Strategies to Address Head-on Crashes

Final Report

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DISCLAIMER

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

METRIC CONVERSION TABLE

U.S. UNITS TO SI* (MODERN METRIC) UNITS

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in	inches	25.400	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.610	kilometers	km
mm	millimeters	0.039	inches	in
m	meters	3.280	feet	ft
m	meters	1.090	yards	yd
km	kilometers	0.621	miles	mi

AREA

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in^2	square inches	645.200	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.590	square kilometers	km^2
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.470	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

VOLUME

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
fl oz	fluid ounces	29.570	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
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3

NOTE: volumes greater than 1,000 L shall be shown in m^3.

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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While head-on crashes generally constitute a small proportion of total crash occurrences, they often result in fatal and incapacitating injuries. As a result, many agencies are exploring strategies to mitigate head-on crashes and resulting injuries. This research examined head-on crashes that occurred in Florida Department of Transportation (FDOT) District 7 during the years 2018–2022. A total of 4,309 head-on crashes within the five-year study period were analyzed. A comprehensive literature review of previous studies related to head-on crash occurrence and injury severity was conducted. Effective countermeasures discussed in existing literature were also identified.
Crash data were analyzed using descriptive statistics, police crash reports, and spatial analysis to determine contributing factors associated with head-on crashes, as well as crash patterns and trends. Primary roadway factors associated with the head-on crashes in District 7 include straight roadway segments, no physical barriers present (i.e., guard rails, cable, or concrete barriers), roadways with vegetation medians, locations with reflective pavement markers (RPMs) installed, and dark unlighted areas.
Hot spots were determined using an optimized hot spot analysis of crash data and geographical data. Model results revealed 215 hot spots, all located in Hillsborough County in District 7. Crash modification factors (CMFs) were also developed based on a cross-sectional analysis of crash data and roadway characteristics. Findings revealed that an inside shoulder with curb and gutter offers the greatest reduction in fatal and serious injury head-on crashes for urban arterials (CMF = 0.68). Compared to undivided roadways, a median offers the greatest reduction in fatal and serious injury head-on crashes for urban collectors (CMF = 0.21). Near-term and long-term action plans to reduce head-on crashes in FDOT District 7 were also proposed.
Understanding the factors associated with head-on crashes is essential for determining appropriate countermeasures to reduce head-on crash occurrence and injury severity. Findings from this research can assist FDOT and other transportation agencies in developing effective mitigation strategies.</td></tr>
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EXECUTIVE SUMMARY

While head-on crashes generally constitute a small proportion of total crash occurrences, they often result in fatal and serious (FS) injuries. Although head-on crashes accounted for only 1% of all crashes (i.e., 4,523 out of 450,623) in District 7 between 2018 and 2022, they accounted for about 4.3% of all traffic related fatal and serious injuries. Generally, a head-on crash occurs when two vehicles traveling in opposite directions collide. Because injuries resulting from this type of crash can be severe, many transportation agencies are exploring strategies to mitigate head-on crash occurrence on their roadway network, including Florida Department of Transportation (FDOT). This research examined head-on crashes in FDOT District 7.

The objective of this research was to develop strategies to address head-on crashes in FDOT District 7. To achieve this goal, a comprehensive analysis was conducted to determine contributing factors in crash occurrence and injury severity. Previous studies were reviewed to identify roadway-, environment-, vehicle-, and human-related factors, as well as primary factors affecting the propensity for head-on crash occurrence. Effective countermeasures discussed in existing literature were also identified.

To determine causes and patterns of head-on crashes throughout District 7, crash analyses were performed, consisting of descriptive statistics, spatial analysis, and police crash report review. Crash data were collected for each of the five District 7 counties from Signal4 Analytics for the five most recent years (2018–2022). A total of 4,523 head-on crashes were recorded within the 5-year study period. Following the removal of crashes with missing data, the final dataset included 4,309 head-on crashes used for analysis.

Descriptive statistical analysis of crash and roadway characteristics, environmental conditions, driver characteristics, and vehicle factors was performed to reveal districtwide trends in head-on collisions. To identify head-on crash hot spots within each District 7 county, a spatial analysis was performed using the optimized hot spot analysis tool in ArcGIS. The crash dataset was also analyzed to develop crash modification (CMFs). A cross-sectional analysis was performed to develop the CMFs for total crashes and FS crashes for the following six roadway functional classifications: (1) rural freeways; (2) urban freeways; (3) rural arterials; (4) urban arterials; (5) rural collectors; and (6) urban collectors.

Out of the 4,309 head-on crashes that occurred between 2018 and 2022, a total of 505 crashes (11.72%) resulted in fatal and serious (i.e., incapacitating) injuries. Police reports of these fatal and serious injury crashes were reviewed.

Districtwide Trends

Findings from the descriptive statistical analysis of the 4,309 head-on crashes recorded within the 5-year study period include:

- Almost 3.23% of all head-on crashes in District 7 from 2018–2022 resulted in fatalities.
- The proportion of DUI related crashes that were fatal was 13.17%.
- The proportion of motorcycle crashes that resulted in fatalities was 11.93%.
- The highest proportion of fatal crashes occurred between midnight and 4:00 AM (9%).
- Nearly 3% of fatal head-on crashes occurred during clear conditions; however, adverse weather conditions, especially rain and fog, increased the likelihood of fatalities.
- Almost 10% of head-on crashes on roadways with vegetation medians resulted in a fatality.
- Higher speed roadways were associated with an increased likelihood of fatal head-on crashes.
- Rural areas were observed to have a higher fatality proportion (5.6%) than urban areas (1.2%).
- Of the total fatal and serious injury head-on crashes on two-lane roadways, nearly 84% occurred on rural two-lane segments, and 16% occurred on urban two-lane segments.
- Crashes that occurred in dark unlighted conditions exhibited the highest proportion of fatal head-on crashes.

Factors Associated with FS Head-On Crashes

Police crash reports were reviewed for head-on crashes that resulted in fatal and serious (FS) injuries to explore crash patterns. Site evaluations were conducted for each of the 505 head-on crashes to identify roadway factors associated with these FS crashes. Table E.1 summarizes the total number of FS crashes in each District 7 county based on police reports.

Table E.1: Summary of Fatal and Serious Injury Head-On Crashes (2018–2022)

County	Number of Fatal and Serious Injury Crashes
Citrus	51
Hernando	49
Hillsborough	174
Pasco	159
Pinellas	72
Total Head-On Crashes	**505**

Key findings include:

- The majority of fatal head-on crashes (88.5%) and serious injury crashes (94%) occurred on straight roadway segments.
- The majority of fatal and serious injury crashes occurred on roadways where no physical barriers, such as guard rails or concrete barriers, were present.
- Nearly 39% of fatal and 40% of serious injury head-on crashes occurred on undivided roadways with double yellow centerline markings.
- Over 65% of fatal head-on crashes occurred at locations with reflective pavement markers (RPMs). At locations without RPMs, the primary factor contributing to fatal and serious injury head-on crashes was likely "reduced roadway visibility."

Hot Spots

A spatial analysis, combining the crash data and roadway characteristics, was performed to identify high-risk locations (i.e., hot spots) in District 7. Using GIS techniques, spatial correlations between crashes and relevant road attributes were examined to identify areas where head-on crashes were clustered. Hot spot locations were identified using the optimized hot spot analysis approach. Results revealed 854 census block group locations to be statistically significant, of which 215 were hot spots with a 99% confidence interval. All of the identified hot spots are located in Hillsborough County. Locations identified from crash analyses as hot spots are presented in a separate Excel® file accompanying this report. The Excel® file contains the Census Block Group (CBG) of the hot spot locations, as well as the crash frequency and crash rate within each CBG for each hot spot location.

Crash Modification Factors (CMFs)

Results from the cross-sectional analysis of crash data and roadway characteristics revealed that an inside shoulder with curb and gutter offers the greatest reduction in FS head-on crashes for urban arterials (CMF = 0.68). Compared to undivided roadways, a median offers the greatest reduction in FS crashes for urban collectors (CMF = 0.21).

Recommended Action Plans

Near-term and long-term action plans to mitigate head-on crashes in FDOT District 7 were presented. The proposed countermeasures focus on the 4E's of traffic safety: Engineering, Education, Enforcement, and Emergency Services. Detailed recommendations are provided in Chapter 6 of this report. Understanding the factors associated with head-on crashes is essential for determining appropriate countermeasures to reduce head-on crash occurrence and injury severity. Findings from this research can assist FDOT and other transportation agencies in developing effective mitigation strategies.

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LIST OF ACRONYMS and ABBREVIATIONS

AADT	Annual Average Daily Traffic
AEB	Automatic Emergency Braking
ADT	Average Daily Traffic
AVT	Audible and Vibratory Treatments
CARS	Crash Analysis Reporting System
CBG	Census Block Group
CMF	Crash Modification Factor
CRF	Crash Reduction Factor
DOT	Department of Transportation
DUI	Driving Under the Influence
ESRI	Environmental Systems Research Institute
FARS	Fatality Analysis Reporting System
FDM	FDOT Design Manual
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FLHSMV	Florida Department of Highway Safety and Motor Vehicles
FS	Fatal and Serious Injury
GIS	Geographic Information System
GLM	Generalized Linear Model
HFST	High-Friction Surface Treatment
iiRPM	Internally Illuminated Raised Pavement Markers
MPH	Miles per Hour
NB	Negative Binomial
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
OHSA	Optimized Hot Spot Analysis
OIT	Office of Information Technology
PDO	Property Damage Only
PHB	Pedestrian Hybrid Beacons
RCI	Roadway Characteristics Inventory
Red-RRFB	Red-Rectangular Rapid Flashing Beacon
RPM	Reflective Pavement Marker
RRFB	Rectangular Rapid Flashing Beacons
RwD	Roadway Departure
SDCWS	Sequential Dynamic Curve Warning Systems
SHS	State Highway System
SHSP	Strategic Highway Safety Plan
SPF	Safety Performance Function
SVROR	Single-Vehicle-Run-Off-Road
TWLT	Two-Way Left-Turn
VPD	Vehicles per Day
WWD	Wrong-Way Driving
ZINB	Zero-Inflated Negative Binomial
ZIP	Zero-Inflated Poisson

CHAPTER 1
INTRODUCTION

Although head-on collisions are few in number with respect to total traffic crashes, they account for a high percentage of fatalities and serious injuries. Typically, a head-on crash, also referred to as a frontal collision, is when two vehicles traveling in opposite directions collide (Florin Roebig, 2023). The Federal Highway Administration (FHWA) refers to these types of crashes as *roadway departure* (RwD) crashes, also known as *lane departure* crashes. FHWA defines an RwD crash as "a crash which occurs after a vehicle crosses an edge line or a center line, or otherwise leaves the traveled way" (Federal Highway Administration [FHWA], 2023).

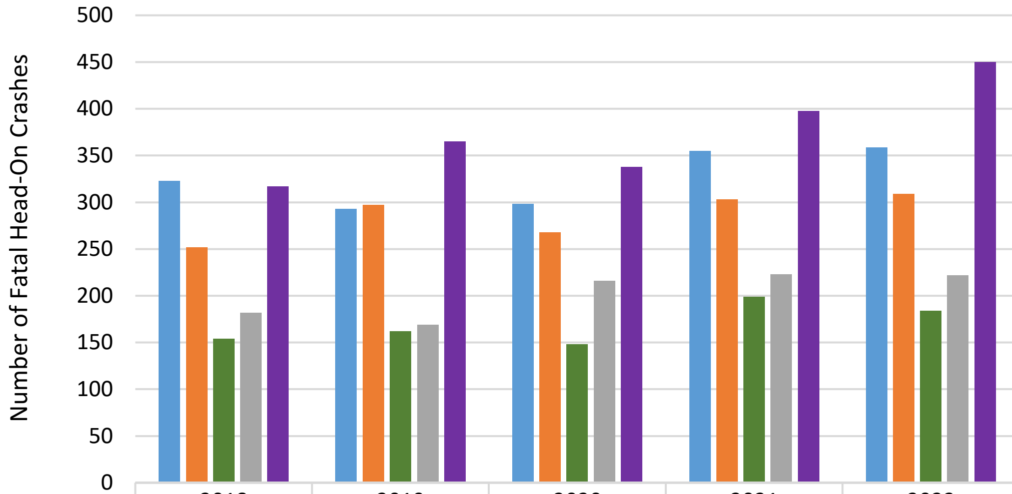
Annually, deaths resulting from head-on collisions account for approximately 14% of all U.S. traffic fatalities (FHWA, 2022a). Furthermore, between 2016 and 2018, over 27% of RwD fatalities nationwide resulted from head-on collisions (FHWA, 2022a). Based on crash statistics from the Fatality Analysis Reporting System (FARS), Florida was one of five states with the highest number of head-on crash fatalities from 2018 to 2022 (National Highway Traffic Safety Administration [NHTSA], 2024a). As shown in Figure 1.1, Florida was third in the nation, with 1,429 fatal head-on crashes, accounting for 9.1% of all fatal crashes statewide from 2018 to 2022, and nearly 48% of these crashes were RwD-related (NHTSA, 2024a). In light of these statistics, the Florida Department of Transportation (FDOT) District 7 is actively exploring strategies to address head-on collisions.

To reduce the number of RwD crashes occurring on U.S. roadways, FHWA created the *Roadway Departure Safety* Program, one of several safety programs promoting the agency's goal of zero deaths (FHWA, 2023). Using a strategic approach, FHWA developed the *Roadway Departure Strategic Plan* (FHWA, 2020), with the mission of assisting transportation agencies with achieving their RwD-related Strategic Highway Safety Plan (SHSP) goals through:

- Development, evaluation, and deployment of life-saving countermeasures, and
- Promoting data-driven application of safety treatments.

The primary emphasis of the strategic plan is to reduce the most harmful events in RwD fatalities resulting from vehicle head-on collisions, rollovers, and collisions with trees, the three highest fatality crash types. A secondary emphasis is to reduce RwD crashes with other fixed objects, such as signs, poles, signals, and barriers, as well as collisions involving roadside ditches and embankments. The goal of the FHWA RwD strategic plan is to reduce annual average U.S. RwD fatalities to 10,000 by the year 2030 (FHWA, 2020) through:

- Strategic planning,
- Implementing RwD countermeasures systematically based on data, and
- Promoting safety in all facets of transportation decision making.



	2018	2019	2020	2021	2022
California	323	293	298	355	359
Florida	252	297	268	303	309
Georgia	154	162	148	199	184
North Carolina	182	169	216	223	222
Texas	317	365	338	398	450

Figure 1.1: Total Fatal Head-On Collisions by State (2018–2022) (NHTSA, 2024a)

This report presents the findings from a comprehensive analysis of head-on crashes in FDOT District 7. Contributing factors in head-on crash occurrence and injury severity found in previous studies are discussed, as well as the primary factors affecting the propensity of head-on crashes identified in these studies. Suggested countermeasures found in existing literature are also presented. Findings from crash analyses are presented, and crash modification factors (CMFs) are also discussed. Recommended near-term and long-term implementation plans to mitigate head-on crashes in District 7 are also presented.

This report is organized as follows:

- Chapter 1 provides an introduction of head-on crashes.
- Chapter 2 discusses contributing factors in head-on crashes found in existing literature.
- Chapter 3 discusses countermeasures currently utilized to reduce head-on crashes.
- Chapter 4 discusses head-on crash causes and patterns in FDOT District 7.
- Chapter 5 discusses crash modification factors (CMFs) developed from crash analyses.
- Chapter 6 presents near-term and long-term action plans to reduce head-on crashes.
- Chapter 7 presents the conclusions from this research effort.

CHAPTER 2
LITERATURE REVIEW

This chapter discusses the review of existing literature on head-on crashes. To identify contributing factors and crash severity associated with head-on collisions, previous studies and online sources were examined.

An early study by Al-Senan and Wright (1987) analyzed head-on crashes that occurred from 1979 through 1981 on two-lane roadways in Georgia to determine areas of head-on crash proneness. Only 1-mile segments of rural routes with average daily traffic (ADT) volumes of at least 2,000 vehicles per day (vpd) were selected, and categorized into two groups: head-on crash sites and control sites. Site selection resulted in 62 head-on sites and 62 control sites, where head-on sites had at least three head-on collisions during the study period and control sites had fewer than three head-on collisions. Findings concluded that seven of the 25 roadway-related variables were significant in predicting the proneness of head-on crash occurrence on two-lane highways.

While numerous studies have been conducted, over time, on factors contributing to accident and severity rates, in general, few studies have focused specifically on head-on crashes. The majority of existing literature focused on head-on crashes on two-lane roadways. Zhang and Ivan (2005) examined head-on crashes that occurred on state-maintained two-lane rural roads in Connecticut from 1996 through 2001. The study analyzed 655 highway segments of 1 km (0.62 miles) containing only minor intersections (i.e., no signal or stop control on the major approaches) to evaluate the effects of roadway geometric features on the occurrence of head-on crashes. A total of 167 head-on crashes occurred during the study period, of which 14.4% were fatal and 67.0% involved injuries.

A study by Deng et al. (2006) also analyzed head-on crashes that occurred on two-lane roadways in Connecticut from 1996 through 2001. The focus of the study was the association between crash severity and potential causal factors of head-on crashes involving vehicles traveling in opposite directions on rural two-lane highways. Study sites were randomly selected and included segments of 1 km (0.62 miles) in length, with consistent roadway cross-sections and no traffic control along the main road. A total of 228 head-on collisions were included in the analysis, and crash severity was modeled using the KABCO injury scale, where 'K' represents a fatality, 'A' represents a disabling injury, 'B' represents a non-disabling injury, 'C' represents a probable injury, and 'O' represents no injury.

A study by Gårder (2006) analyzed crash severity and contributing factors in head-on crashes on two-lane roadways in Maine. Over the 3-year study period (2000 – 2002), 3,136 head-on crashes occurred, consisting of 127 fatal crashes and 235 non-fatal incapacitating crashes.

A recent study by Liu and Fan (2020) analyzed contributing factors affecting injury severity in head-on crashes in the State of North Carolina using a two-step method of integrating latent class clustering analysis with mixed logit models. Crash data consisted of 9,153 head-on crashes, statewide, for all roadway types and cross-sections, from 2002 to 2013. A number of driver, vehicle, roadway, and environmental variables were considered, and divided into four clusters for analysis: (1) head-on crashes on roadways with median and traffic control and speed limit is over 50 mph, (2) head-on crashes on rural roadways with speed limit 30–49 mph, (3) head-on crashes on rural roadways with speed limit over 50 mph, and (4) head-on crashes on urban roadways. Mixed logit models were developed for each cluster to estimate the injury effects for the various variables measured. Findings on injury severity associated with head-on crashes were based on these four pre-defined scenarios.

A number of factors may contribute to the occurrence and injury severity of head-on crashes. These factors may be roadway-related, environment-related, vehicle-related, or human-related, or a combination of two or more. Driver characteristics, such as the age and gender, may also increase the risk of serious injury. Oftentimes, the cause of a head-on crash may be difficult to attribute to only one factor. The following sections discuss factors identified among exiting literature.

2.1 Roadway Factors

A number of roadway-related factors may contribute to the occurrence of head-on collisions. While additional factors may exist, roadway factors analyzed in previous studies include:

- Roadway alignment: straight segment or curve (Gårder, 2006; Liu & Fan, 2020)
- Roadway geometrics: degree of horizontal curvature, change rate of curvature, etc. (Zhang & Ivan, 2005; Deng et al., 2006; Al-Senan & Wright, 1987; Liu & Fan, 2020)
- Roadway functional classification: local, minor collector, major collector, minor arterial, principal arterial, or Interstate (Gårder, 2006; Liu & Fan, 2020)
- Pavement width (Zhang & Ivan, 2005; Deng et al., 2006; Al-Senan & Wright, 1987)
- Shoulder width (Gårder, 2006; Zhang & Ivan, 2005; Deng et al., 2006; Al-Senan & Wright, 1987)
- Lane width (Deng et al., 2006)
- Number of lanes (Gårder, 2006)
- Speed limit (Gårder, 2006; Deng et al., 2006; Al-Senan & Wright, 1987; Liu & Fan, 2020)
- Annual Average Daily Traffic (AADT) (Gårder, 2006; Liu & Fan, 2020)
- Number of access points (Deng et al., 2006; Al-Senan & Wright, 1987)

2.1.1 Roadway Alignment

Based on data collected from the Fatality Analysis Reporting System (FARS), Gårder (2006) found that 66% of the 93 fatal head-on crashes on two-lane roads in Maine occurred on 'straight' segments, and 34% occurred on 'curves' over the 3-year study period. Liu and Fan (2020) found that straight segments significantly influenced the risk of fatal head-on crashes on rural roadways with posted speeds >50 mph.

Consistent with findings by Gårder (2006), FARS data for years 2016 to 2018 show that 31% of roadway departure (RwD) fatalities were head-on collisions that occurred on curves (FHWA, 2022a). Conversely, a study by Liu and Fan (2020) found that curved roadway sections increase the likelihood of fatal injury in head-on collisions by up to 3.52%, a lower percentage than other research findings. Interestingly, Gårder (2006) observed a tendency towards curves having a lower percentage of head-on crashes occurring during inclement weather; however, the difference was not statistically confirmed.

2.1.2 Roadway Geometrics

Zhang and Ivan (2005) developed surrogate measures to examine the association between roadway geometrics and head-on crash occurrence, because a direct measure of geometric features at crash locations from police reports was not possible. Study findings indicate that horizontal curve radius, weighted mean of absolute vertical curve (grade), minimum K value of all vertical curves on the segment, and the sum of combined horizontal curvature and vertical curve did not increase the risk of head-on collisions. However, the sum of absolute change rate of horizontal curvature, maximum degree of horizontal curve, and sum of absolute change rate of vertical curvature were found to significantly influence head-on crash occurrence (Zhang & Ivan, 2005). This finding correlates with FARS data for RwD crashes between 2016 and 2018, where 31% of head-on crash fatalities were associated with roadway curves (FHWA, 2022a).

Deng et al. (2006) also analyzed the curvature and grade conditions on each study segment using the following surrogate measures: weighted mean of absolute horizontal and vertical curvature, sum of absolute horizontal or vertical curvature change rate, maximum absolute horizontal curvature or minimum grade change rate, and sum of combined horizontal and vertical curvature. Although these horizontal and vertical curve variables were found to significantly correlate with the occurrence of head-on collisions, model results indicated that these variables were not significant predictors of head-on crash severity (Deng et al., 2006).

Of the geometric variables analyzed by Al-Senan and Wright (1987), two were found to be significant in predicting the proneness of head-on collisions: percentage of the roadway section not level and the number of reverse curves. In other words, these two geometric factors increase the likelihood of three or more head-on crashes occurring over a 3-year period. The following geometric variables were found to be insignificant in predicting the proneness of head-on collision occurrence: number of horizontal curves, percent horizontal curvature, sum of central angles of the horizontal curves in the section, number of grades greater than zero, percentage of grade greater than 3%, consistency of grade (sum of products of the grades times their lengths), percentage of distance where passing was not permitted in both directions, minimum radius in the section, ratio of minimum to maximum radii in the section, number of crests, number of crests formed with grades summing to 5% or higher, percent combined vertical and horizontal alignments, and percent combined alignments of at least 3° curves and at least 2% grade.

