercial driveways. The selection process for the driveways located along the corridors is explained in the following steps.

Step 1: Map all driveway access-related crashes on eligible roadways.

All the crashes were mapped on the corresponding roadway segments based on the FDOT Roadway ID – a unique eight-character identification number assigned to a roadway or section of a roadway either on or off the State Highway System for which information is maintained in the FDOT Roadway Characteristics Inventory (RCI). The first two characters of the eight-character ID are the county code, the next three are the section code, and the final three are the subsection code. Six functional classes representative of major corridors in Florida were considered for the study: Principal Arterial-Other Rural, Minor Arterial Rural, Major Collector Rural, Principal Arterial-Other Urban, Minor Arterial Urban, and Major Collector Urban. Using these functional classes, a total of 7,711 eligible roadway segments across Florida were selected for further processing (Figure 15). Driveway-related crash records were then linked to these roadway segments based on the eight-digit Roadway ID.

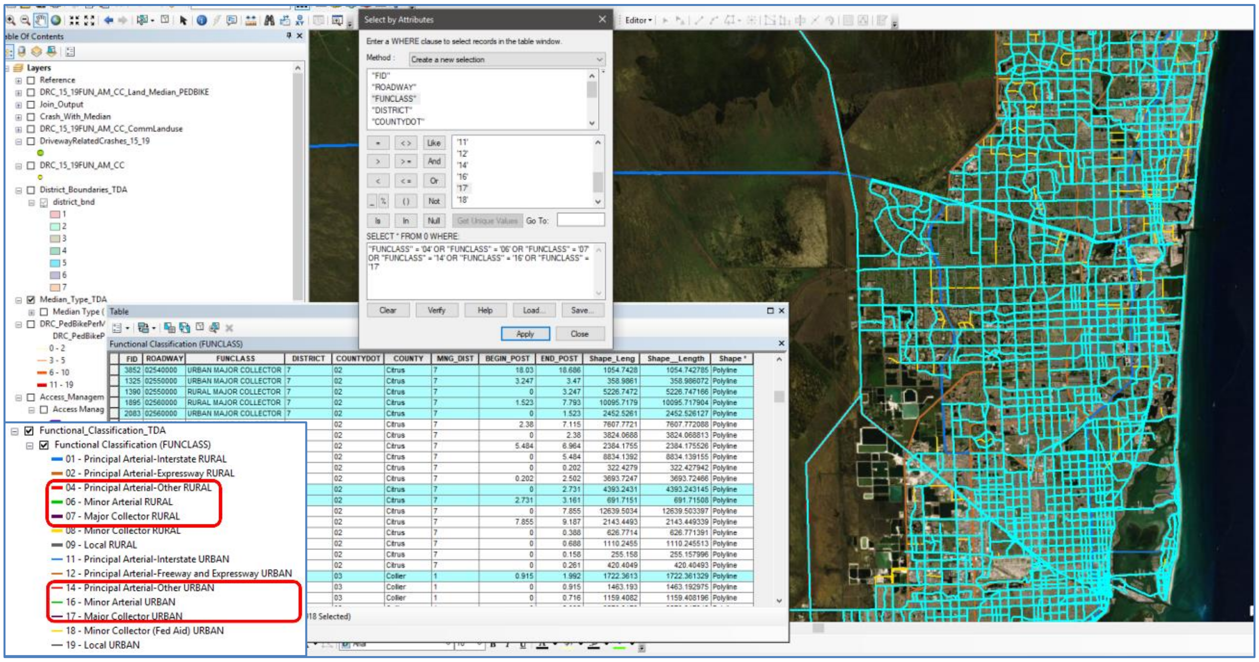


Figure 15. Eligible roadway segments based on functional class.

Step 2: Select crashes within or near commercial land use types.

Next the FDEP GIS land use and cover data were used to select those crashes related to commercial driveways. In the land use GIS data, roadways have a unique "transportation" land use category within their right-of-way and are not considered part of the adjacent land use types. Traffic crashes falling into commercial land use areas, or along the boundary of the commercial land use parcels (Figure 16) were considered crashes related to commercial driveways.

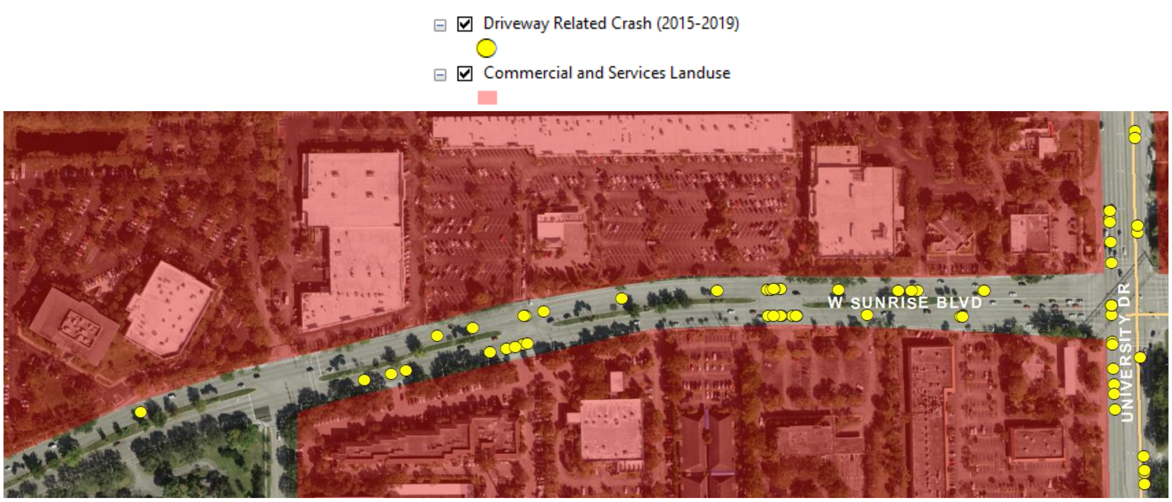


Figure 16. Commercial driveway access-related crash selection based on land use data.

Step 3: Rank all eligible roadway segments based on the 5-year driveway access crash rate.

A provisional crash rate measurement, defined as the number of commercial driveway-related crashes per mile over 2015-2019, was calculated for each eligible roadway segment based on Equation (1).

$$Crash\ Rate = \frac{No.\ of\ Crashes\ in\ 5\text{-}years}{Road\ Segment\ Length\ (in\ miles)} \quad (1)$$

This crash rate measurement was used to rank all eligible corridors and identify corridors with a high number of commercial driveway-related crashes. The provisional crash rate measurement was used rather than the total number of crashes to normalize the comparison of roadway segments of varying lengths and crash frequencies. The roadway segments were then ranked based on the calculated crash rate and color coded in ArcGIS as shown in Figure 17. Finally, using 10 crashes/mile as a threshold, a total of 174 roadway segments were selected for further analysis.

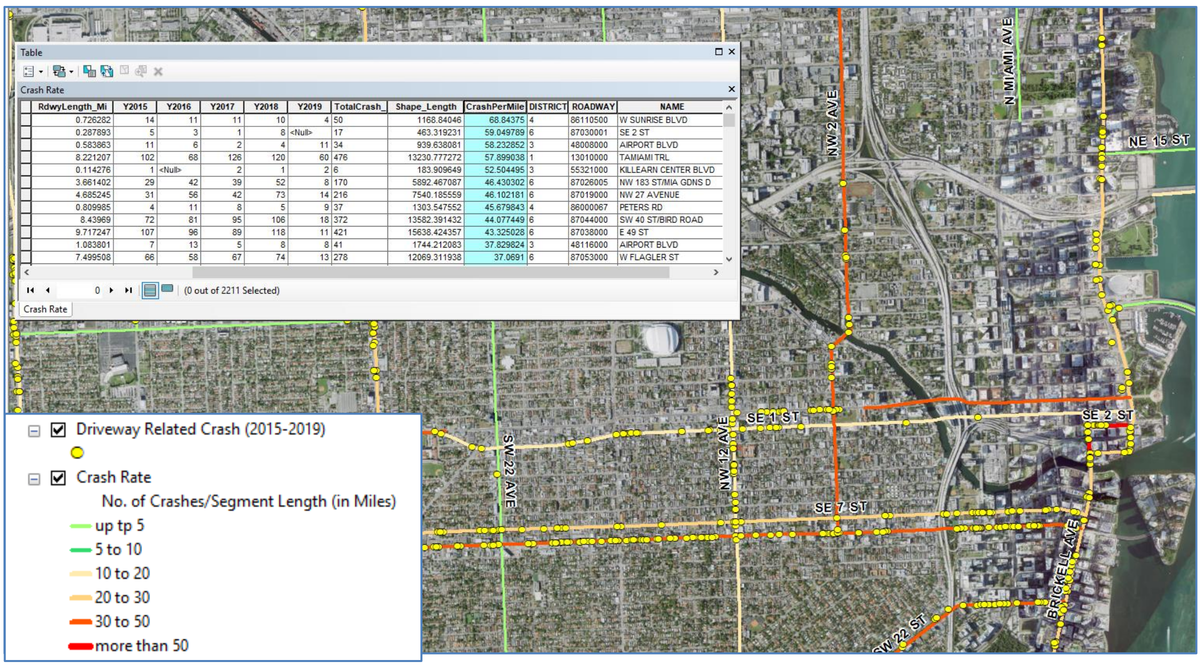


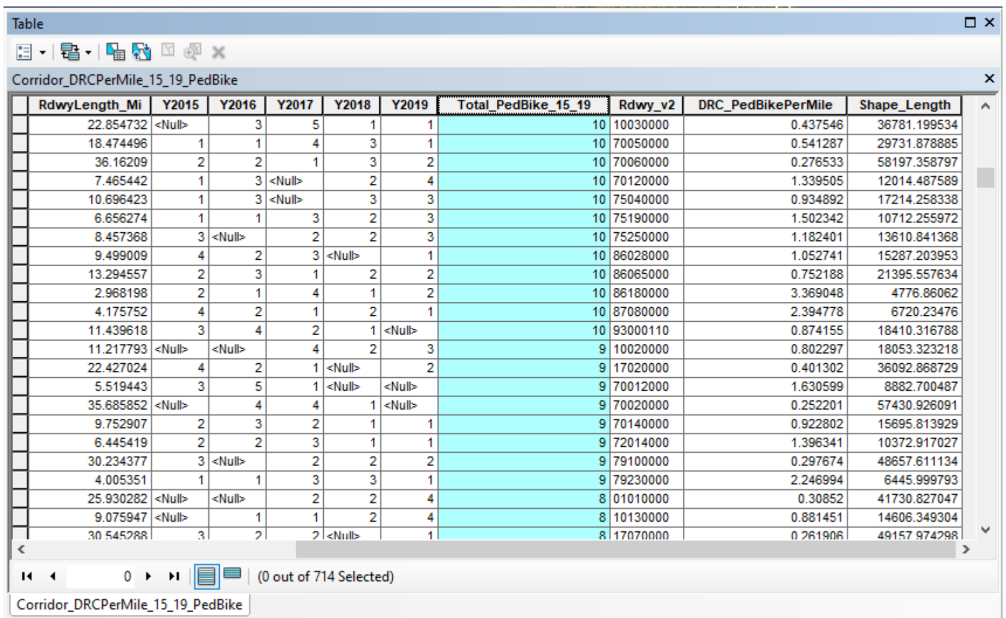
Figure 17. Roadway segment ranking and color coding based on crash rate.

Step 4: Rank roadway segments based on pedestrian/bicycle involved commercial driveway crashes.

In the previous steps, candidate corridors were selected based on the total number of commercial driveway-related crashes. For insight into the impact of driveway type and location on bicycle and pedestrian safety, the eligible roadway segments were also ranked based on pedestrian- or bicycle-involved driveway-related crashes. However, the dataset for pedestrian and bicycle crashes was less complete than that for vehicular crashes, as indicated by the “Null” value shown in Figure 18. Due to the limited numbers, the total number of bicycle and pedestrian crashes was used to rank these segments rather than the provisional crash rate.

Figure 19 shows the roadway segment ranking and color coding based on the total number of pedestrian/bicycle driveway-related crashes in 2015-2019. Corridors with 15 or more pedestrian/bicycle driveway-related crashes over the five-year period were selected, and roadway segments with “Null” values in any of the five years were removed. This resulted in the selection of 60 roadway segments. These 60 segments were compared with the 174 candidate segments selected in Step 3, and 18 previously not selected were added to the candidate corridor list.

The final sample included a total of 192 roadway segments across seven FDOT Districts, as shown in Appendix A. A roadway segment with a given eight-digit Roadway ID may be associated with more than one functional class or access class value due to changes in geometrics, land use density, travel needs, and other considerations. Therefore, smaller segments, together with Roadway ID, were used in the ranking procedure to calculate the total number of crashes, roadway length, and total crash rate. The final corridor sample represented those with the highest commercial driveway access-related crash rates for different functional classifications, access classes, median types, and regions of Florida.



Table

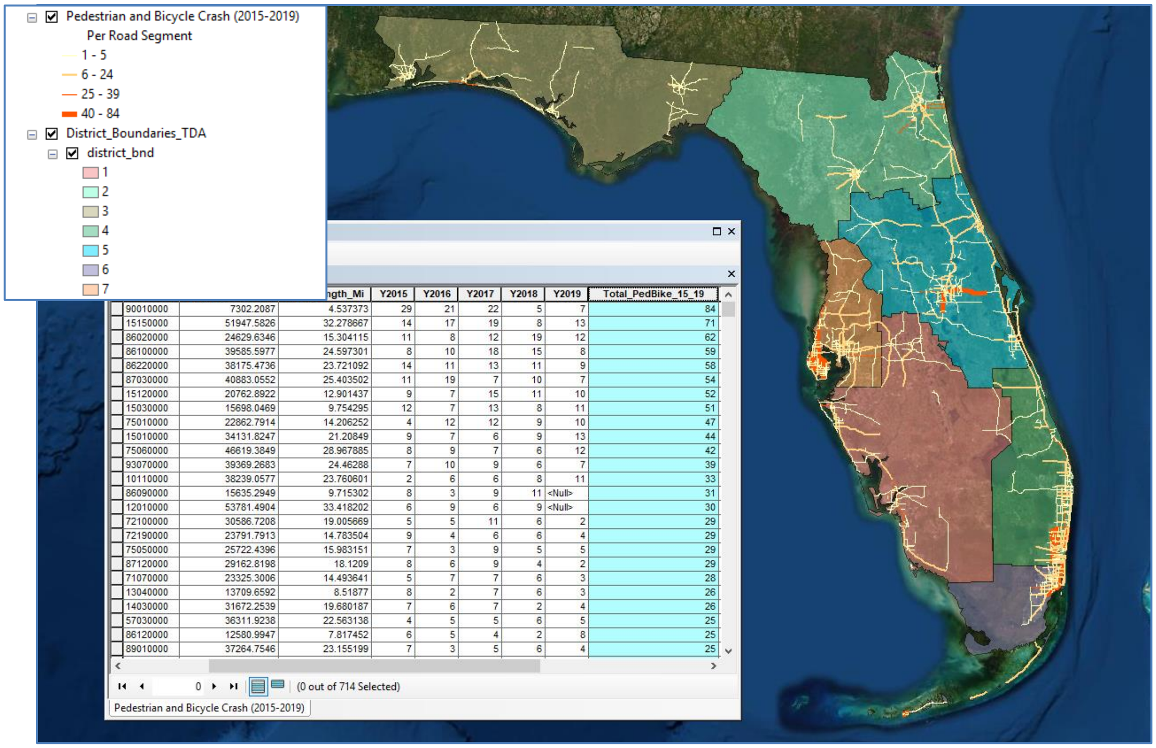
Corridor_DRCPerMile_15_19_PedBike

RdwyLength_Mi	Y2015	Y2016	Y2017	Y2018	Y2019	Total_PedBike_15_19	Rdwy_v2	DRC_PedBikePerMile	Shape_Length
22.854732	<Null>	3	5	1	1	10	10030000	0.437546	36781.199534
18.474496	1	1	4	3	1	10	70050000	0.541287	29731.878885
36.16209	2	2	1	3	2	10	70060000	0.276533	58197.358797
7.465442	1	3	<Null>	2	4	10	70120000	1.339505	12014.487589
10.696423	1	3	<Null>	3	3	10	75040000	0.934892	17214.258338
6.656274	1	1	3	2	3	10	75190000	1.502342	10712.255972
8.457368	3	<Null>	2	2	3	10	75250000	1.182401	13610.841368
9.499009	4	2	3	<Null>	1	10	86028000	1.052741	15287.203953
13.294557	2	3	1	2	2	10	86065000	0.752188	21395.557634
2.968198	2	1	4	1	2	10	86180000	3.369048	4776.86062
4.175752	4	2	1	2	1	10	87080000	2.394778	6720.23476
11.439618	3	4	2	1	<Null>	10	93000110	0.874155	18410.316788
11.217793	<Null>	<Null>	4	2	3	9	10020000	0.802297	18053.323218
22.427024	4	2	1	<Null>	2	9	17020000	0.401302	36092.868729
5.519443	3	5	1	<Null>	<Null>	9	70012000	1.630599	8882.700487
35.685852	<Null>	4	4	1	<Null>	9	70020000	0.252201	57430.926091
9.752907	2	3	2	1	1	9	70140000	0.922802	15695.813929
6.445419	2	2	3	1	1	9	72014000	1.396341	10372.917027
30.234377	3	<Null>	2	2	2	9	79100000	0.297674	48657.611134
4.005351	1	1	3	3	1	9	79230000	2.246994	6445.999793
25.930282	<Null>	<Null>	2	2	4	8	01010000	0.30852	41730.827047
9.075947	<Null>	1	1	2	4	8	10130000	0.881451	14606.349304
30.545288	3	2	2	<Null>	1	8	17070000	0.261906	49157.974298

0 (0 out of 714 Selected)

Corridor_DRCPerMile_15_19_PedBike

Figure 18. Five-year pedestrian/bicycle driveway access crashes by roadway segments.



		ngth_Mi	Y2015	Y2016	Y2017	Y2018	Y2019	Total_PedBike_15_19
90010000	7302.2087	4.537373	29	21	22	5	7	84
15150000	51947.5826	32.278667	14	17	19	8	13	71
86020000	24629.6346	15.304115	11	8	12	19	12	62
86100000	39585.5977	24.597301	8	10	18	15	8	59
86220000	38175.4736	23.721092	14	11	13	11	9	58
87030000	40883.0552	25.403502	11	19	7	10	7	54
15120000	20762.8922	12.901437	9	7	15	11	10	52
15030000	15698.0469	9.754295	12	7	13	8	11	51
75010000	22862.7914	14.206252	4	12	12	9	10	47
15010000	34131.8247	21.20849	9	7	6	9	13	44
75060000	46619.3849	28.967885	8	9	7	6	12	42
93070000	39369.2683	24.46288	7	10	9	6	7	39
10110000	38239.0577	23.760601	2	6	6	8	11	33
86090000	15635.2949	9.715302	8	3	9	11	<Null>	31
12010000	53781.4904	33.418202	6	9	6	9	<Null>	30
72100000	30586.7208	19.005669	5	5	11	6	2	29
72190000	23791.7913	14.783504	9	4	6	6	4	29
75050000	25722.4396	15.983151	7	3	9	5	5	29
87120000	29162.8198	18.1209	8	6	9	4	2	29
71070000	23325.3006	14.493641	5	7	7	6	3	28
13040000	13709.6592	8.51877	8	2	7	6	3	26
14030000	31672.2539	19.680187	7	6	7	2	4	26
57030000	36311.9238	22.563138	4	5	5	6	5	25
86120000	12580.9947	7.817452	6	5	4	2	8	25
89010000	37264.7546	23.155199	7	3	5	6	4	25

Figure 19. Roadway segment ranking and color coding based on total pedestrian/bicycle commercial driveway-related crashes.

Step 5: Location and documentation of commercial driveways

Next, the commercial driveways were manually identified along each of the candidate corridors, as shown in Figure 20. The centerline of the driveways was manually geolocated and its latitude and longitude were recorded and incorporated into the driveway characteristics review process. A similar process was used to review commercial driveways in the vicinity of interchanges, as shown in Figure 21.

Figure 20. Identification of commercial driveways and crash clusters along a major corridor.

(Segment of SR-10/W Tennessee St, Tallahassee, FL)

Figure 21. Identification of commercial driveways in interchange influence areas.

(SW 8th St at Palmetto Expwy, Miami, FL)

Trained student assistants then manually reviewed each driveway on the candidate corridors and interchange areas to document the driveway characteristics data and variables listed in Table 6**Error! Reference source not found.**. The review was conducted using satellite layer and street view images in Google Maps. The characteristics of driveways and adjacent roads were documented by reviewing the street view images as someone leaving the driveway and moving along the adjacent roads and interchanges. The detailed definitions and values for each attribute for commercial driveways along major corridors and in the vicinity of interchanges were included in Appendix D (Corridor Driveway Review Form) and Appendix E (Interchange Driveway Review Form), respectively. A total of 9,889 commercial driveways along corridors and 832 driveways in vicinity of interchanges were reviewed and included in the analysis.

Table 6. Reviewed Attributes

Attributes	
Roadway Characteristics • Functional Class • Access Class • Context Class • Number of Lanes on Adjacent Road • Posted Speed • AADT • Frontage Road* • Median Type • Median Opening Type • Distance from Off-ramp Taper End to First Full Median Opening*	**Driveway Characteristics** • Driveway Design • Driveway Number of Lanes • Driveway Traffic Operations • Driveway Channelization • Traffic Control Device at Driveway • Right-Turn Lane Type • Driveway Throat Length • Temporary Closure • Driveway ID • Latitude/Longitude • First Driveway after Off-ramp OR Last Driveway before On-ramp* • Distance from Ramp Taper End to Each Unsignalized or Signalized Driveway*
Non-Motorist Facility Features • Bike Lane Type • Bike Lane Paint • Sidewalk • Marked Crossing Signal • Pedestrian Refuge Island	

* Collected only for driveways in the vicinity of interchanges.

Upon completion of the driveway and roadway characteristics review process, the driveway characteristics data was integrated with the roadway characteristics data and driveway-related crash data, as follows.

- First, the driveway characteristics data was incorporated with roadway characteristics data, including AADT data, based on FDOT Roadway ID information. The data entries with the same Roadway ID and Road Section Numbers were linked together.
- Second, each driveway-related crash location was mapped and associated with the corresponding FDOT Roadway ID and Functional Class attributes in the crash dataset, so they were correctly linked to the roadway characteristics and AADT datasets.
- Third, each driveway-related crash record was examined to determine if it fell into the influence areas of driveways before it was associated with the closest driveways as shown in Figure 22. The driveway influence area defined by the Florida Design Manual (FDOT, 2020) is 250 ft upstream and downstream from the driveway location. Therefore, crashes located farther than 250 ft from a commercial driveway were excluded from the analysis. Due to the large number of driveways along urban corridors, the influence areas of multiple driveways may overlap. Therefore, the influence areas under such scenarios were divided into segments based on the distance between adjacent driveways, using the method applied by Williamson and Zhou (2014).

Figure 22. Example of crash clusters and crash assignment to corridor driveways.

(Segment of SR-10 (W Tennessee St), Tallahassee, FL)

For the crash frequency analysis datasets, each data entry is a driveway record with all linked features and crash frequency at the driveway site. For the crash severity analysis datasets, each data entry is a crash record linked with all roadway, traffic, and driveway characteristics. Detailed descriptive statistics for these crash datasets are summarized in Section 5.

3.2 Selection of Interchange Area and Driveway Sites

Because interchange areas have unique safety and operational characteristics, these locations were selected separately. The objective was to identify potential commercial driveway-related crashes, including pedestrian and bicycle crashes, that may be impacted by interaction with traffic entering and exiting an interchange. The data used to identify the interchanges are described in Section 3. The selection process for commercial driveway sites near interchanges is explained in the following steps.

Step 1: Define interchange influence area.

For purposes of the study, interchange influence area was defined as the area up to 0.5 mile on either side of an interchange on- or off- ramp or to the first signalized intersection, whichever is less (Figure 23). This includes the area of special safety and operational concern from interchange ramps of 0.25 mile, as identified by FDOT (2020), as well as the 0.5 mile access spacing criteria for signalized intersections from interchanges in national research-based guidance (Williams et al., 2014).

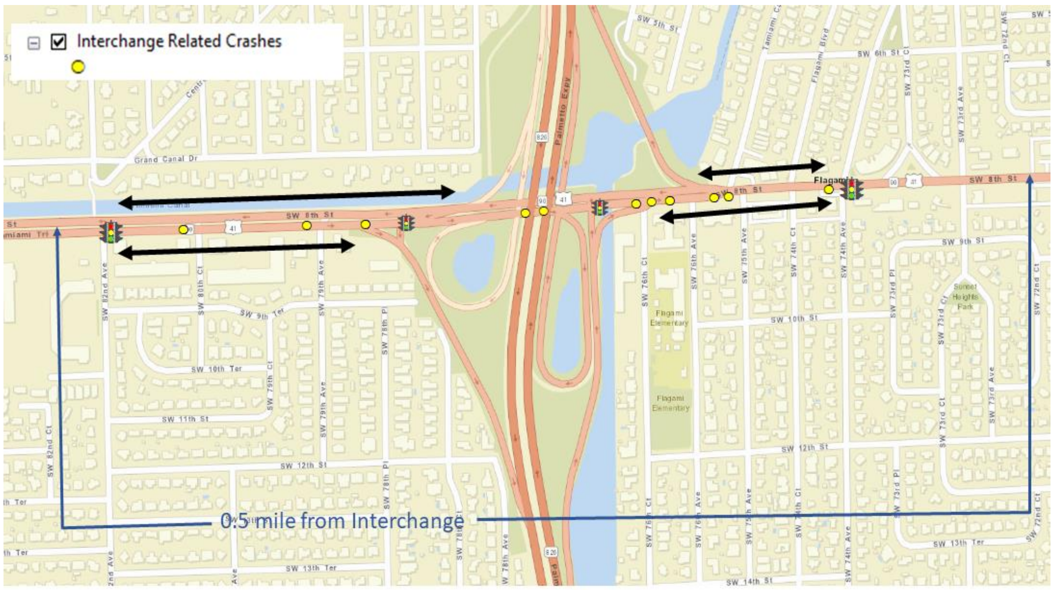


Figure 23. Interchange influence area for driveway analysis.

(SW 8th St at Palmetto Expwy, Miami, FL FDOT District 6)

Step 2: Screen and select crashes in the interchange area.

All the crashes were mapped and overlaid with the FDOT interchanges layer and those roadways connecting with the interchange were selected. Six functional classes were considered for the study: Principal Arterial-Other Rural, Minor Arterial Rural, Major Collector Rural, Principal Arterial-Other Urban, Minor Arterial Urban, and Major Collector Urban. Driveway-related crash records were linked to the interchanges if they were located within 0.5 mile. Figure 24 shows the interchange-related crashes in red and interchanges by type in Florida from the FDOT GIS database.

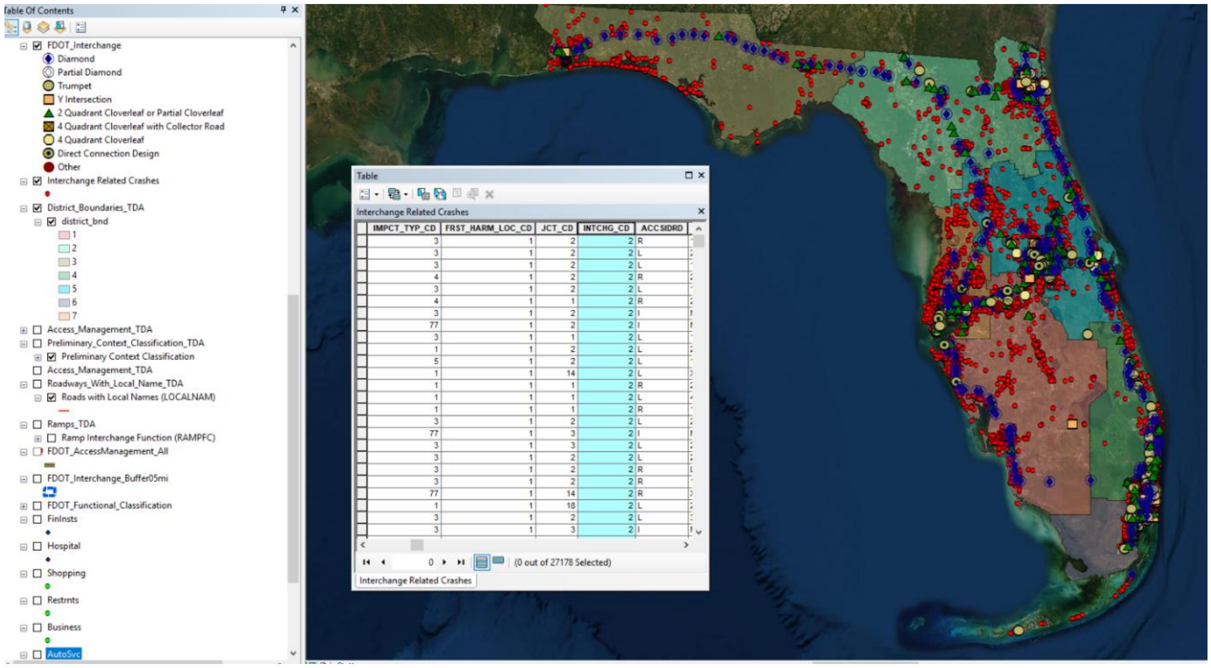


Figure 24. Data integration for interchange-related crash site selection.

Next, the 27,178 interchange-related crashes were evaluated using GIS to remove those outside of the defined interchange influence area. Only those located on the crossroad within the influence area that intersected with commercial land uses were retained. Figure 25 shows the interchange-related crashes in the influence area of one interchange over the analysis period.

Figure 25. Example of crashes in an interchange influence area.

(SW 8th St at Palmetto Expwy, Miami, District 6, FL)

Step 3: Identify commercial driveway crashes.

Next, the crashes within the interchange influence area were further screened to determine if they may be related to commercial driveways. Typical commercial driveways in this area include fast food, restaurants, auto and gas services, hotels, and stores. Crashes were identified at both unsignalized and signalized commercial driveways. This process reduced the total initial number of crash locations identified for analysis to 853 across 69 interchange sites. Figure 26 shows the commercial areas of one of the interchange locations, as depicted in Google.

Figure 26. Identifying commercial driveway-related crashes in interchange influence areas.
(SW 8th St at Palmetto Expwy, Miami, District 6, FL)

Step 4: Document characteristics of the interchange areas and select final sample.

Interchanges with crashes related to commercial driveways in the influence area were then further documented in terms of their access class, context class, and interchange type (i.e., diamond, partial cloverleaf, full cloverleaf, trumpet, etc.). The interchange areas were also sorted by number of crashes. The final sample represented interchanges over represented by crashes and representative of different types of interchanges with different operational controls (i.e., free flow ramps, stop controlled ramps, signalized). The candidate interchanges were narrowed to those where 3 or more commercial driveway-related crashes occurred.

Table 7 summarizes the commercial driveway crash locations by interchange types in Florida by FDOT District. District 5 has 27% of the crash sites, followed by District 2 (22%) and District 6 (21%). The diamond interchange ranks highest in crash locations at 59% of the analysis sites, followed by partial cloverleaf interchanges, which represented 39% of the total crash sites. The full list of interchange locations by FDOT District, access classification, context classification, interchange type, and crash frequency is provided in Appendix B. Appendix C shows the selected commercial driveway locations within each interchange influence area by FDOT District.

Table 7. Distribution of Crashes by Interchange Type and FDOT District

FDOT District	Partial Cloverleaf	Diamond	Partial Diamond	Other	Total	Percent
1	6	21	–	–	27	3%
2	29	137	11	13	190	22%
3	10	16	18	–	44	5%
4	37	53	–	8	98	11%
5	72	156	–	–	228	27%
6	102	67	–	11	180	21%
7	–	54	32	–	86	10%
Total	256	504	61	32	853	100%
Percent	30%	59%	7%	4%	100%	

Step 5: Location and documentation of commercial driveways

The process used to locate and document the characteristics of commercial driveways in interchange areas is the same as that used for driveways along corridors as described in Section 3.1, Step 5.

4. Methodology

Studies quantifying the safety effects of driveway and roadway characteristics commonly employ discrete choice models, such as negative binomial regression models to model crash frequency and logit model to model crash severity, which are used in this research. It is the preferred method to model crash data "due to its ability to model the discrete, non-negative characteristics of crashes" (Williamson et al., 2018). Other methods include micro-simulation using software such as PTV Vissim, FHWA's Surrogate Safety Assessment Model (SSAM), Traffic Software Integrated System–Corridor Simulation (TSIS-CORSIM), and statistical analysis using analysis of variance (ANOVA), and analysis of covariance (ANCOVA).

Collision diagrams, site photos, or aerial mapping using software such as Google Maps™ are used to identify and examine factors in the built environment that contribute to unsafe conditions. These assessments typically rely on a combination of observation and other data sources such as police reports or details in available crash data. Case studies are used to provide a more in-depth exploration of select study sites and provide explanations for specific safety issues. For example, during the development of an access management best practices manual for Oregon, Dixon et al. (2013) used case studies to test available data and evaluate performance measures.

Several of these analytical methods were used in this study to assess the safety effects of driveway type and location on crash type and severity in relation to roadway and interchange characteristics. They include summary statistics and statistical analysis, generalized linear modeling techniques, and exploratory case studies. These methods have been proven effective in previous studies (Williamson and Zhou, 2014; Chen et al., 2018; Dixon et al., 2016).

The analysis was divided into qualitative and quantitative assessments. The qualitative assessment encompasses descriptive statistics of crashes, severity levels, and crash, traffic, and geometric attributes. The quantitative analysis involved statistical analysis and generalized linear modeling considering frequency (e.g., negative binomial) and severity (e.g., multinomial logit) of crashes at corridors and interchange areas.

Figure 27 presents the overall methodology for the safety assessment of commercial driveways focusing on two aspects – corridors and interchange areas. The methodology for both the qualitative and quantitative analysis is discussed below. Interchange areas were examined separately due to their operational and design differences, such as higher speeds and traffic volumes, interchange types, weaving activity, and tendency for higher commercial development intensity that increases the potential for traffic conflicts. The screening and site selection processes for these two aspects are based on their respective criteria and supporting datasets for the analysis.

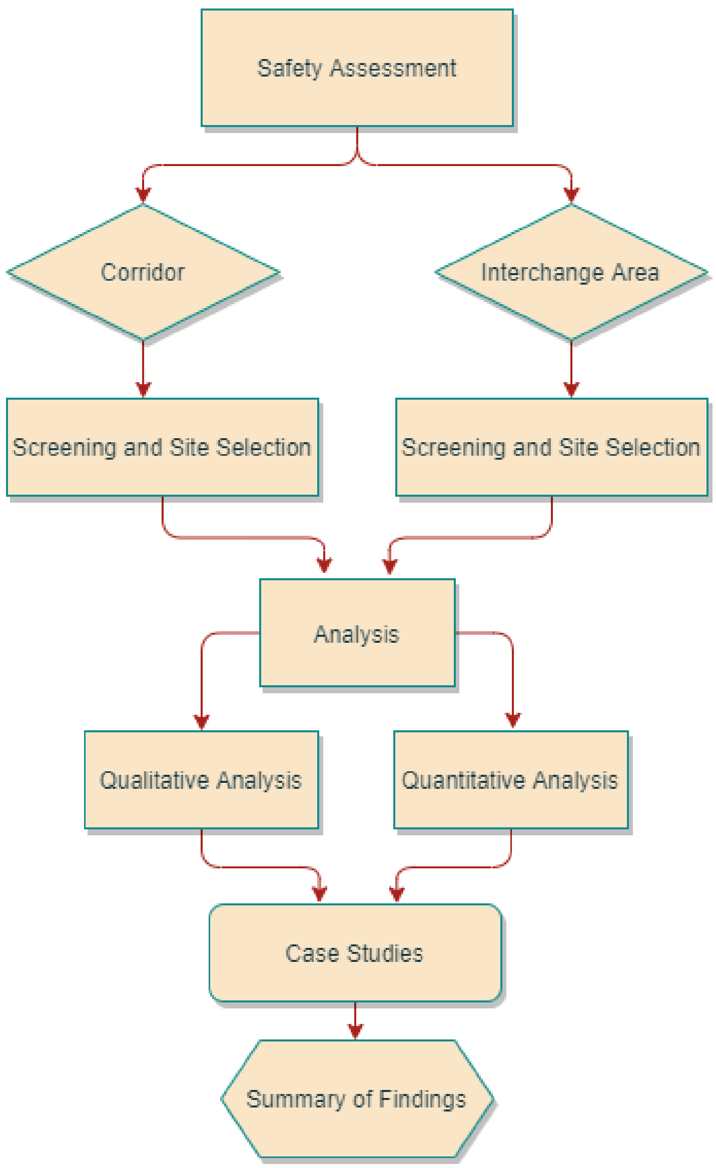


Figure 27. Conceptual methodology for driveway safety assessment.