Liu and Fan (2020) found that vertical grade roadway sections increase the probability of head-on crashes being fatal by 2.74% on rural roadways with posted speeds >50 mph, and by 0.74% on urban roadways.

2.1.3 Roadway Classification

Gårder (2006) found that major collectors, minor arterials, and principal arterials had the highest percentage of fatal head-on collisions, consisting of 23%, 22%, and 22%, respectively, of the 127 fatal crashes analyzed in the study. In a later study, Liu and Fan (2020) analyzed rural versus urban head-on collisions in North Carolina. Findings revealed, in general, an increased risk of 8.36% of fatal injury in head-on crashes that occur on rural roadways. FARS data, for the years 2016 to 2018, show that 65% of RwD fatalities were head-on collisions that occurred on rural roadways, and 85% of these crashes occurred on undivided roadways (FHWA, 2022a).

2.1.4 Pavement Width

Zhang and Ivan (2005) found that lane width (10 to 13 ft) and directional paved roadway width (shoulder + lane, for a total of 10 to 20 ft) did not increase the potential for head-on crash occurrence. Deng et al. (2006) modeled both 'lane width' and 'roadway width' for two-lane roadways. Roadway width was defined as one-half of the entire paved surface (both lanes plus paved shoulders). Findings indicated that, on two-lane highways, roadway width of 15 ft or less (≤ 30 ft for entire paved surface) was a more significant factor in head-on crash severity, rather than considering lane width and shoulder width individually.

Al-Senan and Wright (1987) found that the number of changes in pavement width greater than one foot was found to be insignificant in predicting proneness of head-on collision occurrence. However, the percentage of pavement width less than 24 ft and the weighted pavement width were both significant in predicting the propensity of head-on collisions on two-lane roadways, i.e., increased the likelihood of three or more head-on crashes occurring over a 3-year period. The variable 'pavement width' was defined as the 'percentage of pavement width of less than 24 ft' to account for varying pavement widths within the selected roadway segments studied. The variable 'weighted pavement width' represented the summation of the products of width multiplied by the length over which the width is uniform, divided by the total length of the study segment (1.0 mile).

2.1.5 Shoulder Width

Gårder (2006) examined the influence of shoulder width, independently and combined with AADT, for two-lane roads in Maine with 45-mph posted speed limits. The analysis revealed that roadways with 5-ft shoulders or wider have a higher risk of fatal or incapacitating injuries from head-on crashes. However, AADT does not significantly influence the risk of serious injury for a given shoulder width.

Zhang and Ivan (2005) found that an 8-ft shoulder width did not increase the potential for head-on crash occurrence. An earlier study by Al-Senan and Wright (1987) found that the percentage of shoulder width less than 6 ft is a significant factor in predicting the proneness of head-on collisions on two-lane roads. In other words, a roadway segment with a higher percentage of shoulder widths less than 6 ft increases the likelihood of three or more head-on crashes occurring over a 3-year period.

Gårder (2006) found that few serious injuries were observed with higher AADT volumes for 45-mph two-lane roadways with no shoulders or narrow shoulders. However, for 45-mph two-lane roadways with higher AADT volumes (>4,000 vpd), wider shoulders (7 ft or wider) have a greater risk of head-on crashes producing fatalities and incapacitating injuries (Gårder, 2006).

Deng et al. (2006) analyzed available directional pavement width (15 ft total) for a shoulder width of 3 ft with a 12-ft lane or a shoulder width of 4 ft with an 11-ft lane. Findings suggested that there was no differentiation between lane and shoulder with respect to the effect on safety, that only the available roadway width was more important in reducing potential head-on crashes.

2.1.6 Lane Width

Al-Senan and Wright (1987) found that the frequency of head-on crashes decreases with increased lane width. In a later study, Deng et al. (2006) modeled both 'lane width' and 'roadway width'. Findings indicated that, on two-lane highways, roadway width was a more significant factor in head-on crash severity, rather than considering lane width and shoulder width individually (Deng et al., 2006). In a study by Zhang and Ivan (2005), lane width was found not to be a statistically significant factor affecting the propensity of head-on crash occurrence.

2.1.7 Number of Lanes

Number of lanes was not fully examined by previous studies. Instead, more focus was placed pavement width, lane width, and shoulder width, or a combination of lane and shoulder widths. However, in an analysis of all rural roadways with speed limits of 45-55 mph in Maine, Gårder (2006) found that only 1.3% of head-on crashes occurred on roadways with more than two lanes, yet 4% of these crashes were fatal. Gårder (2006) concluded that more lanes does not necessarily lead to less severe injuries from head-on crashes, i.e., higher-speed rural roadways with more than two lanes increase injury severity in head-on crashes.

2.1.8 Speed Limit

Average highway speed limit (mph) was found to be significant in predicting the proneness of head-on collisions on two-way highways (Al-Senan & Wright, 1987). In a later study, Zhang and Ivan (2005) also found that speed limit (25-50 mph) significantly influenced head-on crash occurrence.

Gårder (2006) found that illegal/unsafe speed was a factor in 28.6% of non-fatal crashes, and 32% of all head-on crashes. In addition, Gårder (2006) noted that head-on collisions at any speed limit above 25 mph were, on average, more severe than a typical roadway crash. Higher-speed multilane roadways (two or more travel lanes) also increase the crash severity of head-on collisions (Gårder, 2006).

FARS data for years 2016 to 2018 show that 70% of RwD fatalities were head-on collisions that occurred on roadways with speed limits ≥ 50 mph (FHWA, 2022a). However, Liu and Fan (2020) found an increased risk in fatal injury (3.61%) and serious injury (4.97%) in head-on crashes occurring on rural roadways with posted speeds of 30-49 mph.

2.1.9 Annual Average Daily Traffic (AADT)

Gårder (2006) examined the influence of AADT, independently and combined with shoulder width, for two-lane roads in Maine with 45-mph posted speed limits. Findings revealed that AADT volumes above 2,000 vpd increase the risk of crashes leading to serious injuries. However, shoulder width does not significantly influence the risk for a given AADT (Gårder, 2006). For example, for 45-mph two-lane roadways with no shoulders or narrow shoulders, few serious injuries were observed with AADT >8,000 vpd. The analysis also revealed that for AADT volumes above 4,000 vpd, shoulder widths of 7 ft or wider significantly increased the risk of head-on crash fatalities and incapacitating injuries on roadways with posted speeds of 45-mph and 50-mph.

Zhang and Ivan (2005) found a decreasing trend in head-on crash rates with increasing AADT, consistent with findings by Gårder (2006). In contrast, Liu and Fan (2020) found that AADT volumes greater than 13,000 vpd significantly increase the probability of fatal injury by 3.89% on rural roadways with posted speeds of 30-49 mph.

2.1.10 Number of Access Points

Al-Senan and Wright (1987) analyzed the frequency of access points on both sides of the roadway segments studied. Findings indicate that the number of minor access points (residential and small business driveways) was insignificant in predicting the propensity of head-on crash occurrence. However, the number of major access points was a significant factor in increased likelihood of three or more head-on crash occurring over a 3-year period. Similar to findings by Al-Senan and Wright (1987), Zhang and Ivan (2005) found that the number of access points (driveways or minor intersections) did not increase the risk of head-on collisions.

Deng et al. (2006) examined the number of access points, including minor intersections and driveways by type (residential, office, retail, and industrial), as an indicator of land use environment. Findings indicate that a large number of office driveways correlated with less severe crashes, while a large number of retail driveways or minor intersections correlated with more severe crashes. Overall results indicated that head-on crash severity was significantly lower for roadway segments with fewer than 10 access points along a 1-km (0.62 miles) roadway segment, and fatal crashes were more likely to occur in areas with a large number of access points (Deng et al., 2006).

2.2 Environmental Factors

Environmental factors analyzed in previous studies include:

- Snow or ice on the roadway (Gårder, 2006)
- Dry or wet roadway conditions (Gårder, 2006; Deng et al., 2006)
- Vision obscured by sun or object (Gårder, 2006)
- Light conditions (Deng et al., 2006; Liu & Fan, 2020)
- Weather conditions (Deng et al., 2006; Liu & Fan, 2020)

2.2.1 Snow or Ice on the Roadway

A study by Gårder (2006) analyzed crashes in Maine, which experiences a considerable amount of winter weather conditions. Findings revealed, however, that only 9% of fatal head-on collisions occurred on snow covered or icy curves, compared to 23% that occurred on straight segments with similar roadway surface conditions (Gårder, 2006). Overall, Gårder (2006) found that nearly one-third of head-on crashes occurred on wintry roads, with skidding a primary contributing factor.

2.2.2 Dry or Wet Roadway Conditions

Gårder (2006) found that the majority of fatal head-on crashes occurred on dry pavement conditions, on both straight roadway segments (67%) and curves (81%). Similar findings were observed for non-fatal head-on crashes, with 56.1% occurring on dry pavement conditions and

13% occurring on wet roadways (Gårder, 2006). Deng et al. (2006) found that wet roadway conditions were a significant indicator of head-on crash severity, where wet pavement was found to increase injury severity.

2.2.3 Vision Obscured by Sun or Object

Of the 127 fatal head-on crashes examined by Gårder (2006), driver vision obscured by sun or an object was found to be the primary contributing factor in only two crashes. This factor was not examined in other previous studies.

2.2.4 Light Conditions

Liu and Fan (2020) found dark conditions significantly increase the probability of possible injury for head-on crashes that occur on rural roadways with posted speeds of 30-49 mph. However, the probability of possible injury significantly decreases during dusk or dawn in head-on collisions occurring on rural roadways with posted speeds >50 mph.

2.2.5 Weather Conditions

Liu and Fan (2020) found adverse weather conditions, such as rain or snow, significantly decrease the probability of fatal injury in head-on collisions by 5.07% on roadways with a median, traffic control, and posted speeds >50 mph, by 1.86% on rural roadways with posted speeds of 30-49 mph, by 7.80% on rural roadways with posted speeds >50 mph, and by 0.77% on urban roadways.

Deng et al. (2006) found that the variable 'weather conditions' actually correlated with roadway surface conditions, i.e., when rain was reported at the time of the crash, then the crash occurred on wet pavement. Analyses indicated that 'weather', in general, was a poor predictor of head-on crash severity.

2.3 Vehicle Factors

Vehicle factors identified in previous studies include:

- Defective tire (Gårder, 2006)
- Other vehicle defect (Gårder, 2006)
- Type of vehicle (Deng et al., 2006)

Typically, very few head-on crashes can be attributed to vehicle factors. Of the 127 fatal crashes examined by Gårder (2006), only two crashes were caused by vehicle issues: one where the primary cause of the crash was a defective tire and the other had an unidentified vehicle defect.

Related to vehicle type, Liu and Fan (2020) found that the risk of non-fatal injury while driving a pickup truck decreases significantly for head-on crashes occurring on rural roadways with posted speeds >50 mph. However, for motorcycles, the probability of fatal injury significantly increases by 7.95% in head-on crashes occurring on rural roadways with posted speeds of 30-49 mph, by 8.26% on rural roadways with posted speeds of >50 mph, and by 2.79% on urban roadways.

2.4 Human Factors

A study by Gårder (2006), on two-lane rural roads in Maine, found that a majority of the head-on crashes resulted from driver error. The primary focus of the study was head-on crashes that resulted in fatalities or incapacitating injuries sustained from centerline crossovers.

Gårder (2006) categorized driver actions that result in a head-on crash after crossing the centerline as *intentional* or *unintentional*. However, determining the intent of a driver involved in any crash is unrealistic. Therefore, human factors categorized as *intentional* or *unintentional* can be viewed as *behavioral* or *impairment* factors, respectively.

Intentional (behavioral) reasons for centerline crossovers noted by Gårder (2006) include:

- Overtaking a slower vehicle
- Avoiding a vehicle changing lanes
- Avoiding a vehicle slowing
- Avoiding another vehicle, object, pedestrian, or animal in the road
- Turning left, right, or U-turn
- Making a shortcut through a left-hand curve
- Intent to do self-harm (not included in the analysis)
- Driving under the influence (DUI) of alcohol or drugs
- Speeding, i.e., driving above the posted speed limit

Unintentional (impairment) reasons for centerline crossovers noted by Gårder (2006) include:

- Inattentiveness or distraction
- Fatigue or falling asleep
- Misjudging a situation
- Driver inexperience
- Physical impairment or ill
- Inability to see the centerline, e.g., when roadway is covered by snow
- Skidding on snow, ice, or wet pavement
- Losing control because of speeding, especially in right-hand curves
- Overcorrection after running off the right edge of the pavement

Analyses revealed that many of the head-on crash events also had secondary, and sometimes tertiary, causes that contributed to the crash, such as the pre-crash action of turning left while being distracted (Gårder, 2006). At the time of the crash, many *intentional* actions may be considered *unintentional*, depending on the pre-crash actions of the drivers involved. Factors investigated in previous studies that are considered to be *intentional (behavioral)* or *unintentional (impairment)* in this report are discussed in the following subsections.

2.4.1 *Intentional (Behavioral) Actions*

Gårder (2006) found that alcohol or drugs was a factor in one in 12 non-fatal head-on crashes and one in nine fatal head-on crashes. Liu and Fan (2020) found that driving under the influence (DUI) of alcohol or drugs significantly increase the likelihood of fatal injury in head-on collisions, by up to 10.85%. Generally, a driver choosing to drive under the influence is considered to be an intentional action by the driver. However, driving under the influence of alcohol or drugs may also be considered an unintentional action, since alcohol and drugs can impair a person's judgement.

Multiple studies analyzed speed limit as a potential contributing factor in head-on collisions. However, speed limit is different from travel speed. Only one previous study, Gårder (2006), discussed travel speed as a factor in head-on crash injury severity. In a study on two-lane roads in Maine, Gårder (2006) found that traveling at illegal/unsafe speeds was the greatest factor in fatal head-on crashes.

Less than 8% of head-on crash fatalities involved someone overtaking another vehicle, and only around 14% involved a driver intentionally crossing the centerline (Gårder, 2006). Regarding other maneuvers, the pre-crash action of making a left turn was the primary contributing factor in 20.9% of non-fatal head-on crashes (Gårder, 2006).

2.4.2 *Unintentional (Impairment) Actions*

Gårder (2006) found that fatigue was responsible for around one in 40 crashes and one in 12 fatal crashes on two-lane roads in Maine. Driver inattention/distraction was a primary factor in 28% of fatal head-on collisions and a contributing factor in 55.7% of non-fatal crashes (Gårder, 2006).

The National Highway Traffic Safety Administration (NHTSA) describes 'distraction' as a specific type of driver inattention, where a driver diverts attention from the driving task to focus on other activities, such as cell phone use, texting, eating, talking to passengers, adjusting the radio/climate controls or other vehicle controls (NHTSA, 2023). NHTSA also terms crashes involving a distracted driver, at the time of the crash, as distracted-affected crashes. Nationwide, 8% of all fatal crashes and 14% of injury crashes occurring in 2021 were reported as distracted-affected crashes (NHTSA, 2023).

Skidding, due to ice or snow on the roadway, was a factor in a number of head-on crashes on two-lane roadways in Maine. Overall, Gårder (2006) found that nearly one-third of head-on crashes occurred on wintry roads, with skidding a primary contributing factor.

2.5 Driver Characteristics

Liu and Fan (2020) found that male drivers are more likely to suffer a fatal injury in head-on collisions occurring on roadways with a median, traffic control, and posted speeds >50 mph, as well as on urban roadways. Model results also indicated a significant increase in fatal head-on collisions for drivers of age 50+ on roadways with a median, traffic control, and posted speeds >50 mph, as well as on rural roadways with posted speeds >50 mph.

2.6 Primary Risk Factors for Head-On Crashes

A number of factors have been examined in previous studies to determine their effect on the propensity of head-on crash occurrence and injury severity. Findings reveal that more than one factor contributes to most, if not all, head-on crash events. However, certain factors have been determined to be primary risk factors in the majority of head-on collisions. This section discusses the primary factors in head-on crashes identified in existing literature. Countermeasures for each primary factor are also discussed.

Table 2.1 lists the primary risk factors affecting the propensity of head-on crash occurrence. as identified in previous studies. These factors include:

- Specific roadway features
- Number of access points
- Specific human factors

Table 2.1: Primary Risk Factors in Head-On Collisions

Primary Contributing Factors in Head-On Collisions	
Factor	Contributing Characteristics
Roadway Features	Rural roadways
	Two-lane roadways
	Undivided roadways
	Straight alignment sections
	Shoulder width (≤ 5 ft), narrow, unpaved
	Vertical grade or percentage of section not level
	Horizontal curves, number of reverse curve per 1-mile roadway
	Speed Limit (≥ 50 mph)
Access Points	More than 10 access points per 1-km roadway segment, both sides)
	Major access points (>5 total per 1-mile roadway segment, both sides)
Human Factors	Driver distracted/inattentive
	Under influence of alcohol/drugs
	Traveling at illegal/unsafe speeds

Fatal RwD head-on crashes are overrepresented among crashes on undivided rural roadways, nationwide (FHWA, 2022a). Findings are consistent among existing literature – the majority of fatal head-on crashes occur on rural two-lane roadways. Gårder (2006) concluded that head-on collisions produce fatalities more than six times as frequent as other types of crashes. Rural highways typically consist of two lanes with few, if any, medians or passing-lane sections, thus, creating the susceptibility of head-on crash occurrence and fatal injuries. As a result, rural two-lane undivided roadways present a primary risk factor for the propensity of head-on crash occurrence.

Straight roadway segments also present a greater proneness to the occurrence of fatal head-on crashes. While curves contribute to approximately 30% of fatal head-on collisions (Gårder, 2006; FHWA, 2022a), the majority occur on straight segments. Moreover, straight segments significantly influence the risk of fatal head-on crashes on rural roadways with posted speeds >50 mph (Liu & Fan, 2020). Therefore, straight segments, especially on rural two-lane roadways, present a primary risk factor for the propensity of head-on crash occurrence.

Several studies found shoulder width to be a primary contributing factor in fatal head-on collisions (Gårder, 2006; Zhang & Ivan, 2005; Deng et al., 2006; Al-Senan & Wright, 1987). However, results varied among the studies. Shoulder widths found to increase the likelihood of head-on crash occurrence or severity on two-lane rural roadways range from less than or equal to 4 ft, less than or equal to 5 ft, greater than 7 ft for higher AADT volumes, and percentage of shoulder widths less than 6 ft over a 1-mile section. Therefore, based on a later study by Zeng et al. (2013) (discussed in the next section on countermeasures), a conservative value of ≤ 5 ft for shoulder width may be used as a primary risk factor in affecting the propensity of head-on crash occurrence.

Horizontal curves and associated variables were found to influence the occurrence of head-on collisions by a number of studies (Zhang & Ivan, 2005; Deng et al., 2006; Liu & Fan, 2020). Al-Senan and Wright (1987) found that the number of reverse curves per 1-mile roadway segment increase the proneness of head-on crash occurrence. Several studies also found a significant correlation with head-on crash occurrence and vertical grades (Al-Senan & Wright, 1987; Liu & Fan, 2020).

Zhang and Ivan (2005) found that speed limit significantly influenced the incidence of head-on crash occurrence. However, analysis results on speed limit vary among existing literature. Several studies found that speed limits ranging from 25 mph to 50 mph significantly influence head-on crash occurrence and crash severity. FARS data for years 2016 to 2018 show that 70% of RwD fatalities were head-on collisions that occurred on roadways with speed limits ≥ 50 mph (FHWA, 2022a). Therefore, two-lane roadways with posted speeds of ≥ 50 mph should be considered to have a higher likelihood of head-on crash occurrence.

Several studies found that the number of access points can influence head-on crash occurrence and crash severity. Fatal crashes are more likely to occur in areas with a large number of access points along 1-km (0.62 miles) sections of roadway, while fewer than 10 access points is associated with less crash severity (Deng et al., 2006). The number of major access points (both sides) within a 1-mile roadway segment is a significant factor in the likelihood of head-on crash occurrence. Based on a nomograph developed by Al-Senan and Wright (1987), using practical ranges for specific site characteristics, more than five major access points per mile increases the probability of head-on crash proneness.

Gårder (2006) concluded that human factors are the most common risk factors in head-on crashes. Distracted or inattentive drivers and DUI infractions are primary risk factors that increase the propensity of head-on crash occurrence. Traveling too fast for roadway conditions is also a key risk factor (Gårder, 2006).

2.7 Chapter Summary

This chapter discussed contributing factors in head-on crashes, as well as primary risk factors affecting the propensity of head-on crash occurrence identified in previous studies. A number of factors were found to be significant in contributing to the occurrence or injury severity of head-on crashes. Table 2.2 summarizes the contributing factors crashes identified in existing literature.

Table 2.2: Summary of Contributing Factors in Head-On Collisions

Category	Factor Type	Source(s)
Roadway Factors	• Alignment • Geometrics • Classification • Pavement width • Shoulder width • Lane width • Number of lanes • Posted speed limit • AADT • Number of access points	Al-Senan and Wright (1987); Zhang and Ivan (2005); Deng et al. (2006); Gårder (2006); Liu & Fan (2020)
Environmental Factors	• Pavement conditions • Light conditions • Weather conditions	Gårder (2006); Deng et al. (2006); Liu & Fan (2020)
Vehicle Factors	• Type of vehicle • Defective tire • Other vehicle defects	Gårder (2006); Deng et al. (2006)
Human Factors	• Intentional (behavioral) • Unintentional (impairment)	Gårder (2006)
Driver Characteristics	• Age • Gender	Liu & Fan (2020)

Primary risk factors affecting the propensity of head-on crashes identified in previous studies include:

- Rural two-lane undivided roadways
- Straight alignment roadways sections
- Narrow and unpaved shoulders
- Vertical grade or percentage of roadway section not level
- Horizontal curves and number of reverse curves
- Posted speed limit greater than or equal to 50 mph
- Greater than 10 access points per 1-mile roadway section
- Greater than five major access points per 1-mile roadway section
- Distracted/inattentive drivers
- Driving under the influence of alcohol/drugs
- Speeding

CHAPTER 3
COUNTERMEASURES TO REDUCE HEAD-ON CRASHES

A variety of countermeasures have been implemented to keep vehicles on the roadway and reduce the occurrence and injury severity of head-on crashes. Effective countermeasures identified in existing literature include:

- Pavement Markings
- Curve Warning Signs at Horizontal Curves
- Sequential Dynamic Curve Warning Systems (SDCWS)
- Audible and Vibratory Treatments
- Centerline Buffer Areas
- Friction Treatments
- Median Barriers
- Shoulder Treatments
- Speed Reduction Measures
- Removing Roadside or Shielding Objects
- Wrong-Way Driving Countermeasures
- In-vehicle Technology
- Educational Programs

3.1 Pavement Markings

Adding edge lines and widening both centerline and edge line pavement markings better delineate the travel lane and reduce head-on crash occurrence. Illinois Department of Transportation (DOT) widened the centerline stripes from four inches to five inches on two-lane roadways. This strategy resulted in a 14% reduction in opposite direction fatal and injury crashes (FHWA, 2022a). Kansas DOT widened the edge line on two-lane roadways from four inches to six inches, resulting in a 53% reduction in opposite-direction fatal and injury crashes (FHWA, 2022a).

3.2 Curve Warning Signs at Horizontal Curves

Installing or improving curve warning signs and delineation signs, such as chevrons, horizontal arrows, and advanced warning signs, at horizontal curves on two-lane undivided roadways can reduce head-on crash occurrence and overall crash severity. Chevron signs can reduce non-intersection head-on crashes and opposite-direction sideswipes by up to 25% (FHWA, 2022a). Srinivasan et al. (2009) found that installing new fluorescent warning signs and delineation signs at two-lane undivided roadway curves can reduce non-intersection fatal and injury head-on crashes, as well as run-off-road and sideswipe collisions, by 18%. In addition, upgrading existing curve warning signs using fluorescent yellow sheeting can result in a 34% reduction in nighttime collisions (Srinivasan et al., 2009). Improving curve delineation with signing improvements is a cost-effective treatment with a benefit-cost ratio exceeding 8:1 (Srinivasan et al., 2009). Examples of typical curve warning signs are presented in Figure 3.1.

(a) Curve warning sign with advisory speed

(b) Chevron signs with retroreflective strips on sign posts

Figure 3.1: Curve Warning Sign Examples (FHWA, 2016)

3.3 Sequential Dynamic Curve Warning Systems (SDCWS)

Sequential Dynamic Curve Warning Systems (SDCWS) are used as a countermeasure on two-lane and multilane highways to reduce vehicle operating speeds and improve curve delineation (FHWA, 2016). SDCWS consist of horizontal curve chevrons with embedded solar powered flashing lights, as shown in Figure 3.2. Locations with high crash frequency, especially FS crashes, may be candidates for SDCWS. Recent studies have found that both operating speeds and crash frequency have been reduced following SDCWS installations (FHWA, 2016).

Figure 3.2: Sequential Dynamic Curve Warning Systems (SDCWS) Example (FHWA, 2016)

3.4 Audible and Vibratory Treatments

An effective strategy for reducing RwD crashes is the installation of Audible and Vibratory Treatments (AVTs), such as rumble strips/stripes (Himes et al., 2017). The noise and vibration experienced when a vehicle makes contact with a rumble strip can alert a fatigued or distracted/inattentive driver that they are leaving the travel lane. Center line rumble strips installed on two-lane undivided roadways can reduce FS head-on crashes, as well as opposite-direction sideswipe crashes, by 45%, and all severity types by 37% (Torbic et al., 2009). Shoulder rumble strips can be installed atop or to the right of the edge line. Examples of rumble strips are shown in Figure 3.3. Other AVTs identified in Florida to reduce head-on crashes include profiled thermoplastic, and sinusoidal ground-in rumble strips (FHWA, 2022b).

(a) Center line rumble stripes

(b) Shoulder rumble strips

Figure 3.3: Rumble Strip Examples (FHWA, 2023)

3.5 Centerline Buffer Areas

A centerline buffer area along sections of two-lane undivided roadways can provide vehicles with additional pavement to avoid head-on and sideswipe collisions, especially in locations prone to RwD crashes. As shown in Figure 3.4, centerline buffer areas provide additional lateral distance between the center line pavement stripes. This strategy can reduce the occurrence of head-on crashes by 25%, 64%, and 90% for buffer widths of 2 ft, 4 ft, and 10 ft, respectively (FHWA, 2022a).

Figure 3.4: Centerline Buffer Area Example (FHWA, 2022a)

3.6 Friction Treatments

High-friction surface treatment (HFST) can be installed at specific locations with high friction demand, such as curves, ramps, and intersection approaches. This strategy has been deployed in a number of States over the past 20 years, including several sites in Florida. A before and after evaluation of the effectiveness of HFST installation showed a reduction in head-on and sideswipe crashes at the application sites (Merritt et al., 2020). A crash modification factor (CMF) of 0.691 and crash reduction factor (CRF) of 30.9 indicates an estimated 31% reduction in head-on and sideswipe collisions (Merritt et al., 2020). Figure 3.5 shows an example of a manual HFST installation and a roadway surface after HFST was installed.

(a) HFST installation **(b) HFST after**

Figure 3.5: High-Friction Surface Treatment (HFST) (Merritt et al., 2020)

3.7 Median Barriers

Head-on crashes account for approximately 8% of all fatalities occurring on rural divided highways (FHWA, 2021a). Installing median barriers can reduce cross-median head-on crashes by 97% (FHWA, 2021a). Median barriers typically used to improve safety include: cable barriers, metal-beam guardrails, and concrete barriers. As shown in Figure 3.6(a), cable barriers are flexible barriers, made from steel cables mounted on weak steel posts. The weak steel posts lessen the impact force when struck by a vehicle following a RwD incident. Although cable barriers are an effective countermeasure in preventing head-on crashes and reducing fatal and serious injuries from RwD collisions, they require more frequent maintenance and repair than other barrier types (FHWA, 2021a).

Metal-beam guardrails are semi-rigid barriers constructed of W-beams or box-beams mounted to steel or timber posts. This barrier type absorbs some of the impact energy and generally requires little maintenance following minor incidences. Since metal-beam guardrails deflect less than cable barriers, they can be installed closer to the roadway and where median space is limited (FHWA, 2021a).

Concrete barriers are another barrier type that can be installed in locations with a history of head-on crashes. As shown in Figure 3.6(b), these barriers are rigid and experience little to no deflection if impacted by a vehicle leaving the travel way. Concrete barriers redirect rather than absorb energy from the impact (FHWA, 2021a), and can be constructed using portable concrete units.

(a) Cable median barriers
Source: Schmaltz (2016)

(b) Concrete median barriers
Source: Gårder (2006)

Figure 3.6: Median Barrier Examples

3.8 Increasing Median Width

For divided rural highways, increasing the median width can reduce cross-median crashes. Harkey et al. (2008) found a significant correlation between wider medians and fewer cross-median crashes on rural highways. Widening an existing 10-ft median to 20 ft can reduce rural cross-median crashes by 16%, and widening to 40 ft and 60 ft results in an estimated 40% and 57% reduction in cross-median crashes, respectively.

3.9 Shoulder Treatments

Shoulder treatments can help drivers stay in the travelway and avoid roadway departures that may lead to a head-on crash. or recover and safely re-enter the roadway. Shoulder treatments, such as increasing the shoulder width and installing SafetyEdge^{SM}, can help reduce the risk of a crash when vehicles veer onto the shoulder.

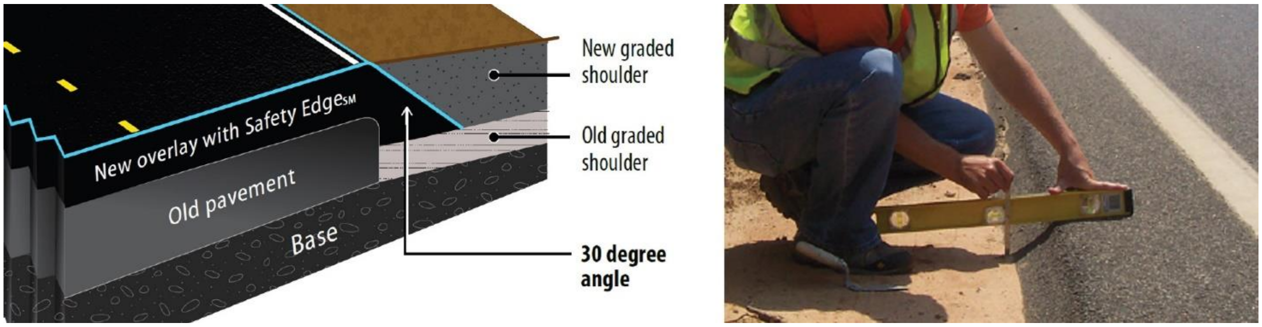
3.9.1 Increasing Shoulder Width

Increasing shoulder width is an effective countermeasure that provides more area for drivers to stay on the road and potentially avoid a head-on crash on two-lane roadways (FHWA, 2022a). Zeng et al. (2013) analyzed the safety benefits of upgrading narrow unpaved shoulders to wider composite or paved shoulders on two-lane rural highways in Kansas. CRFs developed indicate that upgrading narrow unpaved shoulders of <5 ft to paved shoulders >5 ft is expected to reduce head-on, run-off-road, and sideswipe crashes by 77% (CRF = 77). Unpaved shoulders of >5 ft should reduce head-on, run-off-road, and sideswipe crashes by 79% (CRF = 79). Upgrading narrow unpaved shoulders (<5 ft) to composite shoulders (3 ft paved with the remainder turf or aggregate) also improves safety, but slightly less than a paved shoulder of >5 ft (Zeng et al., 2013).

The general idea is that providing enough available surface area for a vehicle to potentially avoid a head-on collision and/or recover from a run-off-road incident would help to reduce crash occurrence and injury severity. Note that speed limit and AADT should also be considered in determining the appropriate shoulder width in areas of high head-on crash occurrence.

3.9.2 SafetyEdge^{SM}

Installing SafetyEdge^{SM} during paving or resurfacing projects is an effective countermeasure for helping drivers that drift off the travelway, onto the shoulder, to return to the road safely, thus reducing the potential of losing control of the vehicle and colliding with on-coming traffic (FHWA, 2017). The SafetyEdge^{SM} is constructed with a low-cost paver attachment that enables the pavement edge to be paved and compacted to a finished 30-degree angle. Compacted backfill material is then installed on the shoulder and graded flush with the paved road surface, as shown in Figure 3.7(a) (FHWA, 2017). Over time, as the backfill material settles or erodes, the exposed angled SafetyEdge^{SM} provides a traversable surface, allowing vehicles to safely re-enter the travelway (see Figure 3.7(b)). With conventional paving techniques (i.e., graded backfill to the pavement edge), a vertical or near-vertical drop-off can develop at the pavement edge and cause tire-scrubbing, which may lead to loss of control of the vehicle (FHWA, 2017).



(a) SafetyEdge^{SM} after installation.

(b) SafetyEdge^{SM} after backfill settles or erodes.

Figure 3.7: SafetyEdge^{SM} Examples (FHWA, 2017)

3.10 Speed Reduction Measures

Throughout existing literature, speed limit has been correlated with occurrence and injury severity of head-on collisions. Speed limit, however, is different from traveling speed or impact speed at the time of the crash. Gårder (2006) concluded that a primary factor in centerline crossover head-on collisions was due to drivers traveling at illegal or unsafe speeds for the roadway conditions. Gårder (2006) also argues that getting drivers to slow down only through curves is not enough, since a high percentage of head-on crashes occur on straight roadways segments.

The FDOT Design Manual (FDM) discusses a number of speed management strategies to promote desired operating speeds for low-speed facilities where conventional controls have limited applicability (FDOT, 2024). These strategies may also be implemented on arterials and collectors when consistent with the context classification of the roadway (FDOT, 2024). Speed management strategies presented in the FDM include:

- Roundabouts
- On-street parking
- Chicanes
- Lane narrowing
- Horizontal deflection
- Street trees
- Short blocks
- Vertical deflection
- Speed feedback signs
- Posted speed pavement marking
- Islands
- Curbs Extensions (Bulb-Outs)
- Rectangular Rapid Flashing Beacons (RRFBs) and Pedestrian Hybrid Beacons (PHBs)
- Terminated vista

Speed enforcement measures are somewhat limited, especially in rural areas. However, several potential speed reduction measures are available, including:

- Lowering the speed limit
- Driver feedback speed signs
- Additional law enforcement
- Photo enforcement

Lowering the posted speed limit is one option for reducing traveling speeds and potentially reducing head-on crashes. However, this strategy relies on driver compliance. One tool that can alert a driver of their current speed is driver feedback signs, as shown in Figure 3.8. Driver feedback signs use radar to measure a vehicle's speed on approach, and then flash the current speed to inform the driver that they are speeding. This option can also alert a distracted driver or inattentive driver, another primary factor in head-on collisions.

Additional law enforcement is another option for reducing speeds. However, this strategy is based on the available resources of the jurisdictional agencies, which may be considerably limited in rural areas. Photo enforcement at locations with a history of head-on crashes may be a more plausible solution. Automated speed enforcement cameras, as shown in Figure 3.9, can automatically detect and record speeding vehicles, and issue tickets to the address associated with the vehicle registration. However, the use of photo enforcement devices may be limited or restricted, based on location and local or jurisdictional policies. In some locations, a combination of driver feedback signs and photo enforcement may be an effective strategy.

Figure 3.8: Driver Feedback Speed Sign (Radarsign™, 2023)

Figure 3.9: Photo Radar Camera Example (Keller, 2022)

3.11 Removing or Shielding Roadside Objects

Roadside objects, such as trees and utility poles, located within the right-of-way or clear zone can present a hazard to vehicles that leave the roadway. To reduce the crash potential and injury severity, FHWA reccommends three broad strategies: a) keep vehicles on the roadway, b) reduce roadside crash potential, and c) minimize crash severity (FHWA, 2023). The FDM presents various safety measures to address roadside objects (FDOT, 2024), including:

- Lateral offset criteria.
- Warrents for roadside barriers.
- Barrier type selection and placement.

3.12 Wrong-Way Driving Countermeasures

Wrong-way driving (WWD) incidents most often result in a head-on crash. Some studies have categorized head-on crashes into three types: wrong-way driving head-on crashes, cross-median head-on crashes, and head-on collisions on freeways (Zhou et al., 2012). A recent study by Alluri et al. (2018) investigated the occurrence of wrong-way driving (which potentially leads to head-on crashes) and identified several countermeasures, particularly on freeway off-ramps. These countermeasures include:

- For impaired drivers susceptible to WWD, which could lead to head-on crashes: A combination of Red-Rectangular Rapid Flashing Beacons (Red-RRFBs) and Red flush-mount internally illuminated raised pavement markers (iiRPMs) were identified as feasible countermeasures.
- For drivers aged 65 and older: LED lights around WRONG WAY signs and iiRPMs were identified as feasible countermeasures.

- For tourist drivers or drivers not familiar with the roadway system: The use of either Red-RRFBs or LED lights around WRONG WAY signs were identified as feasible countermeasures.

In another study, Alluri et al. (2019) listed the following countermeasures that could be implemented to mitigate WWD incidents on arterials:

Engineering:

- Signing
  - Standard “WRONG WAY” sign package
  - Improved static signs
  - Redundant signs
  - Lowered sign height
  - Oversized signs
  - Multiple signs on the same post
  - Red retro-reflective tape on vertical posts
- Pavement Markings
  - Stop bar
  - Wrong-way arrow
  - Turn/through lane-only arrow
  - Raised pavement markers
  - Short dashed line to delineate turning path
- Geometric Improvements
  - Raised curb median
  - Longitudinal channelizers
- ITS Technologies
  - LED-illuminated signs
  - Dynamic message signs to warn right-way drivers
  - Existing GPS navigation technologies to provide wrong-way movement alerts, especially on one-way streets

Education:

- Public awareness and understanding of the basics of road designs and interchange types and proactive behaviors (witnessing a wrong-way driver)
- Focus groups involving older drivers, impaired drivers, and young drivers

Enforcement:

- Provide warnings and citations to wrong-way drivers
- Enforce DUI laws
- Warn right-way drivers using DMSs

Emergency Response:

- Identify the wrong-way vehicles as soon as possible
- Develop a communication plan to inform all the relevant agencies of a potential wrong-way incident

3.13 In-vehicle Technology

In-vehicle technologies are becoming mainstream in the automotive industry. Many newer vehicles now come equipped with technologies that enhance safety, performance, convenience, and communication. Advanced driver assist systems employ technology that can react swiftly to risks, minimize drowsy driving, and potential collisions (TechCEOs, n.d.). These system packages often include the following features (TechCEOs, n.d.):

- Adaptive cruise control
- Lane departure warning
- Lane-keeping assistance
- Blind-spot alert
- Automatic Emergency Braking (AEB)

Automatic Emergency Braking (AEB) activates the vehicle's brakes when it detects an impending collision, potentially averting or avoiding an accident, and can begin operating before the brakes are applied (TechCEOs, n.d.). AEB is such a critical safety feature that up to 20 automakers have pledged to make AEB standard throughout their entire vehicle line (TechCEOs, n.d.).

3.14 Educational Programs

Educational programs on the potential hazards of distracted driving and speeding on two-lane roadways may better inform the public and promote safety. These programs should be tailored to the specific needs and characteristics of the affected areas. However, educational efforts may be more effective when combined with additional countermeasures.

3.15 Chapter Summary

This chapter discussed countermeasures found to be effective in reducing the occurrence and injury severity of head-on crashes. Effective countermeasures used to reduce head-on crash occurrence include:

- Pavement Markings
- Curve Warning Signs at Horizontal Curves
- Sequential Dynamic Curve Warning Systems (SDCWS)
- Audible and Vibratory Treatments
- Centerline Buffer Areas
- Friction Treatments
- Median Barriers
- Increasing Median Width
- Shoulder Treatments
- Speed Reduction Measures
- Removing or Shielding Roadside Objects
- Wrong-Way Driving Countermeasures
- In-vehicle Technology
- Educational Programs

CHAPTER 4
HEAD-ON CRASH CAUSES AND PATTERNS

This chapter discusses the causes, contributing factors, and patterns of head-on crashes in FDOT District 7. Crash analyses were performed on reported head-on crashes in the study area using the most recent five years of crash data (2018–2022). Although wrong-way driving (WWD) incidents often result in head-on crashes, WWD crashes were not examined in this study. The analysis process included the following four steps:

Step 1: Descriptive Statistics: This step focused on performing a descriptive statistical analysis of crash and roadway characteristics, environmental conditions, driver characteristics, and vehicle factors. This analysis aimed to uncover overarching districtwide trends in head-on collisions and the factors that contribute to the occurrence and severity of these head-on crashes.

Step 2: Police Report Review: Police crash reports were reviewed for all fatal and serious (i.e., incapacitating) injury crashes within the study period. This comprehensive examination of police reports assisted in acquiring further crash-specific information, including details provided in police narratives and illustrations, which are not present in crash summary records. In addition, by using Google Earth, more information was obtained from the crash locations in relation to the existing road signs and pavement markings.

Step 3: Spatial Analysis: The spatial analysis was conducted for the entire District 7 region to accurately identify hot spot locations for head-on crashes. Identifying hot spot locations will guide efforts to develop systemic projects to proactively implement head-on crash remediation measures. The Optimized Hot Spot Analysis (OHSA), known for its advanced and automated configuration of parameters, was utilized to identify statistically significant spatial clusters of crashes within the District 7 region by classifying them into different confidence intervals.

Step 4: Documentation: This step focused on recording the findings regarding contributing factors and patterns in head-on crashes obtained from the three mentioned approaches: descriptive statistics, police report review, and spatial analysis.

4.1 Study Area

The FDOT District 7 study area contains five counties: Citrus, Hernando, Pasco, Pinellas, and Hillsborough, as shown in Figure 4.1. District 7 has a total land area of 3,332 square miles, with nearly 2.9 million residents in the Tampa Bay area. Drivers in the district travel more than 33.6 million miles daily (FDOT, n.d.). The State Highway System in District 7 includes (FDOT, n.d.):

- Centerline miles: 1,064
- Lane miles: 4,267
- Fixed bridges: 633
- Movable bridges: 13

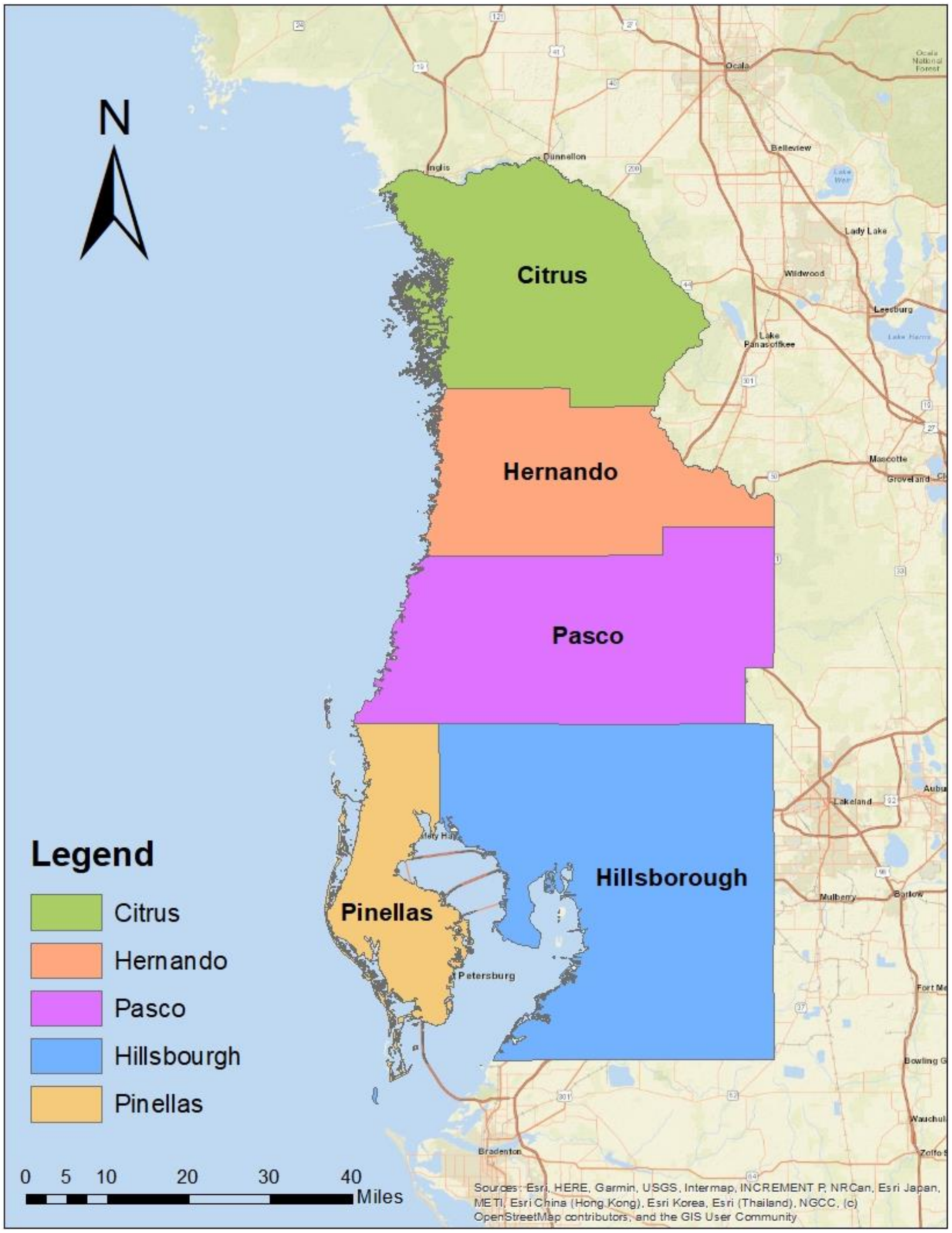


Figure 4.1: FDOT District 7 Study Area

4.2 Descriptive Statistics

Descriptive statistics are a fundamental component of statistics that involves organizing, summarizing, and presenting data meaningfully. Descriptive statistics are often the first step in data analysis and are crucial for gaining insights into the data's overall patterns and characteristics. This section presents the descriptive statistics for the District 7 region from years 2018 to 2022. The statistics provide a comprehensive overview of the crash data in relation to crash and roadway characteristics, environmental conditions, driver characteristics, and vehicle factors.