4.1 Qualitative Analysis

For the qualitative analysis, a statistical approach was used to reveal the effects of roadway, interchange, driveway, traffic, and crash features on crash frequency and severity. This analysis was conducted in two steps.

- **Step one**: a comprehensive descriptive summary of the data was provided to illustrate the distribution of driveway-related crashes and severities with respect to potential contributing factors, such as driveway type, driveway location, median opening type, interchange type, traffic volume, posted speed limit, land use context, presence of pedestrian or bicycle facility (i.e., crosswalk, sidewalk, bike lane).
- **Step two:** significance tests were conducted to examine the statistical difference of crash frequency or severity with respect to these contributing factors by comparing the sample means. The data was first tested using the analysis of variance (ANOVA) method to identify differences across sample means of different values of a variable. The result of the ANOVA formula, the F statistic (also called the F-ratio), allows for the analysis of multiple groups of data to determine the variability between samples and within samples. The general hypothesis and test statistics for ANOVA are expressed with Equation (2) (Williamson and Zhou, 2014):

$$H_0: u_1 = u_2 = \cdots = u_k,\ Fo < F\alpha,\ k\text{-}1,\ N\text{-}k \quad (2)$$

$$H_1: Some\ of\ these\ means\ are\ different,\ Fo > F\alpha,\ k\text{-}1,\ N\text{-}k$$

  where, α is the significance level of the test, k is the number of sample means under comparison, and N is the sample data size. In this research, α=0.05 was used.

Where the ANOVA analysis revealed that some of the tested means were different, a paired t-test was then performed to further identify which pair(s) of two sample means differed. The p-value (p=0.05) is commonly used to determine if the difference is significant between the two compared groups with a 95% confidence level.

In this study, this process tested for differences in crash rates associated with each contributing factor tested (e.g., driveway type, driveway location, median opening type, interchange type, traffic volume, posted speed limit, land use context, presence of pedestrian or bicycle facility). The general hypothesis and test statistics for paired t-test is shown in Equations (3) and (4) (Williamson and Zhou, 2014):

$$H_0: u_i = u_j, |t_0| < t_{\alpha,N-1} \quad (3)$$

$$H_1: u_i \neq u_j, |t_0| < t_{\alpha,N-1} \quad (4)$$

where α is the significance level of the test, and N is the sample data size. A significance level of α=0.05 is also used for the paired t-test.

4.2 Quantitative Analysis

The statistical analysis method can reveal the distribution of driveway-related crashes across different values of a potential contributing factor and highlight the factors worthy of special attention. However, it may not accurately capture the distinctive impacts of these factors solely based on the descriptive analysis, as these distributions are also affected by other unobserved factors to some extent. In contemporary literature, regression modeling techniques are generally used to examine the individual effect of a contributing factor on driveway related crash frequency and severity (Avelar et al., 2013; Chen et al., 2018; Gorthy, 2017; Gross et al., 2018; Kwigizile et al., 2014). Different models were therefore used in our study, including a negative binomial model for crash frequency analysis, and a multinomial logit model for crash severity analysis. The details of these models follow.

Crash Frequency Analysis

Traffic crashes are discrete and random events, and crash frequency is always non-negative. Many crash distributions have been proven to follow the negative binomial distribution, which is now the most used method when modeling crash data (Williamson et al., 2018). In this study, a non-negative binomial regression model was employed to investigate the influence of roadway, driveway, and traffic characteristics on driveway-related crash distributions.

A general structure of the negative binomial model is shown in Equation (5) (Gorthy, 2017).

$$\ln \lambda_i = \beta X_i + \varepsilon_i \tag{5}$$

where,
λ_i is the expected number of crashes or crash rate for driveway i;
X_i is a vector of explanatory variables to be examined;
β is a vector of coefficients to be estimated; and,
e^{ε_i} is a gamma-distributed error term with the mean equal to 1.

The explanatory variables for the negative binomial regression model included the aforementioned crash, traffic, roadway, and driveway characteristics. Nominal variables were converted to variables with a limited number of categorical values for modeling purposes. For example, median opening type (i.e., no physical median, no opening, directional opening, full opening) was converted to 1-no median (undivided or painted median), 2-no opening, 3-directional opening, and 4-full opening, before being included in the modeling process. A Type 3 analysis through Chi-square test was conducted to examine the significance of each explanatory variable, considering all other variables are present in the model (SAS Institute Inc., 2022). All the significant variables are identified at the significance level of p=0.05 (95% confidence level).

Crash Severity Analysis

The multinomial logit model (MNL) was used to examine crash severity outcomes at commercial driveways and the contributing factors relative to roadway features, traffic conditions, driveway characteristics, and other crash-related variables. Florida adopted the "KABCO" injury scale defined by the Federal Highway Administration (FHWA) to document crash and road user injury severities, where "K" indicates fatality, "A" represents "incapacitating injury", "B" denotes non-incapacitating injury, "C" is possible injury, and "O" is no injury (property damage only). Fatal and incapacitating injury crashes are of the highest interest in traffic safety but often account for a very small proportion of all crashes. Therefore, three injury severity levels were defined for this study, including no injury (**NI**, including all "O" crashes), minor injury (**MI**, including "B" and "C" crashes) and severe injury (**SI**, including "K" and "A" crashes).

As noted by Kim et al. (2007), the positivity or negativity of a coefficient estimated from a logit model with three or more crash severity levels in the response variable cannot be intuitively interpreted as the increase or decrease in the probability of that crash severity. To properly evaluate the influence of contributing factors on crash severity outcomes, a direct average pseudo-elasticity analysis is necessary, which works by altering the values of each contributing factor and examining the probability change. For this study, the variables were all converted to 0-1 indicator variables for logit modeling. The average pseudo-elasticity is defined by the percentage change in probability when an indicator variable is changed from 0 to 1 (and 1 to 0), and is calculated as follows:

$$E_{\boldsymbol{x}_{nk}}^{P_{ni}} = \frac{P_{ni}[\boldsymbol{x}_{nk}=1]-P_{ni}[\boldsymbol{x}_{nk}=0]}{P_{ni}[\boldsymbol{x}_{nk}=0]} \quad (6)$$

where $E_{\boldsymbol{x}_{nk}}^{P_{ni}}$ is the direct average pseudo-elasticity of the *k*th variable from the vector $\boldsymbol{x}_n$. P_{ni} is the probability of crash *n* resulting in injury severity level *i* and is defined as the following according to the basic structure of multinomial logit model:

$$P_{ni} = \frac{e^{\beta_i x_n}}{\sum_{i'} e^{\beta_{i'} x_n}} \quad (7)$$

where β_i is the vector of coefficients estimated specific to crash severity level *i* and $\boldsymbol{x}_n$ is a vector of exogenous variables for crash *n*. This average pseudo-elasticity method has been used in several authentic traffic safety studies (Shankar and Mannering, 1996; Ulfarsson and Mannering, 2004), and therefore is also used in this study to evaluate the marginal effects of the contributing factors.

4.3 Case Study Analysis

Case studies are an effective approach for more in-depth exploration of select study sites and potential explanations for specific safety issues (Dixon et al., 2013; FDOT District 7, 2015). Toward that end, the team supplemented the quantitative and qualitative analyses of statewide crash data on commercial driveways, with case study analysis. The case studies considered potential interactions among commercial driveway characteristics and other corridor or interchange area characteristics, such as:

- Roadway characteristics
- AADT
- Context, functional class, access class
- Number of lanes
- Driveway geometrics
- Driveway volume (i.e., number of parking spaces or FDOT driveway category)
- Driveway entry and exit movements (i.e., one-way, two-way, right-in/right-out)
- Driveway location in relation to signalized intersections and interchange ramps
- Median type
- Median opening type (i.e., full opening, directional opening, no opening)
- Median end treatment (i.e., no left-turn lane, one left-turn lane, two left-turn lanes)
- Presence of pedestrian or bicycle facilities (i.e., sidewalk, crosswalk, bike lane) and bus stops
- Interchange type (i.e., diamond, partial cloverleaf, full cloverleaf, trumpet, etc.)
- Type of ramp control (i.e., signalized, stop controlled, free flow)

The case study sites were selected through an iterative process. A geographically diverse subset of potential study areas with a high proportion of commercial driveway-related crashes over the five-year period (2015-2019) was identified based on the study methodology. The sample was further reduced based on evidence of crash clusters at commercial driveways and different corridor or interchange area characteristics. A set of crash clusters was then identified at specific commercial driveway locations in the study areas for further analysis, as were driveway-related crashes involving interactions with other corridor or interchange characteristics as indicated by crash reports.

Crash locations were verified based on crash reports and relocated in ArcGIS where incorrectly geolocated in the data set. For commercial sites with more than one driveway, the team made informed decisions as to which driveway was implicated in the crash based on the narrative and crash diagram, if any, in the crash report. Crash diagrams were prepared to illustrate the safety issues identified. Results of the case study site selection and analysis are presented in Section 6.

5. Findings

5.1 Qualitative Analysis

As explained in Section 4.1, the qualitative analysis procedure consisted of two parts – descriptive statistics and significance tests. Findings of this analysis are presented here.

5.1.1 Descriptive Statistics

A comprehensive descriptive summary of six datasets was prepared – three crash frequency datasets (Table 8) and three crash severity datasets (Table 9. Descriptive Statistics for Three Driveway Crash Datasets for Crash Severity AnalysisTable 9). Each of the three datasets included one dataset for all crashes (corridors), one for pedestrian and bicycle crashes (corridors), and one for all crashes near interchanges. Due to the limited number of pedestrian and bicycle crashes at commercial driveways near interchanges, crash frequency and severity analyses were not conducted on this crash data group. The summaries illustrate the distribution of driveways and crashes in relation to potential contributing factors, such as driveway type, driveway location, median opening type, interchange type, traffic volume, posted speed limit, land use context, and presence of pedestrian or bicycle facilities.

Table 8. Descriptive Statistics for Crash Frequency Analysis

Variable Description	Commercial Driveways along Corridors		Commercial Driveways along Ped/Bike High Crash Corridors		Commercial Driveways Near Interchanges	
	Total	%	Total	%	Total	%
Total Number	9889	100.00	7369	100.00	832	100.00
Roadway Characteristics Variable						
Number of All Lanes on Connecting Street (One-direction, including right- and left-turn lane if available)						
One	229	2.32	155	2.10	47	5.65
Two	2727	27.58	1603	21.75	253	30.41
Three	4385	44.34	3431	46.56	293	35.22
Four or more	2548	25.77	2180	29.58	239	28.73
Posted Speed Limit						
<35 mph	2450	24.78	1869	25.36	123	14.78
40-45 mph	6636	67.10	4698	63.75	689	82.81
≥50 mph	803	8.12	802	10.88	20	2.40
AADT						
≤10,000	14	0.14	2	0.03	74	8.89
10,000<AADT≤20,000	491	4.97	36	0.49	234	28.13
20,000<AADT≤30,000	1761	17.81	1246	16.91	157	18.87
30,000<AADT≤40,000	2436	24.63	2002	27.17	132	15.87
40,000<AADT≤50,000	3368	34.06	2591	35.16	161	19.35
50,000<AADT≤60,000	1011	10.22	684	9.28	74	8.89
60,000<AADT≤70,000	808	8.17	808	10.96	0	0.00

Table 8, continued

Variable Description	Commercial Driveways along Corridors		Commercial Driveways along Ped/Bike High Crash Corridors		Commercial Driveways Near Interchanges	
	Total	%	Total	%	Total	%
Functional Classification						
Principal Arterial-Other - Rural	12	0.12	71	0.96	79	9.50
Minor Arterial - Rural	0	0	9	0.12	45	5.41
Principal Arterial-Other - Urban	6969	70.47	6244	84.73	479	57.57
Minor Arterial - Urban	2679	27.09	1037	14.07	208	25.00
Major Collector - Urban	229	3.32	8	0.11	21	2.52
Median Type						
Undivided or Painted Median	1726	17.45	1057	14.34	76	9.13
Non-traversable Median (Grass, Curb, etc.)	6921	69.99	5531	75.06	572	68.75
Two-way Left Turn Lane	1242	12.56	781	10.60	184	22.12
Median Opening Type						
No Physical Median	1726	17.45	1057	14.34	76	9.13
No Opening	6206	62.76	4991	67.73	508	61.06
Directional Opening	771	7.80	575	7.80	37	4.45
Full Median Opening	1186	11.99	746	10.12	211	25.36
Driveway Characteristics Variable						
Driveway Design						
Flush Radial	802	8.11	663	9.00	96	11.54
Curb Radial	1993	20.15	1602	21.74	235	28.25
Curb Flare	5314	53.74	3782	51.32	329	39.54
Wide-open frontage or other types	1780	17.00	1322	17.94	172	20.67

Table 8, continued

Variable Description	Commercial Driveways along Corridors		Commercial Driveways along Ped/Bike High Crash Corridors		Commercial Driveways Near Interchanges	
	Total	%	Total	%	Total	%
Driveway Number of Lanes						
One	1235	12.49	885	12.01	66	7.93
Two	8059	81.49	6091	82.66	712	85.58
Three	161	1.63	107	1.45	33	3.97
Four or more	434	4.39	286	3.88	21	2.52
Driveway Traffic Operations						
One-way Entry	511	5.17	390	5.29	34	4.09
One-way Exit	520	5.26	383	5.20	35	4.21
Right-in/Right-out (No Opening or Channelizing Island)	6813	68.89	5182	70.32	518	62.26
Right-in/Left-in/Right-out (Directional Opening)	440	4.45	360	4.89	37	4.45
Full Traffic Movement	1494	15.11	947	12.85	208	25.00
Left-in/Left-out	111	1.12	107	1.45	0	0.00
Driveway Channelization						
None	7409	74.92	5548	75.29	590	70.91
Painted/Island	2480	25.08	1821	24.71	242	29.09
Traffic Control at Driveway						
No Control	6393	64.65	4719	64.04	519	62.38
Sign Control	3358	33.96	2544	34.52	278	33.41
Traffic Signal	138	1.40	106	1.44	35	4.21
Right-turn Lane Type						
Exclusive Right-turn Lane (serves one site)	274	2.77	210	2.85	37	4.45
Shared/Continuous Right-turn Lane	642	6.49	489	6.64	142	17.07
No Right-turn Lane	8973	90.74	6670	90.51	653	78.49

Table 8, continued

Variable Description	Commercial Driveways along Corridors		Commercial Driveways along Ped/Bike High Crash Corridors		Commercial Driveways Near Interchanges	
	Total	%	Total	%	Total	%
Driveway Throat Length						
Adequate	4352	44.01	3222	43.72	323	38.82
Short (less than the length of two cars)	3060	30.94	2295	31.14	168	20.19
None	2477	20.05	1852	25.13	341	40.99
Non-Motorist Facility Characteristics						
Bike Lane Type						
No Exclusive	5676	57.40	3875	52.59	416	50.00
Conventional	2995	30.29	2631	35.70	317	38.10
Other Bike Lane Types (e.g., buffered bike, keyhole lane, etc.)	1218	12.32	863	11.71	99	11.90
Bike Lane Paint						
N/A	5574	56.37	3773	51.20	416	50.00
No	2835	28.67	2177	29.54	101	12.14
Yes	1480	14.97	1419	19.26	315	37.86
Sidewalk						
Not Available	107	1.08	129	1.75	159	19.11
Available	9782	98.92	7240	98.25	673	80.89
Marked Crosswalk						
Not Available	9812	99.22	6759	91.72	710	85.34
Available	77	0.78	610	8.28	122	14.66
Pedestrian Crossing Signal						
Not Available	9812	99.22	7310	99.20	828	99.52
Available	77	0.78	59	0.80	4	0.48

Table 8, continued

Variable Description	Commercial Driveways along Corridors		Commercial Driveways along Ped/Bike High Crash Corridors		Commercial Driveways Near Interchanges	
	Total	%	Total	%	Total	%
Pedestrian Refuge Island						
Not Available	9832	99.42	7336	99.55	828	99.52
Available	57	0.58	33	0.45	4	0.48
Interchange Related Characteristics						
First driveway after off-ramp OR Last driveway before on-ramp						
No					602	72.36
Yes					230	27.64
Connecting Ramp Type						
On-ramp					416	50.00
Off-ramp					416	50.00
Nearby Interchange Configuration						
Partial Cloverleaf					176	21.15
Diamond					577	69.35
Partial Diamond					25	3.00
Other					54	6.49
Interchange Ramp Terminal Type						
Free flow					166	19.95
Stop/Yield Control					431	51.80
Signalized Control					235	28.25
Frontage Road						
No					817	98.20
Yes					15	1.80

Table 8, continued

Variable Description	Commercial Driveways along Corridors		Commercial Driveways along Ped/Bike High Crash Corridors		Commercial Driveways Near Interchanges	
	Total	%	Total	%	Total	%
Distance from ramp taper end to each unsignalized or signalized driveway						
≤500 ft					403	48.44
501 – 1000 ft					291	34.98
1001 – 1500 ft					102	12.26
1501 – 2000 ft					26	3.13
>2000 ft					10	1.20
Distance from off-ramp taper end to the first full median opening (only applies to off-ramp)						
No full median opening exists within interchange influence area					402	48.32
≤500 ft					307	36.90
501 – 1000 ft					93	11.18
1001 – 1500 ft					22	2.64
1501 – 2000 ft					8	0.96
>2000 ft					0	0.00

Table 9. Descriptive Statistics for Three Driveway Crash Datasets for Crash Severity Analysis

Variable Description	Corridor Commercial Driveway-related Crashes		Corridor Commercial Driveway-related Ped/Bike Crashes		Interchange Commercial Driveway-related Crashes	
	Total	%	Total	%	Total	%
Crash Variables	10596	100.00	938	100.00	853	100.00
Injury Severity						
No Injury (PDO)	7035	66.39	140	14.93	559	65.53
Possible and Non-incapacitating	3139	29.62	679	72.39	269	31.54
Incapacitating and Fatal	422	3.98	119	12.69	25	2.93
Alcohol Involved						
No	10481	98.91	925	98.61	841	98.59
Yes	115	1.09	13	1.39	12	1.41
Lighting Condition						
Daylight	8414	79.41	794	84.65	667	78.19
Dawn/dusk	389	3.67	30	3.20	47	5.51
Dark	1793	16.92	114	12.15	139	16.30
Weather						
Clear	8508	80.29	794	84.65	637	74.68
Cloudy	1487	14.03	30	3.20	157	18.41
Rain	601	5.67	114	12.15	59	6.92
Road Surface						
Dry	9617	90.76	879	93.71	762	89.33
Wet	979	9.24	59	6.29	91	10.67

Table 9, continued

Variable Description	Corridor Commercial Driveway-related Crashes		Corridor Commercial Driveway-related Ped/Bike Crashes		Interchange Commercial Driveway-related Crashes	
	Total	%	Total	%	Total	%
Shoulder Type						
Paved	3821	36.06	280	29.85	285	33.41
Unpaved	761	7.18	31	3.30	144	16.88
Curb	6014	56.76	627	66.84	424	49.71
Roadway Characteristics						
Number of All Lanes on Connecting Street (One-direction, including right- and left-turn lane if available)						
One Lane	135	1.27	13	1.39	46	5.39
Two Lanes	2462	23.24	234	24.95	190	22.27
Three Lanes	4756	44.88	435	46.38	332	38.92
Four and more Lanes	3243	30.61	256	27.29	285	33.41
Posted Speed Limit						
<35mph	2643	24.94	285	30.38	83	9.73
40-45mph	7247	68.39	606	64.61	757	88.75
≥45 mph	706	6.66	47	5.01	13	1.52

Table 9, continued

Variable Description	Corridor Commercial Driveway-related Crashes		Corridor Commercial Driveway-related Ped/Bike Crashes		Interchange Commercial Driveway-related Crashes	
	Total	%	Total	%	Total	%
AADT						
≤10,000	127	1.20	13	1.39	162	18.99
10,000<AADT≤20,000	887	8.37	90	9.59	196	22.98
20,000<AADT≤30,000	2757	26.02	215	22.92	151	17.70
30,000<AADT≤40,000	2225	21.00	226	24.09	91	10.67
40,000<AADT≤50,000	2208	20.84	188	20.04	121	14.19
50,000<AADT≤60,000	1324	12.50	118	12.58	101	11.84
60,000<AADT≤70,000	435	4.11	33	3.52	24	2.81
70,000<AADT≤80,000	72	0.68	1	0.11	6	0.70
80,000<AADT≤90,000	239	2.26	23	2.45	1	0.12
>90,000	322	3.04	31	3.30	0	0.00
Functional Class						
Principal Arterial-Other - Rural	3	0.03	0	0.00	76	8.91
Minor Arterial - Rural	0	0.00	0	0.00	40	4.69
Principal Arterial-Other - Urban	7499	70.77	748	79.74	586	68.70
Minor Arterial - Urban	2913	27.49	182	19.40	126	14.77
Major Collector - Urban	181	1.71	8	0.85	25	2.93
Median Type						
Undivided or Painted Median*	2041	19.26	82	4.62	60	7.03
Non-traversable Median (Grass, Curb, etc.)	7433	70.15	1318	74.25	559	65.53
Two-way Left-Turn Lane	1122	10.59	375	21.13	234	27.43

Table 9, continued

Variable Description	Corridor Commercial Driveway-related Crashes		Corridor Commercial Driveway-related Ped/Bike Crashes		Interchange Commercial Driveway-related Crashes	
	Total	%	Total	%	Total	%
Median Opening Type						
No Physical Median	2041	19.26	82	8.74	60	7.03
No Opening	5982	56.46	639	68.12	436	51.11
Directional Opening	846	7.98	59	6.29	72	8.44
Full Median Opening	1727	16.30	158	16.84	285	33.41
Driveway Characteristics Variable						
Driveway Design						
Flush Radial	905	8.54	41	4.37	98	11.49
Curb Radial	2822	26.63	306	32.62	383	44.90
Curb Flare	5619	53.03	463	49.36	254	29.78
Wide-open frontage or Other	1250	11.80	128	13.65	118	13.83
Driveway Number of Lanes						
One	1084	10.23	110	11.73	56	6.57
Two	8639	81.53	773	82.41	676	79.25
Three	456	4.30	28	2.99	89	10.43
Four or more	417	3.94	27	2.88	32	3.75

Table 9, continued

Variable Description	Corridor Commercial Driveway-related Crashes		Corridor Commercial Driveway-related Ped/Bike Crashes		Interchange Commercial Driveway-related Crashes	
	Total	%	Total	%	Total	%
Driveway Traffic Operations						
One-way Entry	484	4.57	41	4.37	542	63.54
One-way Exit	435	4.11	52	5.54	19	2.23
Right-in/Right-out	7048	66.52	626	66.74	42	4.92
Right-in/Left-in	641	6.05	54	5.76	440	51.58
Full Traffic Movement	1851	17.47	152	16.20	68	7.97
Left-in/Left-out	137	1.29	13	1.39	0	0.00
Driveway Channelization						
None	6634	62.61	608	64.82	482	56.51
Painted/Island	3962	37.39	330	35.18	371	43.49
Traffic Control at Driveway						
None	5478	51.70	475	50.64	398	46.66
Sign	4854	45.81	425	45.31	413	48.42
Traffic Signal	264	2.49	38	4.05	42	4.92
Right-turn Lane Type						
Exclusive Right-turn	457	4.31	30	3.20	26	3.05
Shared/Continuous Right-turn Lane	871	8.22	60	6.72	35	4.10
No Right-turn Lane	9268	87.47	845	90.09	698	81.83
Driveway Throat Length						0.00
Adequate	5958	56.23	475	50.75	443	51.93
Short	2764	26.09	267	28.46	147	17.23
None	1874	17.69	195	20.79	263	30.83

Table 9, continued

Variable Description	Corridor Commercial Driveway-related Crashes		Corridor Commercial Driveway-related Ped/Bike Crashes		Interchange Commercial Driveway-related Crashes	
	Total	%	Total	%	Total	%
Temporary Closure						0.00
None	10349	97.67	926	98.72	841	98.59
Work Zone	98	0.92	5	0.53	3	0.35
Other	149	1.41	7	0.75	9	1.06
Non-Motorist Facility Characteristics						
Bike Lane Type						0.00
No Exclusive	6289	59.35	476	50.75	497	58.26
Conventional	2522	23.80	267	28.46	269	31.54
Other Types of Bike Lane (e.g., buffered, keyhole lane, etc.)	1785	16.85	195	20.79	87	10.20
Bike Lane Paint						
N/A	6238	58.87	434	46.27	497	58.26
No	3019	28.49	322	34.33	90	10.55
Yes	1339	12.64	182	19.40	266	31.18
Sidewalk						
Not Available	107	1.01	9	0.96	153	17.94
Available	10489	98.99	929	99.04	700	82.06
Marked Crosswalk						
Not Available	9503	89.68	820	87.42	638	74.79
Available	1093	10.32	118	12.58	215	25.21
Pedestrian Crossing Signal						
Not Available	10424	98.38	910	97.01	852	99.88
Available	172	1.62	28	2.99	1	0.12

Table 9, continued

Variable Description	Corridor Commercial Driveway-related Crashes		Corridor Commercial Driveway-related Ped/Bike Crashes		Interchange Commercial Driveway-related Crashes	
	Total	%	Total	%	Total	%
Pedestrian Refuge Island						
Not Available	10494	99.04	931	99.25	851	99.77
Available	102	0.96	7	0.75	2	0.23
Interchange Characteristics						
First driveway after off-ramp OR Last driveway before on-ramp						
No					576	67.53
Yes					277	32.47
Connecting Ramp Type						
On-ramp					430	50.41
Off-ramp					423	49.59
Nearby Interchange Configuration						
Partial Cloverleaf					264	30.95
Diamond					502	58.85
Partial Diamond					62	7.27
Other					25	2.93
Interchange Ramp Terminal Type						
Free Flow					196	22.98
Stop/Yield Control					414	48.53
Signalized Control					243	28.49
Frontage Road						
No					829	97.19
Yes					24	2.81

Table 9, continued

Variable Description	Corridor Commercial Driveway-related Crashes		Corridor Commercial Driveway-related Ped/Bike Crashes		Interchange Commercial Driveway-related Crashes	
	Total	%	Total	%	Total	%
Distance from ramp taper end to each unsignalized or signalized driveway						
≤500 ft					440	51.58
501 -1000 ft					280	32.83
1001 – 1500 ft					90	10.55
1501 – 2000 ft					38	4.45
>2001 ft					5	0.59
Distance from off-ramp taper end to the first full median opening (only applies to off-ramp)						
No full median opening exists within interchange influence area					368	43.14
≤500 ft					320	37.51
501 -1000 ft					93	10.90
1001 - 1500 ft					49	5.74
1501 - 2000 ft					23	2.70
>2000 ft					0	0.00

5.1.2 Significance Tests on Driveway Crash Distribution

Significance tests were conducted to examine the statistical difference in crash frequency relative to the potential contributing factors by comparing the sample means. The data were first tested using the analysis of variance (ANOVA) method to identify differences across sample means of different values of a variable. If a significant difference was found, a paired t-test was then performed to further identify which pair(s) of two sample means were different. A p-value (p=0.05) was used to determine if the difference between the two compared groups was significant in explaining the number of crashes at driveways at a 5% significance level (95% confidence).

The ANOVA and paired t-tests are the accepted analysis procedures to test statistical differences in responses across different groups (e.g., the significance of differences in average numbers of crashes at driveway groups with respect to posted speed limits on the connecting street), and the most robust methods where the sample size across different groups is equal. However, as shown in Table 8, the same dataset has different numbers of driveways for different categorical values of the same variable (e.g., posted speed limit). It is impossible to control the data review process and only review the same number of records for all without introducing significant bias in the modeling analysis. Therefore, for this study, the significance test was used as additive to the crash frequency modeling analysis, and tests were only conducted with respect to the identified significant variables, such as those listed in Table 10. See Section 5.2 for more detailed explanation and discussion.

5.2 Crash Frequency Analysis for Commercial Driveways along Corridors

5.2.1 Crash Frequency Analysis for All Vehicular Crashes

First, a negative binomial model along with Type 3 analysis was used to identify factors that significantly increase or decrease the crash frequency at commercial driveways along corridors. Using the Chi-squared significance test and based on the p-value (Pr>ChiSq), six variables were found to explain the difference in vehicular crash numbers at commercial driveways at a 5% significance level (p=0.05): Number of Lanes on Connecting Street, Posted Speed Limit on Connecting Street, Driveway Design Feature, Driveway Number of Lanes, Median Type, and Connecting Street 5-year AADT (see Table 4). Next, differences in the categorical values under each of these significant variables were further evaluated using the negative binomial logit approach to explore their implications on crash frequency. The results are shown in Table 5, and findings for variables found to be significant predictors of crash frequency at commercial driveways along corridors are summarized below.

- **Number of Lanes on Connecting Street**: This variable compares the influence of the number of lanes on the connecting street in the primary travel direction on commercial driveway crashes, with one lane as the base condition. In this comparison, commercial driveways connecting with two lanes (0.5019), three lanes (0.7791), and four or more lanes (1.0746) in the primary direction had more crashes than those connecting to one lane, as indicated by the positive estimated coefficients. The odds ratio statistics further explain that the average number of crashes at commercial driveways on connecting streets with two lanes, three lanes, and four or more lanes in the primary direction were 1.65 times, 2.18 times, and 2.93 times higher than the average number of crashes at commercial driveways with only one lane on the connecting street. These results are understandable as the number of lanes is a surrogate for roadway AADT, and the greater number of lanes also suggests increased lane changing behavior and more potential conflicts between through traffic and driveway traffic.

- **Speed Limit on Connecting Street**: Compared to a posted speed limit of 35 mph or lower as the base condition, commercial driveways on connecting streets with a posted speed limit of 40-45 mph or 50 mph and higher tended to have fewer crashes. The odds ratio statistics indicated that the commercial driveway crash frequency tended to be 15.2% lower (1 − 0.8476) at a speed limit of 40-45 mph and 44.9% (1 − 0.5508) lower at a speed limit of 50 mph and higher. A possible explanation could be that higher speed limits usually indicate greater levels of access control and relatively less access density than roads with lower speeds. Alternatively, roadways with lower speed limits generally have higher access densities, more complex traffic conditions, such as multimodal traffic conditions or more non-motorist traffic, leading to more potential conflicts at driveways.
- **Driveway Design Feature**: With curb flare design as the base condition, commercial driveways with flush radial design were found on average to have 39.8% (1.3978 − 1) more crashes. Those with curb radial design had on average 24.7% (1.2466 − 1) more crashes, and those with wide-open access or other infrequently encountered types of entry design tended to have 37.4% fewer crashes on average. According to the FDOT Access Management Guidebook (FDOT, 2019) and FDOT Design Manual Section 214 - Driveways (FDOT, 2020), the type of driveway design needed is based on roadway type and driveway traffic volumes. Flared driveways are used on curbed roadways where driveway traffic does not exceed 600 trips per day or 60 trips per hour, whereas radial return designs are generally used on all flush shoulder roadways and curbed roadways with driveway traffic greater than 600 trips per day. Flared or radial return designs are also associated with vehicle turning movements at driveways as well as driveway entry/exit speed, and large radius or flare allows for quick and more efficient ingress and egress but may pose increased threat to non-motorist traffic crossing the driveway.
- **Driveway Number of Lanes**: With one-lane, one-way driveways as the base condition, driveways with two lanes, three lanes, and four or more lanes or wide-open access had on average 26.5%, 179.2%, and 57.5% more crashes, respectively. This is because driveways with multiple lanes or wide-open access can experience more complex traffic movements with increased potential for conflicts. Driveway number of lanes could be treated as a surrogate measure for driveway volume, and driveways with a larger number of lanes typically have higher volumes. Multiple lanes on driveways are also often associated with directional or full median openings, while single-lane driveways are generally interacting with only one direction of traffic on the connecting street and no median openings, which can also contribute to differences in driveway crash frequencies.
- **Median Type**: Using undivided or painted median as the base condition, non-traversable medians were found to decrease the average number of crashes at commercial driveways by about 19.9%, and two-way left turn lanes (TWLTLs) decreased the average number of crashes at commercial driveways by 24.7%. Note that the findings are based on direct comparison with the base condition (undivided or painted median) and the percentage value difference does not necessarily explain the effects of the two non-base conditions (non-traversable median vs TWLTLs) as they were not directly compared in the model. Non-traversable medians, such as grass or curbs, improve driveway safety more than an undivided or painted median as they provide physical barriers that limit turning movements for both through traffic and driveway traffic. The variable "non-traversable median" also includes all opening types (i.e., no opening, directional opening, and full opening with or without left-turn lanes) each of which create different numbers of potential traffic conflict points at the driveway sites. With an undivided or painted median, through traffic will slow/stop on the road to turn into a driveway and driveway traffic can turn left into opposing through traffic, causing significant collision risk. Two-way left turn lanes provide space for turning vehicles to slow down, stop and wait to turn into a driveway without blocking

through lanes and provide a waiting zone for vehicles turning left out of a driveway to merge into the opposing lanes, hence reducing potential traffic conflicts.

- **Connecting Street 5-year Average AADT:** For this variable, the lowest AADT category, AADT<10,000, was used as the base condition for the modeling analysis. Although the average number of crashes at commercial driveways tended to increase for all of the AADT categories, as indicated by the positive estimated coefficients, only 30,000<AADT≤40,000 was shown to have significantly higher crash frequencies at a 5% significance level, as indicated by the p-value (0.0449).

Table 10. Significant Variables for Crash Frequency Prediction at Commercial Driveways along Corridors (All Vehicular Crashes)

Variables	Degree of Freedom	Chi-Square	Pr > ChiSq
Number of Lanes on Connecting Street	3	115.02	<.0001
Speed Limit of Connecting Street	2	34.88	<.0001
Driveway Design Feature	3	130.52	<.0001
Driveway Number of Lanes	3	71.54	<.0001
Median Type	2	22.39	<.0001
Connecting Street 5-year Average AADT	6	88.69	<.0001

Table 11. Negative Binomial Modeling Results on Crash Frequency at Commercial Driveways along Corridors (All Crashes)

Parameter	Estimate	Std Error	Odds Ratio	Wald Chi-Square	Pr > ChiSq
Intercept	−1.6498	0.6509	0.1921	6.42	0.0113
Number of Lanes on Connecting Street (One-way, including all lanes)					
One Lane*					
Two Lanes	0.5019	0.1348	1.6519	13.86	0.0002
Three Lanes	0.7791	0.1373	2.1795	32.19	<.0001
Four Lanes or More	1.0746	0.1416	2.9288	57.6	<.0001
Speed Limit of Connecting Street					
35 mph and lower*					
40-45 mph	−0.1653	0.048	0.8476	11.87	0.0006
50 mph or higher	−0.5964	0.1023	0.5508	34	<.0001
Driveway Design Feature					
Curb Flare*					
Flush Radial	0.3349	0.0806	1.3978	17.28	<.0001
Curb Radial	0.2204	0.046	1.2466	23	<.0001
Wide open frontage access and other	−0.4679	0.0582	0.6263	64.65	<.0001

Table 11, continued

Parameter	Estimate	Std Error	Odds Ratio	Wald Chi-Square	Pr > ChiSq
Driveway Number of Lanes (including both directions if available)					
One Lane*					
Two Lanes	0.2353	0.0557	1.2653	17.82	<.0001
Three Lanes	1.0267	0.135	2.7918	57.87	<.0001
Four Lanes or more or Wide-open Access	0.4544	0.1091	1.5752	17.34	<.0001
Median Type					
Undivided or Painted Median*					
Nontraversable Median (Grass, Curb, etc.)	−0.2211	0.0578	0.8016	14.66	0.0001
Two-way Left Turn Lane	−0.2843	0.0673	0.7525	17.86	<.0001
Connecting Street 5-year Average AADT					
AADT≤10,000*					
10,000<AADT≤20,000	0.9677	0.6423	2.6319	2.27	0.1319
20,000<AADT≤30,000	1.0647	0.6367	2.9000	2.8	0.0945
30,000<AADT≤40,000	1.2757	0.6362	3.5812	4.02	0.0449
40,000<AADT≤50,000	1.0073	0.636	2.7382	2.51	0.1132
50,000<AADT≤60,000	0.6426	0.6382	1.9014	1.01	0.314
60,000<AADT≤70,000	0.8363	0.6404	2.3078	1.71	0.1916
Dispersion	2.0079	0.0554			

* Indicates base condition used for analysis.

The above results were presented based on the same base condition in each variable, but the comparative effects among other non-base variables were not revealed. For example, all results shown above for Number of Lanes on Connecting Street were comparative results to "One Lane" as the base category. Additional analysis was done using through ANOVA and paired T-test analyses to determine if significant differences occurred among any two "Two Lanes", "Three Lanes" and "Four Lanes or More" conditions. Significant differences in the average number of crashes at commercial driveways along corridors were found at a 5% significance level for the following comparisons. (NOTE: All values were calculated using the average number of crashes of the former category minus the average number of crashes of the latter category.)

- **Number of Lanes on Connecting Street:** all three paired comparisons were significant.
  - Two Lane versus Three Lane: the difference in the average number of crashes at commercial driveways was −0.1739 with p-value=0.0024
  - Two Lanes vs. Four Lanes or More: the difference in the average number of crashes at commercial driveways was −0.3646 with p-value<0.0001
  - Three Lanes vs. Four Lanes: the difference in the average number of crashes at commercial driveways was -0.1907 with p-value<0.0001
- **Posted Speed Limit**
  - 40-45 mph versus 50 mph or higher: the difference in the average number of crashes at commercial driveways was 0.2242 with p-value=0.0045

- **Driveway Design**: all three paired comparisons were significant.
  - Flush Radial vs. Curb Radial: the difference in the average number of crashes at commercial driveways was −0.3167 with p-value=0.0124
  - Flush Radial vs. Wide-open access and other: the difference in the average number of crashes at commercial driveways was 0.4264 with p-value<0.0001
  - Curb Radial vs. Wide-open access and other: the difference in the average number of crashes at commercial driveways was 0.7431 with p-value<0.0001

- **Driveway Number of Lanes:** two of the three paired comparisons were significant.
  - Two Lanes vs Three Lanes: the difference in the average number of crashes at commercial driveways was −0.00621 with p-value=0.9912
  - Two Lanes vs Four Lanes or more or Wide-open Access: the difference in the average number of crashes at commercial driveways was 1.8634 with p-value<0.0001
  - Three Lanes vs Four Lanes or more or Wide-open Access: the difference in the average number of crashes at commercial driveways was 1.8696 with p-value<0.0001

- **Median Type**
  - Non-traversable Median vs Two-Way Left-Turn Lane: the difference in the average number of crashes at commercial driveways was 0.1948 with p-value=0.0295

- **Connecting Street 5-year Average AADT:** 5 out of 15 paired comparison groups were significant. NOTE: When interpreting these comparisons note that the closing square brackets denote inclusion of the adjacent value and closing parenthesis brackets denote exclusion of the adjacent value. Therefore, (10,000, 20,000] means 10,000<AADT≤20,000, where AADT=10,000 is not included in this range but AADT=20,000 is included.
  - (10,000, 20,000] vs (30,000, 40,000]: the difference in the average number of crashes at commercial driveways was -0.6314 with p-value<0.0001
  - (20,000, 30,000] vs (30,000, 40,000]: the difference in the average number of crashes at commercial driveways was -0.5397 with p-value=0.0002
  - (30,000, 40,000] vs (40,000, 50,000]: the difference in the average number of crashes at commercial driveway was 0.4236 with p-value=0.0033
  - (30,000, 40,000] vs (50,000, 60,000]: the difference in the average number of crashes at commercial driveways was 0.6395 with p-value<0.0001
  - (30,000, 40,000] vs (60,000, 70,000]: the difference in the average number of crashes at commercial driveways was 0.5519 with p-value<0.0001

Table 12. Vehicular Crash Frequency at Commercial Driveways along Corridors Using ANOVA and Paired T-test of Significant Variables

Variable	Testing Method	Difference (Former minus Latter)	F-Value (ANOVA) Or T-value (for T-test)	P-Value	Significant at 5% Level?
Number of Lanes on Connecting Street	ANOVA, Comparing Multiple Groups	N/A	17.2	<.0001	Yes
	T-test, Two Lanes vs. Three Lanes	−0.1739	−3.03	0.0024	Yes
	T-test, Two Lanes vs. Four Lanes or More	−0.3646	−5.91	<.0001	Yes
	T-test, Three Lanes vs. Four Lanes	−0.1907	−2.84	<.0001	Yes
Posted Speed Limit	ANOVA, 40-45mph vs 50 mph or higher	0.2242	4.15	0.0045	Yes
Driveway Design	ANOVA, Comparing Multiple Groups	N/A	19.88	<.0001	Yes
	T-test, Flush Radial vs. Curb Radial	−0.3167	−2.5	0.0124	Yes
	T-test, Flush Radial vs. Wide-open access and other	0.4264	4.16	<.0001	Yes
	T-test, Curb Radial vs. Wide-open access and other	0.7431	5.98	<.0001	Yes
Driveway Number of Lanes	ANOVA, Comparing Multiple Groups	N/A	10.3	<.0001	Yes
	T-test, Two Lanes vs Three Lanes	−0.00621	−0.01	0.9912	No
	T-test, Two Lanes vs Four Lanes or more or Wide-open Access	1.8634	3.94	<0.0001	Yes
	T-test, Three Lanes vs Four Lanes or more or Wide-open Access	1.8696	5.13	<.0001	Yes
Median Type	ANOVA, Non-traversable Median vs Two-way Left Turn Lane	0.1948	4.75	0.0295	Yes

Table 12, continued

Variable	Testing Method	Difference (Former minus Latter)	F-Value (ANOVA) Or T-value (for T-test)	P-Value	Significant at 5% Level?
AADT	ANOVA, Comparing Multiple Groups	N/A	6.11	<.0001	Yes
	T-test, (10,000, 20,000] vs (20,000, 30,000]	−0.0916	−0.73	0.4676	No
	T-test, (10,000, 20,000] vs (30,000, 40,000]	−0.6314	−4.75	<.0001	Yes
	T-test, (10,000, 20,000] vs (40,000, 50,000]	−0.2077	−1.64	0.1008	No
	T-test, (10,000, 20,000] vs (50,000, 60,000]	0.00815	0.06	0.9522	No
	T-test, (10,000, 20,000] vs (60,000, 70,000]	−0.0794	−0.65	0.513	No
	T-test, (20,000, 30,000] vs (30,000, 40,000]	−0.5397	−3.76	0.0002	Yes
	T-test, (20,000, 30,000] vs (40,000, 50,000]	−0.1161	−0.84	0.3993	No
	T-test, (20,000, 30,000] vs (50,000, 60,000]	0.0998	0.68	0.4953	No
	T-test, (20,000, 30,000] vs (60,000, 70,000]	0.0122	0.09	0.9268	No
	T-test, (30,000, 40,000] vs (40,000, 50,000]	0.4236	2.95	0.0033	Yes
	T-test, (30,000, 40,000] vs (50,000, 60,000]	0.6395	4.2	<.0001	Yes
	T-test, (30,000, 40,000] vs (60,000, 70,000]	0.5519	3.96	<.0001	Yes
	T-test, (40,000, 50,000] vs (50,000, 60,000]	0.2159	1.47	0.1412	No
	T-test, (40,000, 50,000] vs (60,000, 70,000]	0.1283	0.96	0.3362	No
	T-test, (50,000, 60,000] vs (60,000, 70,000]	−0.0876	−0.62	0.5382	No

5.2.2 Crash Frequency Analysis for Pedestrian and Bicycle Crashes

Similarly, negative binomial modeling and significance tests were also used to analyze pedestrian and bicycle crash frequency at commercial driveways along major corridors, identify the significant variables, and estimate their influence. Modeling analysis results are presented in Table 13, Table 14, and Table 15. As shown in Table 13, a total of five variables was found to be significant in determining the number of pedestrian/bicycle crashes at commercial driveways along corridors at a 5% significance level, including Number of Lanes on Connecting Street, Driveway Design Feature, Median Opening Type, Traffic Control Device, and Painted Bike Lane. Looking into more detail using the negative binomial model, Table 14 presents the estimated influence on pedestrian/bicycle crash frequency at commercial driveways of these significant variables for each categorical value. Findings for these significant variables are summarized below.

- **Number of Lanes on Connecting Street**: Overall this variable was significant in explaining the number of crashes at driveways, but detailed modeling shows that none of the detailed lane numbers is statistically significant when compared with one-lane as the base. Using odds ratio statistics, we found that commercial driveways connecting with two lanes (76.1% higher), three lanes (47.47% higher), and four or more lanes in the primary direction (32.3% higher) tend to induce more crashes compared to a connecting street with one lane in the primary travel direction. As noted in Section 5.2.1, the number of lanes on the connecting street is a surrogate indicator for roadway AADT, which increases pedestrian and bicycle exposure to traffic. More lanes on a connecting street also entail longer crossing times and greater exposure of pedestrians or bicyclists to through-traffic conflicts.
- **Driveway Design Feature**: Compared to curb flare design as the base condition, commercial driveways with flush radial design tended to have 52% fewer pedestrian/bicycle crashes , while those with curb radial design tended to have 35.2% more pedestrian/bicycle crashes. Wide-open access or other rare types were not found to be significant on pedestrian//bicycle crash frequency. Based on the applicability of different types of driveway designs in FDOT Design Manual (2020) Section 214-Driveway and Section 222-Pedestrian Facilities, radial return designs are generally used on all flush shoulder roadways and curbed roadways with driveway traffic greater than 600 trips per day. In addition, sidewalks on flush shoulder roadways are not to be constructed directly adjacent to the roadway or shoulder pavement and rather are preferred to be placed outside the clear zone or five feet beyond the shoulder pavement to provide adequate protection for pedestrians or bicyclists. Therefore, flush radial and curb radial designs are likely to introduce more pedestrian/bicycle crashes when compared with curb flare design.
- **Median Opening Type**: Compared with no physical median at the driveway site, locations with a physical median with no opening had 21.3% fewer pedestrian/bicycle crashes and those with a directional median opening tended to have 36.9% fewer pedestrian/bicycle crashes. Full opening was not found to be significant statistically, and the estimated positive coefficient indicates an increase in pedestrian/bicycle crash frequency. These results are understandable, because no median opening or a directional median opening prohibit or limit vehicular turning movements thereby reducing driveway conflicts and a physical median reduces exposure of pedestrians and cyclists to through traffic while crossing. Roadways with no physical median (i.e., undivided or painted median) or locations with full median openings increase exposure of non-motorist traffic to through traffic and vehicular turning conflicts when crossing the connecting street or commercial driveway.
- **Traffic Control Device:** Compared to commercial driveway sites with no traffic control devices, those with sign control had a 52.2% higher average number of pedestrian/bicycle crashes, and those with traffic signals had a 137.9% higher average number of pedestrian/bicycle crashes. Potential explanations are that the absence of traffic control devices is associated with driveways having lower traffic volumes, whereas the presence of these devices is associated with higher volume driveways that generate more traffic conflicts – the purpose of installing the device is to reduce the crash potential at higher volume driveways. Nonetheless, there is still a higher crash potential compared to driveway sites without traffic control devices.
- **Painted Bike Lane:** Compared to no bike lane on the connecting street as the base condition, commercial driveways crossed by a standard bike lane without color paint had an average of

39.7% more pedestrian/bicycle crashes and this effect was significant. A possible reason for this finding is that, if there is no bike lane, pedestrians and bicyclists will use the sidewalk if available, which reduces their exposure to through traffic. Sidewalks also provide a waiting area for bicyclists when motor vehicles are turning into or out of the driveway site. However, if a standard unpainted bike lane is available, bicyclists will generally use the bike lane to travel. In turn, motor vehicles need to cross the bike lane when turning into or out of the driveway and may overlook the bicyclists in the absence of color paint to alert them that bicyclists may be present.

Table 13. Significant Variables for Ped/Bike Crash Frequency Prediction at Commercial Driveways along Corridors

Source	Degree of Freedom	Chi-Square	Pr > ChiSq
Number of Lanes on Connecting Street	3	8.28	0.0406
Driveway Design Feature	3	42.66	<.0001
Median Opening Type	3	11.65	0.0087
Traffic Control Device	2	33.33	<.0001
Painted Bike Lane	2	15.84	0.0004

Table 14. Negative Binomial Modeling Results for Ped/Bike Crash Frequency at Commercial Driveways along Corridors

Parameter	Estimate	Std Error	Odds Ratio	Wald Chi-Square	Pr > ChiSq
Intercept	−2.6027	0.3043	0.0741	73.14	<.0001
Number of Lanes on Connecting Street (One-way, including all lanes)					
One Lane*					
Two Lanes	0.5657	0.3071	1.7607	3.39	0.0655
Three Lanes	0.39	0.3061	1.4770	1.62	0.2025
Four Lanes or More	0.2801	0.3107	1.3233	0.81	0.3673
Driveway Design Feature					
Curb Flare*					
Flush Radial	−0.733	0.1744	0.4805	17.67	<.0001
Curb Radial	0.3014	0.0895	1.3517	11.34	0.0008
Wide-open Access and Other	−0.1407	0.1195	0.8687	1.39	0.2389
Median Opening Type					
No Physical Median*					
No Opening	−0.2392	0.1118	0.7873	4.58	0.0323
Directional Opening	−0.4607	0.1721	0.6308	7.17	0.0074
Full Median Opening	0.0464	0.135	1.0475	0.12	0.7313
Traffic Control Device					
No Control*					
Sign Control	0.4202	0.0805	1.5223	27.28	<.0001
Signal Control	0.8666	0.2318	2.3788	13.98	0.0002

Table 14, continued

Parameter	Estimate	Std Error	Odds Ratio	Wald Chi-Square	Pr > ChiSq
Painted Bike Lane					
Not Applicable (if no bike lane)*					
Not Painted	0.3341	0.0833	1.3967	16.11	<.0001
Painted	0.1275	0.1043	1.1360	1.49	0.2216
Dispersion	1.2514	0.1978			

* Indicates the base condition used for analysis.

ANOVA and paired T-test analyses were again used to assess the significance of differences in the average number of pedestrian/bicycle crashes at commercial driveways along corridors between any paired categorical values in the same variable. All of these values were calculated using the average number of pedestrian/bicycle crashes of the former category minus the average number of crashes of the latter category.

- **Number of Lanes on Connecting Street:** none of the three paired comparisons were significant.
- **Driveway Design**: all three paired comparisons were significant.
    - Flush Radial vs. Curb Radial: the difference in the average number of crashes at commercial driveways is −0.1312 with p-value<0.0001.
    - Flush Radial vs. Wide-open Access and Other: the difference in the average number of crashes at commercial driveways was −0.0362 with p-value=0.0256.
    - Curb Radial vs. Wide-open Access and Other: the difference in the average number of crashes at commercial driveways was 0.095 with p-value<0.0001.
- **Driveway Number of Lanes:** two of the three paired comparisons were significant.
    - Two Lanes vs Three Lanes: the difference in the average number of crashes at commercial driveways was −0.00621 with p-value=0.9912.
    - Two Lanes vs Four Lanes or more or Wide-open Access: the difference in average number of crashes at commercial driveways was 1.8634 with p-value<0.0001.
    - Three Lanes vs Four Lanes or more or Wide-open Access: the difference in the average number of crashes at commercial driveways was 1.8696 with p-value<0.0001.
- **Median Opening Type:** two of the three paired comparisons were significant.
    - No Opening vs. Full Opening: the difference in the average number of crashes at commercial driveways was −0.0783 with p-value=0.0107.
    - Directional Opening vs. Full Opening: the difference in the average number of crashes at commercial driveways was −0.0922 with p-value=0.002.

- **Traffic Control Device**
    - Sign Control vs Signal Control: the difference in the average number of crashes at commercial driveways was −0.1887 with p-value=0.0228.
- **Painted Bike Lane:** the Painted vs Not Painted comparison was not found to be significantly different.

Table 15. Significant Variables for Determining Ped/Bike Crash Frequency at Commercial Driveways along Corridors using ANOVA and T-test

Variable	Testing Method	Difference	F-Value (ANOVA) Or T-value (for T-test)	P-Value	Significant at 5% Level?
Number of Lanes on Connecting Street	ANOVA, Comparing Multiple Groups	N/A	1.85	0.1573	No
	T-test, Two Lanes vs. Three Lanes	0.0187	1.18	0.2381	No
	T-test, Two Lanes vs. Four Lanes or More	0.0281	1.86	0.0624	No
	T-test, Three Lanes vs. Four Lanes	0.0936	0.69	0.4905	No
Driveway Design	ANOVA, Comparing Multiple Groups	N/A	21.12	<.0001	Yes
	T-test, Flush Radial vs. Curb Radial	−0.1312	−5.97	<.0001	Yes
	T-test, Flush Radial vs. Wide-open access and other	−0.0362	−2.24	0.0256	Yes
	T-test, Curb Radial vs. Wide-open access and other	0.095	4.01	<.0001	Yes
Median Opening Type	ANOVA, Comparing Multiple Groups	N/A	6.57	0.0014	Yes
	T-test, No Opening vs. Directional Opening	0.0139	0.67	0.5057	No
	T-test, No Opening vs. Full Opening	−0.0783	−2.56	0.0107	Yes
	T-test, Directional Opening vs. Full Opening	−0.0922	−3.1	0.002	Yes
Traffic Control	ANOVA, Sign Control vs Signal Control	−0.1887	5.26	0.0228	Yes
Bike Paint	ANOVA, Not Painted vs Painted	0.0226	1.71	0.1911	No

5.3 Crash Severity Analysis for Commercial Driveways along Major Corridors

5.3.1 Crash Severity Analysis for All Crashes

Results of the multinomial logit modeling and average pseudo-elasticity estimation results are provided in Table 16 and Table 17, respectively. When a crash occurs, it has the possibility to receive any of the three injury severity levels, and the sum of the three probabilities is always equal to 100%. However, the three severity levels are exclusive of each other, and the crash will only have one severity level based on the actual crash outcome. Therefore, in the elasticity analysis, a factor that is found to increase the potential of a specific injury severity level will reduce the potential of the other one or two severity levels.

Using No Injury (NI) as the base condition, a total of 12 variables were found to be significant in determining Minor Injury (MI) or Severe Injury (SI) or both at a 5% significance level. Detailed discussions are presented below.

- **Type of Shoulder**: Table 16 indicates that an unpaved shoulder is a significant predictor of minor injury crashes, and a curb shoulder is a significant predictor of both minor injury and severe injury crashes. The average pseudo-elasticity results in Table 17 show that the presence of an unpaved shoulder increases the risk of minor injury by 16.4% and reduces the risk of no injury and severe injury by 6.7% and 7.6% accordingly. The presence of a curb shoulder significantly increases the risk of minor injury by 33.6% and the risk of severe injury by 79.3%. These results suggest that it may be necessary to reconsider the installation of curb shoulders at commercial driveways near interchanges, possibly because vehicular traffic near interchanges is generally relatively high speed, and vehicles turning at the driveways may be prone to hitting or running over the curb and colliding with other road users or objects.
- **Weather Condition**: Cloudy weather significantly increased the probability of minor injury crashes by 12.1% and reduced the potential of the other injury severity levels accordingly. On the other hand, rainy weather significantly reduced the potential for severe injury crashes by 59.3%. A possible reason for the findings on rainy weather is that drivers tend to be more cautious and drive at relatively slower speeds in inclement weather, thereby reducing the potential for severe crashes.
- **Lighting Condition**: For this variable, daylight condition at crash time was found to significantly reduce the risk of severe injury crashes by 29.8% and slightly increase the risks of the other two injury severity levels by 2%. This result verifies that daylight or sufficient lighting conditions are critical to ensure good visibility and reduce crash severity.
- **Speed Limit on Connecting Street**: Lower speed limits tend to significantly reduce the probabilities of minor injury and severe injury crashes. The elasticity results showed that a speed limit of 35 mph or lower significantly reduced the probability of minor injury crashes by 27.5% and also reduced the probability of severe injury crashes by 69.9%. Similarly, a speed limit of 40 or 45 mph also significantly reduced the potential of minor injury crashes by 18.1% and the potential of severe injury crashes by 43.6%. These results are expected as lower speed limits create less kinetic energy upon collision and therefore less impact on the body.
- **Right-Turn Lane Type:** For right-turn lane type, the presence of a shared/continuous right-turn lane was found to significantly reduce the probability of severe injury crashes by 35.3%, while slightly increasing the risk of the other severity levels by less than 2%. This result is understandable given that vehicles on shared right-turn lanes tend to be travelling at lower speeds

than those in the through lanes and drivers tend to travel more carefully over longer distances while attempting to locate their target driveways than do those on exclusive right-turn lanes, where the point of entry is more obvious.

- **Driveway Design Feature**: Flush radial design was found to significantly increase the potential for minor injury crashes by 20.5%, while curb flare design was significant in decreasing the potential for minor injury by 15.6% and for severe injury by 43.0%. As previously mentioned, flush radial design is generally used to allow efficient turning movements at driveways at relatively high speeds. Therefore, a crash at a driveway with flush radial design generally induces more collision impact. Curb flare design at driveways generally indicates lower daily driveway traffic than other design types, and curb delineation at driveway sites forces drivers to slow down and make turns cautiously, hence reducing injury severities.
- **Driveway Traffic Operations**: Full traffic movement at commercial driveways was found to significantly increased the potential of minor injury crashes by 17.3%. In addition, left-in/left-out only traffic movement at driveways significantly reduced the risk of minor injury crashes by 34.5%. Therefore, although full traffic movement may offer more traffic mobility at driveways, it also increases the potential risk of minor injuries. Left-in/left-out only movement limits the number of potential conflicts but still has the potential for angle collisions between through traffic and vehicles turning into and out of the driveway.
- **Driveway Channelization:** As expected, driveway channelization is statistically significant in reducing the potential of severe injury crashes (by 19.8%). This result verifies the protective effects of driveway channelization by separating opposing traffic flows and preventing encroachments.
- **Bike Lane Type**: As shown in Table 17, having no exclusive bike lane on the connecting street significantly reduced the potential for minor injury crashes by 23.6% for commercial driveway-related crashes along corridors but increase the potential of severe injury/fatality by 14.2%; and similar results were found for conventional bike lanes, which significantly reduced the potential for minor injury crashes by 20.6% but increased the risk for severe injury crashes by 10.4%. These results suggest that a conventional bike lane on a major roadway with commercial driveways is not always safe. Vehicles in the adjacent through lane may easily encroach into the bike lane. A conventional bike lane across a driveway entrance may also increase the risk of rear-end collisions when a leading vehicle slows or stops suddenly to avoid a collision with an approaching bicyclist, or increase the angle-collision risk between through traffic and vehicles turning from median openings, which thereby induces more injuries or higher injury severities.
- **Driveway Throat Length**: A short driveway throat length (less than the length of two vehicles) significantly increased the potential for severe injury crashes by 60.5% while only increasing the potential of minor injury crashes by less than 5%. These results are expected and verify the safety importance of sufficient driveway throat length, which should be considered when feasible.
- **Median Opening Type:** For median opening type, only the no opening configuration was found to be significant, and it reduced the potential for severe injury crashes by 44.5%. This is reasonable since no opening in the physical median would prevent left-turn movements at the driveway and thereby reduce the potential for angle or head-on collisions – two major crash types causing more severe injuries on drivers or passengers.
- **Connecting Street AADT at Crash Year**: The AADT range of $60{,}000 < AADT \le 70{,}000$ is the only category found to be significant, with an estimated 17% increase in the potential of minor injury crashes.

Table 16. Multinomial Logit Modeling Results on All Crash Severity at Commercial Driveways along Corridors

Variable	Specific to Injury Level	Estimated Coefficient	Standard Error	p-value
Intercept	MI	−0.41400***	0.1154	0.0003
Intercept	SI	−1.40017***	0.2194	<0.0001
Type of Shoulder				
Unpaved Shoulder	MI	0.23024**	0.0947	0.0151
Curb	MI	0.46499***	0.0494	<0.0001
Curb	SI	0.76618***	0.1161	<0.0001
Weather Condition				
Cloudy	MI	0.17114***	0.0607	0.0048
Rain	SI	−0.93576***	0.31	0.0025
Lighting Condition				
Daylight	SI	−0.37691***	0.1141	0.001
Speed Limit on Connecting Street				
35mph or lower	MI	−0.52645***	0.1193	<0.0001
40 mph or 45 mph	MI	−0.36094***	0.1101	0.001
35mph or lower	SI	−1.42352***	0.2247	<0.0001
40-45 mph	SI	−0.75224***	0.1934	0.0001
Right Turn Lane Type				
Shared/continuous right turn lane	SI	−0.45683**	0.2206	0.0384
Driveway Design Feature				
Flush Radial	MI	0.28266***	0.1025	0.0058
Curb Flare	MI	−0.28988***	0.0501	<0.0001
Curb Flare	SI	−0.68954***	0.1154	<0.0001
Driveway Traffic Operation				
Full Traffic Movements	MI	0.24027***	0.0576	<0.0001
Left In/Left Out (For One-way Traffic, No Opening or Channelizing Island)	MI	−0.57677**	0.2591	0.026
Driveway Channelization				
With Channelization	SI	−0.23474**	0.1098	0.0325
Bike Lane Type				
No Exclusive Bike Lane	MI	−0.39856***	0.054	<0.0001
Conventional Bike Lane	MI	−0.33005***	0.0722	<0.0001
Driveway Throat Length				
Short Driveway Throat Length	MI	0.10833**	0.0534	0.0425
Short Driveway Throat Length	SI	0.54343***	0.1171	<0.0001

Table 16, continued

Variable	Specific to Injury Level	Estimated Coefficient	Standard Error	p-value
Median Opening Type				
No Opening	SI	−0.62565***	0.1104	<0.0001
Connecting Street AADT at Crash Year				
60,000<AADT≤70,000	MI	0.23940**	0.1057	0.0236
Note: *, **, * ==> Significance at 1%, 5%, 10% level.**				

Table 17. Average Pseudo-elasticity of Significant Variables for All Vehicular Crash Severity at Commercial Driveways along Corridors

Variable	Injury Severity Level		
	NI	MI	SI
Type of Shoulder			
Unpaved Shoulder	−6.7%	16.4%	−7.6%
Curb	−14.5%	33.6%	79.3%
Weather Condition			
Cloudy	−4.9%	12.1%	−5.6%
Rain	2.4%	2.9%	−59.3%
Lighting Condition			
Daylight	1.6%	1.8%	−29.8%
Speed Limit on Connecting Street			
35mph or lower	19.8%	−27.5%	−69.9%
40 mph or 45 mph	14.8%	−18.1%	−43.6%
Right Turn Lane Type			
Shared/Continuous right-turn lane	1.4%	1.7%	−35.3%
Driveway Design			
Flush Radial	−8.3%	20.5%	−9.4%
Curb Flare	11.6%	−15.6%	−43.0%
Driveway Traffic Operation			
Full Traffic Movements	−6.9%	17.3%	−7.7%
Left In/Left Out (For One-way Traffic, No Opening or Channelizing Island)	14.5%	−34.5%	16.8%
Driveway Channelization			
With Channelization	0.9%	1.0%	−19.8%
Bike Lane Type			
No Exclusive Bike Lane	12.4%	−23.6%	14.2%
Conventional Bike Lane	9.1%	−20.6%	10.4%
Driveway Throat Length			
Short Driveway Throat Length	−5.2%	4.7%	60.5%

Table 17, continued

Variable	Injury Severity Level		
	NI	MI	SI
Median Opening Type			
No Opening	2.7%	3.1%	−44.5%
Connecting Street AADT at Crash Year			
60,000<AADT≤70,000	−7.0%	17.0%	−8.0%

<u>5.3.2 Crash Severity Analysis for Pedestrian and Bicycle Crashes</u>

Similar modeling analysis was also conducted to analyze pedestrian and bicycle crash severity at commercial driveways along corridors. Table 12 illustrates the significant factors identified by the multinomial logit model that explain the pedestrian and bicycle crash injury severity outcomes, and Table 13 provides detailed average pseudo-elasticity analysis results for each significant variable. As shown in Table 12, a total of six variables were significant in influencing pedestrian and bicycle crash injury severity at commercial driveways along corridors. These findings are summarized below.

- **Type of Shoulder**: Type of shoulder was found to be a significant factor affecting the pedestrian and bicycle crash severity at commercial driveways along corridors. Specifically, the presence of a paved shoulder significantly reduced the risk of both minor injuries and severe injuries by 2.0% and 37.6%, respectively. These results suggest a significant statistical dependence between paved shoulders and pedestrian/bicycle crash severity reduction. Therefore, paved shoulders should be considered near commercial driveways in areas with high pedestrian/bicycle activity.
- **Alcohol or Drug Involved:** As expected, alcohol or drug involvement either by the driver or the non-motorist or both, significantly increased the risk of severe injuries in commercial driveway crashes. Compared to crashes without alcohol or drug involvement, alcohol involvement increased the potential of severe injury crashes by 208.95%**.** Although not specific to access management per se, this result demonstrates the extremely negative impact of alcohol or drug involvement on traffic safety and verifies the necessity of law enforcement and zero tolerance on driving under the influence (DUI).
- **Driveway Number of Lanes:** Two-lane driveways were found to significantly increase the risk of severe injury in pedestrian and bicycle crashes by 162.2%. Driveways with four or more lanes or wide-open access increased the risk of severe injury in pedestrian and bicycle crashes by 231.5%. A possible reason for these findings is that higher number of lanes on commercial driveways is generally associated with more daily driveway trips and higher non-motorist activity, therefore leading to higher risk for more severe pedestrian/bicycle crashes. These results show a significant dependence between pedestrian and bicycle crash severity and driveway number of lane configuration and are worth further in-depth investigation.
- **Bike Lane Type**: Having no bike lane was found to be a significant factor in reducing the probability of minor injury pedestrian/bicycle crashes by 8.8%; however, the pseudo-elasticity analysis showed that absence of a bike lane increased the risk of severe injury pedestrian/bicycle crashes by 27.1%. These results are reasonable, because bicyclists typically travel on roadway shoulders or sidewalks if there is no bike lane; when a bicycle crash occurs, it is more likely that the bicyclist is traveling next to the travel lane with higher exposure. Therefore, a dedicated bike lane is recommended to reduce pedestrian/bicycle crash severity. These results also verify the

need to conduct both MNL modeling and pseudo-elasticity analysis since the MNL results in Table 12 do not reveal this influence on severe injuries. If there is no bike lane available, it is very likely that bicyclists are traveling on the sidewalk, keeping a distance from mainstream traffic. If bicyclists choose to travel next to the travel lane when there is no bike lane available, crashes are more likely to occur and those that occur are more likely to result in severe injuries or fatalities.

- **Driveway Throat Length**: Insufficient driveway throat length also significantly increased the risk of severe injury pedestrian/bicycle crashes by 46.4%, as shown in Table 13. As with vehicular safety findings, these results verify the importance of sufficient driveway throat length at commercial driveways to pedestrian and bicycle safety along corridors.
- **Connecting Street AADT at Crash Year:** For pedestrian/bicycle crashes at commercial driveways along corridors, the AADT range of (50,000, 60,000) was the only category found to be significant and was estimated to increase the potential for minor injury crashes by 15.5%.

Table 18. Multinomial Logit Modeling Results for Ped/Bike Crash Severity at Commercial Driveways along Corridors

Variable	Specific to Injury Severity	Estimated Coefficient	Standard Error	P-value
Intercept	MI	1.47098***	0.2216	<0.0001
Intercept	SI	−1.36825***	0.4343	0.0016
Type of Shoulder				
Paved Shoulder	MI	−0.45372**	0.1935	0.019
Paved Shoulder	SI	−0.91696***	0.2864	0.0014
Alcohol or Drug Involvement				
Alcohol or Drug Involved	SI	1.54170***	0.596	0.0097
Driveway Number of Lanes				
Two Lanes	MI	0.45875**	0.2218	0.0386
Two Lanes	SI	1.47117***	0.441	0.0008
Four or More OR Wide-open Access	SI	1.68231***	0.6403	0.0086
Bike Lane Type				
No Bike Lane	MI	−0.33891**	0.1485	0.0225
Driveway Throat Length				
Short Throat Length	SI	0.45598**	0.2117	0.0312
Connecting Street AADT at Crash Year				
50,000<AADT≤60,000	MI	0.63122**	0.2514	0.012
Note: *, **, * ==> Significance at 1%, 5%, 10% level.**				

Table 19. Average Pseudo-elasticity of Significant Variables for Ped/Bike Crash Severity at Commercial Driveways along Corridors

Variable	Injury Severity Level		
	NI	MI	SI
Type of Shoulder			
Paved Shoulder	53.3%	−2.0%	−37.6%
Alcohol or Drug Involved			
Alcohol or Drug Involved Crash	−28.56%	−29.54%	208.95%
Driveway Number of Lanes			
Two Lanes	−37.2%	−1.4%	162.2%
Four or More OR Wide-open Access	−31.2%	−32.6%	231.5%
Bike Lane Type			
No Bike Lane	27.5%	−8.8%	27.1%
Driveway Throat Length			
Short Throat Length	−5.7%	−5.9%	46.4%
Connecting Street AADT at Crash Year			
50,000<AADT≤60,000	−38.2%	15.5%	−37.8%

5.4 Crash Frequency and Severity Analysis for Commercial Driveways in the Vicinity of Interchanges

5.4.1 Crash Frequency Analysis for All Crashes

Negative binomial modeling and significance tests were also used to analyze vehicle crash frequency at commercial driveways near interchanges, identify the significant variables, and estimate their influence. The modeling analysis results are presented in Table 20, Table 21, and

Table 22.. As shown in Table 20, seven variables were found to be significant in determining the number of vehicular crashes at commercial driveways near interchanges at a 5% significance level, including Number of Lanes on Connecting Street, Right-Turn Lane Type, Driveway Design Feature, Driveway Number of Lanes, Traffic Control Device, Bike Lane Type, and Connecting Street 5-year Average AADT. Table 21 presents the negative binomial model results for each categorical value of these significant variables. Specific findings are discussed below.

- **Number of Lanes on Connecting Street**: When compared with interchange crossroads (connecting streets) having one lane in the primary travel direction, commercial driveways connecting with two lanes, three lanes, and four or more lanes in the primary direction tended to incur more crashes, but these effects were only significant at a 5% level for three lanes (87.8% higher) and four or more lanes (113.5% higher). As stated previously, the number of lanes on the connecting street is a surrogate indicator for roadway AADT and a higher number of lanes also suggests increased lane changing behavior and more potential conflicts between through traffic and driveway traffic.
- **Right-turn Lane Type**: Compared with exclusive right-turn lanes that serve only one driveway site, shared/continuous right turn lanes were likely to increase the average number of crashes at commercial driveways near interchanges by 99.1%, and a “no right-turn lane” configuration

increased these crashes by 177.9%. In other words, when compared with shared/continuous right-turn lanes, exclusive right-turn lanes were likely to reduce the average number of crashes at commercial driveways near interchanges by 49.7%; similarly, when compared to “no right-turn lane” configuration, exclusive right-turn lanes were likely to reduce the average number of crashes at commercial driveways near interchanges by 64.0%. An explanation for these results is that drivers expect driveway turning movements at locations with exclusive right-turn lanes and turning vehicles are also removed from the through lanes thereby reducing the potential for rear-end collisions. Shared right-turn lanes or locations with no right-turn lane serve more than one driveway site, leading to lower driver expectancy as to where turns will occur and creating a higher potential for conflicts and rear-end collisions. Following drivers may be expecting the leading vehicle to merge onto the interchange ramp rather than slow suddenly before the ramp to turn into a driveway. This effect was identified in the interchange area case studies, as well, and is higher where no right-turn lanes are present, thereby explaining the highest number of crashes for this scenario among the three right-turn lane groups.

- **Driveway Design Feature**: Driveway design features were also significant in determining crash frequency at commercial driveway sites near interchanges, but when compared with curb flare design, only curb radial design had a significant influence and was estimated to increase the average number of crashes by 93.9%. Flush radial design was found to increase the crash frequency and wide-open access was found to reduce the crash frequency, but neither of these influences was significant at a 5% significance level.
- **Traffic Control Device:** Compared with commercial driveway sites near interchanges with no traffic control devices, those with sign control were estimated to have an average of 34.8% more pedestrian/bicycle crashes, and this influence was significant. Similar reasoning can be applied here as was provided for corridors for this variable. Driveways with traffic signals tended to have 25.4% fewer crashes, but this reduction was not statistically significant.
- **Bike Lane Type**: Bike lane type was found to be a significant factor in determining the number of crashes at commercial driveways near interchanges. Using no bike lane on the interchange crossroad as the base condition, conventional bike lanes (without physical separators or surface paint) was found to decrease the average number of crashes at commercial driveways near interchanges by 26.8%, and this estimation was statistically significant at 95% level. Other bike lane types (i.e., buffered bike lane, painted bike lane, contra-flow bike lane, etc.) were found to decrease the average number of crashes at commercial driveways near interchanges by 31.6%, and it was significant at a 90% significance level (p-value=0.0736). The results show that, the presence of a bike lane at commercial driveways near interchanges helps to reduce crash frequency, regardless of bike lane type.
- **Connecting Street 5-year Average AADT:** The 5-year average AADT on the connecting street is significant in predicting the number of crashes at commercial driveways near interchanges. Using AADT<10,000 as the base category, the negative binomial modeling analysis revealed that all other AADT categories tended to have fewer crashes at these driveways, as indicated by the negativity sign of the estimated coefficients as well as the odds ratio statistics, and all of these reduction effects were statistically significant. It is possible that, as the AADT increased on connecting streets, fewer driveways were permitted in the interchange influence area, thereby reducing the average number of driveway-related crashes. Additional research is needed to verify this assumption.