4.2.1 Data Sources

The data used for descriptive statistics was obtained from two primary sources: the Signal4 Analytics database and the Roadway Characteristics Inventory (RCI) database. For this analysis, the data were filtered for the 5-year study period (2018–2022).

4.2.1.1 Signal4 Analytics Database

Signal4 Analytics is an interactive web platform created to assist the crash mapping and analysis requirements of law enforcement, traffic engineering, transportation planning agencies, and research institutions in Florida. The database was designed and created by the GeoPlan Center at the University of Florida (UF, 2022). Crash, roadway characteristics, environmental conditions, driver characteristics, and vehicle factors are all included in the database. Every crash has its unique report number that can be used to identify a particular crash. Injury severity levels are categorized using the KABCO scale defined by NHTSA (2024b), as follows:

- K – Fatal injury
- A – Incapacitating injury (i.e., 'Serious' injury in this report)
- B – Non-Incapacitating injury
- C – Possible injury
- O – No injury

4.2.1.2 Roadway Characteristics Inventory (RCI)

RCI is a comprehensive database encompassing details about road infrastructure, administrative aspects, and various conditions. Developed by the FDOT Office of Information Technology (OIT) in 1977, the database is frequently updated with statewide coverage and roadway geographical resolution. Some of the features in the RCI database include functional classification of the roadways, inside and outside median type and widths, AADT, truck volume, managed lanes, number of lanes and surface widths, shoulder widths, intersections, interchanges, and many others. A number of variables available in the RCI data were used for the descriptive statistics to identify the relationship between the features and injury severity of head-on crashes within District 7. The variables used for descriptive statistics include: number of lanes, median width, and shoulder width. The head-on crash data extracted from the Signal4 Analytics database were mapped with a particular RCI shapefile (e.g., shoulder width), and a spatially joined analysis was conducted so that each crash would obtain the RCI information. The data were extracted into Microsoft Excel® for the descriptive statistics analysis.

4.2.2 Head-On Crashes by Year

In analyzing crash data spanning multiple years, the descriptive statistics revealed significant insights into the frequency of crashes and the severity of outcomes. Figure 4.2 shows the distribution of crashes across the study period based on their severity. The year 2022 was observed to have more crashes compared to other years. However, fewer fatal and incapacitating (i.e., serious) injuries occurred in the year 2022 compared to other years.

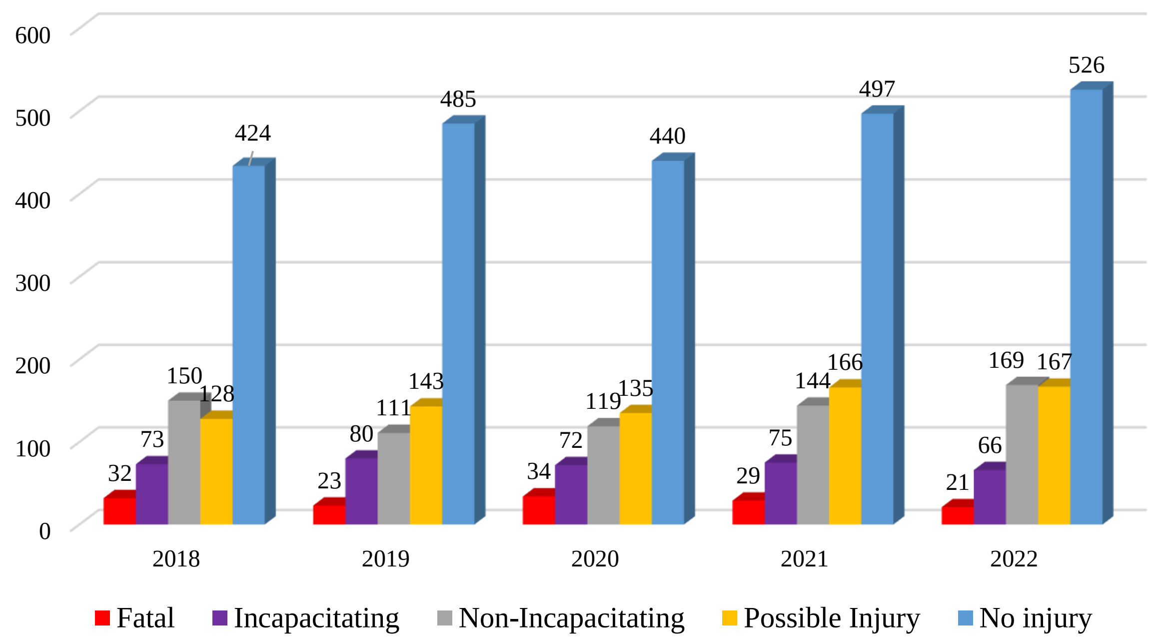


Figure 4.2: Head-On Crashes by Year and Crash Severity

A total of 4,523 head-on crashes were recorded within the 5-year study period. Following the removal of crashes with missing data, the final dataset included 4,309 head-on crashes, as shown in Table 4.1. The data illustrates that the number of crashes experienced periodic variations, displaying both an increase and decrease during different time intervals. Year 2020 exhibited a significantly higher occurrence of fatal crashes than other years within the analysis period. As expected, crashes that resulted in property damage only (O) were more prevalent in all years, constituting an average of 55.05% of all head-on crashes.

Table 4.1: Head-On Crash Statistics by Year and Crash Severity

Crash Year	K		A		B		C		O		Total
	Count	%	Count	%	Count	%	Count	%	Count	%	
2018	32	3.97%	73	9.05%	150	18.59%	128	15.86%	424	52.54%	807
2019	23	2.73%	80	9.50%	111	13.18%	143	16.98%	485	57.60%	842
2020	34	4.25%	72	9.00%	119	14.88%	135	16.88%	440	55.00%	800
2021	29	3.18%	75	8.23%	144	15.81%	166	18.22%	497	54.56%	911
2022	21	2.21%	66	6.95%	169	17.81%	167	17.60%	526	55.43%	949
Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,372**	**55.05%**	**4,309**

4.2.3 Roadway Characteristics

Roadway characteristics refer to various physical and environmental attributes of a road or highway that influence its design, safety, and overall functionality. These characteristics are essential for understanding how a road is constructed, how it operates, and how it can impact safety among road users. Common roadway characteristics include roadway gradient, number of lanes, intersection type, presence of and width of medians and shoulders, lighting conditions, and others. The following subsections discuss the roadway characteristics included in the descriptive statistics analysis.

4.2.3.1 Roadway Gradient

As shown in Table 4.2, the crash data analysis revealed distinct patterns in fatal crashes across different roadway gradients. Notably, a significantly higher percentage of fatal crashes occurred on hillcrest, sag bottom, and downhill gradients, indicating an elevated risk of severe outcomes in crashes on these gradient types. The elevation changes of hillcrest, sag bottom, and downhill gradients result in limited visibility and reduced sight distance. Consequently, this presents challenges for drivers to anticipate and react to potential hazards, which increases the likelihood of crashes, especially at higher speeds. Although the majority of head-on crashes occurred on level gradients, the overall percentage of fatal crashes (3.08% of 4,061 crashes) was lower than all other gradients studied.

Table 4.2: Head-On Crash Statistics by Roadway Gradient and Crash Severity

Roadway Gradient	K		A		B		C		O		Total
	Count	%	Count	%	Count	%	Count	%	Count	%	
Level	125	3.08%	343	8.45%	664	16.35%	711	17.51%	2,218	54.62%	4,061
Downhill	8	13.56%	6	10.17%	11	18.64%	9	15.25%	25	42.37%	59
Uphill	3	5.17%	11	18.97%	6	10.34%	9	15.52%	29	50.00%	58
Hillcrest	2	14.29%	3	21.43%	3	21.43%	1	7.14%	5	35.71%	14
Sag (bottom)	1	12.50%	2	25.00%	2	25.00%	3	37.50%	0	0.00%	8
Unknown	0	0.00%	1	0.92%	7	6.42%	6	5.50%	95	87.16%	109
Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,372**	**55.05%**	**4,309**

4.2.3.2 Shoulder Type

Table 4.3 provides the crash severity statistics based on the type of roadway shoulder. Shoulder types were characterized as curb, paved, and unpaved roadway shoulder. The data revealed a higher frequency of fatal crashes on paved shoulders (4.55%) and unpaved shoulders (4.42%), compared to curbed shoulders (1.5%). Paved shoulders may attract more vehicles due to their smooth and accessible surface. Crashes were also observed to be higher on roadways with unpaved shoulders, potentially due to loose gravel or uneven shoulder surfaces. Therefore, crashes occurring on roadways with paved or unpaved shoulders are associated with a significantly higher probability of fatal outcomes.

Table 4.3: Head-On Crash Statistics by Type of Roadway Shoulder and Crash Severity

Roadway Shoulder	K		A		B		C		O		Total
	Count	%	Count	%	Count	%	Count	%	Count	%	
Curb	27	1.50%	93	5.16%	268	14.87%	299	16.59%	1,115	61.88%	1,802
Paved	57	4.55%	100	7.98%	182	14.53%	207	16.52%	707	56.42%	1,253
Unpaved	55	4.42%	173	13.92%	243	19.55%	231	18.58%	541	43.52%	1,243
Unknown	0	0.00%	0	0.00%	0	0.00%	2	18.18%	9	81.82%	11
Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,372**	**55.05%**	**4,309**

4.2.3.3 Type of Intersection

Table 4.4 provides the head-on crash statistics based on the roadway intersection type. The roadway intersection type notably affects crash severity. T-intersections (i.e., 3-leg) were observed to have the highest proportion of head-on fatal crashes (2.05%) compared to other types of intersections. However, the statistics revealed that more crashes occurred at non-intersection locations compared to intersection locations. Non-intersection locations include segments and midblock sections, where the higher occurrence of crashes may be attributed to higher speeds. This is because most drivers may tend to drive at higher speeds when traversing straight segments and may tend to lower their speeds when approaching intersections.

Table 4.4: Head-On Crash Statistics by Type of Intersection and Crash Severity

Type of Intersection	K		A		B		C		O		Total
	Count	%	Count	%	Count	%	Count	%	Count	%	
Four-Way Intersection	5	0.44%	44	3.89%	150	13.26%	198	17.51%	734	64.90%	1,131
T-Intersection	9	2.05%	30	6.86%	76	17.39%	71	16.24%	251	57.43%	437
Five-Point or More	0	0.00%	0	0.00%	1	33.33%	1	33.33%	1	33.33%	3
Roundabout	0	0.00%	0	0.00%	1	16.67%	0	0.00%	5	83.33%	6
Other	1	1.22%	5	6.10%	14	17.07%	20	24.39%	42	51.22%	82
Not at Intersection	124	4.68%	287	10.83%	451	17.02%	449	16.94%	1,339	50.53%	2,650
Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,372**	**55.05%**	**4,309**

4.2.3.4 Roadway Surface Condition

Table 4.5 provides the head-on crash statistics based on roadway surface condition and crash severity. The majority of head-on crashes occurred on dry surface conditions. Among these, 3.17% of total crashes that occurred on dry roadway surfaces resulted in fatalities. However, a relatively higher proportion of head-on crashes that occurred on wet surface conditions (3.65%) resulted in one or more fatalities. A total of 53.3% of crashes on wet surface conditions resulted in property damage only (PDO), while 18.75% and 17.71% resulted in non-incapacitating and possible injuries, respectively. The relatively higher percentage of fatal injury crashes during wet conditions highlights the risk that wet road surface conditions pose.

Table 4.5: Head-On Crash Statistics by Roadway Surface Condition and Crash Severity

Surface Condition	K		A		B		C		O		Total
	Count	%	Count	%	Count	%	Count	%	Count	%	
Dry	118	3.17%	324	8.70%	585	15.71%	637	17.11%	2,059	55.30%	3,723
Dirt/Gravel	0	0.00%	1	33.33%	0	0.00%	0	0.00%	2	66.67%	3
Sand	0	0.00%	3	60.00%	0	0.00%	0	0.00%	2	40.00%	5
Wet	21	3.65%	38	6.60%	108	18.75%	102	17.71%	307	53.30%	576
Unknown	0	0.00%	0	0.00%	0	0.00%	0	0.00%	2	100.00%	2
Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,372**	**55.05%**	**4,309**

4.2.3.5 Lighting Condition

Table 4.6 provides the head-on crash statistics based on lighting condition and crash severity. A significant portion of the daylight incidents were classified as PDO crashes. However, of the head-on crashes that occurred during dark conditions, a significant proportion of fatal crashes occurred in dark unlighted conditions (11.33%). Moreover, 16.56% of the head-on crashes that occurred in dark unlighted conditions resulted in serious injuries, 18.95% resulted in non-incapacitating injuries, while 35.29% resulted in property damage only. The statistics revealed that a significant portion of the crashes led to severe outcomes due to inadequate lighting conditions.

Table 4.6: Head-On Crash Statistics by Lighting Condition and Crash Severity

Roadway Lighting Condition	K		A		B		C		O		Total Count
	Count	%	Count	%	Count	%	Count	%	Count	%	
Daylight	54	1.99	213	7.85	412	15.17	421	15.51	1,615	59.48	2,715
Dark - Not Lighted	52	11.33	76	16.56	87	18.95	82	17.86	162	35.29	459
Dark - Lighted	25	2.83	58	6.57	145	16.42	181	20.50	474	53.68	883
Dark - Unknown	0	0.00	0	0.00	0	0.00	1	14.29	6	85.71	7
Dawn	4	4.82	12	14.46	14	16.87	20	24.10	33	39.76	83
Dusk	4	2.52	6	3.77	35	22.01	34	21.38	80	50.31	159
Other	0	0.00	1	33.33	0	0.00	0	0.00	2	66.67	3
Total	**139**	**3.23**	**366**	**8.49**	**693**	**16.08**	**739**	**17.15**	**2,372**	**55.05**	**4,309**

4.2.3.6 Area Type

Urban roadways have higher density and higher traffic volume and often have more extensive traffic control measures, such as traffic signs, pavement markings, and median dividers. Table 4.7 provides the head-on crash statistics by area type and crash severity. Of the head-on crashes that occurred in urban areas, 1.20% resulted in fatalities. On the other hand, a relatively higher proportion of head-on crashes that occurred on rural roadways resulted in fatalities (5.60%) and serious injuries (13.77%), compared to 1.20% and 4.0%, respectively, on urban roadways. This result be associated with higher speeds, lower enforcement, limited lighting, or complicated roadway geometry, such as sharp curves, absence of shoulders, and limited audible and vibratory treatments common in rural areas. In addition, the presence of long straight roadway stretches in rural areas, which can result in driver fatigue, may also be associated with the occurrence of severe crashes in rural areas compared to urban areas.

Table 4.7: Head-On Crash Statistics by Area Type and Crash Severity

Area	K		A		B		C		O		Total
	Count	%	Count	%	Count	%	Count	%	Count	%	
Urban	28	1.20%	93	4.00%	305	13.11%	382	16.42%	1,518	65.26%	2,326
Rural	111	5.60%	273	13.77%	388	19.57%	357	18.00%	854	43.07%	1,983
Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,372**	**55.05%**	**4,309**

4.2.3.7 Roadway Functional Classification

Functional classification categorizes roads based on their intended function and level of service. Table 4.8 summarizes the crash statistics based on roadway functional classification. U.S. roadways were observed to have the highest proportion of fatal crashes (9.58%), followed by state roads (7.41%) and Interstates (5.0%).

Table 4.8: Head-On Crashes by Roadway Functional Classification and Crash Severity

Functional Classification	K		A		B		C		O		Total
	Count	%	Count	%	Count	%	Count	%	Count	%	
Local	26	1.27%	111	5.41%	303	14.78%	349	17.02%	1,261	61.51%	2,050
County	36	3.51%	127	12.37%	194	18.89%	195	18.99%	475	46.25%	1,027
State	37	7.41%	60	12.02%	93	18.64%	80	16.03%	229	45.89%	499
U.S.	32	9.58%	53	15.87%	67	20.06%	61	18.26%	121	36.23%	334
Parking Lot	1	0.40%	4	1.61%	10	4.03%	25	10.08%	208	83.87%	248
Interstate	5	6.49%	7	9.09%	18	23.38%	12	15.58%	35	45.45%	77
Private Roadway	0	0.00%	2	3.39%	8	13.56%	13	22.03%	36	61.02%	59
Turnpike/Toll	2	25.00%	2	25.00%	0	0.00%	2	25.00%	2	25.00%	8
Other	0	0.00%	0	0.00%	0	0.00%	1	16.67%	5	83.33%	6
Unknown	0	0.00%	0	0.00%	0	0.00%	1	100.00%	0	0.00%	1
Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,372**	**55.05%**	**4,309**

4.2.3.8 Number of Lanes

Table 4.9 presents the statistics for total number of lanes (i.e., both directions) at locations where head-on crashes occurred. Roadways with two lanes had the highest proportion of fatal injury crashes (4.64%) and the relative highest proportion of serious injury crashes (11.63%). In addition, roadways with four lanes and six lanes also exhibited a high proportion of FS head-on crashes. This finding emphasizes the need for specific safety measures for multi-lane roadway facilities.

Table 4.9: Head-On Crash Statistics by Number of Lanes and Crash Severity

Number of Lanes	K		A		B		O		C		Total Count
	Count	%	Count	%	Count	%	Count	%	Count	%	
1	0	0.00%	1	25.00%	0	0.00%	0	0.00%	3	75.00%	4
2	79	4.64%	198	11.63%	302	17.73%	296	17.38%	828	48.62%	1,703
3	1	1.05%	3	3.16%	11	11.58%	20	21.05%	60	63.16%	95
4	36	2.62%	84	6.11%	194	14.11%	236	17.16%	825	60.00%	1375
5		0.00%	4	5.06%	17	21.52%	15	18.99%	43	54.43%	79
6	17	1.86%	68	7.44%	145	15.86%	149	16.30%	535	58.53%	914
7	2	3.39%	5	8.47%	10	16.95%	9	15.25%	33	55.93%	59
8	3	4.23%	2	2.82%	13	18.31%	13	18.31%	40	56.34%	71
9	0	0.00%	0	0.00%	1	20.00%	1	20.00%	3	60.00%	5
10	1	50.00%	1	50.00%	0	0.00%	0	0.00%	0	0.00%	2
Unknown	0	0.00%	0	0.00%	0	0.00%	0	0.00%	2	100.00%	2
Grand Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,372**	**55.05%**	**4,309**

Note: Number of lanes includes both directions of travel.

Fatal and serious injury crashes were also analyzed for urban and rural two-lane roadways. Of the 277 FS head-on crashes that occurred on two-lane roadways, nearly 84% occurred on rural two-lane segments, with 16% occurring on urban two-lane segments. As shown in Table 4.10, 31.47% of FS crashes on rural two-lane roadways resulted in fatalities, and 68.53% resulted in serious injury. Fewer FS head-on crashes occurred on urban two-lane roadway segments, compared to all other lane configurations.

Table 4.10: FS Head-On Crash Frequency on Urban and Rural Two-lane Roadways

Roadway Type	Injury Severity				
	K	%	A	%	Total
Rural					
Two-Lane Segments	73	31.47	159	68.53	232
Other	38	25.00	114	75.00	152
Total	111	28.91	273	71.09	384
Urban					
Two-Lane Segments	6	21.43	39	78.57	45
Other	22	41.94	54	58.06	76
Total	28	37.19	93	62.81	121

4.2.3.9 Posted Speed Limit

Table 4.11 summarizes the crash severity distribution based on the roadway's posted speed limit. As expected, crashes occurring on roadways with a higher posted speed limit were observed to have the highest percentage of fatal crashes. The highest proportion of fatal crashes was observed on roadways with speed limits at or greater than 55 mph (17.51%). Just over 10% of crashes on roadways with a posted speed limit of 50 mph resulted in fatalities. Conversely, roadways with lower speed limits (≤ 35 mph) exhibited the lowest proportion of fatal crashes at less than 1%. This trend is consistent with the expectation that higher-speed crashes result in higher kinetic energy observation. The kinetic energy associated with speed plays a pivotal role in influencing the dynamics and severity of head-on crash collisions. As speed increases, the kinetic energy of the vehicles involved rises exponentially.

Table 4.11: Head-On Crash Statistics by Posted Speed Limit and Crash Severity

Posted Speed Limit	K		A		B		C		O		Total Count
	Count	%	Count	%	Count	%	Count	%	Count	%	
≤ 35 mph	19	0.81%	107	4.56%	290	12.36%	373	15.89%	1,559	66.38%	2,348
40 mph	8	2.00%	27	6.75%	71	17.75%	83	20.75%	211	52.75%	400
45 mph	35	3.30%	127	11.98%	229	21.60%	202	19.06%	467	44.06%	1,060
50 mph	15	10.20%	37	25.17%	28	19.05%	20	13.61%	47	31.97%	147
≥ 55 mph	62	17.51%	68	19.21%	75	21.19%	61	17.23%	88	24.86%	354
Unknown	0	0.00%	0	0.00%	0	0.00%	0	0.00%	1	100.00%	1
Grand Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,373**	**55.05%**	**4,309**

4.2.3.10 Running Speed at Time of Crash

To analyze the running speeds at the time the head-on crashes occurred, vehicle speeds were approximated to the nearest 5-mph multiple. For example, a running speed of 41 mph was categorized as 40 mph, and a speed of 43 mph was categorized as 45 mph, etc. As shown in Table 4.12, the majority of head-on crashes occurred with running speeds less than 35 mph. However, the proportion of fatal crashes increased with increasing speed (from 0.41% with running speeds of ≤35 mph to 23.38% with running speeds of ≥55 mph). Similar findings were observed for serious injury head-on crashes, revealing increasing proportions from 4.10% to 24.68% with running speeds of ≤35 mph and ≥55 mph, respectively.