Table 20. Significant Variables for All Vehicular Crash Frequency Prediction at Commercial Driveways near Interchanges

Source	DF	Chi-Square	Pr > ChiSq
Number of Lanes on Connecting Street	3	20.3	0.0001
Right-turn Lane Type	2	11.31	0.004
Driveway Design Feature	3	26.26	<.0001
Driveway Number of Lanes	3	12.4	0.006
Traffic Control Device	2	8.16	0.017
Bike Lane Type	2	7.39	0.025
Connecting Street 5-year Average AADT	5	16.48	0.006

Table 21. Negative Binomial Modeling Results on All Vehicular Crash Frequency at Commercial Driveways near Interchanges

Parameter	Estimate	Std Error	Odds Ratio	Wald Chi-Square	Pr > ChiSq
Intercept	−1.1419	0.4693	0.3192	5.92	0.015
Number of Lanes on Connecting Street (One-way, including all lanes)					
One Lane*					
Two Lanes	0.041	0.2942	1.0419	0.02	0.8891
Three Lanes	0.6302	0.298	1.8780	4.47	0.0345
Four Lanes or More	0.7586	0.3243	2.1353	5.47	0.0193
Right Turn Lane Type					
Exclusive right-turn lane (serves one site)					
Shared/continuous right turn lane (e.g., marked for right turns and serves more than one site)	0.6886	0.3182	1.9909	4.68	0.0304
No right-turn lane (vehicle turns right from through lane, no marking)	1.0221	0.3164	2.7790	10.43	0.0012
Driveway Design Feature					
Curb Flare*					
Flush Radial	0.1837	0.1968	1.2017	0.87	0.3507
Curb Radial	0.6624	0.1461	1.9394	20.54	<.0001
Wide-Open Access and Other	−0.1352	0.1675	0.8735	0.65	0.4193
Driveway Number of Lanes (including both directions if available)					
One Lane*					
Two Lanes	0.2128	0.2037	1.2371	1.09	0.2963
Three Lanes	0.9114	0.3116	2.4878	8.55	0.0035
Four Lanes or more or Wide-open Access	0.8491	0.387	2.3375	4.81	0.0282
Traffic Control Devices					
No Control*					
Sign Control	0.2986	0.1281	1.3480	5.44	0.0197
Signal Control	−0.2926	0.2998	0.7463	0.95	0.3291
Bike Lane Type					
No Bike Lane*					
Conventional Bike Lane	−0.3128	0.1289	0.7314	5.88	0.0153
Other Bike Lane Types	−0.3794	0.212	0.6843	3.2	0.0736

Table 21, continued

Parameter	Estimate	Std Error	Odds Ratio	Wald Chi-Square	Pr > ChiSq
Connecting Street 5-year Average AADT					
AADT<10,000					
10,000<AADT⩽20,000	−0.6171	0.2235	0.5395	7.63	0.0058
20,000<AADT⩽30,000	−0.9655	0.2576	0.3808	14.04	0.0002
30,000<AADT⩽40,000	−0.796	0.2443	0.4511	10.62	0.0011
40,000<AADT⩽50,000	−0.8288	0.2443	0.4366	11.51	0.0007
50,000<AADT⩽60,000	−0.8712	0.2822	0.4184	9.53	0.002
Dispersion	1.1269	0.1285			

* Indicates the base condition used for analysis.

Table 22. Significance of Variables Determining Vehicular Crash Frequency at Commercial Driveways near Interchanges

Variable	Testing Method	Difference	F-Value (ANOVA) Or T-value (for T-test)	P-Value	Significant at 5% Level?
Number of Lanes on Connecting Street	ANOVA, Comparing Multiple Groups	N/A	3.79	0.231	Yes
	T-test, Two Lanes vs. Three Lanes	−0.4351	−2.58	0.0102	Yes
	T-test, Two Lanes vs. Four Lanes or More	−0.4351	−2.36	0.0187	Yes
	T-test, Three Lanes vs. Four Lanes	−0.3806	0	1	No
Right-Turn Lane	ANOVA, Shared/continuous right turn lane vs No right-turn lane	−0.1197	0.25	0.6184	No
Driveway Design	ANOVA, Comparing Multiple Groups	N/A	4.55	0.0113	Yes
	T-test, Flush Radial vs. Curb Radial	−0.625	−1.7	0.0904	No
	T-test, Flush Radial vs. Wide-open access and other	0.3333	1.43	0.154	No
	T-test, Curb Radial vs. Wide-open access and other	0.9583	2.73	0.0068	Yes

Table 22, continued

Variable	Testing Method	Difference	F-Value (ANOVA) Or T-value (for T-test)	P-Value	Significant at 5% Level?
Driveway Number of Lanes	ANOVA, Comparing Multiple Groups	N/A	1.31	0.2771	No
	T-test, Two Lanes vs Three Lanes	−1.7619	−1.42	0.1642	No
	T-test, Two Lanes vs Four Lanes or more or Wide-open Access	−0.5714	−0.91	0.3691	No
	T-test, Two Lanes vs Four Lanes or more or Wide-open Access	1.1905	0.9	0.3744	No
Traffic Control	ANOVA, Sign Control vs Signal Control	0.2857	0.39	0.5321	No
Bike Lane Type	ANOVA, Conventional Bike Lane vs Other Bike Lane Types	−0.0202	0	0.9461	No
Connecting Street 5-year Average AADT	ANOVA, Comparing Multiple Groups	N/A	0.98	0.4206	No
	T-test, (10,000, 20,000] vs (20,000, 30,000]	0.1622	0.69	0.4883	No
	T-test, (10,000, 20,000] vs (30,000, 40,000]	0.1081	0.45	0.6534	No
	T-test, (10,000, 20,000] vs (40,000, 50,000]	−0.2297	−0.77	0.4416	No
	T-test, (10,000, 20,000] vs (50,000, 60,000]	−0.2432	−0.98	0.3289	No
	T-test, (20,000, 30,000] vs (30,000, 40,000]	−0.0541	−0.22	0.8231	No
	T-test, (20,000, 30,000] vs (40,000, 50,000]	−0.3919	−1.31	0.1913	No
	T-test, (20,000, 30,000] vs (50,000, 60,000]	−0.4054	−1.63	0.1061	No
	T-test, (30,000, 40,000] vs (40,000, 50,000]	−0.3378	−1.11	0.268	No
	T-test, (30,000, 40,000] vs (50,000, 60,000]	−0.3514	−1.37	0.1716	No
	T-test, (40,000, 50,000] vs (50,000, 60,000]	−0.0135	−0.04	0.9653	No

5.4.2 Crash Severity Analysis for All Crashes

As with corridors, the multinomial logit model and average pseudo-elasticity analysis were used to investigate crash severity at commercial driveways near interchanges. Table 23 lists the significant factors identified by the MNL model as helping explain the crash injury severity outcomes, and Table 24 shows detailed average pseudo-elasticity analysis results for each significant variable. Six variables were found to be significant in influencing crash injury severity at commercial driveways near interchanges. These results are discussed below.

- **Alcohol or Drug Involved**: Alcohol or drug involvement was again found to be significant in predicting crash severity at commercial driveways near interchanges. Compared to crashes without alcohol or drug involvement, alcohol or drug involvement increased the potential for minor injury crashes by 170.9%**.** This result again verifies the necessity of law enforcement and zero tolerance on driving under the influence (DUI).
- **Lighting Condition**: Dawn/dusk lighting condition was a significant factor in minor injury severity at commercial driveways near interchanges. Specifically, lack of adequate lighting at this time increased the potential for minor injury crashes by 74.6%. This result verifies the importance of sufficient lighting in ensuring good visibility and improving traffic safety. The dawn/dusk time period is also often associated with fatigue or drowsiness after a long drive overnight or throughout the day.
- **Speed Limit on Connecting Street**: A speed limit of 50 mph or higher on the connecting street was a significant factor and increased the probability of minor injury crashes by 101.3%. This result is reasonable because speed limit is an indicator of traffic operating speed, and higher speed limits suggest a greater impact upon vehicle collision, which is more likely to induce injuries.
- **Driveway Number of Lanes**: For driveway number of lanes, one-lane commercial driveways (in/out only) near interchanges had significantly greater risk of severe injury crashes with an estimated 180.6% increase in these crashes and reduced the potential of other severities by less than 5%. A possible explanation is that one-lane driveways can be more difficult for drivers to identify than multi-lane driveways due to their narrow width. Vehicles on the adjacent street may suddenly slow and turn into one-way entry driveways, which increases the risk of rear-end collisions with following vehicles and other types of collision with nearby parties or objects. Warning or guidance signs in advance may help mitigate this issue by preparing drivers for the entry/exit ahead.
- **Bike Lane Type**: Conventional bike lanes significantly increased the risk of minor injury crashes by 24.3% at commercial driveways near interchanges. As found with corridors, the presence of a bike lane (without a physical separator or surface paint) at commercial driveways near interchanges was positive in that it reduced crash frequency. As to crash severity, the presence of a conventional bike lane indicated a higher potential for minor crash injuries. Possible explanations could be that when a conventional bike lane is not available, non-motorists will use a sidewalk or roadside if available for traveling, which distances them from through traffic. Sidewalks or roadsides also provide a refuge for non-motorists to wait before crossing the driveway, so turning vehicles in through lanes may not need to slow or stop to complete the turning movement, which also decreases the rear-end collision risk with through vehicles. On the other hand, although conventional bike lanes emphasize the right-of-way for bicyclists and provide bicyclists separation from vehicular traffic, they do not provide a physical barrier or buffer to sufficiently reduce exposure to nearby traffic, which increases the injury risk to bicyclists.
- **Distance from Ramp Taper to First Unsignalized Driveway or Signalized Commercial Driveway:** Where unsignalized or signalized commercial driveways are located less than 500 ft from the ramp taper end of an interchange, the potential for severe injury crashes increased by 261%. This result highlights the importance of avoiding commercial driveways in the influence area of highway interchanges. When this distance is short, the road segment may fail to provide sufficient travel distance for vehicles to slow down before diverging from or merging with through traffic, thereby

introducing more severe injuries at commercial driveways. This situation could be exacerbated by median opening configurations, excessive driveway accesses, or other roadway configurations.

Table 23. Multinomial Logit Modeling Results on All Vehicular Crash Severity at Commercial Driveways near Interchanges

Variable	Specific to Injury Severity	Estimated Coefficient	Standard Error	p-value
Intercept	MI	−0.96001***	0.09603	<0.0001
Intercept	SI	−3.49460***	0.25829	<0.0001
Alcohol Involved Crash				
Alcohol Involved Crash	MI	2.47295***	0.78275	0.0016
Lighting Condition				
Dawn/Dusk	MI	0.97484***	0.30582	0.0014
Speed Limit on Connecting Street				
50 mph or Higher	MI	1.34717**	0.57877	0.0199
Driveway Number of Lanes				
One Lane	SI	1.09958**	0.53808	0.041
Bike Lane Type				
Conventional Bike Lane	MI	0.33643**	0.15904	0.0344
Distance From Taper End to Each Unsignalized or Signalized Driveway				
(0, 500 ft)	SI	1.35715***	0.45537	0.0029
Note: *, **, * ==> Significance at 1%, 5%, 10% level.**				

Table 24. Average Pseudo-elasticity of Significant Variables for Vehicular Crash Severity at Commercial Driveways near Interchanges

Variable	Injury Severity Level		
	NI	MI	SI
Alcohol Involved Crash			
Alcohol Involved Crash	−76.1%	170.9%	−75.7%
Lighting Condition			
Dawn/Dusk	−32.5%	74.6%	−32.1%
Speed Limit on Connecting Street			
50 mph or Higher	−45.6%	101.3%	−45.0%
Bike Lane Type			
Conventional Bike Lane	−10.1%	24.3%	−9.9%
Driveway Number of Lanes			
One Lane	−4.8%	−4.6%	180.6%
Distance from Ramp Taper to First Unsignalized or Signalized Commercial Driveway			
(0, 500 ft)	−6.1%	−5.8%	261.0%

6. Case Studies

Six study areas were selected for exploratory commercial driveway safety case studies using the methods discussed in Section 4.3 to supplement the statewide statistical and modeling analyses. The goal of the case studies was to obtain further insight into access-related issues that have contributed to commercial driveway crashes in these areas. The study areas represent high-crash corridors and interchange areas in different regions of Florida and include: (1) John Young Parkway at W. Colonial Drive in Orlando, (2) East Bay Drive (State Road 686) in Largo, (3) West Tennessee Street in Tallahassee, (4) North West 103rd Street and West 49th Street (State Road 932) in Hialeah, (5) West Hallandale Beach Boulevard at I-95 Interchange area in Hallandale Beach, and (6) Scenic Highway at I-10 Interchange area in Escambia County.

Each case study included an overview of corridor or interchange area characteristics, such as traffic volumes, planning-related classifications (e.g., functional, access, context), and existing land uses and access features. Next was a crash analysis and examination of the specific commercial driveway locations identified through the review of crash reports as having common safety issues. The crash types and severity were documented in these locations, as well as interactions with other corridor and/or interchange characteristics. The case studies concluded with a brief discussion of potential strategies and countermeasures to mitigate the safety issues identified.

6.1 John Young Parkway at W. Colonial Drive (Orlando)

6.1.1 Overview

This case study examined safety issues associated with commercial access design on John Young Parkway (State Road 423) near the intersection of W. Colonial Drive in the City of Orlando (Figure 28). The segment is a 6-lane divided highway and classified as an urban principal arterial with an annual average daily traffic (AADT) volume of 48,000 vehicles per day. It has sidewalks on both sides and no bicycle lanes. John Young Parkway is classified as an Access Class 3 and has a posted speed of 45 mph. The FDOT access connection spacing requirement for this access classification is 440 feet and one-half mile for full median openings and signals.

The context classification for this segment is C3C-Suburban Commercial. The commercial area is characterized by a convenience store, ethnic food establishments, and apartments to the west, and a neighborhood shopping plaza to the east with ethnic food establishments, a county sheriff operational center and credit union, discount store, fast food business, and strip commercial development to the east. The eastern area has extensive surface parking and a unified circulation system that connects to John Young Parkway at two locations and accesses W. Colonial Drive at an unsignalized right-turn only and signalized full movement driveway to the north. Several transit stops provide transit access to the area, and there is corresponding evidence of pedestrian activity, as well as cyclists in the area.

Two radial design commercial driveways are of interest on the east side of the segment, shown as driveway “a” and “b” in Figure 28. They are unchannelized driveways serving more than 50 parking spaces and comparable to FDOT Category D driveways (shopping center, vehicle trips/hr. 121-400) per the FDOT Access Management Guide (FDOT, 2019). One commercial driveway (driveway “a”) is directly served by a directional median opening with a 290-ft-long left-turn lane. A transit stop is located directly across the road from this connection. Driveway b is about 309 feet north of driveway “a” and within 240 feet of the signalized intersection.

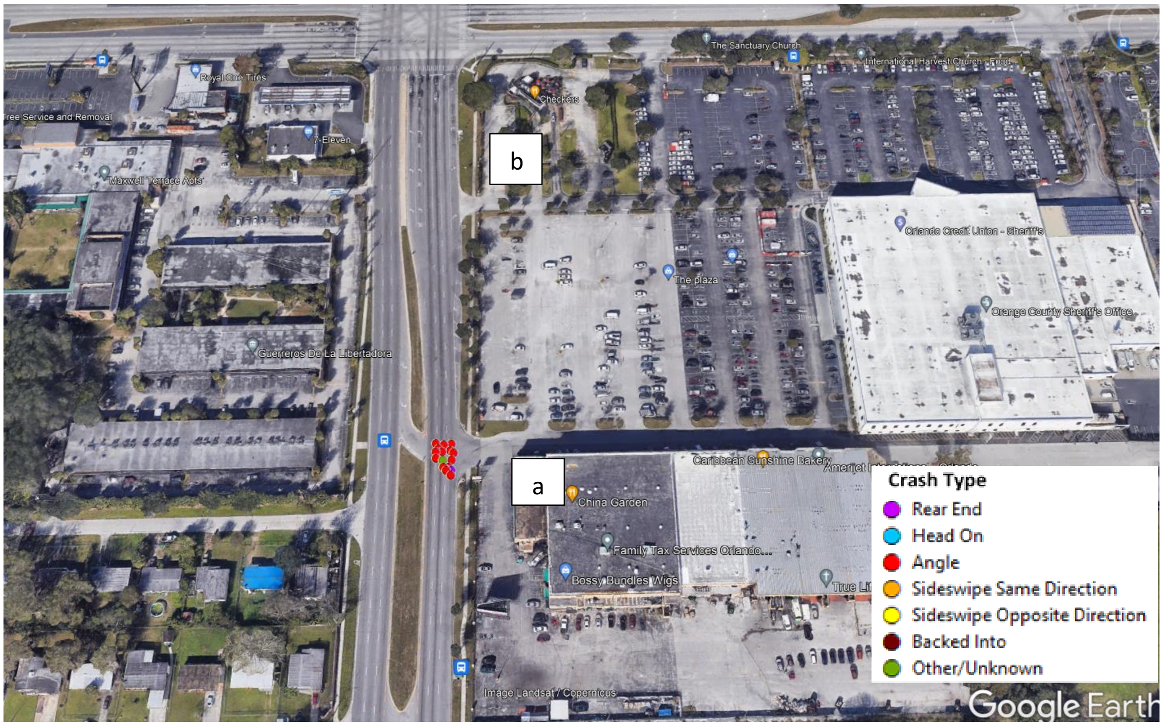


Figure 28. Overview of John Young Parkway study area.

This high-volume major intersection of two six-lane arterial roadways has significant queues, as shown in Figure 29. Both Figure 29 and Figure 30 show the potential for the intersection queue to reduce visibility of the access. Both driveways are disrupted by queueing traffic, with the connection closest to the signalized intersection with W. Colonial Drive (within 240 ft. of the intersection) completely blocked by the queues. This decreases the egress capacity of the driveways and poses potential safety hazards if exiting vehicles attempt to cross several lanes of queueing traffic to turn left at the intersection.

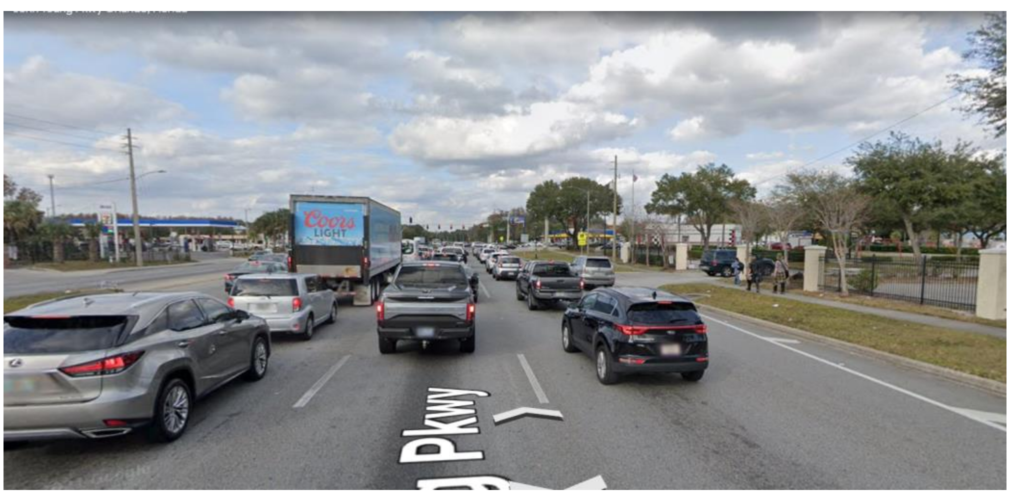


Figure 29. Intersection queue disrupting driveway operations.

Figure 30. Driver view of upcoming access.

6.1.2 Crash Analysis

The focus of the crash analysis is the driveway served by the directional median opening (driveway “a”), which has a throat length of about 35 feet and is located approximately 633 feet south of the signalized intersection of John Young Parkway and West Colonial Drive. Between 2015 and 2019, 16 angle crashes were recorded in the immediate vicinity of the directional median opening, suggesting a serious safety issue with this commercial driveway access location and design. Figure 31 shows the access configuration at this location in more detail. After review of the crash reports, all crashes were largely associated with this commercial driveway, and none were associated with driveway “b”.

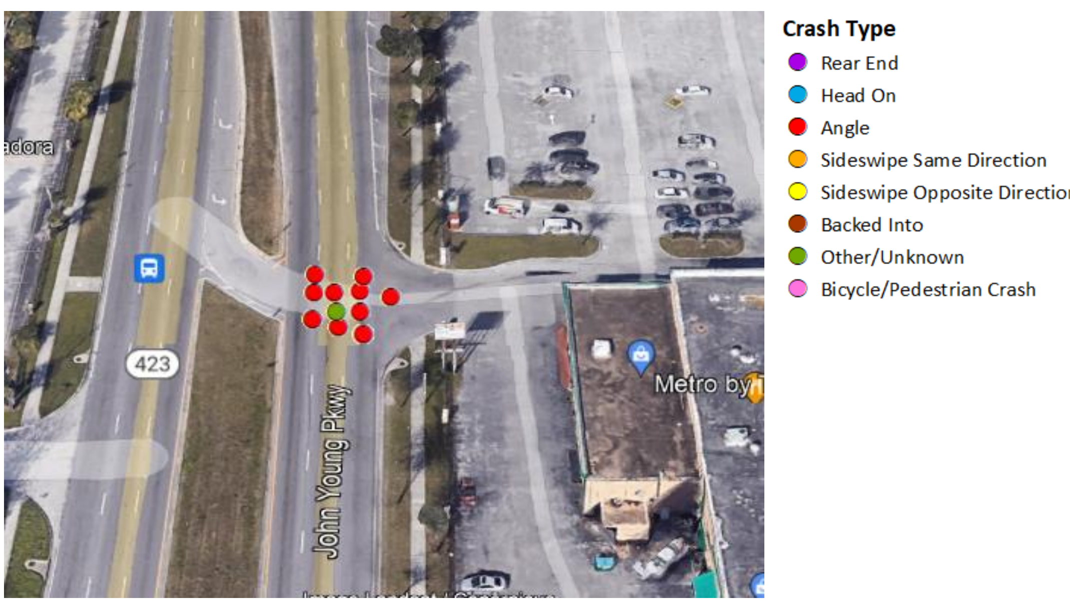


Figure 31. Access configuration and crashes at shopping center driveway.

A total of 15 crashes were reported in the five-year period as involving left turns from the directional opening into the driveway of the shopping center and one involved a crossing maneuver turning right out of the driveway into the far left-turn lane (see Figure 32 and Figure 33). Two of the angle crashes were reported as front to rear passenger side. A review of the crash reports indicates that most of the crashes occurred in daylight, during peak hour traffic, and did not involve serious injuries, suggesting relatively low speeds at the time of the crash.

Figure 32. Typical left-turn-in crash scenario at the John Young Parkway location.

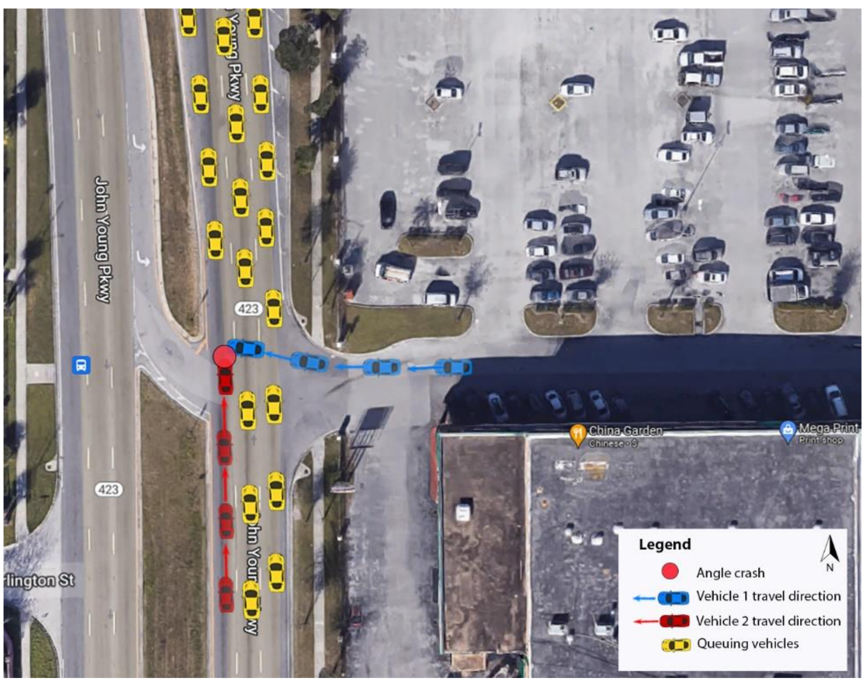


Figure 33. Right-turn-out crash scenario at the John Young Parkway location.

The safety issues associated with the design of commercial access at this location may be summarized as follows:

- Lengthy queues at the signalized intersection disrupt driveway operations and reduce visibility of vehicles crossing the through lanes to enter and exit the connection,
- Conflicts occur between through moving vehicles and those attempting left-in entry to driveway from directional opening or right turn exit, and
- Queueing vehicles allowing the turning vehicles to cross through lanes resulting in crashes in one of the through lanes, sometimes involving more than one vehicle, as the vehicles proceed into or out of the driveway.

No bicycle- and pedestrian-related crashes were recorded along this segment during this period. However, examination of the Google images reveals bicycle and pedestrian activity on this corridor and the driveways pose clear safety concerns. Among these is that drivers looking left to exit these driveways may not notice southbound cyclists and pedestrians on the sidewalk beginning to cross the driveway. Vehicles inch out as they exit, thereby blocking the sidewalk and disrupting these bicycle and pedestrian movements, causing them to enter the paved right-of-way to pass the driveways (Figure 34). Fencing and landscaping at the driveway entrance further obscures visibility increasing the potential for bicycle/pedestrian crashes (Figure 35).

Figure 34. Vehicle blocking sidewalk to exit causes cyclist to enter through lane.

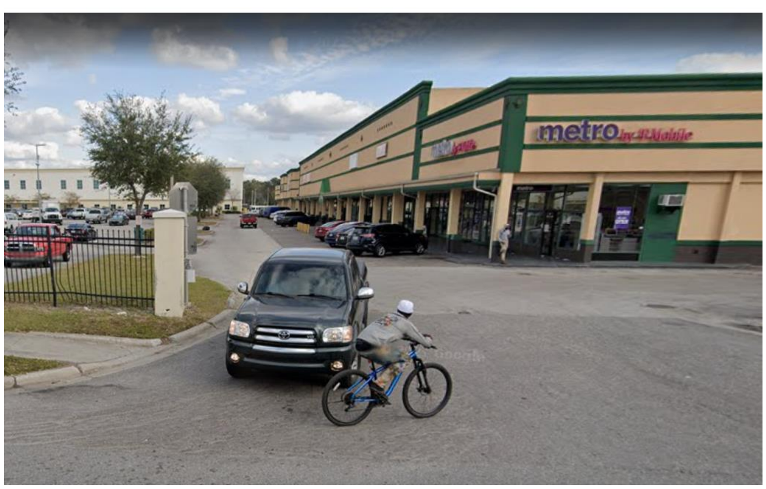


Figure 35. Fencing obscures visibility as vehicles exit commercial driveway.

6.1.3 Potential Countermeasures

Potential countermeasures to ameliorate safety problems associated with the design include:

- Reduce the queue in the through lanes by considering changes such as:
    - redesigning the arterial intersection to separate left turns and allow a two-phase signal cycle, such as a restricted crossing U-Turn (RCUT) or displaced left-turn intersection (DLT) design.
    - extending the northbound left-turn lanes at the intersection to allow more vehicles to be stored.
    - retiming the signals.
- Close the directional opening and prohibit left-in access under similar conditions in the future.
- Relocate the driveway further south to reduce crashes associated with vehicles weaving across several lanes to complete a left turn and to avoid potential conflicts at the driveway entrance with vehicles circulating on-site due to the short throat length.
- Allow U-turns farther south of the connection through a directional median opening.
- Increase minimum corner clearance for left-turn access at high volume unsignalized commercial driveway connections on principal arterials. Ensure any permitted left-turn access is beyond the standing queue.
- Prohibit fencing and landscaping for a specified distance on either side of commercial driveways to improve visibility of pedestrians, cyclists, and vehicles entering and exiting commercial driveways.

6.2 East Bay Drive (Largo)

6.2.1 Overview

This case example explores safety issues along East Bay Drive (State Road 686) in Largo (Pinellas County). Figure 36 shows a 0.35-mile segment of East Bay Drive west of Belcher Road. The segment is a 6-lane divided highway with two median openings – a directional and a full median opening. The posted speed limit is 45 mph, and the annual average daily traffic (AADT) is 56,000 vehicles per day. East Bay Drive has sidewalks on both sides, no bicycle lanes and three bus stops, two to the north of the segment and one to the south of the segment.

East Bay Drive is classified as an Access Class 7. The FDOT access connection spacing requirement for this access classification is 125 feet, 330 feet for directional median openings, 660 feet for full median openings, and a minimum of one-quarter mile for signal spacing. There are approximately 19 access connections along this .35-mile segment. The functional classification for this roadway is urban minor arterial and the context classification is C3C-Suburban Commercial. The area is characterized by several shopping centers, fast food restaurants, apartment complexes, retail shops, and banks.

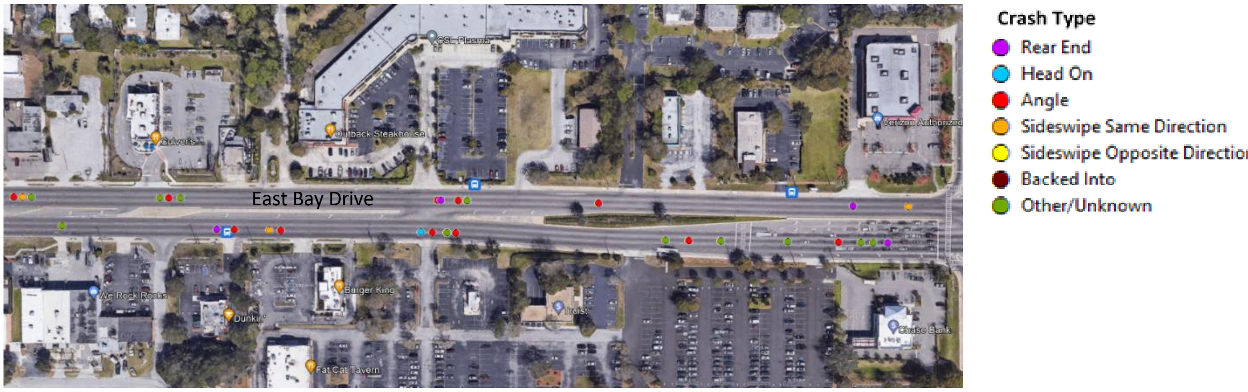


Figure 36. Overview of East Bay Drive study area.

6.2.2 Crash Analysis

Between 2015 and 2019, forty (40) driveway-related crashes were recorded along this segment of East Bay Drive (see Figure 36). Crash types included rear-end (purple), head on (blue), angle (red), sideswipe same direction (orange), and other/unknown (dark green). These crashes included several bicycle and pedestrian related crashes as shown in pink in Figure 37. Several of the crashes (all crash types) were recorded in the same location and are therefore layered on the diagrams in Figure 36 and Figure 37.

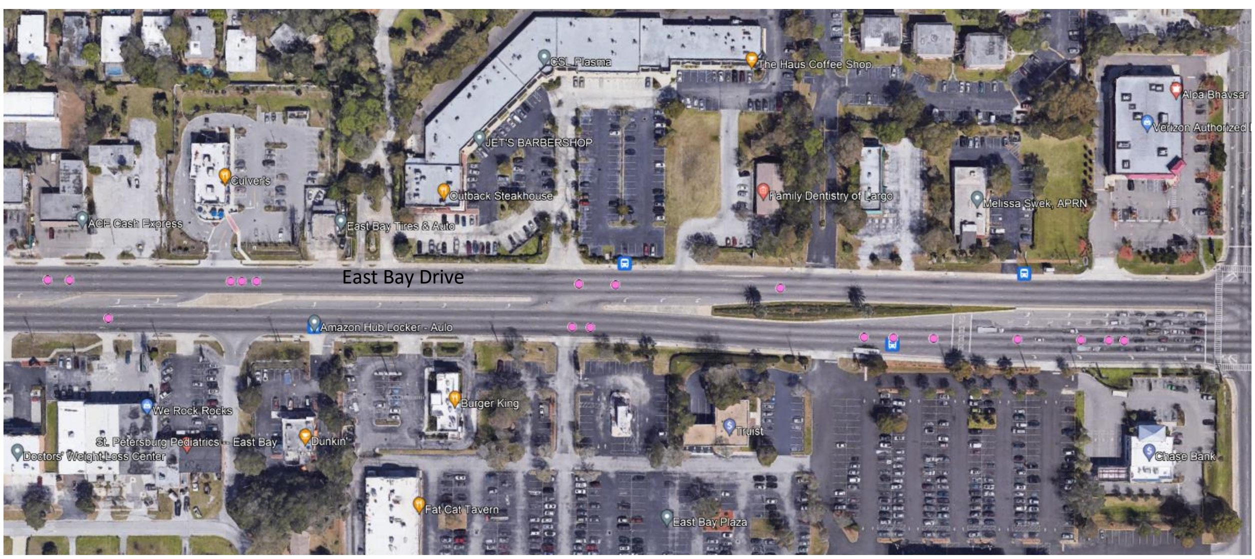


Figure 37. Bicycle and pedestrian crashes on East Bay Drive.

Although there were several crashes reported along the segment, this case example focuses on two clusters of crashes adjacent to two shopping centers shown in Figure 38 and Figure 39. The driveways, shown as “a” and “b” in Figure 38, are opposite a full median opening (60 feet wide) with left-turn lanes. There is a transit stop approximately 60 feet east of driveway “a” and a transit stop approximately 350 feet to the west of driveway “b”.

Figure 38. Vehicular crashes near two shopping centers on East Bay Drive.

Figure 39. Aerial view of all crashes at median opening intersection of shopping centers on East Bay Drive.

Driveway “a” is a flared driveway providing access to a small “strip” shopping center on the northern side of East Bay Drive. This land use is most closely aligned with FDOT driveway category “C”, which is meant to serve 601-1,200 vehicle trips per day and 61-120 vehicle trips per hour (FDOT, 2019). Driveway “a” is a full movement driveway with a physical separator and provides primary access to the strip shopping center. The driveway width is approximately 40 feet, and the throat length is approximately 77 feet. The nearest driveway is approximately 142 feet to the east.

Driveway “b” is a flared driveway providing access to a shopping center on the southern side of East Bay Drive. It is a large shopping center and can be categorized as FDOT driveway category “D”, which is meant to serve 1,201 vehicle trips per day and 121-400 vehicle trips per hour (FDOT, 2019). Driveway “b” is a full movement driveway with a painted separator and provides direct access to the shopping center. The driveway width is approximately 30 feet, and the throat length is approximately 55 feet. The nearest driveway is approximately 120 feet to the west.

Between 2015 and 2019, approximately fifteen (15) vehicular crashes and four bicycle and pedestrian crashes were reported in the immediate vicinity of these two driveways and the median opening. A review of the crash reports indicated several crash types including angle, rear-end, and head on crashes. The bicycle and pedestrian crashes included 1 pedestrian crossing at the median opening, 3 cyclists hit while crossing the driveways, and 1 cyclist hit while entering a driveway.

Figure 40 shows an illustration of a head on crash in the median opening. Vehicle 1 was traveling south onto East Bay Drive attempting to turn left to travel east. Vehicle 2 was traveling north onto East Bay Drive attempting to turn left to travel west. Vehicle 1 and Vehicle 2 collided in the median opening. The narrative in the police report states that vehicle 1 was exiting the shopping center to the north and vehicle 2 was exiting the shopping center to the south when the vehicles collided. Both vehicles were damaged as a result of the crash.

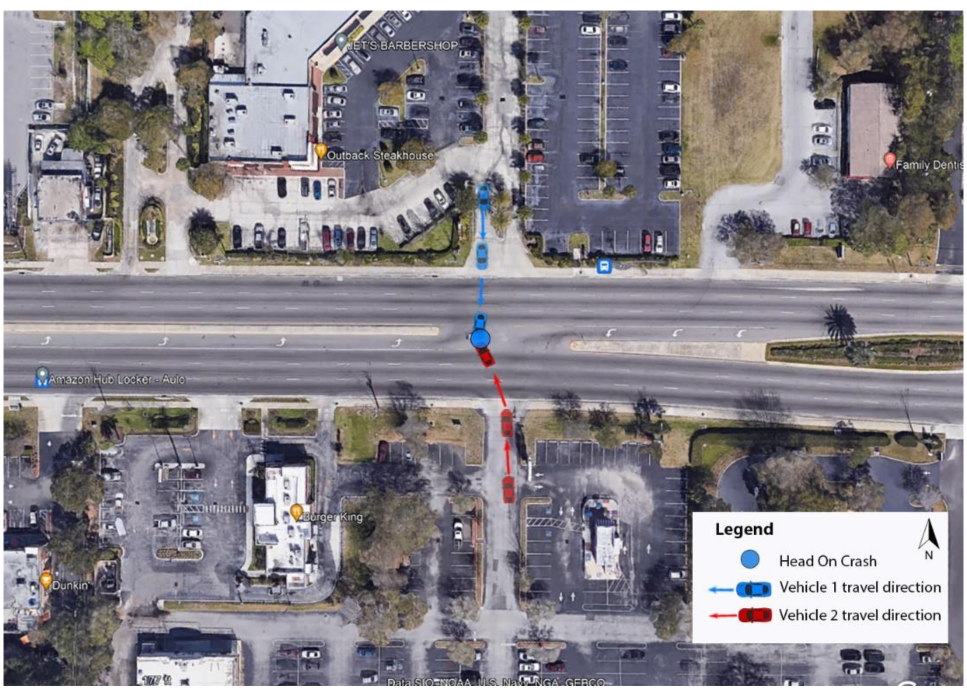


Figure 40. Head-on crash on East Bay Drive.

Figure 41 shows an illustration of a bicycle crash in driveway “a”. The bicyclist was traveling east along the sidewalk and was struck by a vehicle attempting to make a right turn onto East Bay Drive. The bicyclist’s injuries were described as “non-incapacitating” in the crash report.

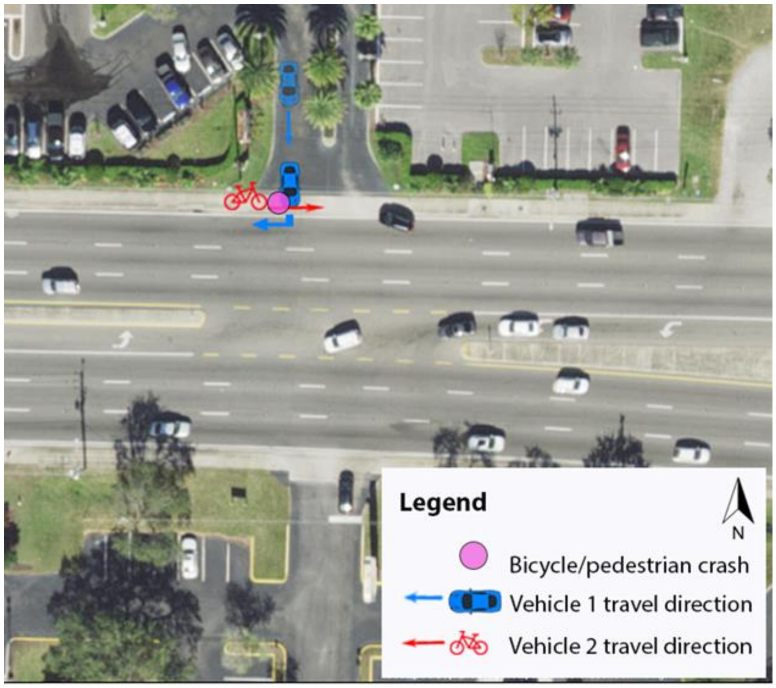


Figure 41. Bicycle crash on East Bay Drive.

The safety issues associated with the design of commercial access at this location may be summarized as follows:

- The location of the median opening in relation to the shopping center driveways results in conflicts between through moving vehicles and those attempting to enter or exit the driveways from/to the full median opening.
- The median opening poses concerns when multiple vehicles are attempting to exit the adjacent driveways and maneuver into the median opening simultaneously, as illustrated in Figure 40.
- Conflicts occur between vehicles entering the driveway from the median opening while pedestrians attempt to cross the driveway, resulting in bicycle/pedestrian crashes and/or additional conflicts with through moving vehicles.
- Drivers looking left while attempting to exit the driveways do not notice bicyclist and/or pedestrians crossing the driveway resulting in bicycle/pedestrian crashes.

6.2.3 Potential Countermeasures

Potential countermeasures to address safety concerns associated with the design include:

- Prohibit left-turn or through movements out of the driveways by redesigning or closing the median opening.
- Improve and use offset left-turn lane design to increase sight distance of the left-turn lane in each direction.

- Consider evaluating the location for installation of a pedestrian crossing warning sign and lights or HAWK Signal (Pedestrian Hybrid Beacon Signal) to improve pedestrian crossing the East Bay Drive.

6.3 W. Tennessee Street (Tallahassee)

6.3.1 Overview

West Tennessee Street in Tallahassee (Leon County) is a 6-lane divided highway with non-traversable medians with turn lanes at the intersections. The posted speed limit is 35 mph and the annual average daily traffic (AADT) is 37,000. Figure 42 shows a segment of West Tennessee Street west of Stadium Drive. The segment has sidewalks on both sides of the roadway and sharrows on the south side of the roadway. There are two bus stops to the south of the segment (see Figure 19).

Figure 42. Overview of crashes on W. Tennessee Street study area.

This roadway is classified as Access Class 7 which has a minimum access connection spacing requirement of 125 feet, 330 feet for directional median openings, 660 feet for full median openings, and a minimum of one-quarter mile for signal spacing. There are approximately twenty-two (22) driveways/access points along this segment. The functional classification for this roadway is urban minor arterial and the context classification is C4- Urban General. The area is characterized by several fast-food restaurants, gas stations, retail stores, and apartment complexes.

6.3.2 Crash Analysis

Between 2015 and 2019, thirty (30) driveway-related crashes were recorded along the segment of West Tennessee Street (see Figure 42). Crash types included rear-end, angle, head on, sideswipe same direction, and other/unknown. The crashes included three bicycle/pedestrian crashes shown in pink in Figure 43.

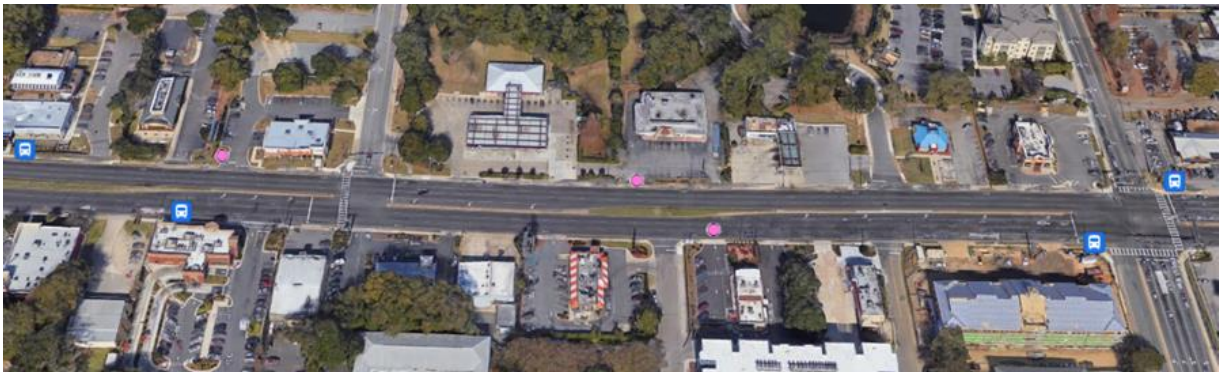


Figure 43. Bicycle and pedestrian crashes on W. Tennessee Street.

Several clusters of crashes are visible along this segment of West Tennessee Street. A review of the crash reports indicated several crash types including angle, rear-end, head on, and sideswipe. Figure 44 illustrates one of several rear-end crashes observed along the segment as drivers slow to enter the fast food businesses and other commercial sites.

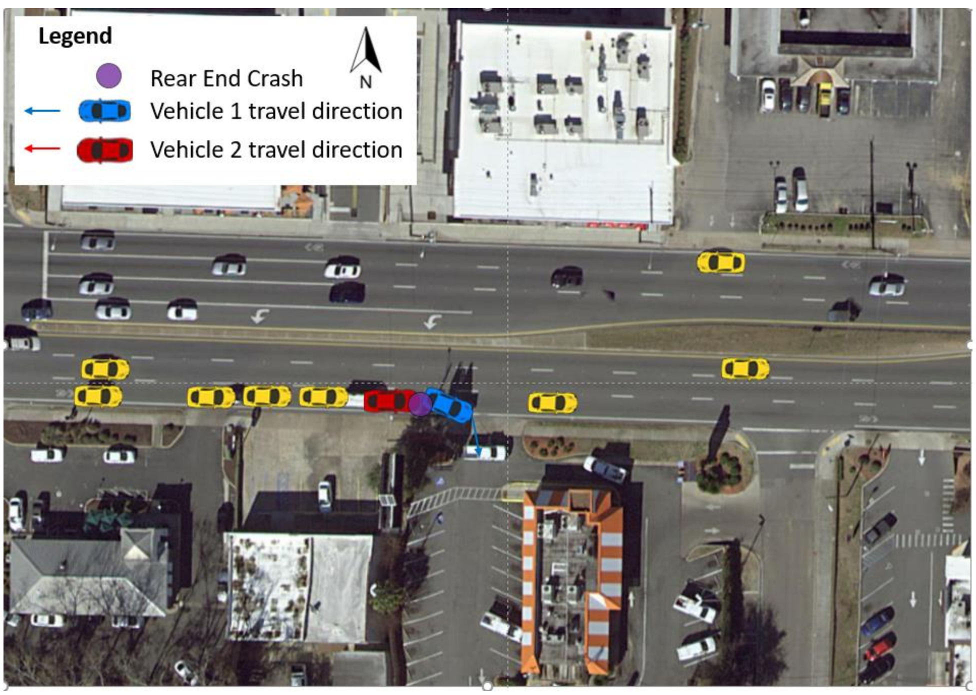


Figure 44. Typical rear-end crash scenario at commercial driveways along the corridor.

The following case example focuses on a cluster of crashes at the intersection of West Tennessee Street and Caliark Street shown in Figure 45. These crashes are located at the fast-food restaurant (Chic-Fil-A) and are influenced by queues at the signalized intersection as well as backups due to inadequate on-site circulation at the upstream coffee shop (Starbucks). A lounge with wide-open access separates the two. Between 2015 and 2019, approximately seventeen (17) crashes were reported in the vicinity of these driveways.

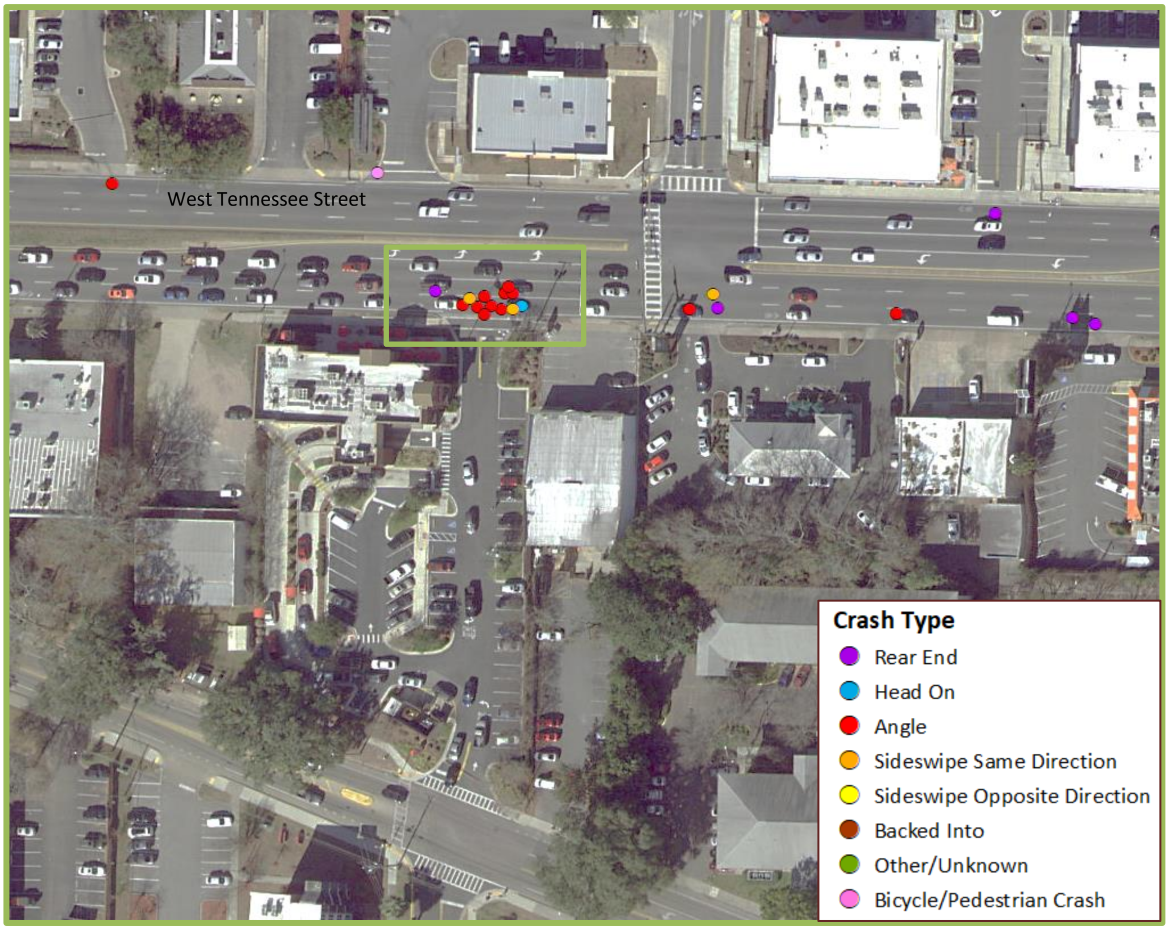


Figure 45. Cluster of crashes near fast food restaurant on W. Tennessee Street.

The driveway shown in Figure 46 is a flared driveway providing access to a popular fast-food restaurant. This land use is most closely aligned with FDOT driveway category "C", which is meant to serve 601-1,200 vehicle trips per day and 61-120 vehicle trips per hour (FDOT, 2019). It is a full movement driveway with a painted separator. The driveway width is approximately 25 feet and the throat length is approximately 70 feet. The driveway is approximately 105 feet west of the intersection of West Tennessee Street and Caliark Street.

Figure 46. Fast-food driveway on W. Tennessee Street.

Figure 47 illustrates an angle crash in the left-turn lane. Vehicle 1 was traveling north to exit the driveway for the fast-food restaurant to enter the left-turn lane at the intersection. Vehicle 2 was traveling east in the left-turn lane and was struck by vehicle 1. Both vehicles were damaged as a result of the crash.

Figure 47. Angle crash on W. Tennessee Street.

The driveway shown in Figure 48 is a flared driveway providing access to a coffee shop. This land use is most closely aligned with FDOT driveway category “C”, which is meant to serve 601-1,200 vehicle trips per day and 61-120 vehicle trips per hour (FDOT, 2019). It is a full movement driveway with no separator. The driveway width is approximately 25 feet and the throat length is approximately 30 feet. The driveway is at the intersection of West Tennessee Street and Caliark Street (see Figure 49).

Figure 48. Coffee shop driveway on W. Tennessee Street.

Figure 49. Aerial of coffee shop driveway on W. Tennessee Street.

Figure 50 shows an illustration of an angle crash on West Tennessee Street. Vehicle 1 was attempting to turn onto West Tennessee Street. Traffic was queuing from the coffee shop to the east. A vehicle stopped to allow vehicle 1 to cross the through lanes. Vehicle 2 was traveling east in the middle lane and was struck by vehicle 1.

Figure 50. Angle crash on W. Tennessee Street.

The spacing between these three driveways, the volumes associated with the land uses, and their proximity to the intersection of West Tennessee Street and Caliark Street result in multiple conflicts. The safety issues associated with the design of commercial access at this location may be summarized as follows:

- Lengthy queues at the coffee shop interfere with through traffic movement and disrupt nearby driveway operations, and
- Conflicts occur between through moving vehicles and those exiting the fast-food restaurant, attempting to access the left turn lane at the intersection.

6.3.3 Potential Countermeasures

Potential countermeasures to address safety concerns associated with the design include:

- Seek opportunities for interparcel cross access to provide improved corner clearance and increase access to traffic signals that can safely accommodate left turns for small commercial establishments.
- Avoid approval of driveways near an intersection where the establishment creates a potential for long queues that may spill back onto roadways and create safety issues.
- Improve the visibility of Starbucks driveway entrance area so drivers can more clearly see and avoid the entrance during queue back-up situations and to reduce the potential for vehicle or pedestrian related crashes. Require such uses to have more internal storage to avoid queues from the drive-through backing into through lanes during peak periods.
- Install a “DO NOT BLOCK INTERSECTION” sign on the eastbound direction to reduce rear-end or right-angle crashes.

6.4 State Road 932 (Hialeah)

6.4.1 Overview

Figure 51 shows a 1.5-mile segment of North West 103rd Street and West 49th Street (State Road 932) in Hialeah (Miami-Dade County) between North West 77th Court and Ludlam Road. The roadway passes under a flyover for the Palmetto Express Lane. This roadway segment is a 6-lane divided highway with an AADT of 45,000 vehicles per day. Sidewalks are continuous and are visible along the north and south sides of the segment and there are no visible bike lanes. There are 13 bus stops along the roadway segment.

West 49th Street east of the Palmetto Express Lane is an Access Class 5 (restrictive) and has a posted speed limit of 40 mph. The FDOT access connection spacing requirement for this access classification is 245 feet, 660 feet for directional median openings, 1,320 feet for full median openings, and a minimum of one-quarter mile for signal spacing. North West 103rd Street west of the Palmetto Express Lane is an Access Class 6, non-restrictive, and also has a posted speed limit of 40 mph. The FDOT access connection spacing requirement for this access classification is 245 feet and a minimum of one-quarter mile for signal spacing.

There are approximately 88 access connections along the observed segment of N.E. 103rd Street and W. 49th Street. The functional classification for West 49th Street is urban principal arterial and the functional classification for North West 103rd Street is urban minor arterial. The context classification for the roadway segment is C4-Urban General. The area is characterized by several hotels, apartments, gas stations, banks, restaurants, retail shops, shopping centers, and a mall.

6.4.2 Crash Analysis

Between 2015 and 2019, 189 driveway-related crashes were recorded along this segment of the corridor (30 to 50 crashes per mile). Crash types included rear-end (purple), angle (red), head on (blue), sideswipe same direction (orange), sideswipe opposite direction (yellow), and other/unknown (dark green). Several of the crashes (all crash types) were recorded in the same location and are therefore layered on the diagrams in Figure 51. These crashes included several bicycle- and pedestrian-related crashes that are shown in pink in Figure 52. The crashes in Figure 51 were not manually verified and geolocated based on crash reports due to their numbers. A more accurate location of the crashes near the interchange based on crash reports is provided in Figure 53.

Figure 51. Overview of N.E. 103rd Street and W. 49th Street.

Figure 52. Bicycle and pedestrian crashes on N.E. 103rd Street and W. 49th Street.

The driveway density and volume of crashes along this roadway segment demonstrates how driveway density affects crash rates. Although the crashes are representative of seven out of eight of the crash types identified in this analysis, most of the crashes are rear-end or angle crashes.

A cluster of crashes adjacent to a driveway for a mall shown in Figure 53 illustrates conflicts resulting from driveway location in relation to the expressway entrance ramp. The driveway shown in Figure 54, which provides access to a mall on the northern side of West 49th Street, is to the east of the entrance ramp for the Palmetto Express Lane. This land use associated with this driveway is most closely aligned with FDOT driveway category F or G, which are meant to serve up to 30,001 vehicle trips per day or more and up to 3,001 vehicle trips per hour (FDOT, 2019). It is a full movement radial design driveway with a physical separator. The driveway width is approximately 50 feet and the throat length is approximately 140 feet. The nearest driveway is approximately 400 feet to the east.

Figure 53. Crashes near a mall and entrance ramp.

Figure 54. Access configuration at mall driveway.

For the 5-year period used during the analysis, a total of seven (7) driveway-related crashes were recorded in the vicinity of this driveway. These collisions largely included rear-end and angle crashes. The rear-end crashes typically involved two vehicles exiting the driveway. The angle crashes involved vehicles exiting the driveway and those traveling west in the through lane or maneuvering into the entrance ramp for the Palmetto Express Lane. The safety issues associated with the design of commercial access at this location may be summarized as follows:

- Vehicles exiting the driveway suddenly stop to yield to through traffic or those accessing the entrance ramp for the express lane (see Figure 55). In some instances, drivers back up to remove themselves from the roadway and back into the vehicle behind them, and
- Vehicles exiting the mall attempt to access the left turn lane and collide with through traffic traveling west and/or vehicles accessing the entrance ramp for the express lane (see Figure 56).

Figure 55. Rear-end crash on W. 49th Street.

Figure 56. Angle crash on W. 49th Street.

6.4.3 Potential Countermeasures

- In the future, this type of commercial driveway would not be approved since it is too close to a freeway on-ramp, which creates many conflicts and safety concerns.
- This commercial driveway could be closed, as there are several alternative access points to the site.

6.5 West Hallandale Beach Boulevard at I-95 Interchange (Hallandale Beach)

6.5.1 Overview

This case study examines commercial driveway safety issues near the interchange of I-95 and Hallandale Beach Blvd (Figure 57). It is a diamond interchange with yield controlled on-ramps and signalized off ramps (Figure 58). Hallandale Beach Blvd is a 6-lane divided highway east of the interchange and a 4-lane divided highway west of the interchange. It is classified as a state urban principal arterial with an annual average daily traffic (AADT) volume of 47,532 vehicles per day. There are sidewalks and bicycle lanes on both sides of the roadway.

The context classification for this area is C4-Urban Commercial and C3C-Suburban Commercial. The commercial area in the immediate vicinity of the interchange includes gas stations, fast food restaurants, a hotel, auto parts and a variety of other low density commercial uses. Railroad tracks are located just west of the interchange with a frontage road providing access to commercial uses between the railroad tracks and I-95. Due to traffic delay as well as safety issues in the area, the interchange was the subject of an interchange operational analysis report and subsequent improvements to the off-ramp configurations and signalization (FDOT 2016).

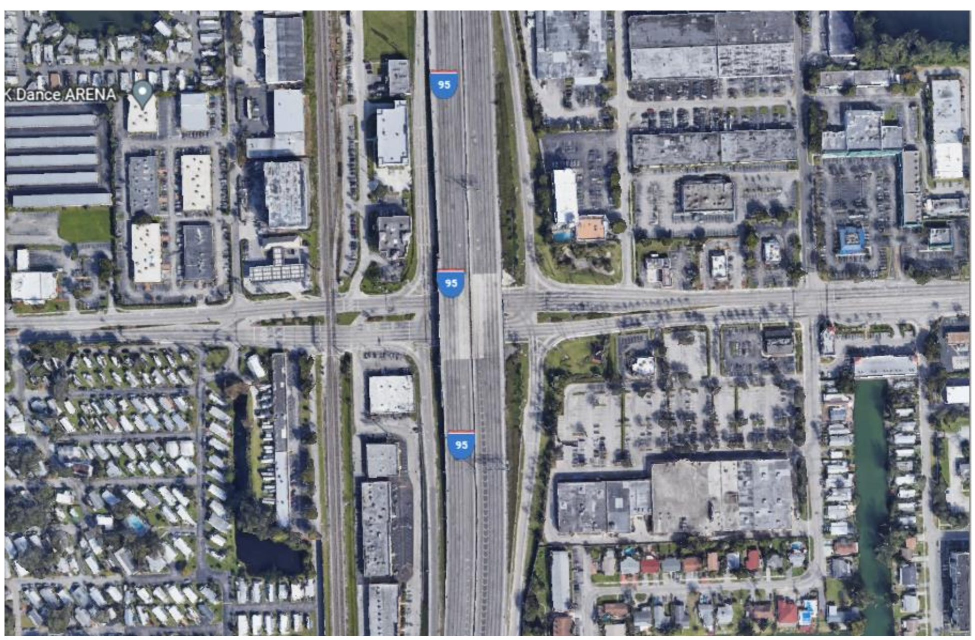


Figure 57. W. Hallandale Beach Blvd at I-95 interchange study area.

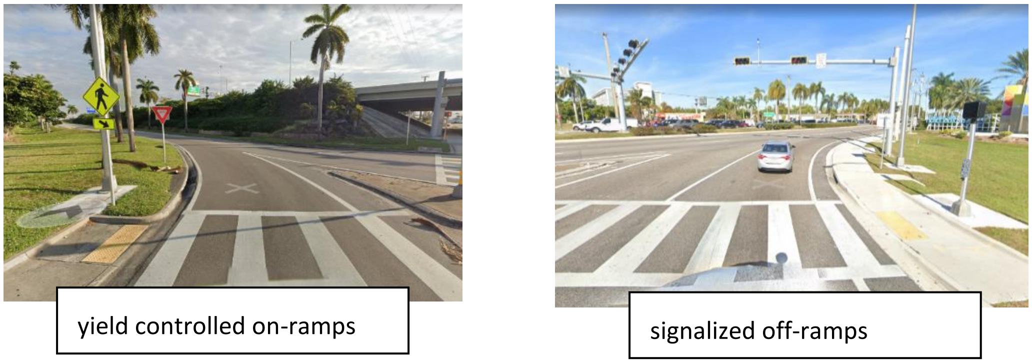


Figure 58. I-95 at W. Hallandale Beach Blvd ramp configuration.

The segment of W Hallandale Beach Blvd that intersects with the interchange is classified as an Access Class 5 and has a posted speed of 40 mph. The FDOT access connection spacing requirement for this access class is 245 feet and ¼ mile for full median openings and signals. Because this is an interchange area, FDOT Rule 14-97.003(3)(h)2 calls for a minimum of ½ mile between the first full median opening and the end of the off-ramp taper and connection spacing of 440 feet where the posted speed is 45 mph or less. Interchange areas are defined in rule as the lessor of ¼ mile from an interchange facility or up to the first intersection with an arterial road.

The driveway access around the interchange is well below FDOT access spacing standards. On the west side of the interchange is a frontage road serving several commercial uses that connects directly to the southbound on-ramp of I-95 (Figure 59). Vehicles must cross the ramp to enter or exit the shopping area via the frontage road. In the northwest quadrant of the interchange, the frontage road connects to W Hallandale Beach Blvd about 67 ft from the I-95 off-ramp, followed by a RaceTrac gas station driveway about 90 ft of the interchange off-ramp (Figure 59).

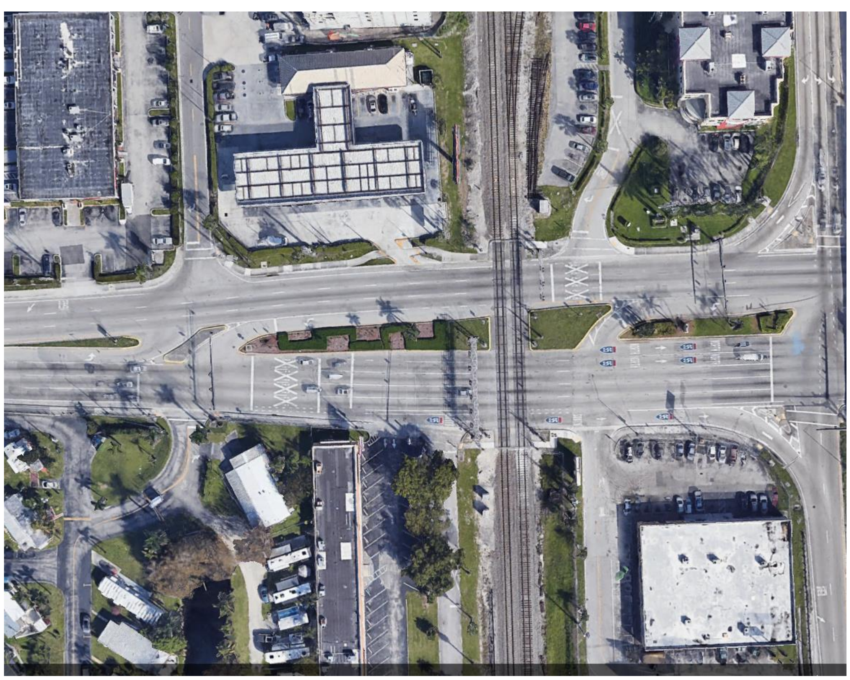


Figure 59. West side of I-95 and W. Hallandale Beach Blvd interchange.

The east side of the interchange is shown in Figure 60. On the southeast quadrant is a right-out only fast-food restaurant (Wendy's) driveway about 267 ft from the eastbound off ramp and a shopping center connection about 400 ft from the off ramp. The northeast quadrant has a frontage road connection (Austin Blvd) and gas station driveway that connect to the northbound on-ramp taper, followed by driveways to two fast food businesses (Taco Bell and Burger King) immediately adjacent to the gas station (Figure 61). Taco Bell has two driveways – an exit within 42 ft of the on-ramp and an entrance within 128 ft. Burger King also has two one-way driveways – a two-lane exit within 148 ft of the on-ramp and a one-lane entrance about 263 ft from the on-ramp and connecting to the edge of the return radius of the first signalized intersection (NW 10th Terrace). The signalized intersection of NW/SW 10th Terrace is only 300 feet from the on-ramp and about 658 ft from the off ramp.

Figure 60. East side of I-95 and W. Hallandale Beach Blvd interchange.

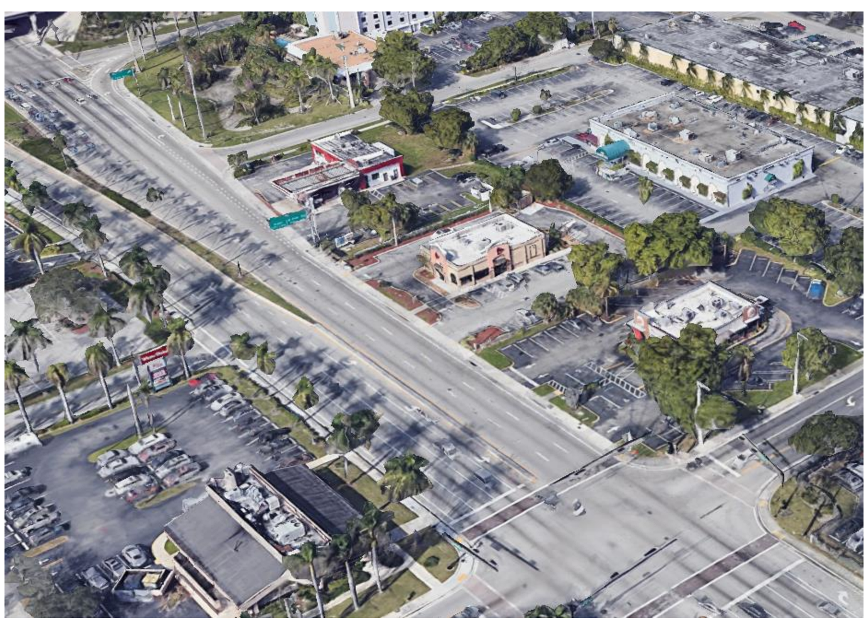


Figure 61. Access connections near northbound on-ramp of I-95.

6.5.2 Crash Analysis

Between 2015 and 2019, approximately fourteen crashes were reported involving vehicles exiting or entering commercial driveways near the interchange ramp tapers. A review of the crash reports indicated that seven were categorized as angle crashes, four as rear-end collisions, three involved cyclists and one of these three crashes involved a motorized bicycle. All but one of the angle and rear-end collisions occurred as drivers entered and exited commercial connections closest to the interchange on or off ramps. As such, the crashes are illustrative of the typical safety issues associated with access connections near interchange ramps.

For example, three crashes occurred as vehicles turned right out of a commercial driveway (Taco Bell) abutting the northbound on-ramp and hit a passed vehicle slowing down, as conceptually illustrated in Figure 62. Drivers looking left to exit these uses apparently failed to notice the passed vehicle in the right lane braking to slow in advance of the interchange signal or possibly to turn into a driveway/street connection or enter the on-ramp. A similar type of crash occurred, although in the opposite direction, when a driver turning right out of the Wendy's driveway east of the interchange off-ramp hit a slowing vehicle in the right through lane.

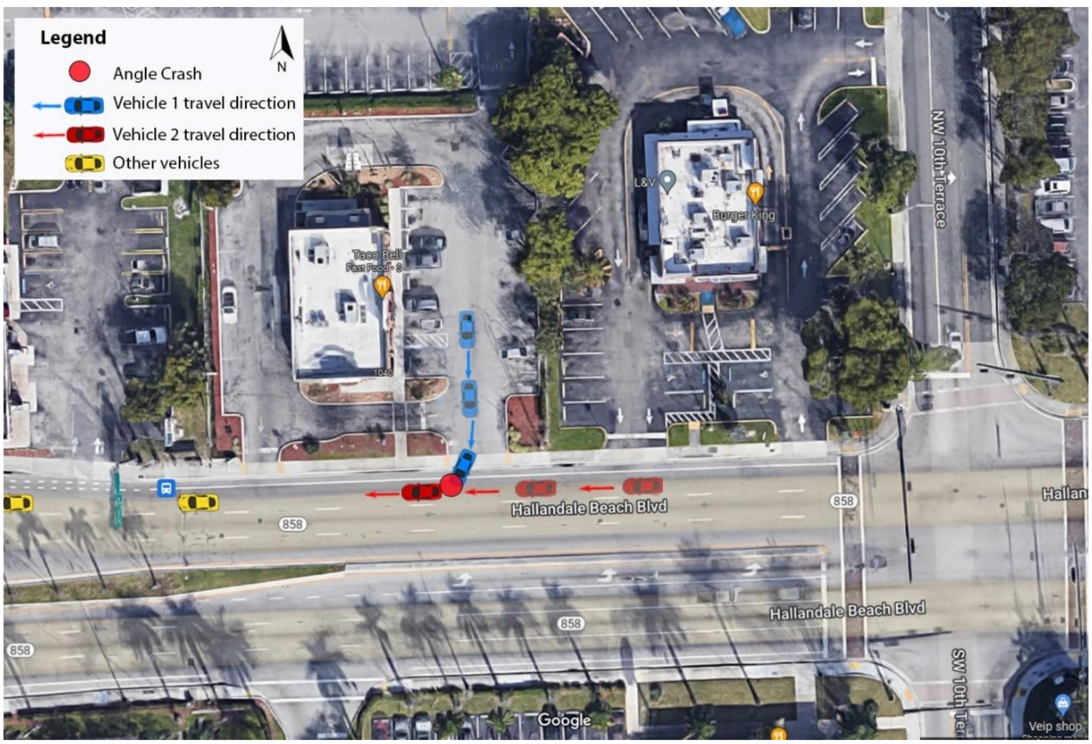


Figure 62. Common crash scenario as vehicles exit commercial driveways near interchange on-ramp.

Safety issues were also observed with regard to commercial driveway ingress in this area. A crash occurred as a vehicle travelling westbound toward the interchange in the right lane hit a car turning right into the Exxon gas station, with a similar crash at the Taco Bell (Figure 63). Following drivers expect the vehicles to continue onto the on-ramp rather than suddenly slow to turn into a driveway. Another crash involved a westbound vehicle merging suddenly into the right lane after NW 10th Terrace to enter the on-ramp or a driveway thereby causing a rear-end collision with a following vehicle in the right lane (Figure 62).

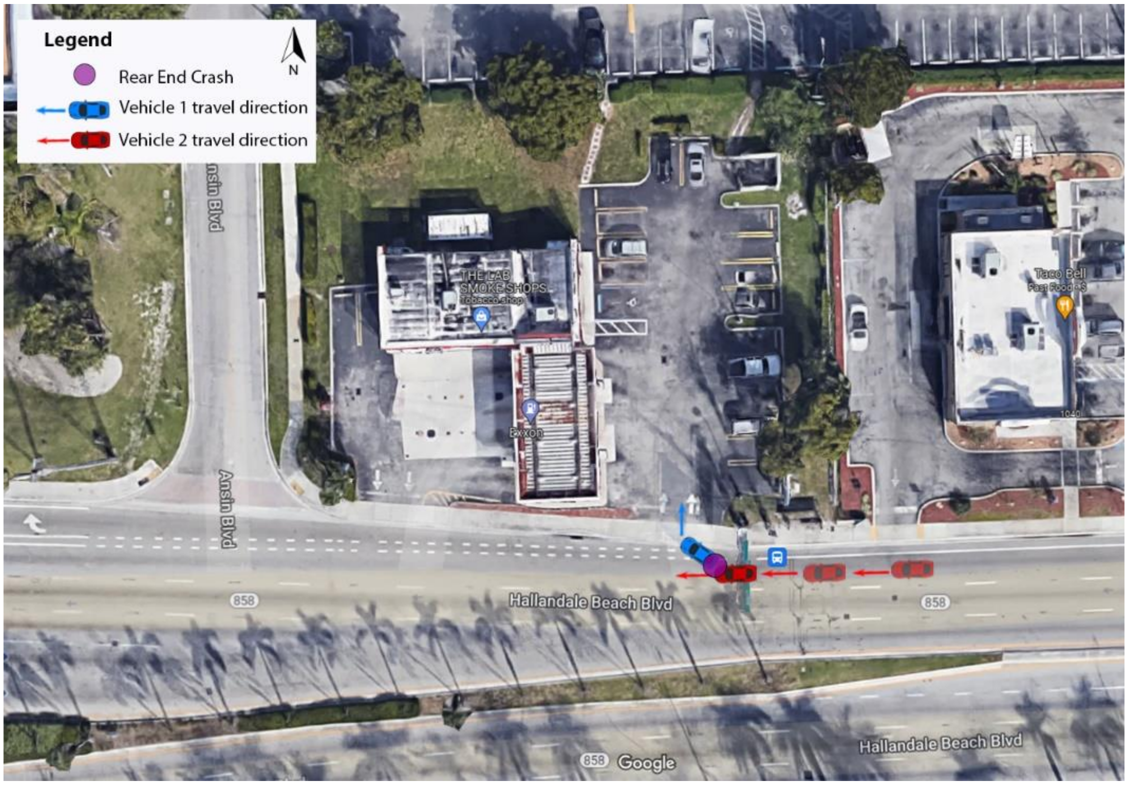


Figure 63. Crash as vehicles enter commercial driveways near interchange on-ramp.