Table 4.12: Head-On Crash Statistics by Vehicle Running Speed and Crash Severity

Speed at the Time of Crash	K		A		B		C		O		Total Count
	Count	%	Count	%	Count	%	Count	%	Count	%	
≤35	13	0.41%	131	4.10%	418	13.09%	531	16.62%	2101	65.78%	3194
40	11	4.60%	36	15.06%	68	28.45%	48	20.08%	76	31.80%	239
45	24	5.57%	86	19.95%	111	25.75%	88	20.42%	122	28.31%	431
50	19	13.87%	37	27.01%	33	24.09%	24	17.52%	24	17.52%	137
≥55	72	23.38%	76	24.68%	63	20.45%	48	15.58%	49	15.91%	308
Grand Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,372**	**55.05%**	**4,309**

4.2.3.11 Geometric Characteristics

The following geometric characteristics were extracted from the RCI database. The analysis specifically focused on crashes that occurred on Interstate, U.S., Turnpike, State, and County roadways. This selection was made because the associated shapefiles did not contain local roads, private roadways, and other areas, such as parking lots. Of the 4,309 head-on crashes identified in this project, 1,945 crashes were retained for further examination within the context of roadway characteristics. The geometric characteristics considered in this analysis included median type, median width, AADT, and shoulder width.

Median Type

As indicated in Table 4.13, head-on crashes that occurred on roadways with vegetation medians exhibited the highest proportion of fatal (9.63%) and serious (12.30%) injury crashes, yet roadways with curbed vegetation medians were associated with lower proportions of fatal (3.42%) and serious (8.07%) injury head-on crashes. On roadways with paved medians, 4.44% of head-on crashes were fatal, and almost 12% resulted in serious injury. Less than 1% of fatal crashes occurred on roadways with raised traffic separators. No fatal head-on crashes were observed in the dataset for roadways with a two-way left-turn lane (TWLT); however, almost 10% resulted in serious injury.

Table 4.13: Head-On Crash Statistics by Median Type and Crash Severity

Median type	K		A		B		C		O		Total Count
	Count	%	Count	%	Count	%	Count	%	Count	%	
Paved	16	4.44%	43	11.94%	66	18.33%	71	19.72%	164	45.56%	360
Raised Traffic Separator	3	0.81%	24	6.47%	75	20.22%	61	16.44%	208	56.06%	371
Vegetation	18	9.63%	23	12.30%	34	18.18%	31	16.58%	81	43.32%	187
Curb & Vegetation	13	3.42%	31	8.07%	49	14.18%	52	18.83%	165	55.50%	310
Two-way Left Turn (TWLT)	0	0.00%	5	9.80%	8	15.69%	8	15.69%	30	58.82%	51
Other	2	15.38%	3	23.08%	2	15.38%	3	23.08%	3	23.08%	13
Unknown	60	9.19%	120	18.38%	138	21.13%	124	18.99%	211	32.31%	653
Total	**112**	**5.76%**	**249**	**12.80%**	**372**	**19.13%**	**350**	**17.99%**	**862**	**44.32%**	**1,945**

Median Width

Table 4.14 presents the head-on crash statistics based on median width. The median width variable was classified into six groups, in 10-ft width increments. Notably, head-on crashes that occurred on roadways with wider medians exhibited the highest percentage of fatal crashes. Specifically, roadways with 41-ft to 50-ft medians had the highest proportion of fatal (8.91%) crashes, with over 14% of crashes resulting in serious injuries. Roadways with medians exceeding 50 ft in width exhibited a slightly lower proportion of fatal head-on crashes at 8.54%. In contrast, roadways with median widths between 11-20 ft and 21-30 ft exhibited a lower proportion of fatal (approximately 3%) and serious (approximately 9.5%) injuries.

Table 4.14: Head-On Crash Statistics by Median Width and Crash Severity

Median Width (Feet)	K		A		B		C		O		Total Count
	Count	%	Count	%	Count	%	Count	%	Count	%	
1 - 10	0	0.00%	4	10.00%	9	22.50%	4	10.00%	23	57.50%	40
11 - 20	16	2.88%	52	9.35%	286	51.44%	91	16.37%	111	19.96%	556
21 - 30	12	3.08%	37	9.49%	72	18.46%	63	16.15%	206	52.82%	390
31 - 40	6	5.61%	11	10.28%	26	24.30%	14	13.08%	50	46.73%	107
41 - 50	9	8.91%	15	14.85%	20	19.80%	12	11.88%	45	44.55%	101
>50	7	8.54%	9	10.98%	16	19.51%	16	19.51%	34	41.46%	82
Unknown	62	9.27%	121	18.09%	138	20.63%	130	19.43%	218	32.59%	669
Grand Total	**112**	**5.76%**	**249**	**12.80%**	**372**	**19.13%**	**350**	**17.99%**	**862**	**44.32%**	**1,945**

Average Annual Daily Traffic (AADT)

Table 4.15 presents the distribution of head-on crashes based on roadway traffic volumes. Surprisingly, crashes occurring on roadways with lower AADT had a higher percentage of FS head-on crashes. Roadways with an AADT of 10,000 vehicles per day (vpd) or less had the highest proportion of fatal crashes, at almost 8.5%, followed closely by roadways with an AADT of 10,000 – 20,000 vpd (7.90%). Almost 4% of crashes on roadways with more than 50,000 vpd resulted in fatal crashes. This trend is also observed in crashes that resulted in serious injuries, where crashes on roadways with lower AADT volumes had higher proportions of incapacitating crashes compared to roadways with higher daily traffic. These statistics indicate that when AADT is low, which signifies less congestion, drivers may engage in unsafe driving behaviors, such as speeding, which may increase the likelihood of fatalities.

Table 4.15: Head-On Crash Statistics by AADT and Crash Severity

AADT (veh/day)	K		A		B		C		O		Total Count
	Count	%	Count	%	Count	%	Count	%	Count	%	
≤ 10,000	34	8.44%	69	17.12%	88	21.84%	76	18.86%	136	33.75%	403
10,001-20,000	38	7.90%	79	16.42%	95	19.75%	99	20.58%	170	35.34%	481
20,001-30,000	18	6.57%	23	8.39%	42	15.33%	47	17.15%	144	52.55%	274
30,001-40,000	9	4.84%	23	12.37%	39	20.97%	23	12.37%	92	49.46%	186
40,001-50,000	2	1.34%	14	9.40%	31	20.81%	24	16.11%	78	52.35%	149
> 50,000	10	3.76%	28	10.53%	51	18.28%	50	17.92%	137	49.10%	279
Unknown	1	0.54%	13	6.99%	52	19.55%	43	16.17%	133	50.00%	266
Total	**112**	**5.76%**	**249**	**12.80%**	**372**	**19.13%**	**350**	**17.99%**	**862**	**44.32%**	**1,945**

Shoulder Width

Table 4.16 presents the distribution of crashes based on shoulder width. The data was categorized into several shoulder width ranges, from 0.5 ft to greater than 12 ft. Head-on crashes that occurred on roadways with shoulder widths between 9.5 ft and 12.0 ft exhibited the highest proportions of FS crashes, at 10.06% and 18.39%, respectively. While the proportion of fatal injuries on roadways with 12-ft or greater shoulder widths was high, the number of crash occurrences was very low. Roadways with shoulder widths between 3.5 ft and 6 ft had over 8% of fatal crashes. Surprisingly, crashes occurring on roadways with shoulders less than 3 ft wide had the lowest proportion of fatal and serious head-on crashes.

Table 4.16: Head-On Crash Statistics by Shoulder Width and Crash Severity

Shoulder Width (feet)	K		A		B		C		O		Total Count
	Count	%	Count	%	Count	%	Count	%	Count	%	
0.5 - 3.0	16	2.27%	61	8.65%	123	17.45%	124	17.59%	381	54.04%	705
3.5 – 6.0	13	8.18%	20	12.58%	31	19.50%	42	19.50%	53	33.33%	159
6.5 – 9.0	10	5.38%	28	15.05%	40	21.51%	27	14.52%	81	43.55%	186
9.5 – 12.	70	10.06%	128	18.39%	150	21.55%	115	16.52%	233	33.48%	696
≥ 12.0	1	16.67%	1	16.67%	1	16.67%	1	16.67%	2	33.33%	6
Unknown	2	1.04%	11	5.70%	27	13.99%	41	21.24%	112	58.03%	193
Total	**112**	**5.76%**	**249**	**12.80%**	**372**	**19.13%**	**350**	**17.99%**	**862**	**44.32%**	**1,945**

4.2.4 Environmental Factors

4.2.4.1 Weather Conditions

Adverse weather conditions increase the likelihood of total and serious injury crashes due to the slipperiness of the roadway surface combined with a low coefficient of friction (Becker et al., 2022), visibility, and distracted/aggressive driver behavior. Rain and wet surfaces can reduce friction, increasing the risk of roadway departures. During adverse weather conditions, such as heavy rain, limited visibility causes difficulty for the driver to see the road ahead or oncoming vehicles, which may potentially lead to head-on crashes.

Pahukula et al. (2015) claim that a dry surface at the time of the crash increases the likelihood of a no-injury crash, while rain at the time of the crash reduces the likelihood of a minor injury crash. Consistent with findings by Pahukula et al. (2015), the majority of head-on crashes occurred during clear weather conditions, as shown in Table 4.17. However, adverse weather conditions exhibited a higher proportion of FS head-on crashes compared to clear weather conditions. For example, among the total number of crashes that occurred during rainy conditions, 3.47% were fatal, while of the crashes that occurred in clear weather had a 2.9% fatality proportion. This observation may be attributed to reduced visibility on roadways, making it challenging for drivers to identify hazards, accurately perceive distances, and promptly react to sudden changes, thereby increasing the risk of fatal and serious injury outcomes.

Table 4.17: Head-On Crash Statistics by Weather Conditions and Crash Severity

Weather Conditions	K		A		B		C		O		Total Count
	Count	%	Count	%	Count	%	Count	%	Count	%	
Clear	98	2.89%	284	8.38%	530	15.64%	565	16.67%	1,912	56.42%	3,389
Cloudy	24	4.86%	58	11.74%	83	16.80%	90	18.22%	239	48.38%	494
Rain	14	3.47%	21	5.20%	75	18.56%	80	19.80%	214	52.97%	404
Fog, Smog	3	14.29%	3	14.29%	5	23.81%	4	19.05%	6	28.57%	21
Other	0	0.00%	0	0.00%	0	0.00%	0	0.00%	1	100.00%	1
Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,372**	**55.05%**	**4,309**

4.2.4.2 Time of the Day

Table 4.18 presents the crash distribution based on the time of the day. Late-night periods between midnight and 3:59 AM exhibited the highest proportion of fatal head-on crashes at almost 9%. This was followed by the time period between 4:00 AM and 8:00 AM, which had over 5% of fatal crashes. The combination of reduced visibility, potential drowsiness and fatigue among drivers, and lower traffic volumes may contribute to the elevated risk during these early hours. On the other hand, during evening hours, a lower proportion of fatal crashes was observed.

Table 4.18: Head-On Crash Statistics by Time of the Day and Crash Severity

Time of the Day	K		A		B		C		O		Total
	Count	%	Count	%	Count	%	Count	%	Count	%	
0:00-3:59 AM	25	8.90%	30	10.68%	123	43.77%	63	22.42%	40	14.23%	281
4:00-7:59 AM	20	5.28%	45	11.87%	190	50.13%	54	14.25%	70	18.47%	379
8:00-11:59 AM	19	2.96%	58	9.03%	369	57.48%	99	15.42%	97	15.11%	642
12:00-03:59 PM	20	1.87%	88	8.23%	639	59.78%	146	13.66%	176	16.46%	1,069
04:00-7:59 PM	22	1.79%	78	6.34%	713	57.92%	209	16.98%	209	16.98%	1,231
8:00-11:59 PM	33	4.67%	67	9.48%	338	47.81%	122	17.26%	147	20.79%	707
Total	**139**	**3.23%**	**366**	**8.49%**	**693**	**16.08%**	**739**	**17.15%**	**2,372**	**55.05%**	**4,309**

4.2.5 Driver Characteristics and Behavior

Table 4.19 provides the distribution of head-on crashes based on driver characteristics and behavior. Three driver characteristics were considered: driver's age, gender, and whether the driver was driving under the influence (DUI) of drugs or alcohol. In relation to driver's age, among the crashes involving older drivers (50+ years of age), almost 2% were fatal. Crashes that involved drivers under the age of 25 years had a 1.5% fatality proportion. Crashes involving impaired drivers exhibited a higher percentage of fatal crashes (13%) compared to those where the driver was not impaired, and crashes involving male drivers had almost a 2% fatality proportion.

4.2.6 Vehicle Characteristics

Table 4.20 shows the head-on crash statistics based on vehicle types and injury severity. Crashes involving motorcycles had the highest fatality proportion (12%) compared to other vehicle types. This was followed by commercial vehicles, which had a 2% fatality rate. The proportion of fatal crashes for passenger cars was 1.54%.

Table 4.19: Head-On Crash Statistics by Driver Demographics and Crash Severity

Variables	Description	K		A		B		C		O		Non-Fatality Injury		Unknown		Total Count
		Count	%	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%	
Age	< 25 years	27	1.51%	117	6.55%	204	11.43%	252	14.12%	1,184	66.33%	0	0.00%	1	0.06%	1,785
	25 – 50 years	62	1.57%	235	5.96%	451	11.44%	560	14.20%	2,635	66.83%	0	0.00%	0	0.00%	3,943
	> 50 years	51	1.91%	166	6.21%	306	11.44%	375	14.02%	1,771	66.21%	3	0.11%	3	0.11%	2,675
Gender	Male	93	1.86%	311	6.22%	539	10.78%	662	13.23%	3,385	67.67%	2	0.04%	10	0.20%	5,002
	Female	47	1.37%	207	6.03%	422	12.29%	533	15.52%	2,220	64.63%	1	0.03%	5	0.15%	3,435
	Unknown	0	0.00%	0	0.00%	1	0.26%	12	3.10%	75	19.38%	0	0.00%	299	77.26%	387
DUI	No	74	0.89%	453	5.44%	898	10.79%	1,137	13.66%	5,444	65.41%	3	0.04%	314	3.77%	8,323
	Yes	66	13.17%	65	12.97%	64	12.77%	70	13.97%	236	47.11%	0	0.00%	0	0.00%	501

Table 4.20: Head-On Crash Statistics by Vehicle Characteristics and Crash Severity

Vehicle Type	K		A		B		C		O		Non-Fatality Injury		Unknown		Total Count
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%	
Passenger Cars	106	1.54%	393	5.72%	782	11.37%	989	14.38%	4,551	66.19%	1	0.01%	54	0.79%	6,876
Commercial Vehicles	20	1.57%	85	6.67%	127	9.97%	167	13.11%	857	67.27%	2	0.16%	16	1.26%	1,274
Medium/Heavy Trucks	0	0.00%	4	2.72%	15	10.20%	15	10.20%	113	76.87%	0	0.00%	0	0.00%	147
Motorcycle	13	11.93%	26	23.85%	27	24.77%	12	11.01%	28	25.69%	0	0.00%	3	2.75%	109
Bus	0	0.00%	0	0.00%	1	4.17%	4	16.67%	18	75.00%	0	0.00%	1	4.17%	24
Moped	0	0.00%	3	20.00%	3	20.00%	5	33.33%	4	26.67%	0	0.00%	0	0.00%	15
Motor Home	0	0.00%	0	0.00%	0	0.00%	0	0.00%	1	100.00%	0	0.00%	0	0.00%	1
Other	1	0.29%	7	2.03%	7	2.03%	13	3.77%	93	26.96%	0	0.00%	224	64.93%	345
Unknown	0	0.00%	0	0.00%	0	0.00%	2	6.06%	15	45.45%	0	0.00%	16	48.48%	33
Grand Total	**140**	**1.59%**	**518**	**5.87%**	**962**	**10.90%**	**1,207**	**13.68%**	**5,680**	**64.37%**	**3**	**0.03%**	**314**	**3.56%**	**8,824**

4.3 Police Reports

This section discusses the emerging trends and patterns of head-on crashes in District 7 derived from an in-depth examination of police crash reports. The goal of the analysis was to identify commonalities and contributing factors of head-on crashes resulting in fatalities and serious injuries.

Figures 4.3 and 4.4 illustrate the distribution of crashes across the five counties in District 7, categorized by crash severity. As shown in Figure 4.3, Hillsborough County had the highest number of fatal head-on crashes, while Pasco County had the highest number of serious injury head-on crashes (see Figure 4.4).

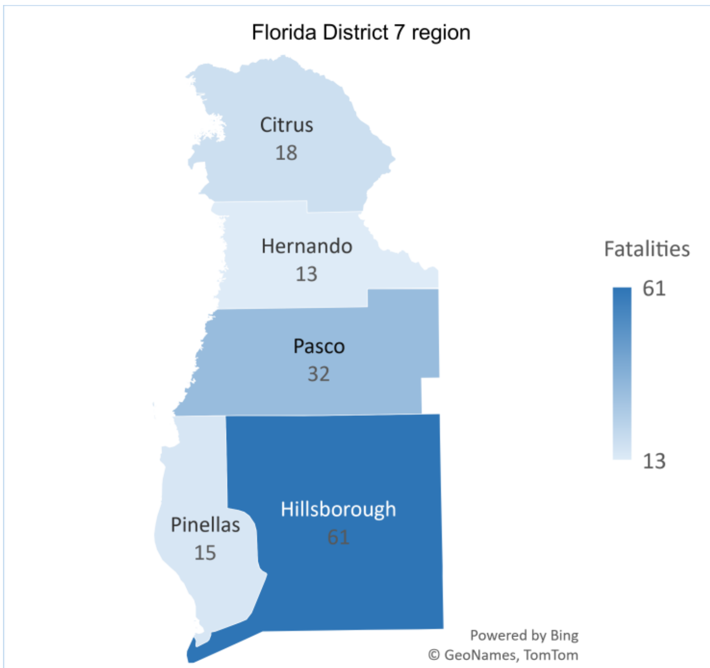


Figure 4.3: Fatal Head-On Crashes by District 7 County

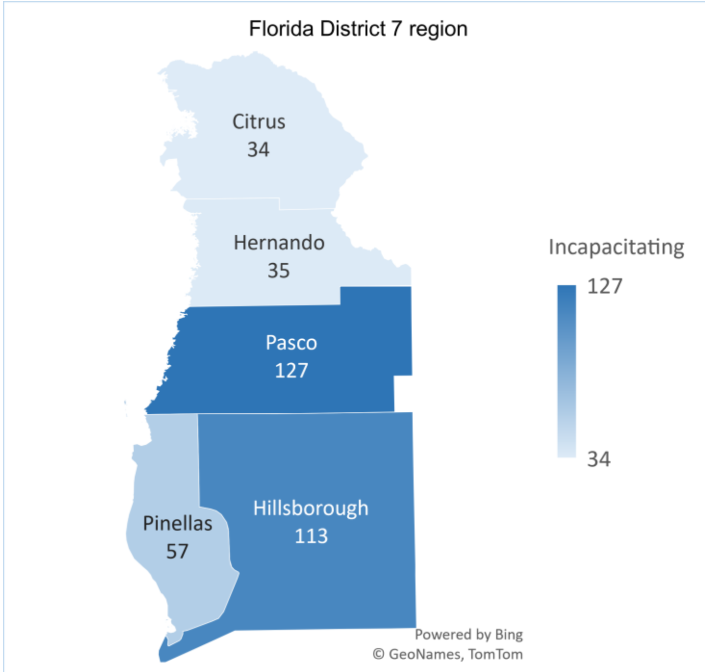


Figure 4.4: Serious Injury Head-On Crashes by District 7 County

4.3.1 Police Report Review

This section discusses the review of police reports generated on FS head-on crashes in District 7. Police reports provide valuable information about the circumstances, contributing factors, and other information related to a crash. Examining these reports is vital for crash analysis, allowing insights to be gained to better understand the root causes of crash types, identify trends and patterns, and pinpoint locations or conditions prone to safety issues. This knowledge is needed for developing targeted safety measures, optimizing road infrastructure, and formulating evidence-based policies aimed at reducing the frequency and severity of traffic crashes.

Police reports for 505 head-on crashes resulting in fatal and serious injuries from 2018–2022 were extracted. Table 4.21 lists the number of head-on crashes by county in District 7. Each crash report was reviewed to better understand the details related to different scenarios and the vehicle/driver maneuvers leading up to the crash. Three head-on crash scenarios describing actual crash incidents documented in the crash reports are presented in the following subsections.

Table 4.21: Fatal and Serious Injury Head-On Crashes by District 7 County

County	**Count**
Citrus	51
Hernando	49
Hillsborough	174
Pasco	159
Pinellas	72
Total head-on crashes	**505**

4.3.1.1 Scenario 1: Crash Involving At-fault Driver on a Straight Roadway Segment.

Figure 4.5 provides an illustration of a fatal head-on crash that occurred on a straight road. In this collision, vehicle 3 (V3) was the leading vehicle in the sequence, followed by vehicle 1 (V1). V1 attempted to overtake V3, but in doing so, failed to observe the presence of vehicle 2 (V2), resulting in a direct fatal head-on collision between V1 and V2. This incident occurred during the morning hours, a period when visibility and traffic conditions should typically be favorable. The primary motivating factor for the overtaking maneuver most likely may have been the need to save time or to reach a destination quickly.

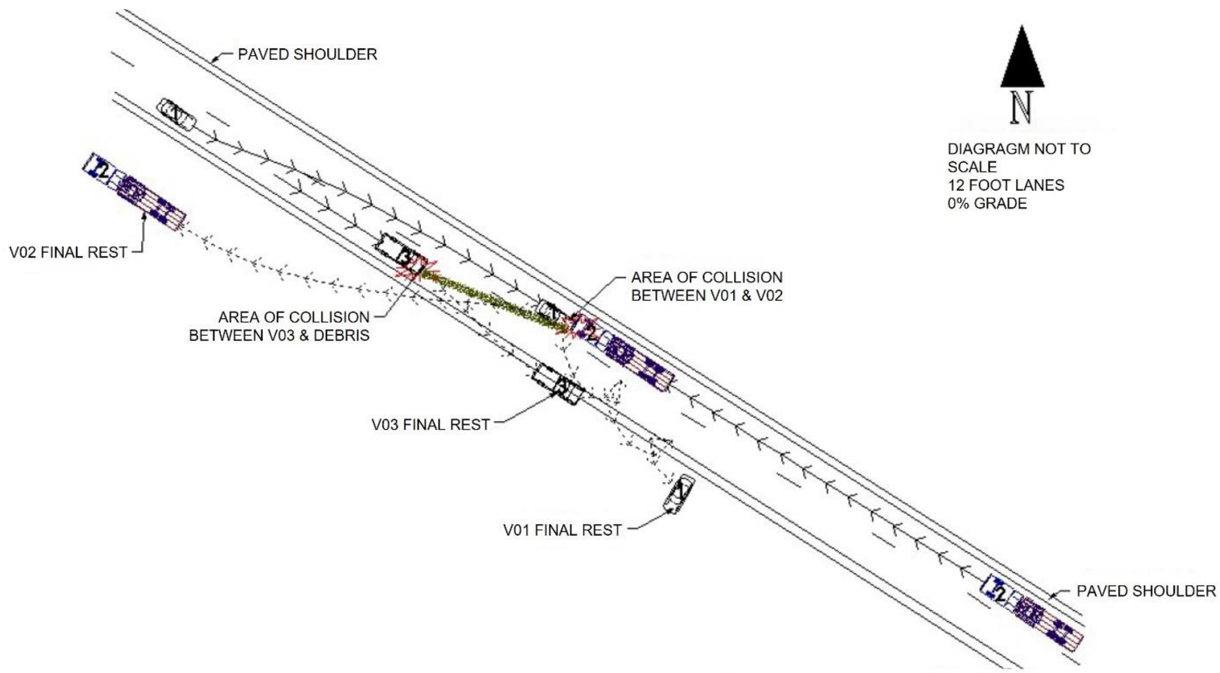


Figure 4.5: Head-On Crash Scenario 1

Site conditions at this crash site consisted of a double solid yellow centerline pavement marking, indicating a no-passing zone, and warning signs emphasizing the restriction against entering this zone were in place. In this context, the primary contributing factors to the crash are related to driver behavior and decision to pass, rather than the existing roadway characteristics.