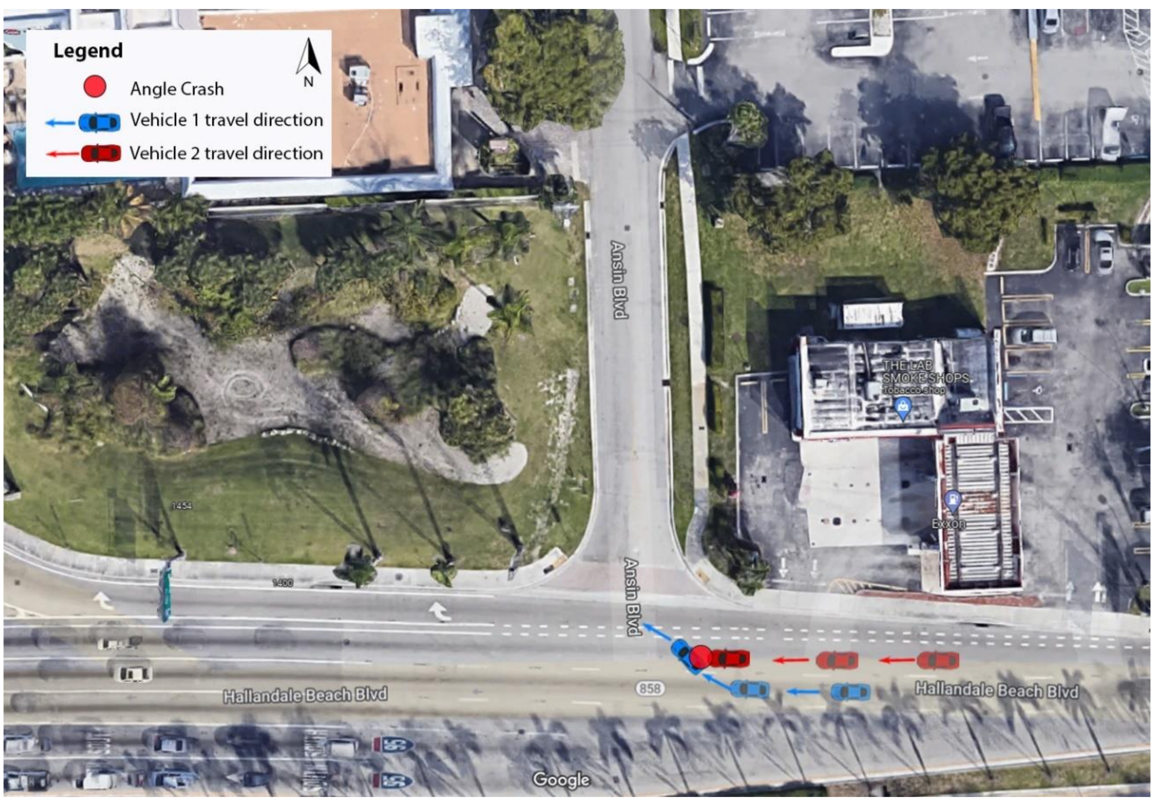


Figure 64. Crash scenario as vehicles merge right at interchange ramps or driveways.

Another safety issue was observed relative to the frontage road connection at the southbound interchange on-ramp. Here a driver entering the on-ramp was confronted with a second driver in the adjacent through lane attempting to turn right into the commercial frontage road, resulting in an angle collision (Figure 65). This crash illustrates how commercial frontage road connections too close to interchanges create conflicts that can lead to crashes.

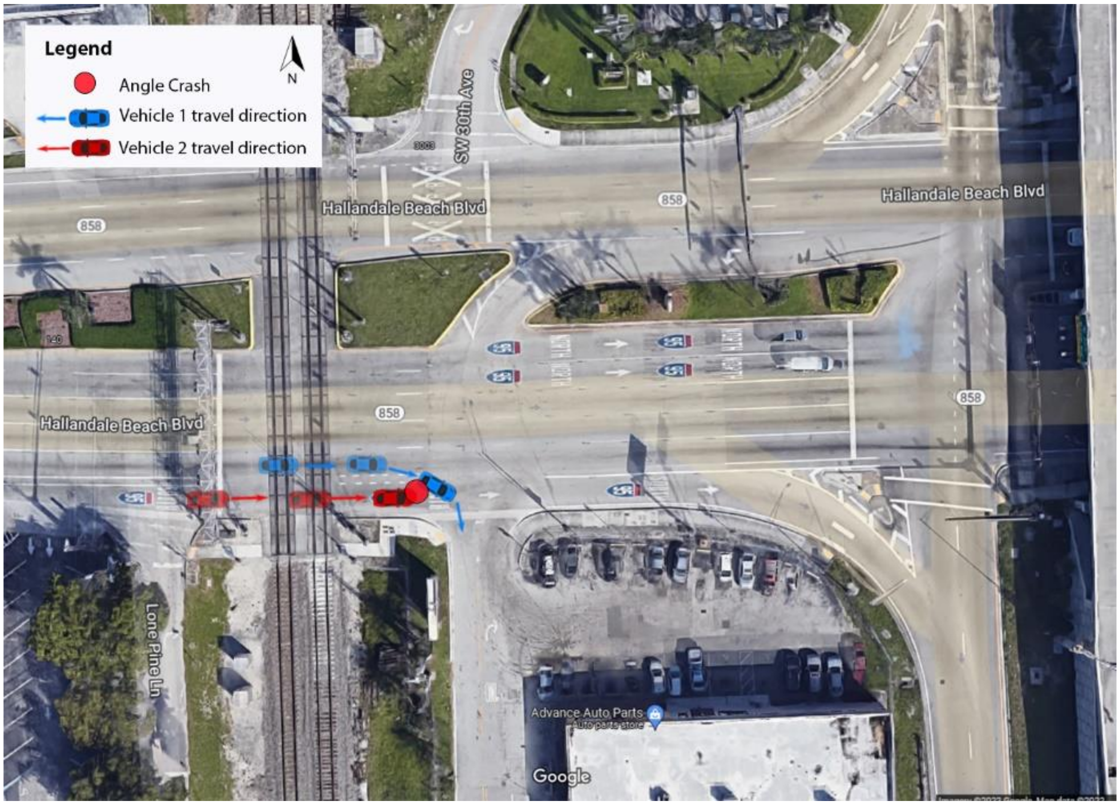


Figure 65. Conflict between commercial frontage road and interchange on-ramp.

The two bicycle crashes occurred as drivers looked left while attempting to exit the driveways and failed to notice the cyclists crossing the driveway from the opposing direction (Figure 66). In both cases the cyclists were travelling the wrong way on the bicycle lane. The motorized bicycle crash occurred as the rider left the sidewalk while travelling westbound to reenter the roadway and was hit by a vehicle turning right into the RaceTrac gas station located within 90 feet of the interchange off-ramp (Figure 67).

Figure 66. Typical crash involving cyclist as vehicles view oncoming traffic while exiting driveway.

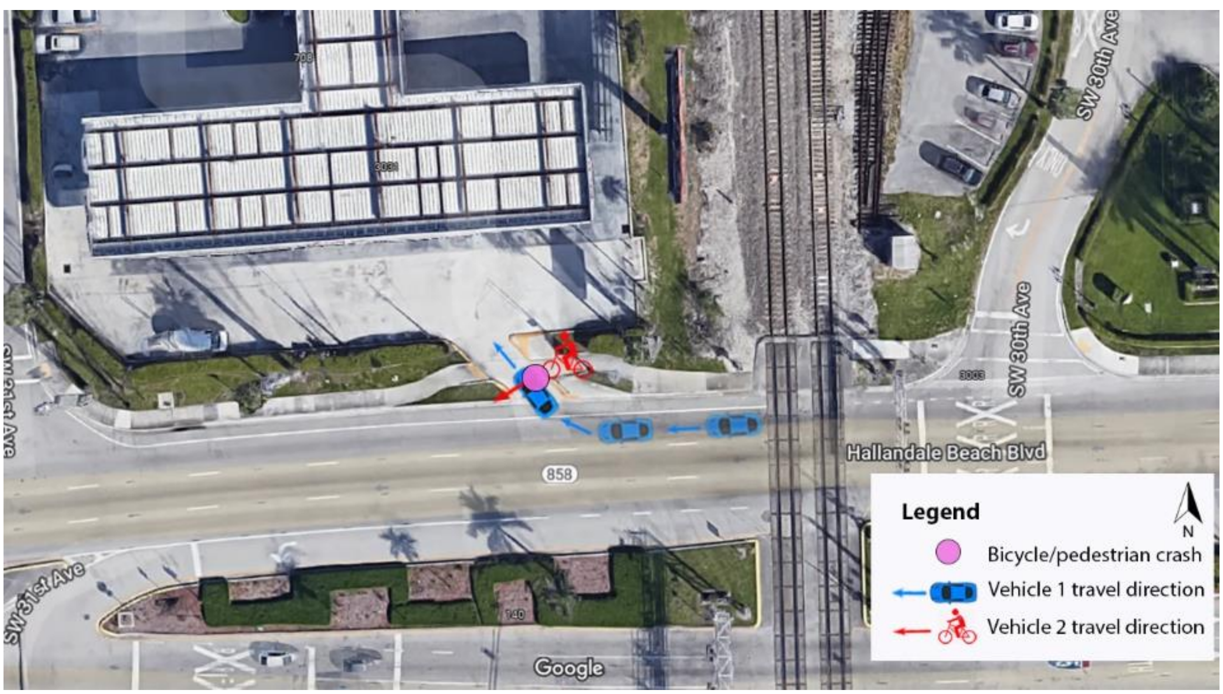


Figure 67. Interchange area crash involving motorized bicycle.

6.5.3 Potential Countermeasures

When land development and access are not properly managed in the vicinity of interchanges, the resulting safety hazards are costly and often challenging to resolve. Interchange area planning can offer some solutions as properties redevelop and there is a change in use. Through the development process, access points may be reduced and internal network reconfigured to offer alternative ways to circulate and obtain access to commercial properties. The railroad tracks create unique constraints for alternatives to commercial frontage road access west of the interchange. However, closure of Ansin Boulevard on the east, which connects to the northbound on-ramp, could be accommodated given the presence of a gridded circulation system. Some agencies are also replacing signalized intersections with roundabouts to accommodate areas where signals too close to interchanges result in delay and safety issues.

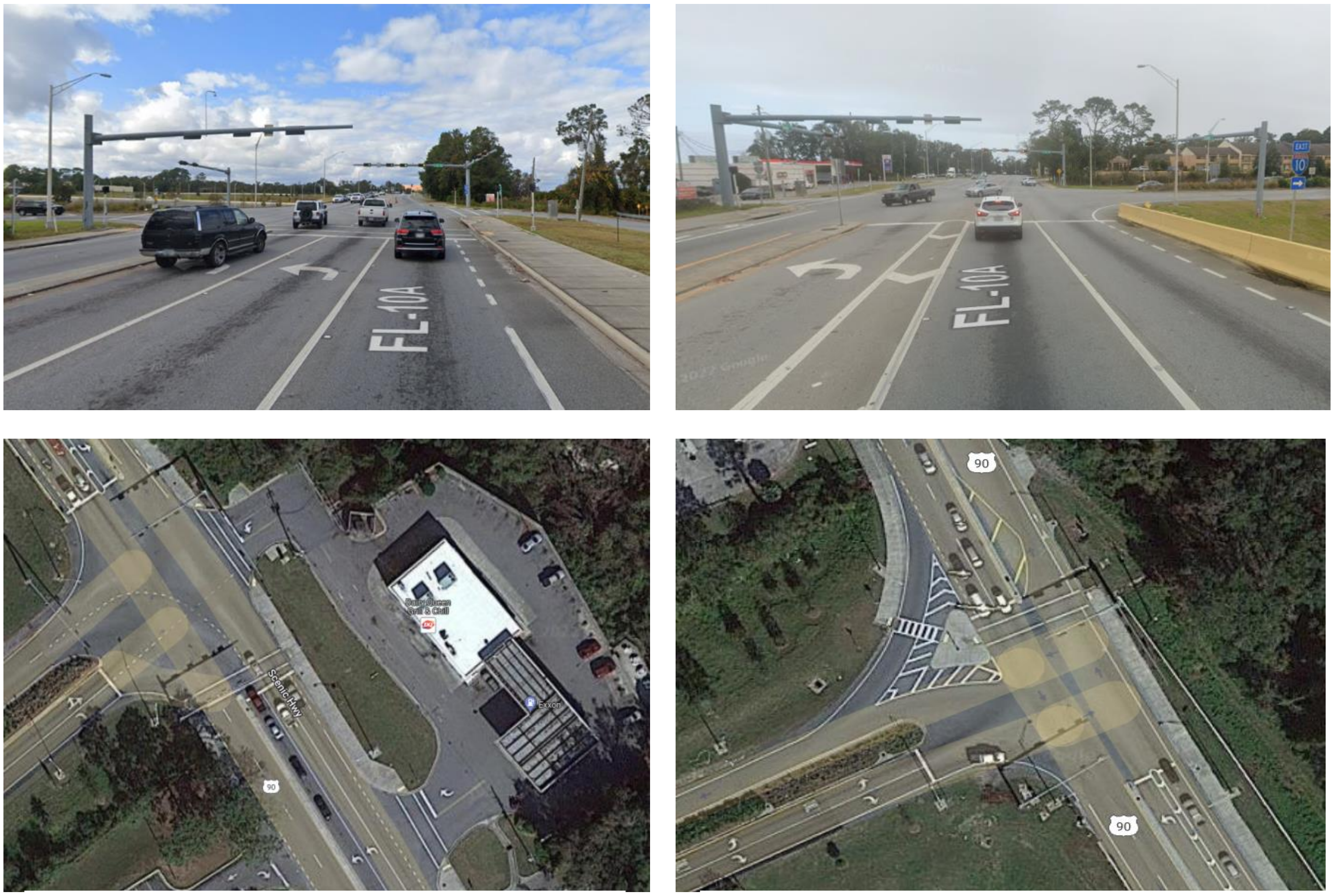
6.6 Scenic Highway at I-10 Interchange (Escambia County)

6.6.1 Overview

This case study examines commercial driveway safety issues at the interchange of State Road 10A/Scenic Highway, and Interstate Highway 10 (I-10) (Figure 68). This is a partial cloverleaf interchange with signalized on and off ramps to the south and a combination of signalized with yield control on- and off-ramps to the north (Figure 69). Scenic Highway is a three-lane divided highway at the interchange with dual left turn lanes for the southernmost on-ramps on one-left turn lane for the northernmost on ramp. It is classified as an urban principal arterial-other south of the interchange and an urban minor arterial north of the interchange with an annual average daily traffic (AADT) volume of 17,400 vehicles per day. Sidewalks and bicycle lanes are present in the vicinity of the interchange. Ramp AADT ranges between 5500 and 6800 vehicles per day.

Figure 68. Scenic Highway at I-10 Interchange study area.

Source: https://tdaappsprod.dot.state.fl.us/fto/



a) Northbound from Scenic Hwy and aerial

b) Southbound from Scenic Hwy and aerial view

Figure 69. Scenic Highway at I-10 Interchange ramp configuration after reconstruction.

Scenic Highway is classified as an Access Class 6 (no restrictive median) near the interchange with a posted speed of 45 mph. The FDOT access connection spacing requirement for this access class is 245 feet. Because this is an interchange area, FDOT Rule 14-97.003(3)(h)2 calls for a minimum of ½ mile between the first full median opening and the end of the off-ramp taper and connection spacing of 440 feet where the posted speed is 45 mph or less. Interchange areas are defined in rule as the lessor of ¼ mile from an interchange facility or up to the first intersection with an arterial road.

The context classification for this area is C3C-Suburban Commercial. Commercial uses in the immediate vicinity of the interchange include a gas station/Dairy queen plaza and hotel just to the south (Figure 70) and a gas station and discount store on the north (Figure 71). The first driveway to the plaza is opposite the interchange ramps. The second driveway is located about 120 ft south of the ramps and offset slightly right of the hotel driveway across Scenic Highway and approximately 80 ft from the southernmost on and off ramps. A second driveway to the hotel is about 600 feet south of the interchange ramps. The gas station driveway on the north side of the interchange is within 160 feet of the northernmost on/off ramps.

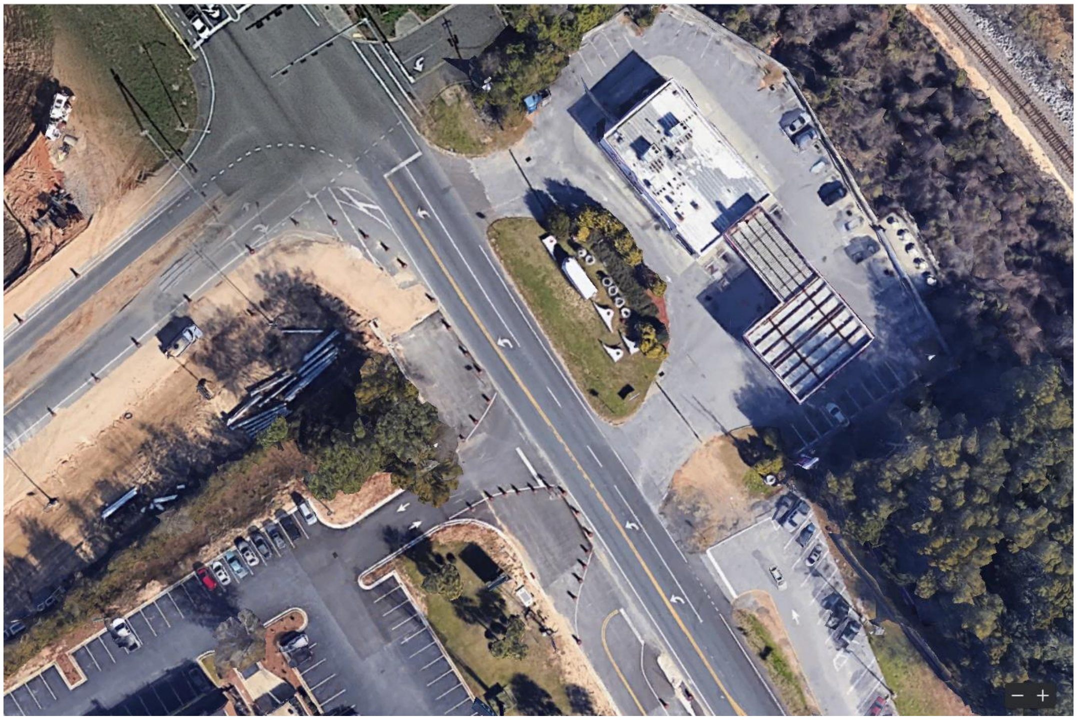


Figure 70. Commercial driveways south of I-10 interchange ramps before reconstruction.

Figure 71. Commercial driveways north of I-10 interchange ramps before reconstruction.

The interchange area was reconstructed in late 2016, which overlaps with the crash analysis period offering insight into how the access changes impacted safety. A narrow median was installed on both sides of the interchange preventing direct left turns into the plaza or the gas station to the north and a second turn lane for the northbound on-ramp was installed, along with sidewalks and bike lanes. The northernmost driveway access to the gas station/Dairy queen plaza was also removed and reconstructed in 2016 as shown in Figure 72, creating a full movement signalized intersection at the interchange ramps. Prior to reconstruction, the first access to the plaza from the interchange was offset slightly from the on-ramps to I-10, as shown in Figure 70. No median was present at this time, thereby allowing left turns into and out of the site, as well as crossing maneuvers at the hotel driveway.

Figure 72. Driveway access as reconstructed in 2016.

Reconstruction also changed the access design north of the interchange. A median was installed, eliminating left turns into the gas station driveway and requiring drivers to make a U-turn at the intersection with Northpointe Parkway just north of the gas station driveway, as shown in Figure 73.

Figure 73. Commercial access and on-ramp design north of interchange following reconstruction.

6.6.2 Crash Analysis

Between 2015 and 2019, a total of nineteen commercial driveway-related angle crashes were recorded in the immediate vicinity of the interchange, illustrating the safety issues associated with commercial access too close to interchange ramps. All but one of these crashes occurred at the gas station/DQ plaza (Figure 74), with ten involving left-turn ingress (Figure 75) and eight involving right-turn egress maneuvers (Figure 76). Only one of these crashes (right-turn out of plaza) occurred following reconstruction in 2016 and installation of the median, which prevented direct left turns into and out of the commercial driveways surrounding the interchange. Some lingering construction may, however, have been an issue in this crash due to barrels impeding sight distance.

The crashes occurred during daylight and largely under normal driving conditions. No serious injuries were reported, indicating that the through vehicles were not travelling at high speeds. One left-turn ingress crash at the plaza involved a second vehicle attempting to turn left into the hotel, illustrating the overlapping conflicts then present at this location prior to the median installation (Figure 77). Figure 78 shows another crash north of the interchange during left turn access into the gas station which is only 16 feet from the interchange ramps. This crash type is also now mitigated by the median.

Figure 74. Configuration of access and crashes south of the Scenic Highway at I-10 interchange.

Figure 75. Left-turn in crashes at Scenic Highway at I-10 Interchange commercial plaza prior to median.

Figure 76. Right-turn out crashes at Scenic Highway at I-10 Interchange commercial plaza.

Figure 77. Crash involving multiple vehicles at plaza and hotel intersection with Scenic Highway.

Figure 78. Left-turn crash at gas station north of interchange near ramps.

This case study illustrates the safety impacts of commercial access in the functional area of an interchange, especially where left-turn access is allowed. The overlapping conflicts from closely spaced commercial driveway access in proximity to interchange ramps clearly impacts both interchange safety and operations. Queues at the intersection with the interchange also obscure visibility as queueing vehicles allow vehicles exiting right out of the commercial plaza driveway to enter the left-turn lanes for the interchange ramp. This crash issue was present before and after the median installation, although was more pronounced prior to reconstruction. Addition of a turn lane may have reduced the length of the queue, thereby reducing blockage of the right-turn crossing maneuver.

6.6.3 Potential Countermeasures

In this case study, the proximity of the commercial plaza driveway access across from the on-ramp left-turn lanes resulted in several crashes involving both left-turn and right-turn maneuvers. The median installation mitigated the left-turn crash issues and signalization of the driveway across from the interchange ramps provides protected movements at this location. However, the presence of commercial driveways so close to this interchange is a lingering safety problem, as are the gas station driveway connections to Northpoint Parkway and Scenic Highway so close to the intersection and the interchange ramps.

Options may include:

- Close and relocate the commercial plaza access further south through cross access with the adjacent supplemental parking area.
- Alternatively, only allow right-in only into the Exon gas station on the northbound Scenic Highway.
- Close the hotel driveway closest to the interchange and require use of the access further south.

- Consider a roundabout or directional median opening design at the Northpointe Parkway intersection with Scenic Highway.

6.7 Summary of Case Study Findings

Safety issues were observed with allowing commercial driveway access in the functional area of roadway intersections, despite the use of mitigating techniques such as nontraversable medians and directional median openings. For example:

- Lengthy queues at signalized intersections disrupted driveway operations and reduced visibility of vehicles crossing through lanes to enter and exit these connections where a median opening was present.
- Crash reports indicate that queueing vehicles allowed driveway traffic to cross through lanes at median openings or near signalized intersections resulting in crashes in one of the through lanes, sometimes involving more than one vehicle, as vehicles proceed into or out of the driveway.

Aligning higher-volume commercial driveways at full median openings was observed to result in a variety of conflicts and crashes. For example:

- The location of the median opening in relation to the shopping center driveways in the Largo case study resulted in numerous conflicts between through moving vehicles and those attempting to enter or exit the driveways from/to the full median opening. Among these is the potential for head on collisions when multiple vehicles are attempting to exit the adjacent driveways and maneuver into the median opening simultaneously. In addition, the number of potential movements and conflicts contributed to bicycle/pedestrian crashes at this location as pedestrians or bicyclists attempted to cross these driveways.

Drivers looking left at oncoming traffic while attempting to exit commercial driveways do not notice bicyclists crossing the driveway, resulting in bicycle-involved crashes. Additional educational measures and signage could help to mitigate this issue as would painted bike lanes and other measures to make it more apparent that bicyclists may be present.

Closely spaced high volume commercial driveways that experience similar peak periods require special attention to ensure that adequate space is provided on-site for circulation and queueing. It is important to avoid approval of driveways near an intersection where the establishment creates a potential for long queues that may spill back onto roadways and create safety issues. Where such driveways are placed near signalized intersections, additional measures are needed to ensure interparcel cross access is provided to increase corner clearance and/or allow left-turn access at the signal.

- In the Tallahassee case example, the short spacing distances between the driveways, the volumes associated with the land uses, and their proximity to a signalized roadway intersection resulted in multiple conflicts and crashes.
- Lengthy queues at the coffee shop interfered with through traffic movement and disrupted nearby driveway operations, even as conflicts and crashes were observed between through vehicles and those exiting the fast-food restaurant, attempting to access the left turn lane at the nearby intersection.

Commercial driveway access near interchange ramps creates clear safety issues. For example,

- As shown in the West Hallandale Beach Boulevard example, rear end collisions are one common safety problem at these locations. Vehicles exiting these driveways may suddenly stop to yield to through traffic or those accessing the entrance ramp for the express lane. In some instances, drivers back up to remove themselves from the roadway and back into the vehicle behind them.

- The Scenic Highway/I-10 interchange case study illustrates the safety impacts of closely spaced access points in proximity to interchange ramps. The combination of left turn conflicts and crashes prior to the median installation, as well as the tendency for queueing vehicles waiting to access the interchange to obscure visibility while “good Samaritans” also allowed vehicles exiting right out of the commercial plaza driveway to enter the left-turn lanes for the interchange ramp resulted in numerous crashes. The median installation clearly mitigated many but not all of these safety issues.

7. Research Findings and Recommendations

7.1 Summary of Research Findings

7.1.1 Findings on Crash Frequency Analysis

Tables 25-27 summarize the findings on crash frequency for variables found to have a significant influence on commercial driveway-related crashes along corridors and interchanges; however, not all values within each category were significant in explaining crash risk. The percentage values indicate the positive or negative influence of each categorical value on crash frequency compared only to the base category (identified by asterisk). From a statistical perspective, the percentage values are meaningful only in comparison to the base category and should not be compared across categories within that variable. For example, the crash risk for commercial driveways on three-lane roadways was 118% higher than on one-lane roadways, but one should not presume it was 53% higher than on two-lane roadways.

Table 25. Crash Frequency at Commercial Driveways along Corridors (All Crashes)

Variables	Categories	Statistically Significant**	Crash Frequency	Notes
Number of Lanes on Connecting Street	One Lane*			
	Two Lanes	Yes	+65.2%	Number of lanes is a surrogate for roadway AADT. More lanes indicate increased lane changing behavior and potential for traffic conflicts.
	Three Lanes	Yes	+118.0%	
	Four Lanes or More	Yes	+192.9%	
Speed Limit on Connecting Street	35mph or lower*			
	40-45mph	Yes	−15.2%	Higher speed limits usually indicate higher levels of access control, whereas lower speed limits generally indicate higher access densities and more complex traffic.
	50mph or higher	Yes	−44.9%	
Driveway Design Features	Curb Flare*			
	Flush Radial	Yes	+39.8%	Flared curbed driveways generally have low driveway traffic; flush or curb radial designs are more common at higher traffic driveways as they allow for efficient ingress and egress; however, they can also increase crash risk.
	Curb Radial	Yes	+24.7%	
	Wide Open Access	Yes	−37.4%	
Driveway Number of Lanes (including both directions if available)	One Lane*			
	Two Lanes	Yes	+26.5%	Driveway number of lanes is a surrogate measure for driveway volume. Multi-lane or wide open driveways can experience more complex traffic movements with increased potential for conflicts.
	Three Lanes	Yes	+179.1%	
	Four Lanes or more or Wide-open Access	Yes	+57.5%	
Median Type	Undivided or Painted Median*			
	Non-traversable Median	Yes	−19.9%	Both non-traversable medians (NTM) and continuous Two-Way Left-Turn Lanes (TWLTL) reduce crash risk compared to undivided roadways. NTMs tend to serve higher-volume roads and have different levels of conflict depending on median opening spacing, location, and type.
	TWLTL	Yes	−24.7%	TWLTLs provide space for vehicles to maneuver and stop as they turn or merge into traffic without blocking through lanes, but allow more conflicts than NTMs.

Table 25, continued

Variables	Categories	Statistically Significant**	Crash Frequency	Notes
Connecting Street 5-year Average AADT	AADT<10,000*			
	10,000<AADT⩽ 20,000	No	N/A	The average number of crashes tended to increase for all AADT categories, but only one category is found statistically significant.
	20,000<AADT⩽ 30,000	No	N/A	
	30,000<AADT⩽ 40,000	Yes	+258.1%	
	40,000<AADT⩽ 50,000	No	N/A	
	50,000<AADT⩽ 60,000	No	N/A	
	60,000<AADT⩽ 70,000	No	N/A	

*Indicates base category for analysis of each variable.
**Significant at 95% confidence level.

Table 26. Ped/Bike Crash Frequency at Commercial Driveways along Corridors

Variable	Values and Base Category	Statistically Significant**	Crash Frequency (±%)?	Note
Number of Lanes on Connecting Street	**One Lane***			
	Two Lanes	No	N/A	The variable is significant in explaining crash frequency; however, none of the categorical values are statistically significant relative to the base category. More lanes entail longer crossing times and greater exposure of pedestrians or bicyclists to through-traffic conflicts.
	Three Lanes	No	N/A	
	Four Lanes or More	No	N/A	
Driveway Design Feature	**Curb Flare***			
	Flush Radial	Yes	−52.0%	Radial return designs are generally used on high-volume driveways, which have higher crash potential. On flush shoulder roadways, FDOT prefers sidewalk placement outside the clear zone or five feet beyond the shoulder pavement to provide adequate protection for pedestrians or bicyclists.
	Curb Radial	Yes	+35.2%	
	Wide Open Access	No	N/A	
Median Opening Type	**No Physical Median***			
	No Opening	Yes	−21.3%	Physical medians (both no opening and directional opening) provide buffer space for pedestrians and cyclists to wait to cross, reducing collision risk with through traffic. No median opening or a directional median opening limits vehicular turning movements thereby also reducing driveway conflicts.
	Directional Opening	Yes	−36.9%	
	Full Opening	No	N/A	

Table 26, continued

Variable	Values and Base Category	Statistically Significant**	Crash Frequency (±%)?	Note
Traffic Control Device	**No Control***			
	Sign Control	Yes	+52.2%	Driveways with sign or traffic signal controls tend to have higher traffic volume and more complex traffic than locations with no traffic controls, and therefore experience higher crash frequencies.
	Traffic Signal Control	Yes	+137.9%	
Painted Bike Lane	**No Bike Lane***			
	No Paint	Yes	+39.7%	Conventional bike lanes without paint do not necessarily provide protection. Motor vehicles must cross bike lanes to enter or exit driveways, leading to conflicts with bicyclists in the bike lane.
	Painted	No	N/A	

* Indicates base category for analysis of each variable.
** Significant at 95% confidence level.

Table 27. Crash Frequency at Commercial Driveways near Interchanges

Variable and Base Category	Values and Base Category	Statistically Significant**	Crash Frequency***	Note
Number of Lanes on Connecting Street	**One Lane***			
	Two Lanes	No	N/A	Number of lanes is a surrogate for roadway AADT; More lanes indicate increased lane changing behavior and potential conflict points.
	Three Lanes	Yes	+87.8%	
	Four Lanes or More	Yes	+113.5%	
Right-turn Lane Type	**Exclusive Right-turn Lanes***			
	Shared/continuous right-turn lane	Yes	+99.1%	Compared to exclusive right-turn lanes, shared right-turn lanes or locations with no right-turn lane serve more than one driveway site, leading to lower driver expectancy as to where turns will occur and creating a higher potential for conflicts and rear-end collisions.
	No Right-turn Lane	Yes	+177.9%	
Driveway Design Feature	**Curb Flare***			
	Flush Radial	No	N/A	Both flare and curb radial tend to increase crash frequency but only curb radial design had a significant influence. Flush or curb radial are used at higher traffic driveways, and large radius or flare allows for quick and more efficient ingress and egress but increases crash risk.
	Curb Radial	Yes	+93.9%	
	Wide Open Access	No	N/A	
Driveway Number of Lanes (including both directions if available)	**One Lane***			
	Two Lanes	No	N/A	Driveway number of lanes could be a surrogate measure for driveway volume; Driveways with multiple lanes or wide-open access can experience more complex traffic movements with increased potential for conflicts.
	Three Lanes	Yes	+148.8%	
	Four Lanes or more or Wide-open Access	Yes	+133.8%	

Table 27, continued

Variable and Base Category	Values and Base Category	Statistically Significant**	Crash Frequency***	Note
Traffic Control Device	**No Control***			
	Sign Control	Yes	+34.8%	Locations with sign control tend to have higher traffic volume and more complex traffic than location with no traffic controls, and therefore still experience higher crash frequencies.
	Traffic Signal Control	No	N/A	
Bike Lane Type	**No Bike Lane***			
	Conventional Bike Lane	Yes	−26.8%	Other bike lane types were also found to decrease crash frequency but not significantly. Therefore, presence of a bike lane at commercial driveways near interchanges helps to reduce crash frequency, regardless of bike lane type.
	Other Bike Lane Types	No	N/A	
Connecting Street 5-year Average AADT	**AADT⩽10,000***			
	10,000<AADT⩽ 20,000	Yes	−46.1%	It is possible that fewer driveways were permitted in the interchange influence area as the AADT increased on connecting streets, thereby reducing the average number of driveway-related crashes.
	20,000<AADT⩽ 30,000	Yes	−61.9%	
	30,000<AADT⩽ 40,000	Yes	−54.9%	
	40,000<AADT⩽ 50,000	Yes	−56.3%	
	50,000<AADT⩽ 60,000	Yes	−58.2%	

* Indicates base category for analysis of each variable.
** Significant at 95% confidence level.
*** Motor vehicles only.

7.1.2 Findings on Crash Severity

Table 28 summarizes findings on vehicle crash severity at commercial driveways along corridors for those variables and categorical values found to have a statistically significant influence on crash severity at a 95% confidence level in MNL modeling. Column 2 shows the significant categorical value with the crash severity level shown in parentheses. Column 3 shows the percentage increase (+) or decrease (−) in the potential for that injury severity level for the variable condition, compared with the absence of that condition.

Three crash severity levels were used in the analysis–No Injury (NI, base category), minor injury (MI), and severe injury (SI). The sum of the probability for all three crash severity levels is equal to 1, so increasing the probability of one severity level will decrease the probability of another, or the other two, crash severity levels. For example, an unpaved shoulder was found to be significant in explaining minor injury (MI) crashes at commercial driveways and, compared to other types of shoulders, its presence increased minor injury (MI) risk by 16.4%. Conditions that influence pedestrian/bicycle crash severity at commercial driveways along corridors are shown in Table 29, and those that influence motor vehicle crash severity at commercial driveways in the vicinity of interchanges are shown in Table 30.

Table 28. Crash Severity at Commercial Driveways along Corridors

Crash Variable	Significant Categorical Value (Severity Level)*	Quantitative Influence (on Specific Severity Level)	Note
Type of Shoulder	Unpaved Shoulder (MI)	+16.4% (MI)	Vehicular traffic near interchanges is often relatively high speed and turning at driveways may lead to hitting or running over the curb, causing minor injury collisions.
	Curb (MI, SI)	+33.6% (MI) +79.3% (SI)	
Weather Condition	Cloudy (MI)	+12.1% (MI)	Drivers may be more cautious and drive at relatively slower speeds in inclement weather, thereby reducing the potential for severe crashes.
	Rain (SI)	−59.3% (SI)	
Lighting Condition	Daylight (SI)	−29.8% (SI)	Daylight or sufficient lighting ensures good visibility and reduce crash severity.
Speed Limit on Connecting Street	35 mph or lower (MI, SI)	−27.5% (MI) −69.9% (SI)	Lower speed limits create less kinetic energy upon collision thereby reducing impact on the body.
	40-45 mph (MI, SI)	−18.1% (MI) −43.6% (SI)	
Right-turn Lane Type	Shared/continuous right-turn lane (SI)	−35.3% (SI)	Drivers tend to travel at lower speeds on shared right-turn lanes while attempting to locate their target driveway.
Driveway Design Feature	Flush Radial (MI)	+20.5% (MI)	Flush radial design is generally used to allow efficient (higher-speed) turning movements. Curb flare design generally indicates lower driveway traffic and curb delineation at driveway sites forces drivers to slow down.
	Curb Flare (MI, SI)	−15.6% (MI) −43.0% (SI)	
Driveway Traffic Operations	Full Traffic Movements (MI)	+17.3% (MI)	Full traffic movement driveways increase the potential risk of minor injuries. Left-in/left-out only driveways have fewer potential conflicts than full movement driveways.
	Left-in/Left-out (MI)	−34.5% (MI)	
Driveway Channelization	With Channelization (SI)	−19.8% (SI)	This result verifies the protective effects of driveway channelization by separating opposing traffic flows and preventing encroachment.
Bike Lane Type	No Exclusive Bike Lane (MI)	−23.6% (MI)	A conventional bike lane reduces minor injury crashes, but absence of a bike lane also has this effect, perhaps due to sidewalk use. Severe injury crashes are not reduced as vehicles in the adjacent through lane may still easily encroach into the bike lane and a conventional bike lane across a driveway entrance may also increase the rear-end or angle-collision risk, thereby inducing more injuries.
	Conventional Bike Lane (MI)	−20.6% (MI)	
Driveway Throat Length	Short Driveway Throat Length (MI, SI)	+4.7% (MI) +60.5% (SI)	This result verifies the safety importance of sufficient driveway throat length.
Median Opening Type	No Opening (SI)	−44.5% (SI)	No openings in the physical median prevent left-turn movements, thereby significantly reducing the potential for severe injuries.
Connecting Street AADT at Crash Year	60,000<AADT≤70,000 (MI)	+17.0% (MI)	Only this AADT categorical value was statistically significant in explaining crash severity outcomes.

* Variable that is significant in explaining the potential of the specific injury severity level listed in the parenthesis.
** Percentage value of influence in increasing (+) or decreasing (−) the risk of specific crash severity level in the parenthesis.

Table 29. Ped/Bike Crash Severity at Commercial Driveways along Corridors

Crash Variable	Significant Categorical Value (Severity Level) *	Quantitative Influence (on Specific Severity Level)**	Note
Type of Shoulder	Paved Shoulder (MI, SI)	−2.0% (MI) −37.6% (SI)	Paved shoulders should be considered near commercial driveways in areas with high pedestrian/bicycle activity.
Alcohol or Drug Involvement	Alcohol or Drug Involved (SI)	+208.95% (SI)	Although not specific to access management, this verifies the serious adverse impact of substance use on traffic safety.
Driveway Number of Lanes	Two Lanes (MI, SI)	−1.4% (MI) +162.2% (SI)	Multiple driveway lanes suggests more complex traffic conditions, relatively higher vehicle speeds, and more pedestrian/bicycle exposure, therefore inducing severe injury.
	Four Lanes or More OR Wide-open Access (SI)	+231.5% (SI)	
Bike Lane Type	No Bike Lane (MI)	−8.8% (MI)	If no bike lane is available, many bicyclists travel on the sidewalk to avoid mainstream traffic; if they travel next to the travel lane severe injuries or fatalities are likely when a crash occurs.
Driveway Throat Length	Short Driveway Throat Length (SI)	+46.4% (SI)	Sufficient driveway throat length at commercial driveways is important to pedestrian and bicycle safety along corridors.
Connecting Street AADT at Crash Year	50,000<AADT≤60,000 (MI)	+15.5% (MI)	Only this AADT categorical value was statistically significant in explaining crash severity outcomes.

* Variable that is significant in explaining the potential of specific injury severity level listed in the parenthesis.
** Percentage value of influence in increasing (+) or decreasing (−) the risk of specific crash severity level in the parenthesis.

Table 30. Motor Vehicle Crash Severity at Commercial Driveways near Interchanges

Crash Variable	Significant Categorical Value (Severity Level Explained)*	Quantitative Influence (on Specific Severity Level)**	Note
Alcohol or Drug Involvement	Alcohol or Drug Involved (MI)	+170.9% (MI)	This verifies the serious adverse impact of substance use on traffic safety.
Lighting Condition	Dawn/Dusk (MI)	+74.6% (MI)	Sufficient lighting ensures good visibility and improves traffic safety, while dawn/dusk is often associated with fatigue or drowsiness.
Speed Limit on Connecting Street	50 mph or higher (MI)	+101.3% (MI)	Speed limit is an indicator of traffic operating speed, and higher speed limits suggest a greater impact upon vehicle collision.
Driveway Number of Lanes	One Lane (SI)	+180.6% (SI)	One-lane driveways are difficult to identify due to narrow widths, and sudden maneuvers upon entry (or potential for lack of compliance on site) may increase severe injury crashes. Warning or guidance signs may be needed.
Bike Lane Type	Conventional Bike Lane (MI)	+24.3% (MI)	Conventional bike lanes do not provide a physical barrier or buffer to sufficiently reduce exposure to nearby traffic, and therefore increase the injury risk to bicyclists.
Distance From Taper End Unsignalized or Signalized Driveway	(0, 500 ft) (SI)	+261.0% (SI)	Commercial driveways in interchange influence areas create conflicts with interchange traffic and insufficient travel distances for vehicles to slow before diverging from or merging with through traffic.

* Variable that is significant in explaining the potential of specific injury severity level listed in the parenthesis.
** Percentage value of influence in increasing (+) or decreasing (−) the risk of specific crash severity level in the parenthesis.

7.1.3 Case Study Findings

Safety issues were observed with allowing commercial driveway access in the functional area of roadway intersections, despite the use of mitigating techniques such as nontraversable medians and directional median openings. For example:

- Lengthy queues at signalized intersections disrupted driveway operations and reduced visibility of vehicles crossing through lanes to enter and exit these connections where a median opening was present.
- Queueing vehicles were observed to be allowing driveway traffic to cross through lanes at median openings or near signalized intersections resulting in crashes in one of the through lanes, sometimes involving more than one vehicle, as vehicles proceed into or out of the driveway.

Aligning higher volume commercial driveways at full median openings was observed to result in a variety of conflicts and crashes. For example:

- The location of the median opening in relation to the shopping center driveways in the Largo case study resulted in numerous conflicts between through moving vehicles and those attempting to enter or exit the driveways from/to the full median opening. Among these is the potential for head on collisions when multiple vehicles are attempting to exit the adjacent driveways and maneuver into the median opening simultaneously. In addition, the number of potential movements and conflicts contributed to bicycle/pedestrian crashes at this location as pedestrians or bicyclists attempted to cross these driveways.

Drivers looking left at oncoming traffic while attempting to exit commercial driveways do not notice bicyclists crossing the driveway, resulting in bicycle-involved crashes. Additional educational measures and signage could help to mitigate this issue as would painted bike lanes and other measures to make it more apparent that bicyclists may be present.

Closely spaced high volume commercial driveways that experience similar peak periods require special attention to ensure that adequate space is provided on-site for circulation and queueing. It is important to avoid approval of driveways near an intersection where the establishment creates a potential for long queues that may spill back onto roadways and create safety issues. Where such driveways are placed near signalized intersections, additional measures are needed to ensure interparcel cross access is provided to increase corner clearance and/or allow left-turn access at the signal.

- In the Tallahassee case example, the short spacing distances between the driveways, the volumes associated with the land uses, and their proximity to a signalized roadway intersection resulted in multiple conflicts and crashes.
- Lengthy queues at the coffee shop interfered with through traffic movement and disrupted nearby driveway operations, even as conflicts and crashes were observed between through vehicles and those exiting the fast-food restaurant, attempting to access the left turn lane at the nearby intersection.

Commercial driveway access near interchange ramps create clear safety issues. For example,

- As shown in the West Hallandale Beach Boulevard example, rear end collisions are one common safety problem at these locations. Vehicles exiting these driveways may suddenly stop to yield to through traffic or those accessing the entrance ramp for the express lane. In some instances, drivers back up to remove themselves from the roadway and back into the vehicle behind them.

- The Scenic Highway/I-10 interchange case study illustrates the safety impacts of closely-spaced access points in proximity to interchange ramps. The combination of left turn conflicts and crashes prior to the median installation, as well as the tendency for queueing vehicles waiting to access the interchange to obscure visibility while "good Samaritans" also allowed vehicles exiting right out of the commercial plaza driveway to enter the left-turn lanes for the interchange ramp resulted in numerous crashes. The median installation clearly mitigated many but not all of these safety issues.

7.2 Discussion

This project performed comprehensive and in-depth analysis on commercial driveway safety in terms of crash frequency and severity along corridors and in the vicinity of interchanges, and there are several important findings that help us better understand access management for commercial driveways.

- Both non-traversable medians and TWLTLs tended to decrease the overall crash frequency at commercial driveways along corridors when compared to undivided or painted medians. These results further validate the safety benefits of these two median types. We do not directly explain the effects of the two non-base conditions in comparison to each other (non-traversable median vs TWLTLs), because they were not directly compared in the model. Past research indicates that nontraversable medians have a greater overall safety benefit of the two median types (Williams et al., 2014).
- Although conventional bike lanes (without a physical separator or surface paint) provide right-of-way for bicycle traffic on major roadway corridors, the analysis indicated that they tend to induce more pedestrian/bicycle crashes at or near commercial driveway locations. This is likely due to the potential for motor vehicles to encroach into the bike lane and/or overlook bicyclists when crossing bike lanes while entering or exiting commercial driveways. Conventional bike lanes were also found to significantly increase the risk of minor injury crashes at commercial driveways near interchanges. Therefore, when a bike lane is needed on a major roadway, buffered bike lanes or other types of physical barriers should be used when feasible, as well as bike lane paint at driveway locations to further alert motorists of the presence of bicyclists.
- Shared/continuous right-turn lanes were found to significantly reduce the probability of severe injury crashes at commercial driveways along corridors. Compared with exclusive right-turn lanes serving a single driveway, however, both the shared/continuous right turn lane and no right-turn lane configuration were likely to increase the average number of crashes at commercial driveways near interchanges. Both findings justified the positive safety effects for the presence of a right-turn lane, with exclusive right-turn lane as the safest option.
- Both sufficient driveway throat length and driveway channelization were shown to be beneficial in improving commercial driveway safety. Driveway channelization was statistically significant in reducing the potential of severe injury crashes for all crashes at commercial driveways along corridors, and short driveway throat length significantly increased the potential for severe injuries in both vehicular crashes and pedestrian/bicycle crashes at commercial driveways along corridors.
- The importance of avoiding commercial driveways in the influence area of highway interchanges is clear, as demonstrated by the finding that unsignalized or signalized commercial driveways are located less than 500 ft from the ramp taper end of an interchange increased the potential for severe injury crashes by 261%.

In addition, some of the findings seemed to be inconsistent with traffic safety understanding and may warrant additional analysis in the future. These include:

- Higher posted speed limits on connecting streets appeared to reduce crash frequency at commercial driveways. A possible reason is that higher speed limits indicate greater levels of access control and relatively less access density than with lower speed roadways. For example, Florida has a multilane facility median policy (Topic #625-000-007 January 1, 2013) requiring the installation of nontraversable medians on all multilane roadways with posted speeds of 45 mph or greater.
- As Connected Street 5-year Average AADT increased, the number of vehicular crashes at driveways near interchanges tended to decrease, likely because fewer driveways were permitted in the interchange influence area thereby reducing the average number of driveway-related crashes.
- Wide-open access or other (rare) design types at commercial driveways along corridors tended on average to have fewer pedestrian/bicycle crashes at commercial driveways along corridors than other more common designs. However, there tends to be increased exposure to traffic conflicts at these locations for each individual pedestrian or bicyclist. Perhaps there tended to be less overall pedestrian or bicycle activity at these locations and therefore fewer crashes. Another explanation is that the geolocation of crash reports was not precise enough to ensure the validity of this finding.
- Compared to driveways with no traffic control devices, those with sign control or traffic controls still had a higher number of pedestrian/bicycle crashes. Although the purpose of installing these devices is to reduce the crash potential at higher volume driveways, it is possible that the crash potential at these locations is still higher than at driveway sites without traffic control devices due to the higher driveway volumes.
- Conventional bike lanes (without a physical separator or surface paint) appeared to increase the risk of severe injury crashes at commercial driveways along corridors, as well as the risk of minor injury crashes at commercial driveways near interchanges. This effect applies to all vehicular crashes and not just pedestrian/bicycle crashes. For bicyclists, the lack of a physical barrier increases exposure to crashes, given that vehicles in the adjacent through lane can easily encroach into the bike lane. Conventional bike lanes may also increase the potential for rear-end collisions near driveways as motor vehicles attempting to enter the driveway stop suddenly to allow bicyclists on the bike lane to proceed. Similarly, the presence of a bicyclist on a bike lane near a driveway could increase the angle-collision risk between through traffic and vehicles turning into driveways from median openings. This finding raises questions as to the safety of the widespread practice in Florida of providing conventional bike lanes on arterials roadways with frequent commercial driveway access.

7.3 Issues and Limitations

A common limitation of driveway safety research is the need to rely on crash data that may not be tied to driveway locations. Our review of crash reports for each of the case studies revealed that some of the crashes were improperly geolocated, and some crash reports did not identify which commercial driveway location(s) were involved in the crash. For the case study analysis, these outliers were manually relocated in the ArcGIS database, given their limited numbers. In the statewide data set, those easily identifiable as inaccurate, such as driveway-related crashes mapped to locations with no nearby driveway, were also corrected based on the crash reports. However, manual correction was not feasible for all the crashes (more than 9,000) included in the modeling process. Therefore, it is reasonable to assume that some of these crashes were not correctly mapped and clustered to the responsible driveway sites. Considering the large number of crashes included in the analysis, these inaccuracies should impose only a minor or negligible influence on our research findings.

Another limitation relates to the influence of relationships among the study variables. Although each variable in the modeling procedure represents a different roadway or driveway characteristic, some of the variables are interrelated. For example, Number of Lanes on Connecting Street and Connecting Street 5-year Average AADT are highly interrelated, with both generally associated with heavier traffic volumes. Nonetheless, we did find different influences by crash group. Despite an overall upward trend on all crash frequencies for both of these variables, different effects were observed regarding pedestrian/bicycle crashes at commercial driveways. The Number of Lanes on Connecting Street was significant overall for predicting pedestrian/bicycle crashes, but none of the categorical values were significant, and AADT was not significant for these crashes in the negative binomial modeling process.

These results suggest that Number of Driveways on Connecting Street and Connecting Street AADT have more influence on overall vehicle crashes than on pedestrian/bicycle crashes at commercial driveways along corridors. For vehicular crashes at commercial driveways near interchanges, the Number of Lanes on Connecting Street illustrated an upward trend on crash frequency but Connecting Street 5-year Average AADT demonstrated a reduction effect. This might be attributed to fewer driveways being permitted in the interchange influence area on higher volume roadways, thereby reducing the average number of driveway-related crashes.

7.4 Suggested Guidance

Another study objective is to consider whether additional guidance may be needed for agency policy or practice to address the safety issues identified with commercial driveway access on corridors or near interchanges. To select appropriate actions, it is necessary to understand how factors such as driveway design, spacing, and location; roadway speed and design; and travel behavior (drivers, bicyclists, and pedestrians) influence safety and operations (Dixon et al., 2020; Dixon et al., 2022; Gluck et al., 1999). The findings of this study offer some insights in this regard. We offer the following suggestions for future consideration by FDOT and other agencies relative to commercial driveway access policy, permitting and mitigation for corridors and interchange areas, as well as median opening type and design, to improve roadway safety.

1) **Consider using traffic volume and land use context, as well as speed, as primary criteria for minimum driveway spacing.** For example, avoid FDOT Access Class 7 on high-volume major or minor urban arterial corridors and especially those with a context classification of C4 (Urban General) or C3C (Suburban Commercial); similarly, avoid FDOT Access Class 5 -7 near highway interchanges in urbanized areas or rural areas where commercial land uses are planned.
    - All high-crash commercial corridors identified through the study were high-volume multilane arterial roadways with suburban or urban general characteristics and relatively high access densities.
    - Flintsch et al., (2020) found that both access volume and spacing significantly impact crash risk of access points and both should be considered in access management criteria and practice.
    - Minh et al. (2014) found significant differences in the safety impacts of different driveway spacing policies and based on these findings recommend that traffic volume

and speed be used as the primary criteria for minimum driveway spacing; they also identified FDOT spacing guidelines as less conservative than other states. Williams et al., (2018) suggested eliminating Access Class 7 entirely due to its adverse impacts on the safety, operations, and livability of major roadway corridors.

- Avelar et al. (2013) found that both land use and the spatial distribution of driveways influence safety and emphasized the importance of accounting for land use rather than a simple variable for driveway density. Higher percentages of intensive land uses along a corridor were clearly associated with crashes.
- Where existing land use conditions preclude compliance with reasonable spacing criteria, consider applying a special category (e.g., Minnesota DOT Category 7 "Specific Area Access Management Plans") that provides for the development of access management plans to serve as a guide for improving access conditions.

2) **Avoid permitting higher-volume commercial driveways on opposite sides of a roadway at or within close proximity to a full median opening that is not signalized.**
   - Our case studies found a tendency for a variety of crash types, including head-on crashes, at these locations.
   - Driveways located within approximately 150 feet of a median opening have a significant impact on median opening operations and can lead to a number of conflicts that can adversely affect safety performance (Dixon et al., 2020).

3) **Carefully consider the crash potential of the "good Samaritan" effect when permitting high-volume commercial driveways in the functional area of intersections or interchanges.**
   - Our case studies reveal several examples of crash clusters where queueing vehicles allow turning vehicles to cross two or more through lanes resulting in angle crashes in a through lane, sometimes involving more than one vehicle, as the vehicles proceed into or out of the driveway.
   - Lengthy queues at signalized intersections can disrupt driveway operations and reduce visibility of vehicles crossing the through lanes to enter and exit a connection from a side street or directional median opening.

4) **Avoid using conventional bike lanes on major roadways with frequent commercial driveway access unless mitigating actions are taken at commercial driveway locations.**
   - The tendency for drivers attempting to turn right out of a driveway to monitor traffic coming from the left without looking for bicyclists and pedestrians to their right is a significant crash issue on commercial corridors to consider in FDOT policies, permitting and design criteria.
   - Crashes involving bicyclists and pedestrians become less common when bicyclist and pedestrian travel patterns are consistent with motorist expectations (National Academies of Sciences, Engineering, and Medicine, 2021). Separated bike lanes with a one-way configuration, for example, can address these conflicts.
   - When a bike lane is needed on a major roadway, buffered bike lanes or other types of physical barriers should be used when feasible, as well as bike lane paint at driveway locations to further alert motorists of the potential presence of bicyclists crossing the driveway.

- Place sidewalks and pedestrian driveway crossings so that pedestrians are visible to the drivers, and drivers are visible to the pedestrians. Do not block pedestrian-driver sightlines with landscaping or signage and optimize sight distance in permitting.
- Consider additions to the FDOT Access Management Guide or rules relative to this issue. For example,
    - VTrans (Vermont) Access Management Program Guidelines include statements requiring access design to provide for the safe and convenient movement of all users, including pedestrians, bicyclists, and the physically handicapped and accesses that cross or affect these modes “shall have the necessary modifications to ensure the safe crossing of the access and safe use of the facility…”
    - Utah DOT’s Access Management Code states that, “Access designs must provide for the safe and convenient movement of all highway right-of-way users and modes of transportation including but not limited to pedestrians, bicyclists, transit, and the physically challenged. Further, sidewalks and bike lanes or paths may be required when deemed appropriate by the department or when required by the local authority.”

5) **Prohibit new access in the vicinity of interchange ramps whenever feasible and use policy, design and funding methods to relocate and/or mitigate the effects of such access in existing developed areas.**
    - Interchange crash frequency and severity analysis and case study analysis clearly indicates that access very close to interchange ramps is a serious safety problem.
    - The first access point near the terminal intersection of interchanges most significantly influences safety (Dixon et al., 2022).
    - Our analysis indicates that unsignalized or signalized commercial driveways located less than 500 ft from the ramp taper end of an interchange increased severe injury crashes by 261% over those located farther from the interchange ramp termini.

6) **Consider taking a more active role in advancing off-system network development along the state highway system to reduce commercial driveways on major corridors and near highway interchanges for improved safety. Examples include (Williams et al., 2018):**
    - Work with MPOs and local agencies to encourage the prioritization of projects that complete gaps in parallel reliever roadways and the collector system along arterial routes.
    - Make such projects eligible for matching state funds if they support access management, and multimodal safety and operations of the state highway system as is the practice of NCDOT, KDOT, and CDOT.
    - Establish a special program for development and funding of access management plans and complementary off-system projects that improve safety and operations on certain corridor segments (e.g., KDOT).
    - Adopt an access management policy that emphasizes the importance of working with local governments on local network development and interparcel connectivity in preserving the safety and operation of arterial roadways and in advancing multimodal and complete streets objectives.

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Appendix A. Candidate Corridors for Analysis by FDOT District

Table A-1 Candidate Corridors in FDOT District 1

No	Roadway Name	FDOT RCI Roadway ID	Total Crash Rate (crashes/mile)	Eligible Functional Class[1]	Access Class[2]
1	TAMIAMI TRL	13010000	57.9	14	06, 07
2	BEE RIDGE RD	17008000	29.1	17	05, 07
3	53rd AVE/ONECO RD	13162000	27.8	14	06
4	CORTEZ RD	13040000	21.5	16	05
5	BAYSHORE GARDENS PKW	13000091	15.9	17	not listed
6	CATTLEMAN RD	17000045	14.6	17	not listed
7	TAMIAMI TRL	13040001	12.6	14	05

No	Roadway Name	FDOT RCI Roadway ID	Total Ped/bike driveway crashes (2015-2019)	Eligible Functional Class	Access Class
1	TAMIAMI TRL	03010000	22	04, 14	03, 04, 05, 07
2	TAMIAMI TRL	17010000	16	04, 14	03, 05, 06

[1] The definitions of functional class can be found here: https://ftp.fdot.gov/file/d/FTP/FDOT/co/planning/transtat/gis/TRANSTAT_metadata/funclass.shp.xml.

[2] The definitions of access class can be found in the FDOT Access Management Guidebook (FDOT, 2019). "Not listed" means the access class information is not available for this roadway in FDOT Access Management GIS Data.

Figure A-1 Candidate Corridors in FDOT District 1

Table A-2 Candidate Corridors in FDOT District 2

No	Roadway Name	FDOT RCI Roadway ID	Total Crash Rate (crashes/mile)	Eligible Functional Class	Access Class
1	CESERY BLVD	72014000	24.2	16	06
2	KINGSLEY AVE	71130000	19.0	16	05, 06
3	BLANDING BLVD	71070000	18.6	14	03, 05
4	EMERSON ST	72015000	16.5	16	06
5	SR-312	78002900	14.8	16	02
6	OLD ST AUGUSTINE RD	72680501	14.4	16	not listed
7	BEACH BLVD	72190000	12.0	14	03, 05, 06
8	BAYMEADOWS RD	72028000	11.7	16	05
9	SW 34th ST	26250000	11.5	16	05, 06
10	NW 43rd ST	26700001	11.4	16	not listed
11	3rd ST N	72100000	10.8	14	06
12	NW 23rd AVE	26003000	10.2	17	06
13	SW 2nd AVE	26070068	10.1	17	07

No	Roadway Name	FDOT RCI Roadway ID	Total Ped/bike driveway crashes (2015-2019)	Eligible Functional Class	Access Class
1	SW 13th/MLK JR HWY	26010000	17	04, 14	03, 05, 06
2	E UNIVERSITY AVE	26070000	16	04, 14	03, 05, 06
3	SW ARCHER RD	26090000	15	06, 14, 16	03, 04, 05, 06

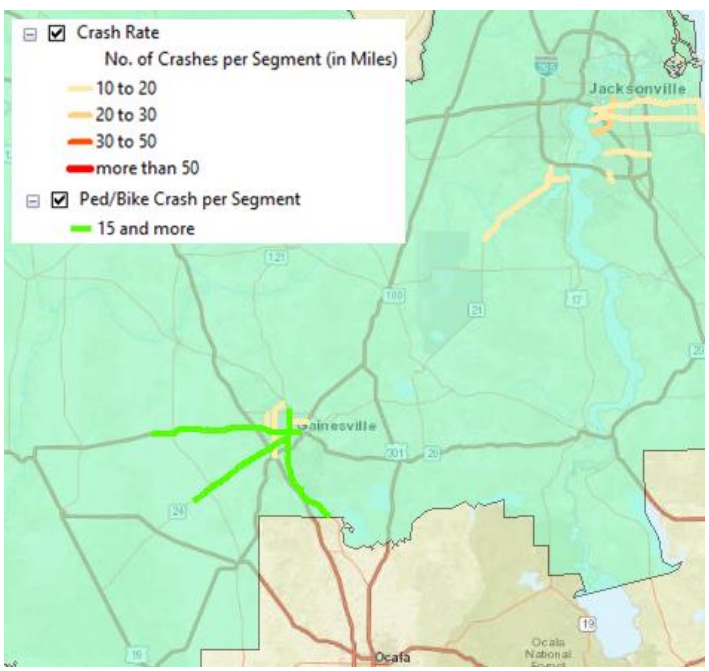

Figure A-2 Candidate Corridors in FDOT District 2

Table A-3 Candidate Corridors in FDOT District 3

No	Roadway Name	FDOT RCI Roadway ID	Total Crash Rate (crashes/mile)	Eligible Functional Class	Access Class
1	AIRPORT BLVD	48008000	58.2	16	06
2	KILLEARN CENTER BLVD	55321000	52.5	17	05
3	AIRPORT BLVD	48116000	37.8	16	06
4	PENSACOLA ST	55090000	35.6	16	06
5	US HWY 90 W	55060000	30.4	16	03, 05, 07
6	RAYMOND DIEHL RD	55050001	26.9	16	not listed
7	23rd ST	46001000	24.0	16	06
8	MARY ESTHER CUT OFF	57110028	20.6	16	05
9	CHIEFS WAY	48080061	19.2	14	07
10	ORANGE AVE	55190000	18.7	16	06
11	MONROE ST	55010000	17.2	14	03
12	S FAIRFIELD DR	48004000	16.9	14, 16	04, 05, 06, 07
13	N 9th AVE	48003000	16.7	16	06, 07
14	W AIRPORT BLVD	48000064	15.8	16	not listed
15	PERRY AVE SE	57040001	15.7	16	06
16	ADAMS ST	55100000	15.7	17	05, 06, 07
17	MICHIGAN AVE	48012000	14.9	16	06
18	N NEW WARRINGTON RD	48080062	14.5	16	05
19	CAPITAL CIR SE	55003000	12.4	14	05
20	S NEW WARRINGTON RD	48080000	12.1	14	07
21	MAGNOLIA DR	55005000	11.3	16	05
22	BEAL PKWY	57110000	10.6	16	05, 06

No	Roadway Name	FDOT RCI Roadway ID	Total Ped/bike driveway crashes (2015-2019)	Eligible Functional Class	Access Class
1	US HWY 98	57030000	25.0	14	03

Figure A-3 Candidate Corridors in FDOT District 3

Table A-4 Candidate Corridors in FDOT District 4

No	Roadway Name	FDOT RCI Roadway ID	Total Crash Rate (crashes/mile)	Eligible Functional Class	Access Class
1	W SUNRISE BLVD	86110500	68.8	14	not listed
2	PETERS RD	86000067	45.7	17	not listed
3	OAKLAND PARK BLVD	86090000	34.8	14	03, 05
4	NE 6th AVE	86010000	34.6	14	05, 06
5	HALLANDALE BCH BLVD	86200000	34.4	14	05, 06
6	DAVIE BLVD	86210000	31.5	16	06
7	SR-7/US-441	86100000	30.0	14	03, 05, 06
8	US-1/SR-5/FEDERAL	86020000	28.6	14	05
9	SUNRISE BLVD	86110000	26.2	14	03
10	UNIVERSITY DR	86220000	25.2	14	03, 05
11	SR A1A	86050100	24.7	16	07
12	PINE ISLAND RD	86000055	24.6	16	not listed
13	BROWARD BLVD	86006000	24.2	14	03, 05
14	STIRLING RD	86016000	21.6	16	03, 05
15	COMMERCIAL BLVD	86014000	21.3	14, 16	03, 05
16	FLL BCH BLVD	86180000	20.6	16	05, 06, 07
17	HOLLYWOOD BLVD	86040005	20.4	16	06
18	SHERIDAN ST	86230000	20.4	14, 16	05, 06
19	SPENCER RD	93575000	19.2	17	not listed
20	PINES BLVD	86040000	19.0	14, 16	03, 05, 06
21	WILES RD	86000230	18.2	16	not listed
22	DAVIE RD	86540000	17.8	16	not listed
23	SW 24 ST	86080000	17.7	16	03, 05
24	PEMBROKE RD	86018000	17.4	14	05, 06
25	NW 19 ST	86570500	16.5	17	not listed
26	HILLSBORO BLVD	86120000	15.6	14, 16	05, 06
27	POWERLINE RD	86065000	14.8	14, 16	05
28	N.E. 4th AVE	86170000	14.8	16	06, 07
29	LINTON BLVD	93022501	14.6	16	not listed
30	BROWARD BLVD	86500000	14.0	16	not listed
31	LAKE WORTH RD	93180000	13.9	14, 16, 17	05, 07
32	OKEECHOBEE BLVD	93280000	13.8	14, 16	03, 05, 06
33	SAMPLE RD	86028000	13.3	14	03, 05
34	SR-805/DIXIE HWY	93050000	13.2	16	06
35	FOREST HILL BLVD	93016000	12.9	14, 16	05, 06
36	S FEDERAL HWY	93010101	12.4	16	07
37	SR714/SE MONTEREY RD	89092000	12.3	14, 16	05, 06
38	PINE ISLAND RD	86000068	12.2	16	not listed
39	TYLER ST	86000216	11.7	17	not listed

Table A-4, continued

No	Roadway Name	FDOT RCI Roadway ID	Total Crash Rate (crashes/mile)	Eligible Functional Class	Access Class
40	CONGRESS AVE	93580501	11.3	14	not listed
41	SE 5 ST	89000115	11.0	17	not listed
42	SUNRISE BLVD	86005000	10.8	16	05
43	ATLANTIC AVE	93030000	10.4	14, 16	03, 05, 07

No	Roadway Name	FDOT RCI Roadway ID	Total Ped/bike driveway crashes (2015-2019)	Eligible Functional Class	Access Class
1	MILITARY TR	93070000	39	14	05
2	FEDERAL HWY	89010000	25	14	03, 05
3	SR809/MILITARY TRAIL	93150000	20	14	05
4	SE 6 AVE	93010000	18	14, 16	05, 06, 07
5	SR A1A/N OCEAN DR	86050000	15	16, 17	05, 06, 07

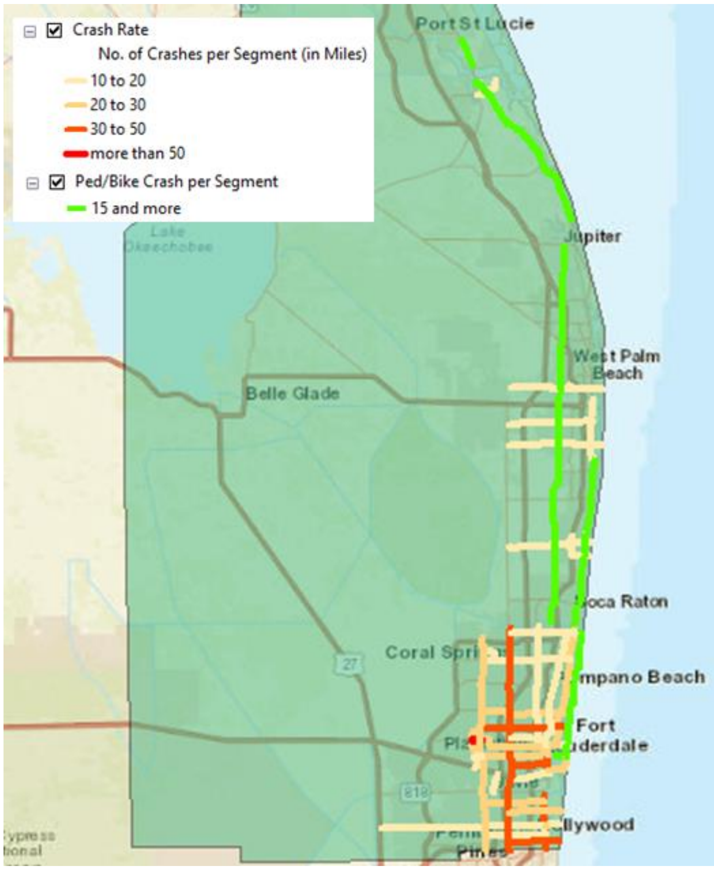

Figure A-4 Candidate Corridors in FDOT District 4

Table A-5 Candidate Corridors in FDOT District 5

No	Roadway Name	FDOT RCI Roadway ID	Total Crash Rate (crashes/mile)	Eligible Functional Class	Access Class
1	JOHN YOUNG PKWY	75190001	26.1	14	03
2	ORANGE BLOSSOM TRL	75010000	17.5	14	05, 06
3	ALAFAYA TRL	75037000	15.7	14	03, 05
4	MICHIGAN AVE	92000060	13.5	16	not listed
5	W COLONIAL DR	75050000	13.3	14	03, 04, 05, 06
6	W COCOA BEACH CSWY	70100121	13.1	17	not listed
7	US-27/441	18120000	12.8	14	05
8	SR-436	75120000	11.4	14	05
9	SR-436	77080000	11.4	14, 16	05
10	SR-44	11683000	11.4	14	not listed
11	GOLDENROD RD	75200000	11.2	16	03
12	SARNO RD	70120000	10.8	16	not listed
13	SEMORAN BLVD	75003000	10.5	14	03,06
14	TAYLOR RD	79230000	10.2	14	05
15	MASON AVE	79220000	10.1	16	06
16	SILVER STAR RD	75250000	10.1	16	03, 05

No	Roadway Name	FDOT RCI Roadway ID	Total Ped/bike driveway crashes (2015-2019)	Eligible Functional Class	Access Class
1	COLONIAL DR	75060000	42	04, 14, 17	03, 05, 07
2	US-1	79010000	24	14	03, 05
3	VINE ST	92090000	24	14	01, 05, 07
4	SR-434	77120000	19	14	05, 06
5	NOVA RD	79190000	19	14	05