4.3.1.2 Scenario 2: Crash at Stop-Controlled Intersection

Figure 4.6 provides an illustration of a fatal head-on crash that occurred at a stop-controlled intersection. The intersection does not have dedicated left or right turn lanes at either approach. The crash narrative and the illustrative sketch, as shown in Figure 4.6, indicates that the driver of the vehicle (V01) failed to remain within their designated eastbound lane and entered the westbound lane of the roadway at the intersection, resulting in a crash with V02. The crash database assigns this as "Law Enforcement," but does not state the sequences of events, such as "driver 1 failed to travel within a single lane," which indicates that driver 1 may have been distracted.

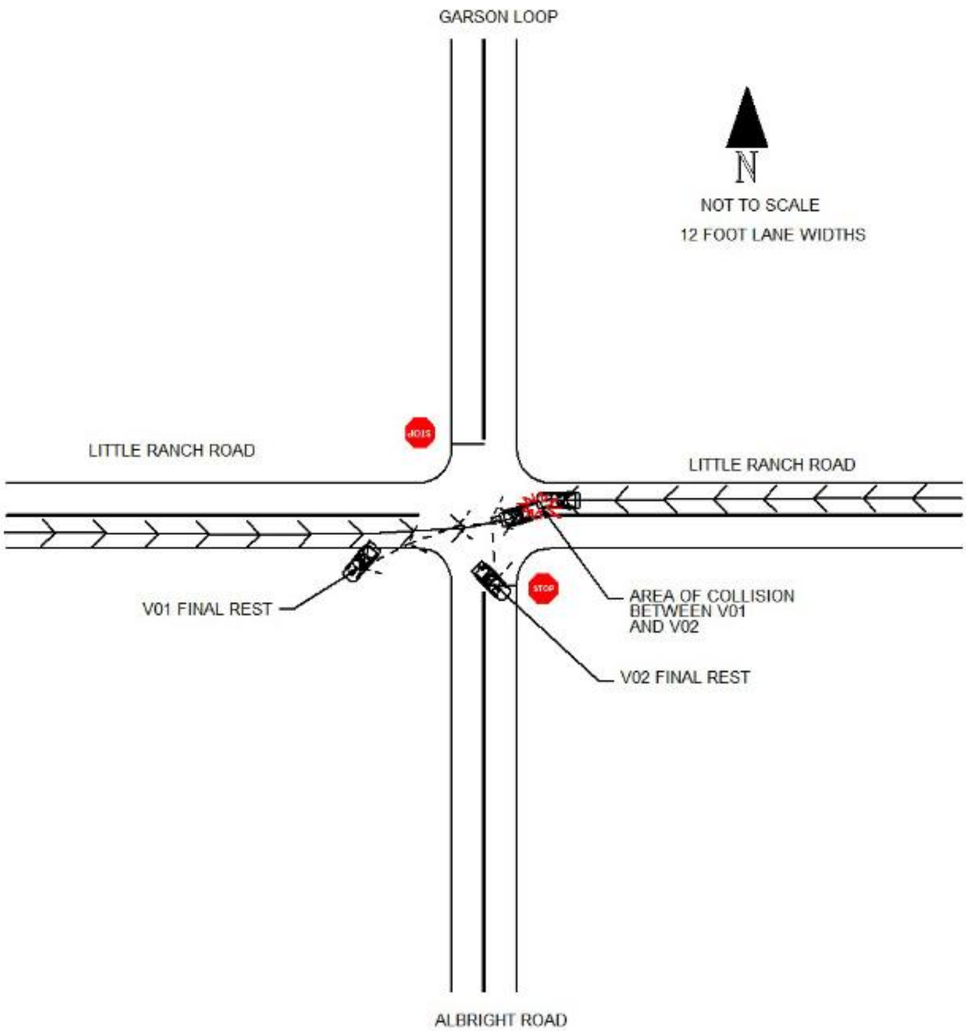


Figure 4.6: Head-On Crash Scenario 2

4.3.1.3 Scenario 3: Crash on a Horizontal Curve

Figure 4.7 provides an illustration of a fatal head-on crash that occurred on a horizontal curve. In this crash, V1 was traveling in the westbound direction, and V2 was traveling in the eastbound direction and was negotiating a right curve. V1 failed to accurately negotiate the curve and traveled into the opposing lane of traffic as V2 approached, resulting in a head-on collision. Per the crash report, the V1 driver stated that there were potholes on the road, which made the car veer six feet into the opposing lane, and was not attempting to take the curve too sharp.

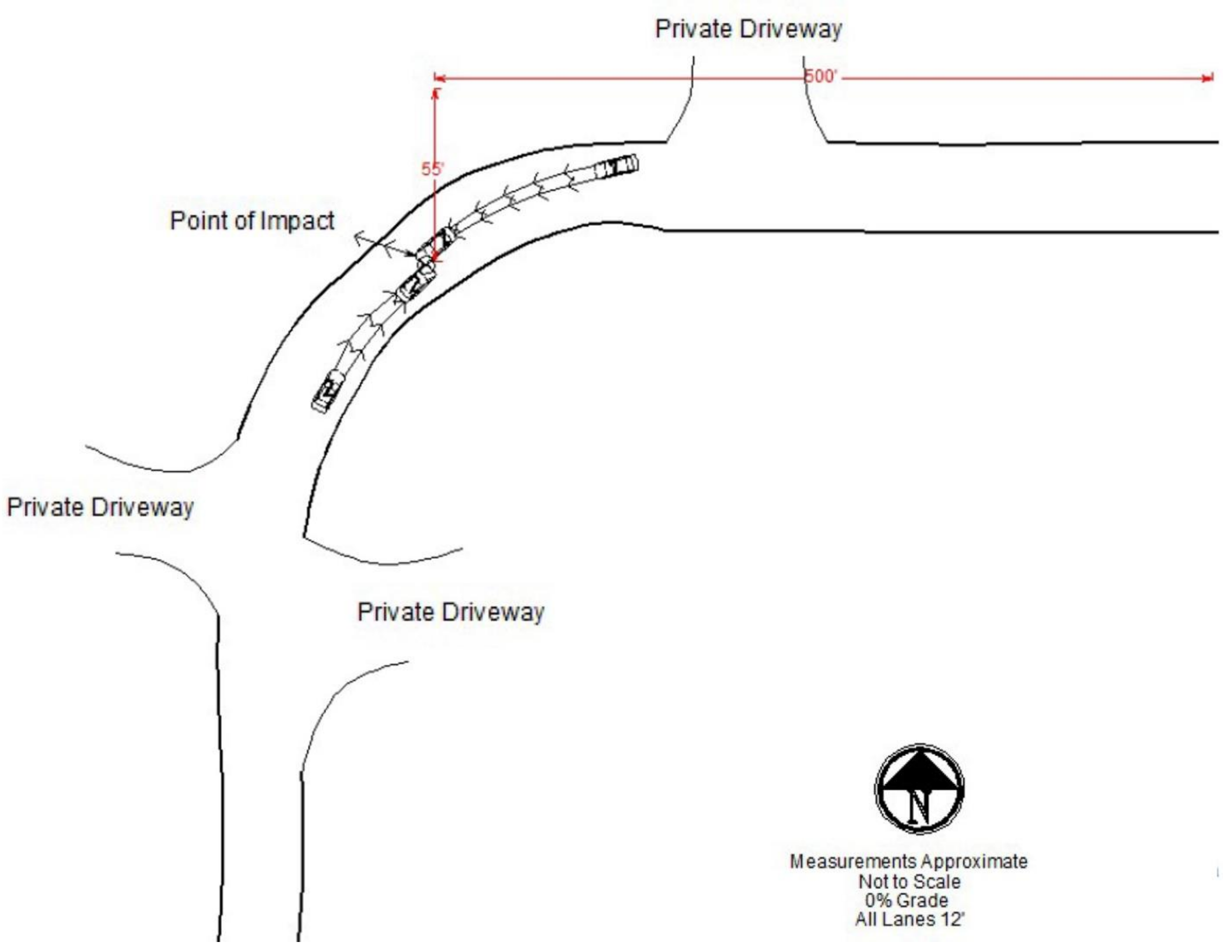


Figure 4.7: Head-On Crash Scenario 3

4.3.2 Site Evaluation

A site-specific evaluation was conducted for each of the 505 FS head-on crashes reviewed. Of the 505 crashes, 139 resulted in fatalities and 366 resulted in serious injuries. This manual evaluation process assisted in gathering valuable insights and information from each crash site. The objective was to identify factors and underlying reasons contributing to the occurrence of the crashes, and to evaluate the site-specific conditions around locations where both fatal and serious injury crashes occurred.

As shown in Table 4.22, the analysis revealed that the majority of fatal head-on crashes (88.5%) and serious injury crashes (94%) occurred on straight roadway segments. Fewer head-on crashes occurred on horizontal curves, with 11.5% (16 out of 139 fatal crashes) resulting in fatalities and 5.7% (21 out of 366 serious injury crashes) resulting in serious injuries. In addition, 16 locations did not contain curve warning signs.

Nearly 39% of the fatal head-on crashes occurred on roadways with double yellow centerline markings. In addition, of the 366 serious injury head-on crashes, 148 crashes (40.4%) occurred on roadways with double yellow centerline markings. Furthermore, the majority of crashes occurred on roadways with no rumble strips present. Few fatal head-on crashes (4.3%) and serious injury crashes (9.3%) occurred on 2-lane roadways with centerline markings permitting passing from one side. Although the majority of fatal and serious injury crashes occurred on roadways without physical barriers, such as guard rails or concrete barriers, 24 fatal crashes (17.3%) occurred in areas where physical barriers were present.

A sizable proportion (65.5%) of the 139 fatal crashes, precisely 91 crashes, occurred at locations with reflective pavement markers (RPMs). However, the remaining 48 crash locations revealed a more detailed breakdown, where 30 crashes occurred at nighttime on the roadways without RPMs. Specifically, among these 30 locations, 20 were characterized by the absence of RPMs and low-light road conditions (Dark - Not Lighted). This observation highlights that the primary factor contributing to these crashes was likely "reduced roadway visibility," a concern that could be effectively addressed through roadway improvement measures.

Table 4.22: Fatal and Serious Injury Head-On Crashes by Site Condition

Factor	Variable	Fatal Crashes	Serious Injury Crashes
Horizontal Curve	At Tangent Section	123	345
	At Horizontal curve	16	21
Type of Center Lane Marking	Broken White Line	15	18
	Broken Yellow Line	25	45
	Double Solid White Line		0
	Double Solid Yellow Line	54	148
	Solid White Line	4	7
	Solid Yellow line	29	75
	Center turn lanes	6	18
	Two-way Road with passing permitted from one side	6	34
	No Marking		18
	Dotted White Line		3
Types of Barriers Present	Cable Barriers	1	1
	Concrete Barriers	22	56
	Metal-beam Guardrails	1	3
	None	115	306
Center Line Reflective Pavement Markers	No	48	229
	Yes	91	137
Presence of Guardrails	Left	4	5
	Median	4	5
	Right	3	1
	No	127	355
Rumble Strips	Yes	9	7
	No	128	359

Appendix A provides a street-level analysis of the FS head-on crashes that occurred in each District 7 county during the study period (2018–2022). In the street-level analysis, head-on crash events were categorized by the roadway on which the crash occurred to identify potential crash patterns. This analysis is beneficial for providing an at-a-glance overview of where head-on crashes have occurred. Tables A.1 – A.5 lists the roadway names and corresponding crash counts for Citrus, Hernando, Hillsborough, Pasco, and Pinellas Counties, respectively.

Key findings include:

- Citrus County: Roadways with the highest number of FS head-on crashes include: County Road 495, State Road 44, and U.S. Highway 41 (see Table A.1).

- Hernando County: Roadways with the highest number of FS head-on crashes include: Mariner Blvd. and State Road 50 (Cortez Blvd.) (see Table A.2).

- Hillsborough County: Roadways with the highest number of FS head-on crashes include: Patterson Road, S West Shore Blvd., State Road 60, U.S. 301 (S.R. 43), and W Columbus Drive (see Table A.3).

- Pasco County: Roadways with the highest number of FS head-on crashes include: State Road 52 and State Road 54 (see Table A.4).

- Pinellas County: Roadways with the highest number of FS head-on crashes include: 22nd Ave S and U.S. Highway 19 N (see Table A.5).

4.4 Head-On Crash Hot Spots

This section discusses the unit of analysis and the data variables (explanatory and response) used to identify head-on crash hot spots within each District 7 county. The five most recent years (2018–2022) of crash data were used in the analysis. Census block groups (CBGs) were used as the main analytical unit, and various elements and characteristics relevant to the analysis were included in the data variables used in this study to locate the hot spots.

As shown in Table 4:23, crash data used in the analysis were obtained from Signal4 Analytics. During the 5-year study period, 450,464 roadway crashes occurred in District 7, and about 1% were head-on crashes. A total of 4,309 head-on crashes were analyzed, specifically selected based on the availability of crash locations, represented by latitude and longitude coordinates.

Table 4.23: Crash Data Analyzed

Data Variable	Attributes	Data Source
Crash Data	• Crash type • Crash Severity • Driver Characteristics • Vehicle Factors • Environmental Conditions	Signal4 Analytics

The objective of the analysis was to develop systemic procedures to proactively implement head-on crash remediation measures in FDOT District 7. Geographical Information Systems (GIS) in crash analysis is a potential analysis and decision-making tool for different transportation purposes. GIS can manage tremendous amounts of data and perform simple to complex spatial analyses. It can also analyze data from different sources. In addition, GIS can be flexible in modeling the cluster of crash data and geographical data to obtain distinct evidence of the causes of high crash rates and their respective locations.

4.4.1 Hot Spot Analysis for Head-On Crashes

An optimized hot spot analysis tool in ArcGIS mapping and analytics software was used to identify and prioritize target regions. This analysis method allows for identifying specific locations or zones where the occurrence of head-on crashes is notably higher, which enables a focused approach to address and mitigate these types of crashes.

4.4.1.1 Optimized Hot Spot Analysis (OHSA)

OHSA is an advanced approach that enhances the ESRI hot spot analysis tool "Getis-Ord Gi*" by automatically configuring the tool's parameters based on the characteristics of the input data (ArcGIS, n.d.). OHSA starts by aggregating point data into weighted features and then analyzes their distribution to determine the most suitable scale for the analysis. This tool is particularly effective at identifying statistically significant spatial clusters, such as hot spots with high values and cold spots with low values (ArcGIS, n.d.). It streamlines the process of pinpointing areas of particular interest in the data while maintaining statistical rigor. The OHSA was conducted using the spatial statistics tools in ArcGIS v10.6, and the following fields were specified during the analysis: input features and an analysis field.

4.4.1.2 Input Features

The input feature includes the input data set, a point feature class for which hot spot analysis will be performed. This research used the polygon feature of crashes as the input feature. These polygons consisted of response variables (total head-on crashes per year per mile of roadway network within District 7). A detailed explanation of how the crashes are assigned to the CGBs and the extraction of roadway mileage within the CGBs is discussed in Section 4.4.2.

4.4.1.3 Analysis Field

Utilizing polygon features as input data necessitates the inclusion of an analysis field, a numeric attribute used for assessing and identifying hot spots. This approach is useful and applicable to various data types, including points, polygons, and even sampled data, while maintaining high accuracy and reliability in the results generated (ArcGIS, n.d.). The selected analysis field is pivotal in pinpointing locations characterized by high and low cluster patterns. In this research, the rate of head-on crashes served as the designated analysis field, enabling the identification of hot spots to enhance the understanding of crash trends.

4.4.2 Steps for Identifying Target Regions

This section explains the steps adopted in identifying target regions.

4.4.2.1 Obtain the Number of Crashes

In this step, five years of crash data were obtained from Signal4 Analytics. Signal4 Analytics data include the latitudes and longitudes of crashes. Crash shape files were generated by importing head-on crashes as csv files into ArcGIS and exporting them as shapefiles. Crash shapefiles were spatially joined to FDOT District 7 CBGs to assign crashes to each CBG. Figure 4.8 demonstrates how to assign crashes into CBGs using ArcGIS.

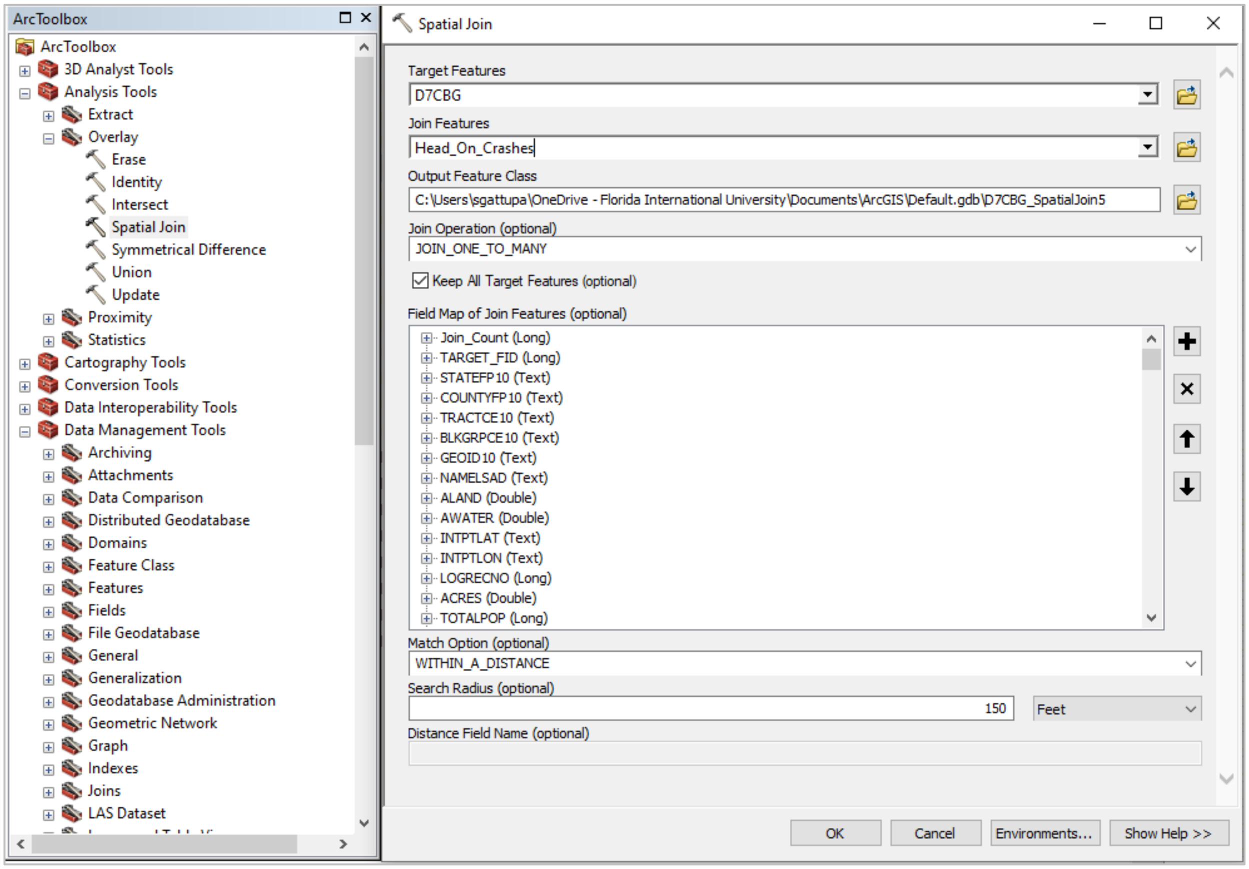


Figure 4.8: Assigning Crashes to CBGs in ArcGIS

After obtaining the results in the attribute table, they were exported as a .dbf file, which can then be converted into an Excel® file (.xlsx). The Excel® pivot table was used to calculate the total number of crashes for analysis.

4.4.2.2 Extract Roadway Miles within CBGs

The process of extracting roadway mileage within the CBGs comprises three additional sub-steps: (a) creating separate shapefiles for each CBG, (b) extracting the roadway mileage within each CBG, and (c) calculating the crash rate to obtain the total crashes per mile.

Generate Individual Shapefiles

The FDOT District 7 census block shapefile includes the data for 2,105 CBGs. Figure 4.9 illustrates the splitting process. The Split function was used to split 2,105 CBGs into 2,105 shapefiles.

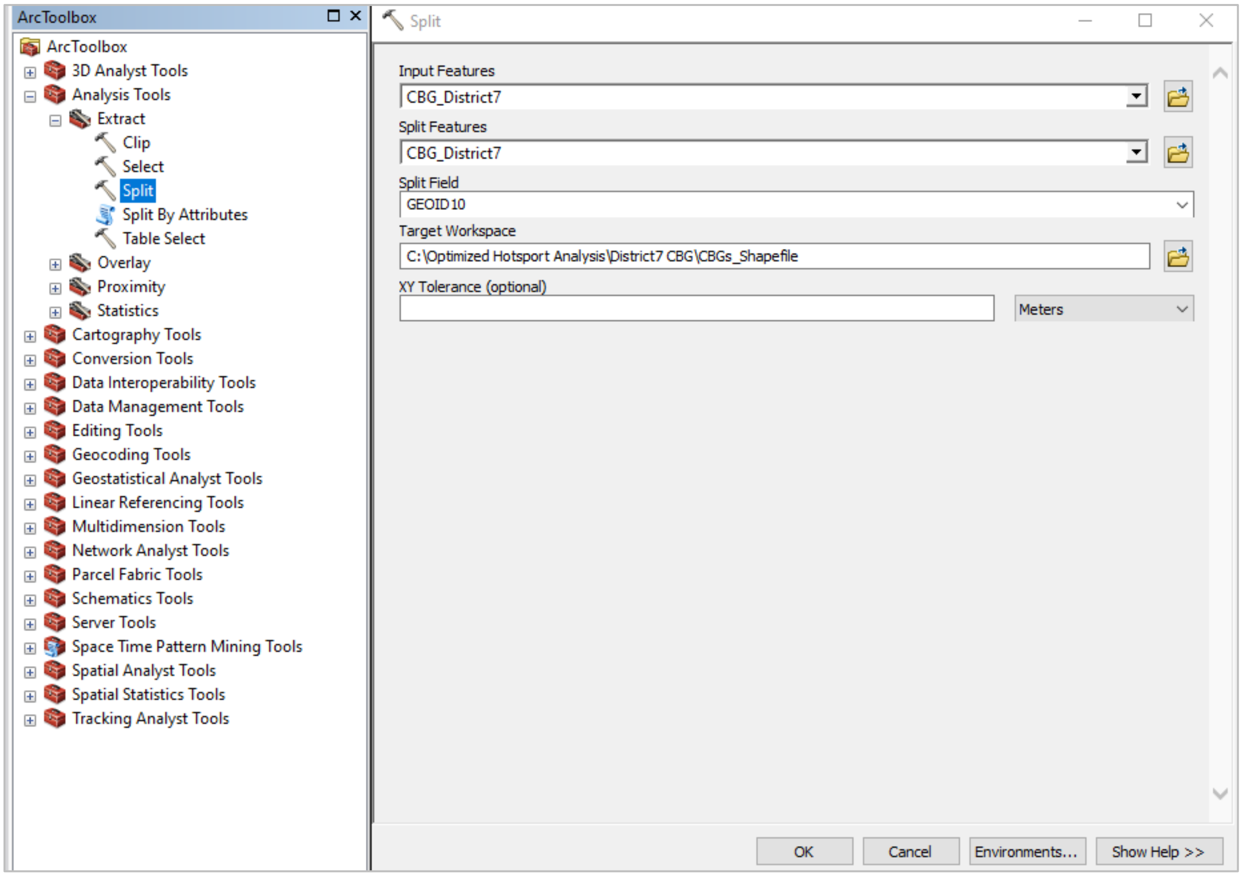


Figure 4.9: Creating Separate Shapefiles in ArcGIS

Extract Roadway Miles within Each CBG

Model Builder was employed to construct a model for generating a graphical buffer, cropping roadways within CBGs, and calculating the total mileage of roadways within each CBG. Figure 4.10 shows the process used for extracting roadway mileage.

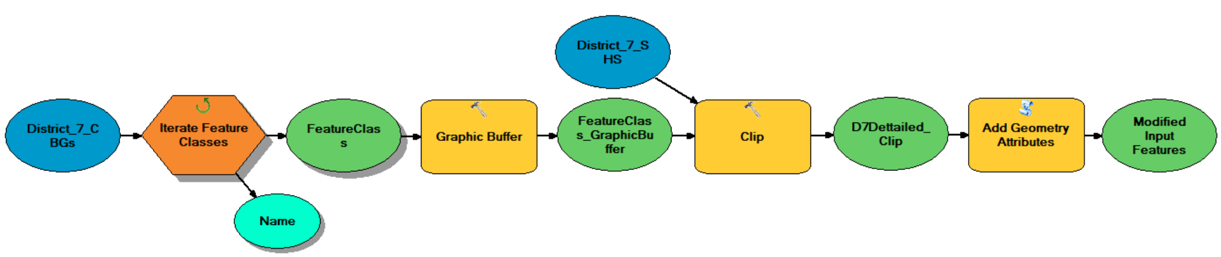


Figure 4.10: Methodology Used for Roadway Mileage Extraction

Model Setup

The model iterates through all CBGs. This recursive option ensures that all feature classes within the specified workspace are included. The process involves two main components: creating a graphic buffer and clipping the roadways. For the graphical buffer, the CBG Unique ID is used as the input feature and specified with a 150-ft buffer to ensure overlap into adjacent CBGs. The buffered CBGs are input, and the roadways are clip features in the clipping process. Through this process, the roadways acting as boundaries are appropriately accounted for by distributing them across multiple CBGs (i.e., shared between the CBGs) to represent roadway miles more accurately.

The 150-ft buffer mitigates the issue of roadways acting as boundaries between CBGs. By overlapping into multiple CBGs, the buffer ensures that crash data is not confined to a single block group, but is shared among neighboring groups based on geographical proximity. This approach minimizes the risk of skewed data concentration and allows for a more distributed and accurate representation of crash locations, considering the influence of significant roadways that cross block group boundaries.

Crash Rate

To obtain crashes per mile, the crashes per mile metric was calculated by dividing the total number of crashes within each CBG by the corresponding total mileage within those CBGs. The crash rate is calculated as the quotient of the crash frequency within a given period and geographic area of CBGs divided by the product of the total miles and the duration in years, in this case five years. Equation 4.1shows the formula for crash rate used in the analysis.

$$Crash\ Rate = \frac{Crash\ Frequency}{Total\ Miles * 5} \tag{4.1}$$

4.4.2.3 Perform Optimized Hot Spot Analysis (OHSA)

Crashes per mile were used as an analysis field to perform the OHSA. This accounts for the density of crashes related to the roadway network, which allows identifying the locations with high-risk areas within the study region and enabling a more accurate identification of high-risk areas. Figure 4.11 illustrates the inputs used to perform the OHSA.

The *Select by Attributes* tool was used for selecting the target areas (i.e., hot spots). As shown in Figure 4.12, "Gi-Bin = 3" was chosen because it targets hot spots at a 99% confidence level, focusing on head-on crashes.

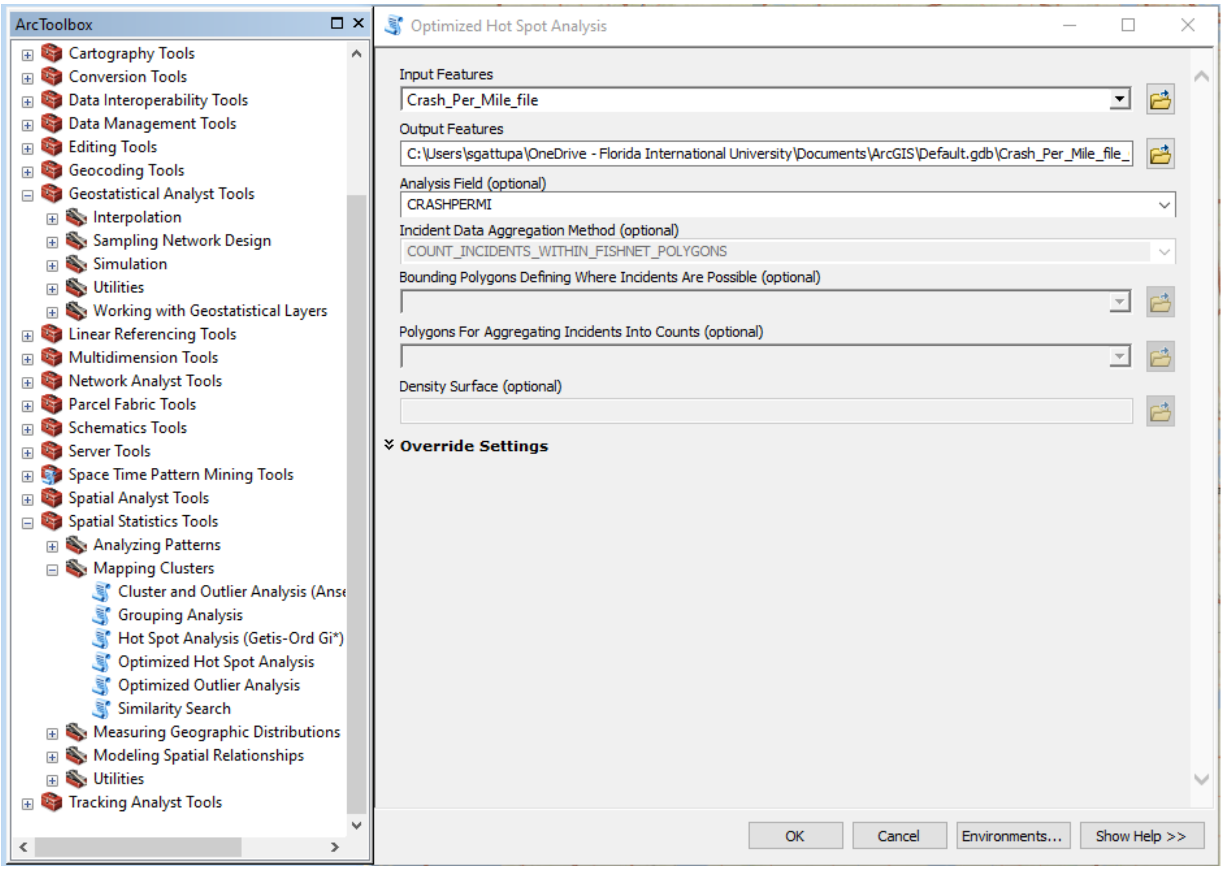


Figure 4.11: Optimized Hot Spot Analysis (OHSA) for Head-on Crashes

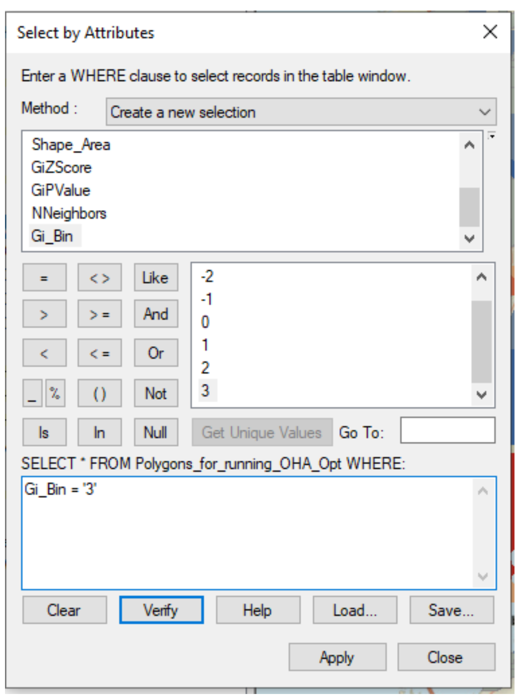


Figure 4.12: Selection of Target Regions

4.4.3 Results

The identification of hot spot locations was conducted by analyzing the Gi_bin values from the OHSA attribute table. These Gi_bin values range from -3 to 3. Negative values (-1, -2, -3) indicate cold spots and positive values (1, 2, 3) indicate hot spots, where ±1 is a 90% confidence interval, ± 2 is a 95% confidence interval, and ± 3 is a 99% confidence interval. Through this analysis, 854 CBG locations were found to be statistically significant, of which 215 CGBs were identified as hot spots with a 99% confidence interval.

Hot spots are areas with a high concentration of head-on crashes, while cold spots have a low concentration of head-on crashes. Cold spots are identified by a statistically significant concentration of low values, indicating fewer head-on crashes. These are marked by negative Gi_bin values (-1, -2, -3), with confidence intervals of 90%, 95%, 99%, respectively. Hot spots are areas where there is a statistically significant concentration of high values, in this context, a high head-on crash rate. These locations are marked by positive Gi_bin values (1, 2, 3), with higher values indicating greater statistical confidence (i.e., +1 for a 90% confidence interval, +2 for a 95% confidence interval, and +3 for a 99% confidence interval). As shown in Figure 4.13, all of the identified hot spots are located in Hillsborough County. Table 4.24 lists the cities in Hillsborough County identified as hot spots. A total of 215 CBGs in Hillsborough County were identified as hot spots.

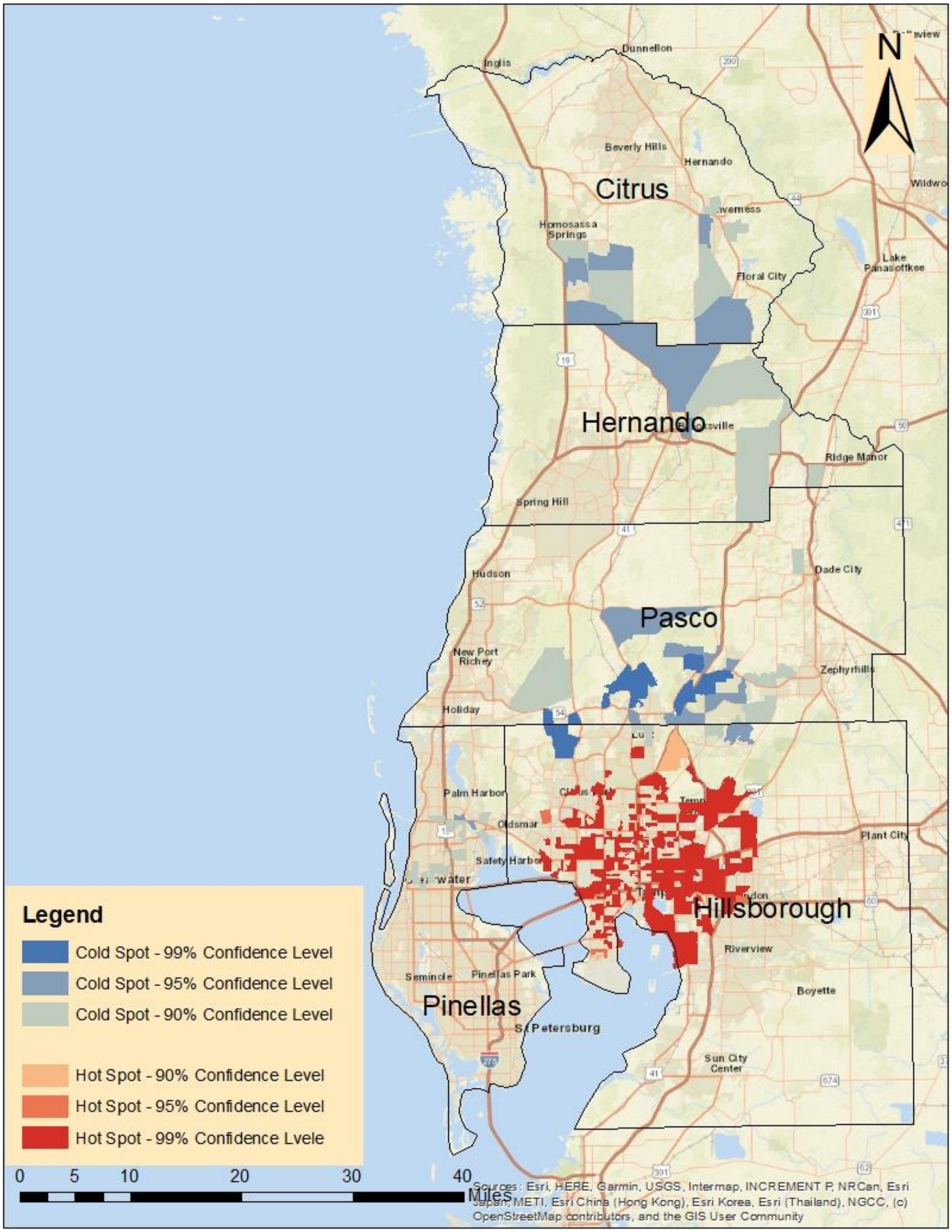


Figure 4.13: District 7 Head-On Crash Hot Spots

Table 4.24: Identified Hot Spot Locations

County Name	Hot Spot City	Total CBGs	Confidence Interval
Hillsborough	Brandon	215	99%
	Carrollwood		
	Citrus Park		
	Clair-Mel City		
	Egypt Lake-Leto		
	Gibsonton		
	Greater Northdale		
	Lake Magdalene		
	Lutz		
	Palm River-Clair Mel		
	Riverview		
	Seffner		
	Tampa		
	Temple Terrace		
	Thonotosassa		
	Town 'N' County		

Note: CBG = Census Block Group.

4.5 Chapter Summary

This chapter discussed the causes and patterns of head-on crashes in District 7. Crash data for the five most recent years (2018–2022) was used to perform the crash analyses. A total of 4,309 head-on crashes within the five-year study period were analyzed. Crash analyses performed include descriptive statistics, review of police reports, and a spatial analysis.

Descriptive statistics were performed to determine contributing factors of head-on crashes in District 7, and factors associated with crashes related to:

- Roadway characteristics
- Environmental characteristics
- Vehicle characteristics
- Driver characteristics

Key findings from the descriptive statistics analysis include:

- The proportion of DUI related crashes that were fatal was 13.17%.
- The proportion of motorcycle crashes that resulted in fatalities was 11.93%.
- The highest proportion of fatal crashes occurred between midnight and 4:00 AM (9%).
- Nearly 3% of fatal head-on crashes occurred during clear conditions; however, adverse weather conditions, especially rain and fog, increased the likelihood of fatalities.
- Almost 10% of head-on crashes on roadways with vegetation medians resulted in a fatality.
- Higher speed roadways were associated with an increased likelihood of fatal head-on crashes.

- Rural areas were observed to have a higher fatality proportion (5.6%) than urban areas (1.2%).
- Of the total fatal and serious injury head-on crashes on two-lane roadways, nearly 84% occurred on rural two-lane segments, and 16% occurred on urban two-lane segments.
- Crashes that occurred in dark unlighted conditions exhibited the highest proportion of fatal head-on crashes.

Of the 4,309 head-on crashes that occurred in District 7 during the study period, 505 police reports were obtained and reviewed for head-on crashes that resulted in fatal and serious injuries to determine crash patterns. Of the 505 crashes, 139 resulted in fatalities and 366 resulted in serious injuries. Three head-on crash scenarios were discussed: a crash involving an at-fault driver on a straight roadway segment, a crash at a stop-controlled intersection, and a crash on a horizontal curve.

Site evaluations were conducted for each of the 505 head-on crashes to identify roadway factors associated with fatal and serious injury crashes. Key findings include:

- The majority of fatal head-on crashes (88.5%) and serious injury crashes (94%) occurred on straight roadway segments.
- The majority of FS head-on crashes occurred on roadways with no physical barriers, such as guard rails or concrete barriers.
- Nearly 39% of fatal and 40% of serious injury head-on crashes occurred on roadways with double yellow centerline markings.
- Over 65% of fatal head-on crashes occurred at locations with reflective pavement markers (RPMs). At locations without RPMs, the primary factor contributing to fatal and serious injury head-on crashes was likely "reduced roadway visibility."

A spatial analysis, combining the crash data and roadway characteristics, was performed to identify high-risk locations (i.e., hot spots) in District 7. Using GIS techniques, spatial correlations between crashes and relevant road attributes were examined to identify areas where head-on crashes were clustered. Hot spot locations were identified using the Optimized Hot Spot Analysis approach. Results revealed 854 census block group locations to be statistically significant, of which 215 were hot spots with a 99% confidence interval. All of the identified hot spots are located in Hillsborough County.

CHAPTER 5
CRASH MODIFICATION FACTORS (CMFs)

This chapter discusses the crash modification factors (CMFs) developed to address head-on crashes in FDOT District 7. A cross-sectional study, using roadway characteristics and crash data, was adopted to estimate the CMFs.

5.1 Introduction

A CMF is a multiplicative factor that is used to compute the expected number of crashes when a particular countermeasure is implemented at a specific site.

- A CMF greater than 1.0 indicates an expected increase in crashes when a particular countermeasure is implemented.
- A CMF less than 1.0 indicates an expected reduction in crashes when a particular countermeasure is implemented.

For example, a CMF of 0.6 indicates a 40% expected reduction in crashes, while a CMF of 1.2 indicates a 20% expected increase in crashes.

The crash reduction that might be expected after implementing a given countermeasure at a specific site may also be expressed as a percentage commonly known as a Crash Reduction Factor (CRF). Both CRFs and CMFs are commonly used in traffic safety, and are related by a simple mathematical formula shown in Equation 5.1.

$$CMF = 1 - (CRF/100) \tag{5.1}$$

A cross-sectional study was adopted to estimate the CMFs. Cross-sectional studies compare the crash occurrences between locations with and without a particular feature, attributing differences in safety to that feature. In its simplest form, the CMF is calculated as the ratio of the average crash frequency for sites with and without the feature. However, this method relies on the assumption that all locations are similar in all other factors influencing crash risk, which can be challenging to fulfill in practice. One major advantage of the cross-sectional method is that the regression models can be used in a sensitivity analysis of alternative highway improvements. However, one major disadvantage is that it does not consider the effects of factors not included in the model (Benekohal & Hashmi, 1992). As such, efforts were made to include all the relevant factors in the regression models.

5.2 Data

5.2.1 Study Area

The study area for this research was FDOT District 7 (see Figure 4.1), comprised of five counties: Citrus, Hernando, Pasco, Hillsborough, and Pinellas. Analyses focused on the state road network in each county.

5.2.2 Roadway Characteristics Data

FDOT's Roadway Characteristics Inventory (RCI) includes over 200 variables. However, only those that could potentially affect head-on crashes were identified and included in the analysis. Table 5.1 lists the roadway characteristic variables included in the analysis. Note that these variables were selected based on an extensive literature review and preliminary analysis of head-on crashes in District 7.

Table 5.1: Roadway Variables Included in the Analysis

RCI Variable	RCI Code
Section Average Annual Daily Traffic	SECTADT
Number of Lanes	NOLANES
Median Width	MEDWIDTH
Maximum Speed Limit	MAXSPEED
Outside Shoulder Width	SHLDTYPE
Functional Classification of Roadway	FUNCLASS
Median Type	RDMEDIAN
Inside Shoulder Width	ISLDWTH
Inside Shoulder Type	SHLDTYPE
Horizontal Curve	CURCLAS
Type of Road	TYPEROAD

Variables listed in Table 5.1 are discussed below in detail.

- *Section AADT*: Section AADT is an estimation of the AADT traveled on the roadway section. The natural logarithm of AADT was considered when developing the regression models.

- *Number of Lanes:* Information on the number of lanes was used to classify roadway segments into different facility types, with distinctions made between divided and undivided roads. For divided roadways, the RCI provided the number of through lanes for each direction separately, while for undivided sections, the database offered the total number of through lanes for both directions combined. To ensure consistency in model fitting, the total number of lanes information for undivided sections was directly used. However, for divided roadways, the total number of through lanes was derived by summing the individual counts for each direction of travel. This approach allowed for a unified consideration of the number of lanes in both divided and undivided segments for the analytical modeling.

- *Maximum Speed Limit*: Information on the maximum speed limit was provided for each direction of travel on divided roads and for both directions of travel on undivided roads. If the maximum speed limit was different for each direction of travel, the highest value was taken as the maximum speed limit of the roadway. The maximum speed limit value was used directly for undivided sections.

- *Type of Median:* Table 5.2 lists the different types of medians included in the RCI. The codes were redefined to yield longer and more homogeneous segments. The table also provides the modified median types considered in this analysis.