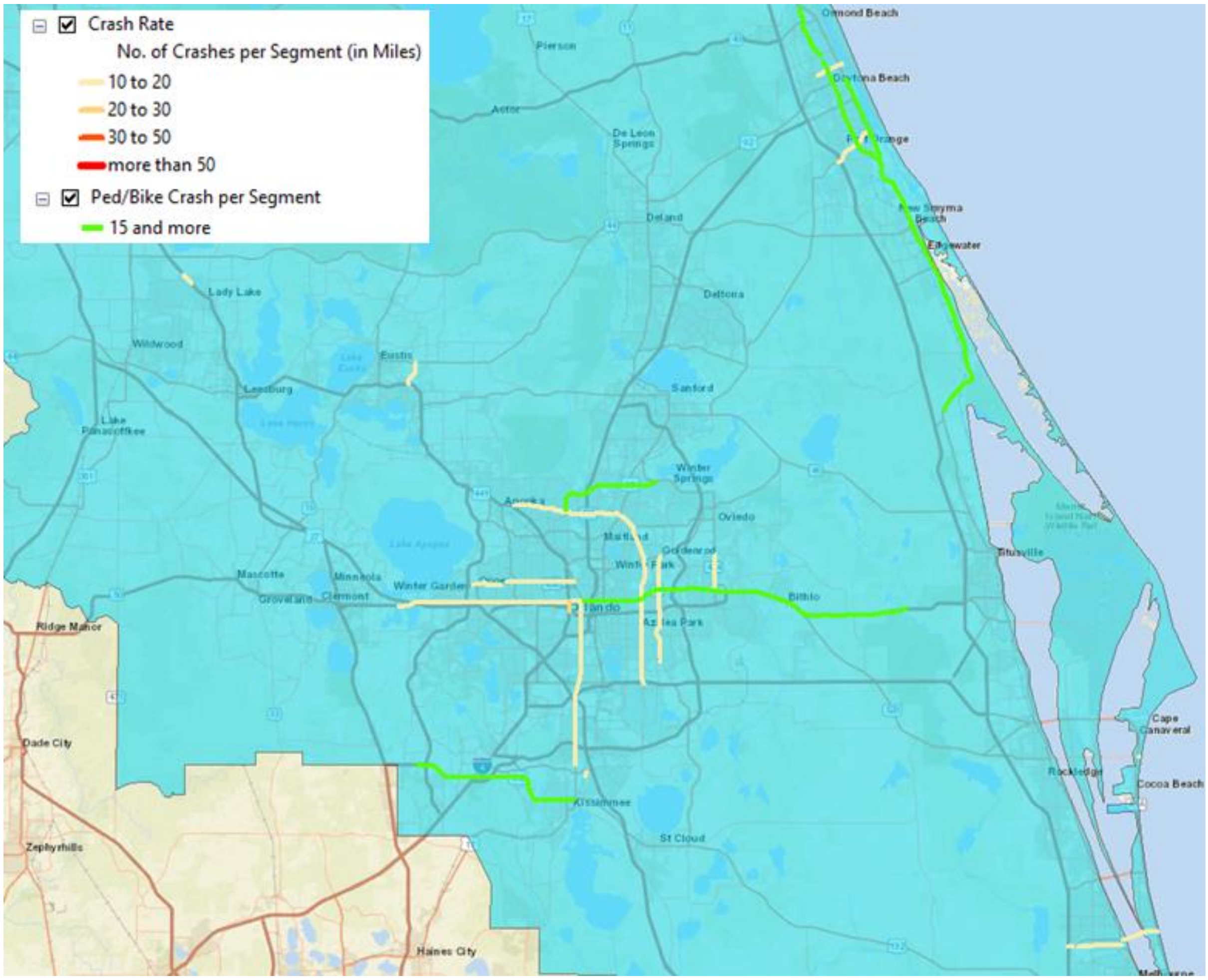

Figure A-5 Candidate Corridors in FDOT District 5

Table A-6 Candidate Corridors in FDOT District 6

No	Roadway Name	FDOT RCI Roadway ID	Total Crash Rate (crashes/mile)	Eligible Functional Class	Access Class
1	SE 2 ST	87030001	59.0	14	07
2	NW 183 ST/MIA GDNS D	87026005	46.4	16	03
3	NW 27 AVENUE	87019000	46.1	14	05
4	SW 40 ST/BIRD ROAD	87044000	44.1	14	05, 07
5	E 49 ST	87038000	43.3	14, 16	05, 06, 07
6	W FLAGLER ST	87053000	37.1	16, 17	05, 07
7	SW 22 ST	87054000	33.5	16	07
8	SOUTH DIXIE HWY	87020000	33.0	14	05, 06
9	TAMIAMI TRAIL/SE 8 ST	87120000	32.5	04, 14	03, 05, 07
10	N KENDALL DR	87001000	32.3	14	03, 05
11	TRUMAN AVE	90010000	32.0	14, 16	05, 06, 07
12	NW 2 AVE	87140000	30.1	14, 16, 17	05, 07
13	SW 72 ST	87055000	28.8	16	05
14	BRICKELL AVE	87030000	24.7	14	05, 07
15	ARTHUR GODFREY RD	87016000	24.5	14	06
16	KANE CONCOURSE/96 ST	87066000	23.6	16	07
17	SW 112 AVE/ALLAPATTAH	87015000	23.5	16	05
18	SW 107 AVE	87072000	23.4	16	05, 06
19	LINDGREN RD/SW 137 A	87133000	22.7	14	03, 05
20	NW 57 AVE/RED RD	87062000	22.0	16	05, 06
21	NE 54 ST	87250000	21.8	16	06, 07
22	SW 200 ST/QUAIL DR	87091000	20.9	07, 16, 17	03, 04
23	NW 27 AVE	87240000	20.9	14, 16	02, 05
24	NE 186 ST/MIA GDNS D	87026000	20.5	16	05
25	NW 167 ST	87170000	20.4	14	02, 07
26	SE 7 ST	87120001	20.3	14	07
27	W 21 ST	87080900	18.1	14, 16	03, 05, 06, 07
28	LEJEUNE RD/SW 42 AVE	87281000	17.7	14	03, 05, 06, 07
29	NE 6 AVE	87034000	17.6	16, 17	05, 06
30	79 ST CSWAY	87080000	17.5	14	05, 06, 07
31	NW 12 AVE	87085000	16.7	16, 17	05, 07
32	OCEAN BLVD	87060000	16.3	14	03, 05, 07
33	MILAM DAIRY RD	87027000	15.1	16	05
34	NW 36 ST	87220000	14.6	14	05
35	SW 152 ST/CORAL REEF	87039000	13.0	14	05
36	NW 119 ST/GRATIGNY D	87052000	12.8	14, 17	03, 05, 07
37	CAMPBELL DR/SW 312 ST	87043500	12.0	16	not listed
38	W 4 AVE/RED RD	87002000	11.7	14	03, 05, 06
39	ALTON RD	87037000	11.3	16	05, 07

Table A-6, continued

No	Roadway Name	FDOT RCI Roadway ID	Total Crash Rate (crashes/mile)	Eligible Functional Class	Access Class
40	NW 87 AVE	87047000	11.3	14, 16	03, 05, 06
41	NW 36 ST	87090000	10.4	04, 14, 16	02, 04, 06, 07
42	SE 1 ST	87053001	10.4	16, 17	07
43	NW 47 AVE	87012000	10.3	16	06

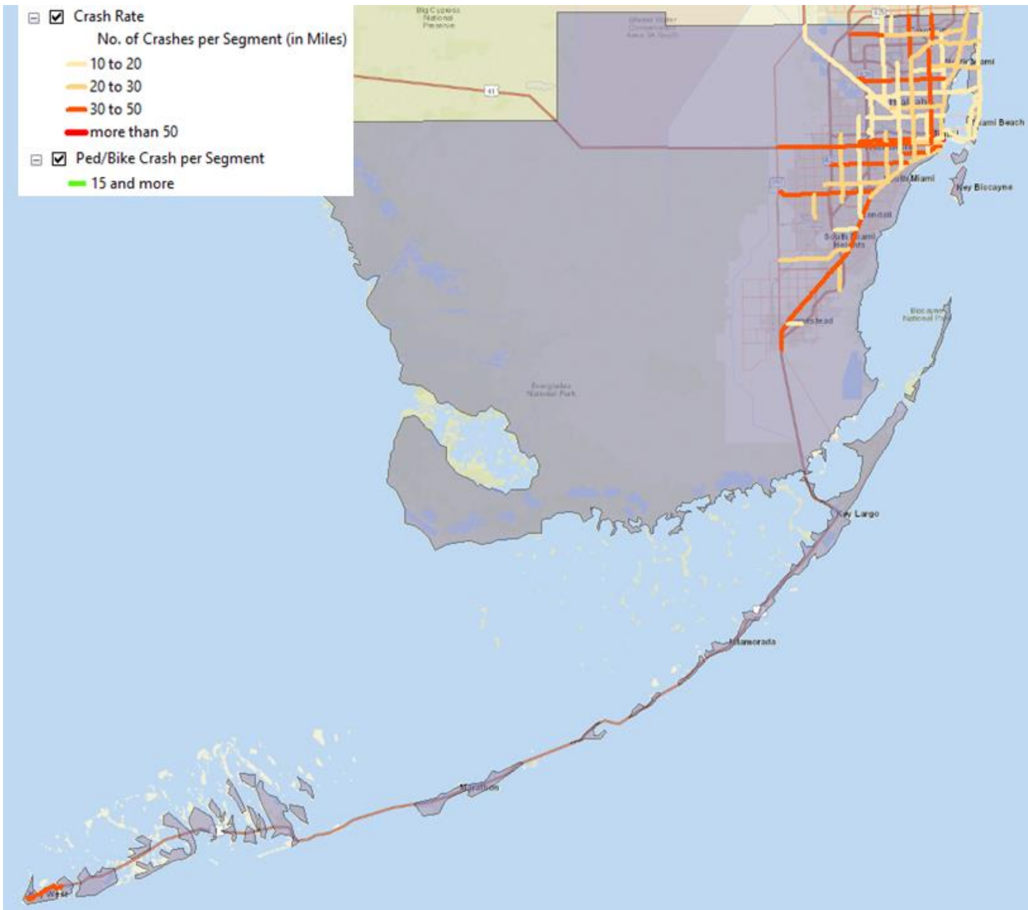

Figure A-6 Candidate Corridors in FDOT District 6

Table A-7 Candidate Corridors in FDOT District 7

No	Roadway Name	FDOT RCI Roadway ID	Total Crash Rate (crashes/mile)	Eligible Functional Class	Access Class
1	SR-54	14570101	35.4	14	5
2	66 ST N	15230000	33.4	16	7
3	3 ST N	15090000	25.0	14	3
4	34 ST S	15150000	24.9	14	3
5	DR MLK JR ST N	15000182	24.7	16	not listed
6	E BEARSS AVE	10360000	23.8	16	7
7	W WATERS AVE	10770000	22.8	16	not listed
8	N DALE MABRY HWY	10160000	21.2	14	03, 05, 07
9	38 AVE N	15540000	20.1	16	not listed
10	22 AVE N	15590001	20.0	16	not listed
11	US ALT 19	14030020	19.8	16	5
12	E FLETCHER AVE	10350000	17.9	16	7
13	WALSINGHAM RD	15120000	16.0	14	03, 05
14	W HILLSBOROUGH AVE	10150000	15.7	14	03, 05
15	S MISSOURI AVE	15007000	15.3	14	7
16	ROOSEVELT BLVD	15030000	14.9	16	03, 07
17	OAKFIELD DR	10000365	14.7	17	not listed
18	E BRANDON BLVD	10110000	14.6	04, 14	03, 07
19	SR 580	15070000	13.6	14, 17	03, 05
20	PARK BLVD N	15061000	13.4	14	05, 07
21	TYRONE BLVD	15010000	12.8	14, 16	2
22	US-19	14030000	12.2	14	3
23	CITRUS PARK DR	10670000	12.1	16	not listed
24	N 50 ST	10330000	12.0	16	05, 07
25	S VILLAGE DR	10000191	11.3	16, 17	not listed
26	4 ST S	15090101	11.0	16	7
27	SR-582/E FOWLER AVE	10290000	11.0	14	not listed
28	GULFPORT BLVD S	15110501	11.0	16	not listed
29	TAMPA RD	15080000	10.7	14, 16	03, 05
30	MEMORIAL HWY	10517000	10.6	16	not listed

No	Roadway Name	FDOT RCI Roadway ID	Total Ped/bike driveway crashes (2015-2019)	Functional Class	Access Class
1	GULF TO BAY BLVD	15040000	24	14, 16	03, 05, 07
2	GULF BLVD	15100000	19	16	7

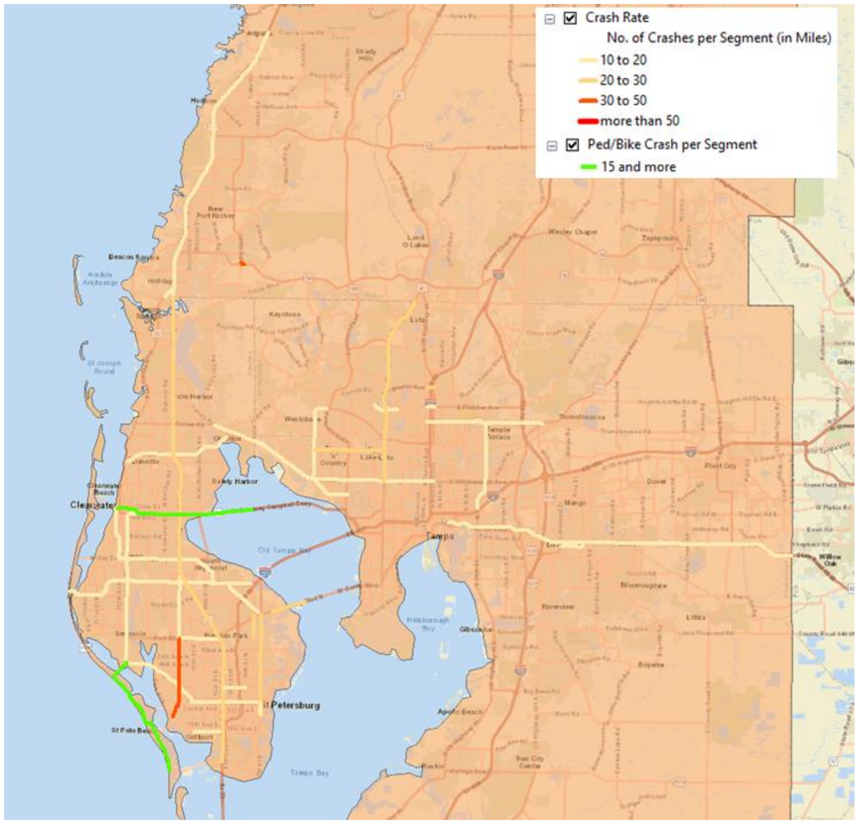

Figure A-7 Candidate Corridors in FDOT District 7

Appendix B. Candidate Interchange Areas for Analysis by Type and FDOT District

Table B-1: Selected Interchange Area Locations by Type and District

District	Site	Location	Access Class	Context Class	Interchange Type	Crash Frequency
1	1	US 98 at I-4	5	C3C	Diamond	5
	2	US 27 at I-4	2	C3C	Partial Cloverleaf	6
	3	10 St W at US-41	7/5	C4/C3C	Diamond	13
	4	SR-559 at I-4	4	C2	Diamond	3
2	1	US 301 at I-10	3	C3C	Partial Cloverleaf	25
	2	SR-16 at I-95	3	C3C	Diamond	21
	3	SR-207 at I-95	5	C2	Diamond	16
	4	SR-206 at I-95	3/4	C2	Diamond	16
	5	US Hwy 129 at I-10	3/4	C3C/C2	Diamond	12
	6	Beach Blvd at US 90 ALT	3/5	C3C	Diamond	12
	7	W Newberry Rd at I-75	3	C3C	Partial Diamond	11
	8	Baymeadows Rd at I-85	5	C3C	Diamond	11
	9	Cassat Ave at I-10	6	C4	Diamond	9
	10	Atlantic Blvd at I-295	6	C3C	Diamond	9
	11	Norwood Ave at I-95	6	C4	Other	8
	12	SR 6 at I-75	4	C2	Diamond	7
	13	US-1 S at I-95	3	C2	Diamond	6
	14	Lane Ave S at I-10	6	C3C	Diamond	6
	15	University Blvd at Arlington Expy			Other	5
	16	Beach Blvd at I-295	6	C4	Diamond	5
	17	Monument Rd at 295	3	C3C	Diamond	4
	18	Bush Dr at I-95	5	C3C	Diamond	4
	19	N US Hwy 441 at I-10	4	C3C/C2	Diamond	3
3	1	Scenic Hwy at I-10	6	C3C	Partial Cloverleaf	20
	2	Duval Hwy at I-10	7	C3C	Partial Cloverleaf	5
	3	Hwy 71 at I-10	5	C3C	Diamond	5
	4	N Monroe St at I-10	5	C3C	Partial Cloverleaf	3
	5	Avalon Blvd at I-10	3	C3C	Diamond	4
	6	Ferdon Blvd at I-13	6	C3C	Diamond	4
	7	US 90 ALT ay I-10	5	C3C	Diamond	3

Table B-1, continued

District	Site	Location	Access Class	Context Class	Interchange Type	Crash Frequency
4	1	Oakland Park Blvd at I-95	5	C4	Diamond3	37
	2	Hallandale Blvd at I-95	5	C3C/C4	Diamond	25
	3	Sterling at I-95	5	C3C	Diamond	11
	4	W Lantana Rd at I-95	5	C4	Diamond	10
	5	Okeechobee Blvd at I-95	5	C4	Other	5
	6	Palm Beach Lakes Blvd at I-95	5	C4	Diamond	4
	7	12th St at I-95	3	C3C	Other	3
	8	Boynton Beach at I-95	65/6	C3C	Diamond	3
5	1	SR-326 at SR-93	3	C2	Partial Cloverleaf	58
	2	W Silver Springs Blvd at I-75	5	C3C	Diamond	36
	3	E SR-44 at I-95	3	C2	Diamond	33
	4	Eau Gallie Blvd W at I-95	3	C3C	Diamond	15
	5	W Sand Lake Rd at I-4	5	C3C	Partial Cloverleaf	14
	6	Semoran Blvd at E Colonial Dr	3	C3C	Diamond	14
	7	CR 514/Malabar Rd at I-95	3	C3C	Diamond	16
	8	Goldenrod Rd at EW Expy	3	C3C	Diamond	13
	9	E Moody Blvd at I-95	3	C3C	Diamond	9
	10	NW Blitchton Rd at I-75	5	C2/C3C	Diamond	8
	11	Cheney Hwy at I-95	3	C3C	Diamond	8
	12	King St at I-95	3	C3C	Diamond	4
6	1	NW 27th at Palmetto Expy	5	C4	Diamond	39
	2	Doral Blvd (NW 36th St) at Palmetto Expwy	5	C3C	Partial Cloverleaf	37
	3	Tamiami Trail/SW 8th St at Palmetto Expwy	5	C4	Partial Cloverleaf	26
	4	N Kendall Dr at Don Shula Expy	5	C4	Partial Diamond	16
	5	W 4 Ave/Red Rd at Gratigny Pkwy	6	C3C	Partial Cloverleaf	12
	6	NW 103 Rd St at Palmetto	5	C4	Diamond	11
	7	W Okeechobee Rd at Palmetto Expwy	4	C4/C3C	Diamond	10
	8	South Dixie Hwy at Florida's Tpke	5	C3C	Partial Cloverleaf	9
	9	NW 57 Ave/Red Rd at Palmetto Expwy	3	C3C	Diamond	9
	10	SW 40th St at Palmetto Exp	5	C4	Diamond	8
	11	NW 103 St at I-95	7	C4	Diamond	3

Table B-1, continued

District	Site	Location	Access Class	Context Class	Interchange Type	Crash Frequency
7	1	SR 52 at I-75	3	C3C	Partial Cloverleaf	32
	2	Orient Rd at I-275	7	C3C	Diamond	12
	3	Bears Ave at I-275	7	C3C	Diamond	11
	4	E Fletcher Ave at I-275	3	C3C	Diamond	8
	5	Forbes Rd at I-4		C3	Diamond	7
	6	Water Ave at Veteran Expwy	3	C2	Diamond	7
	7	SR 54 at I-75	3	C3C	Diamond	5
	8	McIntosh Rd at I-4	3	C3	Diamond	4

Appendix C. Location of Interchange Sites by FDOT District

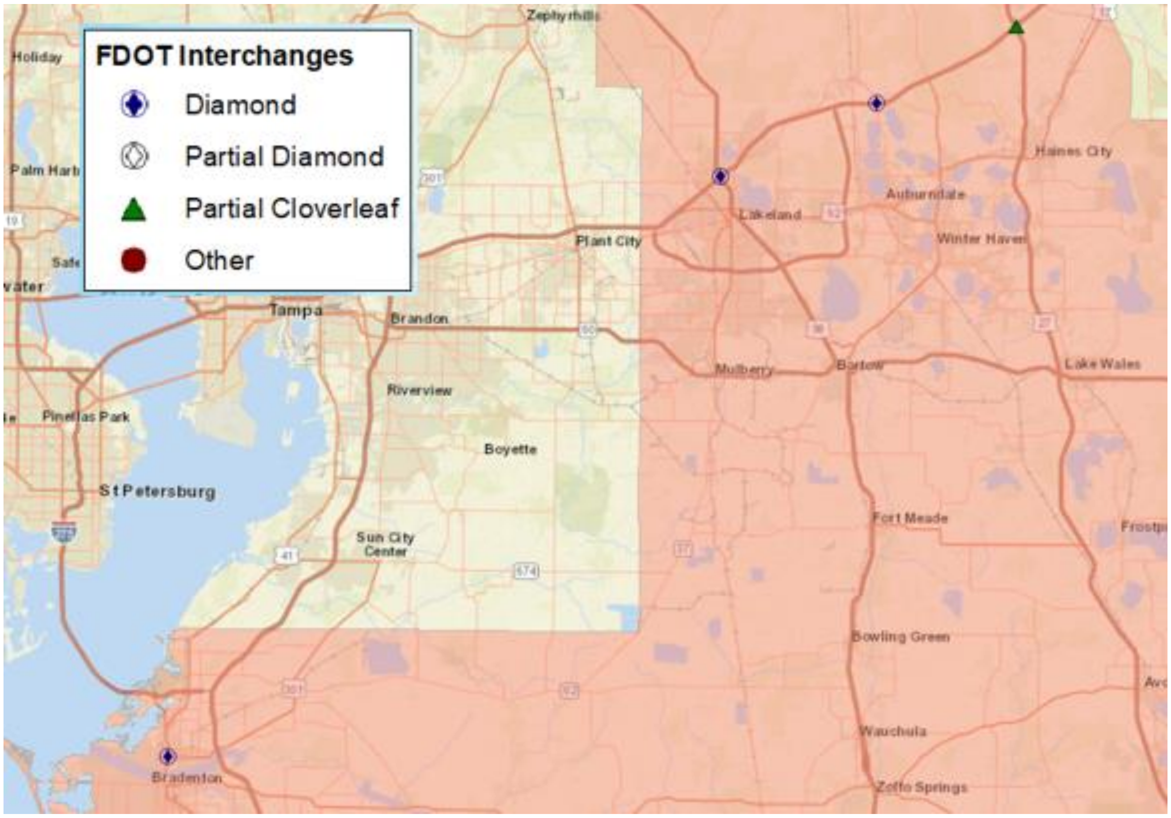

Figure C-1. Candidate Interchange Influence Areas in FDOT District 1

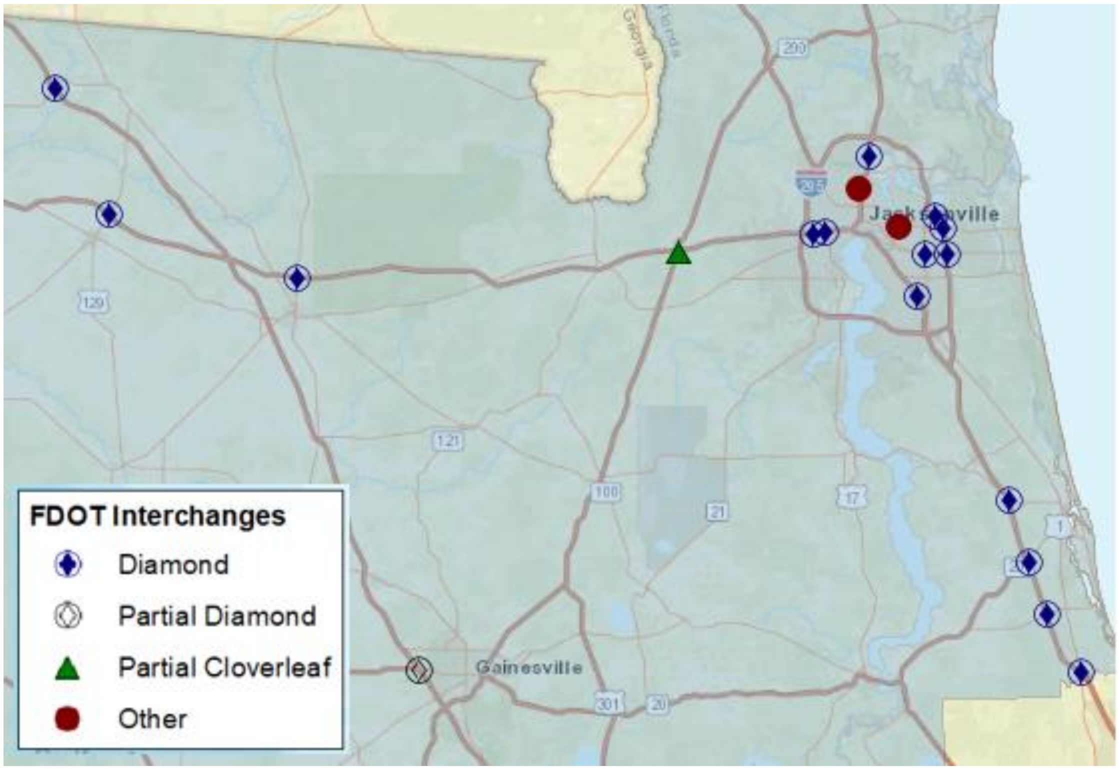

Figure C-2. Candidate Interchange Influence Areas in FDOT District 2

Figure C-3. Candidate Interchange Influence Areas in FDOT District 3

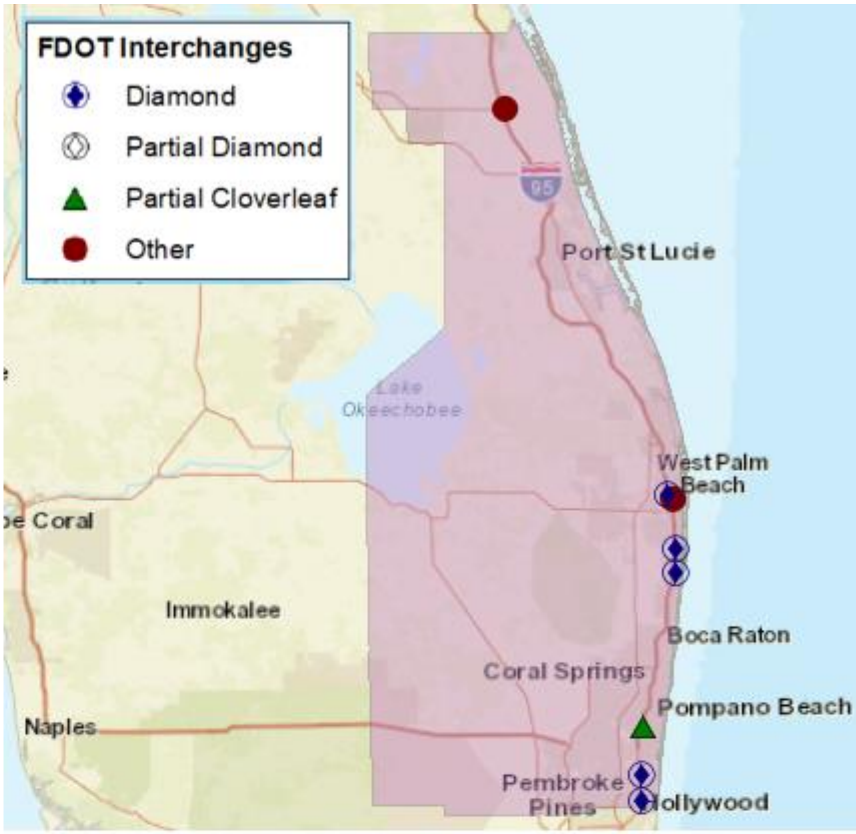

Figure C-4. Candidate Interchange Influence Areas in FDOT District 4

Figure C-5. Candidate Interchange Influence Areas in FDOT District 5

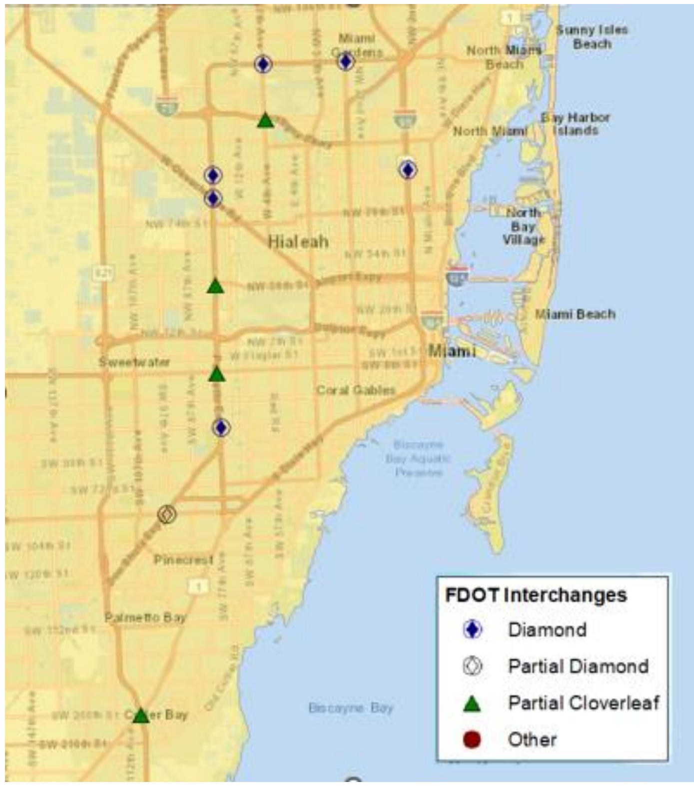

Figure C-6. Candidate Interchange Influence Areas in FDOT District 6

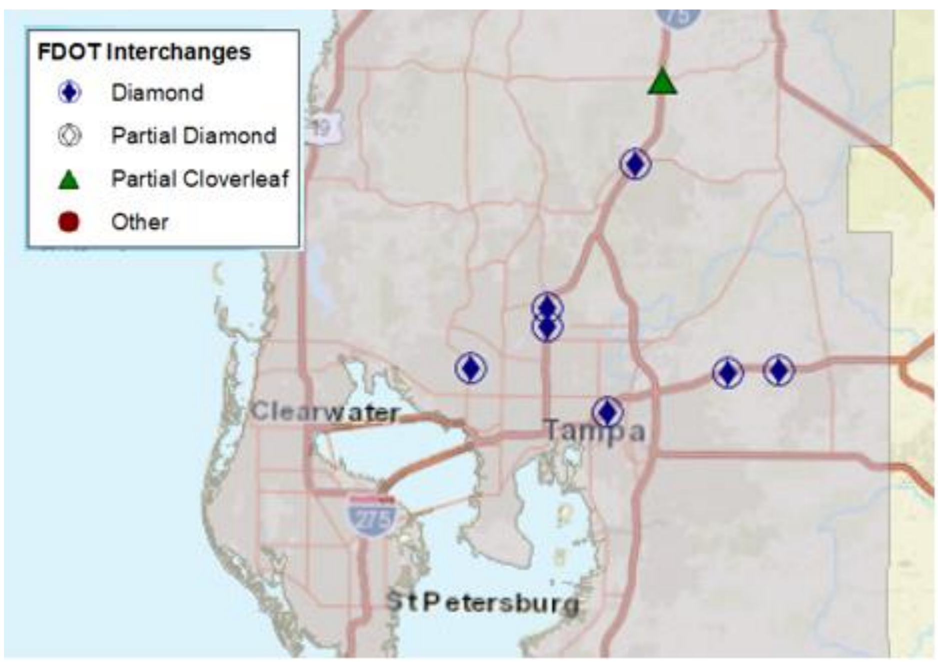

Figure C-7. Candidate Interchange Influence Areas in FDOT District 7

Appendix D. Corridor Driveway Review Form

Variable	Code	Description
Corridor ID	Numeric	Based on the Roadway ID coded by FDOT
Roadway-related		
Functional Class	04 06 07 14 16 17	Rural Principal Arterial Rural Minor Arterial Rural Major Arterial Urban Principal Arterial Urban Minor Arterial Urban Major Collector
Number of lanes on adjacent road including right-turn lane (if available)	1 2 3 4	One Lane Two Lanes Three Lanes Four Lanes or more
Right-turn Lane Type	1 2 3	Exclusive right-turn lane (serves one site) Shared/continuous right turn lane (e.g., marked for right turns and serves more than one site) No right-turn lane (vehicle turns right from through lane, no marking)
Posted Speed Limit (mph)	Numeric (mph)	Speed Limit verified on Google Street View
AADT	Numeric	Obtained from the FDOT website
Driveway Design and Traffic Features		
Driveway Design	1 2 3 4	Flush Radial Curb Radial Curb Flare Wide-open Frontage Access
Driveway Number of Lanes	1 2 3 4 5	One lane Two Lane Three Lanes Four Lanes and more N/A (for driveways with wide-open frontage access)
Driveway Traffic Operation	1 2 3 4 5 6	One-way Entry One-way Exit No right-turn lane (vehicle turns right from through lane, no marking) Right In/Left In/Right Out (Directional Opening) Full Traffic Movements Left In/Left Out (For One-way Traffic, No Opening or Channelizing Island)
Driveway Channelization	0 1 2	None Painted Separator (Solid Line or Painted Median), No Island Physical Separator (Median or Portable Barrier), No Island

Variable	Code	Description
	3 4	Painted Island (regardless of separator type) Physical Island (regardless of separator type)
Traffic Control Device at Driveway	1 2 3	No Control Sign Control (Stop Sign, Yield Sign, No Left Turn Sign, etc.) Traffic Signal Control
Driveway Throat Length	1 2 3	Adequate: provides two car lengths before parking for most small commercial sites. Large shopping center sites should have longer lengths Short: less than two car lengths where vehicles turn into parking site with little transition None: such as wide-open frontages with no transition
Temporary Closure	1 2 3	None Workzone/construction sites Other Circumstances (for example large parking lots where one driveway was blocked)
Driveway ID		Code assigned to each driveway based on the roadway ID, traffic direction, and the number of driveways along the roadway
Approximate Latitude/Longitude	Numeric	Latitude/Longitude
Median Design and Traffic Features		
Median Type	0 1 2 3	Undivided Painted Median Non-traversable Median (Grass, Curb, etc.) Two-way Left Turn Lane
Median Opening Type	1 2 3	No Opening Directional Opening Full Opening without turn lane
Non-motorist Facility Features		
Bike Lane Type	0 1 2 3 4 5	No Exclusive Bike Lane Conventional Bike Lane Buffered Bike Lane Keyhole Bike Lane Sharrows Other Bike Lane Types (Contra-Flow Bike Lane, Left-Side Bike Lane, etc.)
Bike Lane Paint	0 1 2	N/A No Yes
Sidewalk	0 1	Not Available Available
Marked Crossing Signal (RRFB/HAWK)	0 1	Not Available Available
Pedestrian Refuge Island	0 1	Not Available Available

Appendix E. Interchange Driveway Review Form

Variable	Code	Description
Interchange Features		
Interchange Configuration	1 2 3 4 5 6 99	Partial Cloverleaf Diamond Trumpet Partial Diamond Direct Connection Y-Intersection Other
Connecting Ramp Type	1 2	On-ramp Off-ramp
Interchange Ramp Terminal Type	1 2 3	Free-flow Stop/Yield Control Signalized Control
Roadway Features		
Frontage Road	0 1	No Yes
Functional Class	04 06 07 14 16 17	Rural Principal Arterial Rural Minor Arterial Rural Major Collector Urban Principal Arterial Urban Minor Arterial Urban Major Collector
Number of Lanes on adjacent road including right-turn lane (if available)	1 2 3 4	One Lane Two Lanes Three Lanes Four Lanes or more
Right Turn Lane Type	1 2 3	Exclusive right-turn lane (serves one site) Shared/continuous right turn lane (e.g., marked for right turns and serves more than one site) No right-turn lane (vehicle turns right from through lane, no marking)
Posted Speed Limit (mph)	Numeric (mph)	Speed Limit verified on Google Street View
AADT	Numeric	Obtained from the FDOT website
Driveway Design and Traffic Features		
First driveway after off-ramp, OR Last driveway before on-ramp	0 1	No Yes
Distance from ramp taper end to each unsignalized driveway or signalized intersection	Numeric (ft)	Measured from the end of ramp taper to the centerline of the access connection
Distance from off-ramp taper end to the first full median opening	Numeric (ft)	Measure from the end of the ramp taper to the centerline of the access connection
Driveway Design	1 2	Flush Radial Curb Radial

Variable	Code	Description
	3 4	Curb Flare Wide Open Frontage Access
Driveway Number of Lanes	1 2 3 4 5	One lane Two Lane Three Lanes Four Lanes and more N/A (driveways with wide-open frontage access)
Driveway Traffic Operation	1 2 3 4 5 6	One-way Entry One-way Exit No right-turn lane (vehicle turns right from through lane, no marking) Right-in/Left-in/Right-out (Directional Opening) Full Traffic Movements Left-in/Left-out (For One-way Traffic, No Opening or Channelizing Island)
Driveway Channelization	0 1 2 3 4	None Painted Separator (Solid Line or Painted Median), No Island Physical Separator (Median or Portable Barrier), No Island Painted Island (regardless of separator type) Physical Island (regardless of separator type)
Traffic Control Device at Driveway	1 2 3	No Control Sign Control (Stop Sign, Yield Sign, No Left Turn Sign, etc.) Traffic Signal Control
Driveway Throat Length	1 2 3	Adequate: provides a few car lengths before the parking for most small commercial sites. Large shopping center sites should have longer lengths Short: less than two car lengths where vehicles turn directly into the parking site with little transition None: like the wide-open frontages where there is no transition
Temporary Closure	1 2 3	None Workzone/Construction sites Other Circumstances (for example large parking lots where one driveway was blocked)
Driveway ID		Code assigned to each driveway based on the roadway ID, traffic direction, and the number of a driveway along the roadway
Latitude/Longitude	Numeric	Latitude/Longitude
Median Design and Traffic Features		
Median Type	0 1 2	Undivided Painted Median Non-traversable Median (Grass, Curb, etc.)

Variable	Code	Description
	3	Two-way Left-Turn Lane
Median Opening Type	1 2 3	No Opening Directional Opening Full Opening without turn lane
Non-motorist Facility Features		
Bike Lane Type	0 1 2 3 4 5	No Exclusive Bike Lane Conventional Bike Lane Buffered Bike Lane Keyhole Bike Lane Sharrows Other Bike Lane Types (Contra-Flow Bike Lane, Left-Side Bike Lane, etc.)
Bike Lane Paint	0 1 2	N/A No Yes
Sidewalk	0 1	Not Available Available
Marked Crossing Signal (RRFB/HAWK)	0 1	Not Available Available
Pedestrian Refuge Island	0 1	Not Available Available