Table 5.2: Median Type Analyzed

Highway Median Type	Original RCI Code	Modified Code
Paved	01	01
Raised Traffic Separator	02	02
Vegetation	08	08
Curb & Vegetation	17	17
Other	20	20
Counted Roundabout	41	20
Non-counted Roundabout	42	20
Counted Traffic Circle	43	20
Non-counted Traffic Circle	44	20
Non-counted Managed Lanes	50	20

- *Roadway Functional Classification:* Functional classification categorizes roadways based on their intended purpose, level of service, and traffic volume. Table 5.3 provides the roadway functional classification codes on rural and urban facilities.

Table 5.3: Roadway Functional Classification Analyzed

Functional Classification Descriptions	Rural Code	Urban Code
Principal Arterial—Interstate	01	11
Principal Arterial—Freeways & Expressways	02	12
Principal Arterial—Other	04	14
Minor Arterial	06	16
Major Collector	07	17
Minor Collector	08	18
Local	09	19

- *Horizontal Curves:* Horizontal curves are known to be more prone to crashes than tangent sections, particularly with respect to roadway departure crashes, run-off-the-road crashes, and head-on crashes when they occur near the inside shoulders (Ahmed et al., 2024). Horizontal curve data was extracted from the RCI database. The RCI classifies horizontal curves into different categories, such as CURCLASSA, CURCLASSB, CURCLASSC, and CURCLASSD, based on specific parameters. In this analysis, all the curve classes are grouped together and then compared with the tangent section of the road.

- *Inside Shoulder Type:* The RCI includes information about three shoulder types based on offset direction (left, right, and both left and right). When coding the inside shoulder type for the first shoulder, both the right and the left shoulders were considered as separate variables. Table 5.4 provides the descriptions, original code, and modified code for the inside shoulder type.

Table 5.4: Inside Shoulder Type Analyzed

Descriptions	Original Code	Modified Code
Raised Curb (no shoulder or width exists)	0	0
Paved	1	1
Rumble Strips	2	2
Curb & Gutter	6	68
Other	7	7
Curb with Resurfaced Gutter	8	68

- *Outside Shoulder Type:* An outside shoulder refers to the portion of the road adjacent to the travel lanes, typically separated by a solid or dashed line, and serves various functions crucial for road user safety and operational efficiency. Table 5.5 provides the descriptions, original code, and modified code for the outside shoulder type variable.

Table 5.5: Outside Shoulder Type Analyzed

Description	Original Code	Modified Code
Raised Curb	0	0
Paved	1	1
Paved with Warning Device	2	2
Lawn	3	345
Gravel/Marl	4	345
Valley Gutter	5	345
Curb & Gutter	6	68
Other	7	7
Curb with Resurfaced Gutter	8	68

- *Inside Shoulder Width:* The inside shoulder width is measured from the inside stripe of the travel lane to the edge of the shoulder nearest to the median. The width is expressed in feet.

- *Outside Shoulder Width:* The outside shoulder width is the distance between the outer edge of the travel lane and the adjacent roadside, expressed in feet.

5.2.3 Crash Data

This study focused on analyzing head-on crashes that occurred along segments in FDOT District 7. As a first step, intersection-related crashes were identified and excluded from the analysis. Next, the severity of the crashes was determined by categorizing them based on the KABCO scale, discussed in Section 4.2.1.1. Once the head-on crashes were identified by severity, they were assigned to the segments based on the Roadway ID and Milepost.

5.3 Model Development

Crash prediction models and CMFs can quantify the safety impacts of roadway characteristics and provide greater insight into how the roadway geometric characteristics affect safety. A cross-sectional analysis was used in this study to develop CMFs for head-on crashes. As mentioned earlier, a CMF of 0.8 indicates a 20% expected reduction in crashes, while a CMF of 1.15 indicates a 15% expected increase in crashes (Gross et al., 2010). The most common approach to develop

CMFs using the cross-sectional method is through Negative Binomial (NB) models. Table 5.6 provides the descriptive statistics of the variables included in the model.

Table 5.6: Descriptive Statistics of Variables Modeled

Variable	Category	Code	Frequency	Percentage (%)
Median Type	Undivided	0	1,582	47.92
	Paved	1	729	22.08
	Raised Traffic Separator	2	278	8.42
	Vegetation	8	305	9.24
	Curb & Vegetation	17	310	9.39
	Other	20	97	2.94
Horizontal Curve	Curved	1	396	11.71
	Tangent Section	0	2,986	88.29
Functional Class	Rural Freeways	1 and 2	46	1.39
	Urban Freeways	11 and 12	211	6.39
	Urban Arterials	14 and 16	1,129	34.20
	Urban Collectors	17, 18, and 19	1,534	46.47
	Rural Arterials	4 and 6	142	4.30
	Rural Collectors	7, 8, and 9	239	7.24
Road Type	Two Way Undivided	0	1,647	49.89
	Two Way Divided	2	1,521	46.08
	One Way	4	133	4.03
Outside Shoulder Type (Left)	Raised Curb	0	51	1.51
	Paved	1	797	23.57
	Paved (Warning Device)	2	250	7.39
	Lane /Gravel & Vally Gutter	35	298	8.81
	Curb & Gutter	68	402	11.89
	Not Applicable (No shoulder)	99	1,584	46.84
Inside Shoulder Type (Left)	Raised Curb	0	55	1.67
	Paved	1	164	4.97
	Paved (Warning Device)	2	216	6.54
	Curb & Gutter	68	252	7.63
	Not Applicable (No shoulder)	99	2,614	79.19
Inside Shoulder Type (Right)	Raised Curb	0	54	1.64
	Paved	1	168	5.09
	Paved (Warning Device)	2	219	6.63
	Curb & Gutter	68	252	7.63
	Not Applicable (No shoulder)	99	2,608	79.01
Outside Shoulder Type (Right)	Raised Curb	0	15	0.45
	Paved	1	800	24.24
	Paved (Warning Device)	2	235	7.12
	Lane /Gravel & Gutter	35	273	8.27
	Curb & Gutter	68	405	12.27
	Not Applicable (No shoulder)	99	1,573	47.65

Table 5.6: Descriptive Statistics of Variables Modeled (continued)

Continuous Variables				
Variable	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
AADT (veh/day)	18,489	27,552	164	220,800
Speed Limit (mph)	41.74	11.24	15	70
Number of Lanes	2.93	1.53	1	10
Average Median Width (ft)	16.36	34.64	0.00	800.00
Average Outside Shoulder Width (ft)	11.72	6.77	1.00	41.00
Average Inside Shoulder Width (ft)	1.05	3.02	0.00	30.00
Total Crashes	0.77	2.02	0.00	36.00
Fatal & Serious Injury Crashes	0.37	0.98	0.00	13.00

Note: Total number of segments = 830.

Since crashes are rare and random, there can be a large number of locations that have not experienced any crashes. Traditional Poisson and NB models may not be able to handle datasets that have a large number of zero crash observations. Thus, the Zero-inflated Poisson (ZIP) and Zero-inflated Negative Binomial (ZINB) models have frequently been applied to account for the preponderance of excess zeros observed in crash count data (Gross et al., 2010).

A cross-sectional analysis using the generalized linear model (GLM) approach with ZINB distribution was adopted to develop the relevant safety performance functions (SPFs) for head-on crashes. The regression models were prepared based on the following six roadway functional classifications:

- Rural freeways
- Urban freeways
- Rural arterials
- Urban arterials
- Rural collectors
- Urban collectors

For each functional classification, two ZINB models were developed: a) for total crashes and b) for fatal and serious injury (FS) crashes. Note that either the total crash frequency or FS crash frequency was considered as the dependent variable, and roadway geometric characteristics were considered as the explanatory variables. The following sections discuss the ZINB models in more detail.

5.3.1 ZINB Model

Zero-inflated distributions have of two regime models: a) predicting the zero-inflation probability and b) predicting a constant zero-inflation probability across observations. The first model (i.e., the zero-inflation probability model) governs whether the given frequency is a zero or a positive number. The second model of the distribution then takes care of the positive frequency. Both model regimes are used to make full use of the data with excess zeros. The model was computed using the **pscl** package on the open-source program "R" using Equations 5.2 and 5.3.

The probability distribution of the ZINB random variable y_i is:

$$Prob(y_i = j) = \begin{cases} \pi_i + (1-\pi_i)\, g(y_i = 0), if\ j = 0 \\ (1-\pi_i)\, g(y_i), if\ j > 0 \end{cases} \tag{5.2}$$

where π_i is the proportion of true zeros that cannot be explained by the NB model, and $g(y_i)$ follows the negative binomial distribution as:

$$g(y_i) = Prob\ (Y = y_i \mid \mu_i, \alpha) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(y_i + 1)\Gamma(\alpha^{-1})}\ (\frac{1}{1+\alpha\mu_i})^{\alpha^{-1}} (\frac{\alpha\mu_i}{1+\alpha\mu_i})^{y_i} \tag{5.3}$$

where μ_i is the mean crash frequency, and α is the over-dispersion parameter. Equation 5.4 shows basic form of the NB regression model used in this study.

$$\mu_i\ = e^{\ \beta_0 + \beta_1 \times \ln AADT + \ldots + \beta_k \times X_{ik}}\ |\ AADT \tag{5.4}$$

where,

μ_i	=	crash frequency on a road section *i*,
AADT	=	average annual daily traffic on a road section (vehicle/day),
X_{ik}	=	roadway characteristic *k* of road section *i*,
β_0	=	model intercept/constant,
$\beta_1, \beta_2 \ldots, \beta_k$	=	model coefficients, and
OFFSET	=	log (5× (segment length)) for segments to predict crash frequency in crashes per mile. The number 5 was used since the analysis period was five years.

5.3.2 Variable Correlation

Correlation among explanatory variables leads to inaccurate estimates of the coefficients for the highly correlated variables. Correlation analysis is a statistical method used to evaluate the strength of the relationship among the variables. A high correlation means that two or more variables have a strong relationship with each other, while a weak correlation means that the variables are hardly related. The equation of the correlation coefficient between two variables is shown in Equation 5.5.

$$\rho_{XY} = \frac{cov(X,Y)}{\sqrt{Var(X).Var(Y)}} \tag{5.5}$$

where,

ρ_{XY}	=	correlation coefficient between two datasets X and Y,
$cov(X, Y)$	=	covariance of two dataset X and Y,
Var (X)	=	variance of X, and
Var (Y)	=	variance of Y.

Prior to developing the ZINB regression models, all the variables were checked for correlation. Figures 5.1 – 5.6 present the results of the correlation analysis for each roadway functional class included in the analysis. Variables are considered to be highly correlated if the correlation coefficient is 0.5 (Kitali et al., 2018). Note that highly correlated variables were not included in the final model. As can be inferred from Figure 5.1, when rural freeways were analyzed, the variables "Total Number of Lanes" and "Average Inside Shoulder Width" were found to be highly correlated with AADT. Hence, these two variables were excluded from the analysis, while AADT was retained in the models.

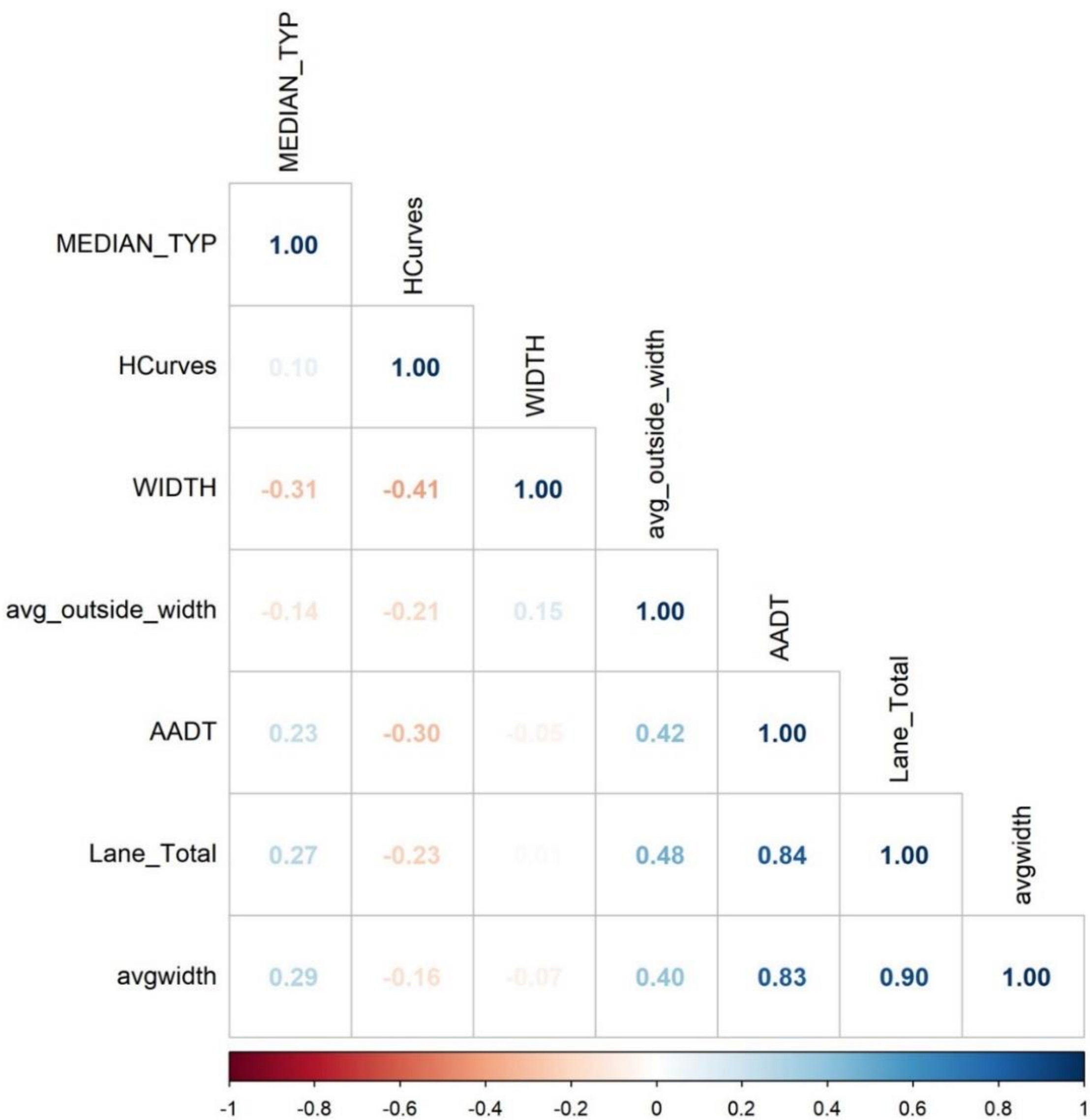


Figure 5.1: Correlation Matix for Rural Freeways

For urban freeways, as can be inferred from Figure 5.2, the following variables were excluded due to high correlation: Road Type, Average Outside Shoulder Type (Left), Average Outside Shoulder Type (Right), Average Inside Shoulder Width, Average Inside Shoulder Type (Left), and Number of Total Lanes.

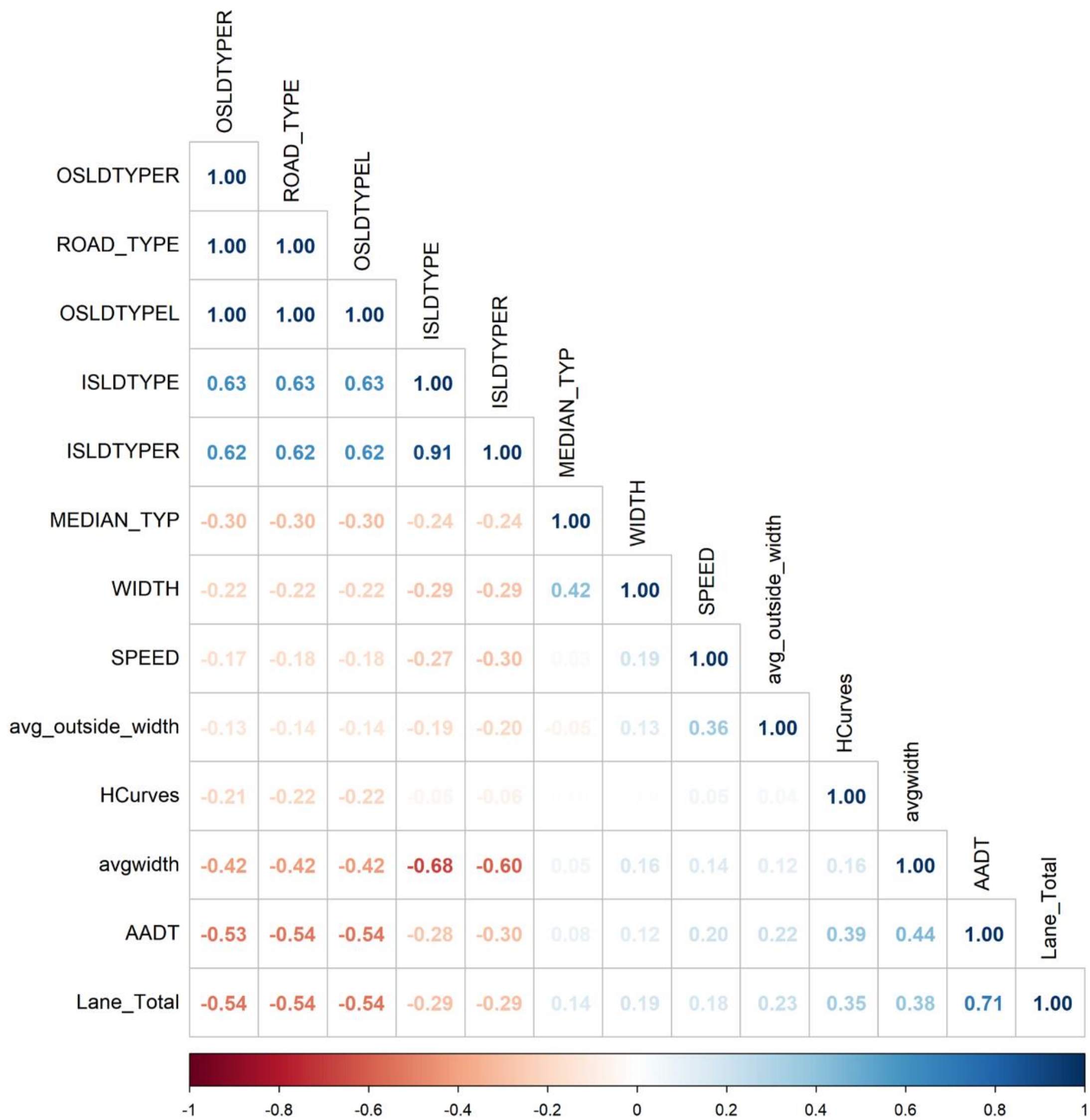


Figure 5.2: Correlation Matix for Urban Freeways

As can be inferred from Figure 5.3, when rural arterials were analyzed, the following variables were excluded due to high correlation: Median Type, Average Outside Shoulder Type (Left and Right), and Road Type.

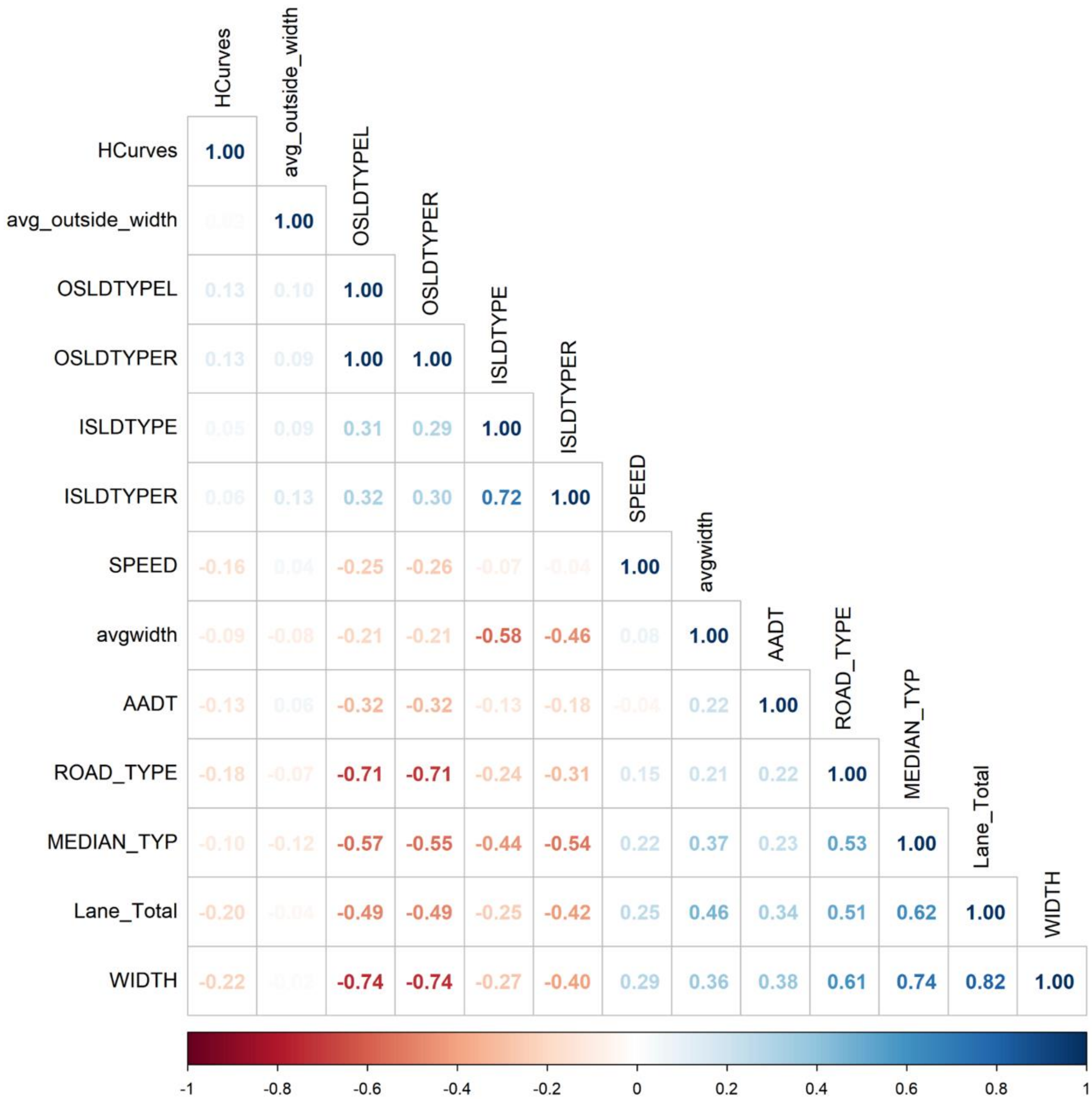


Figure 5.3: Correlation Matix for Rural Arterials

For urban arterials, as can be inferred from Figure 5.4, the following variables were excluded due to high correlation: Average Inside Shoulder Type (Left), Average Inside Shoulder Width, and Number of Lanes.

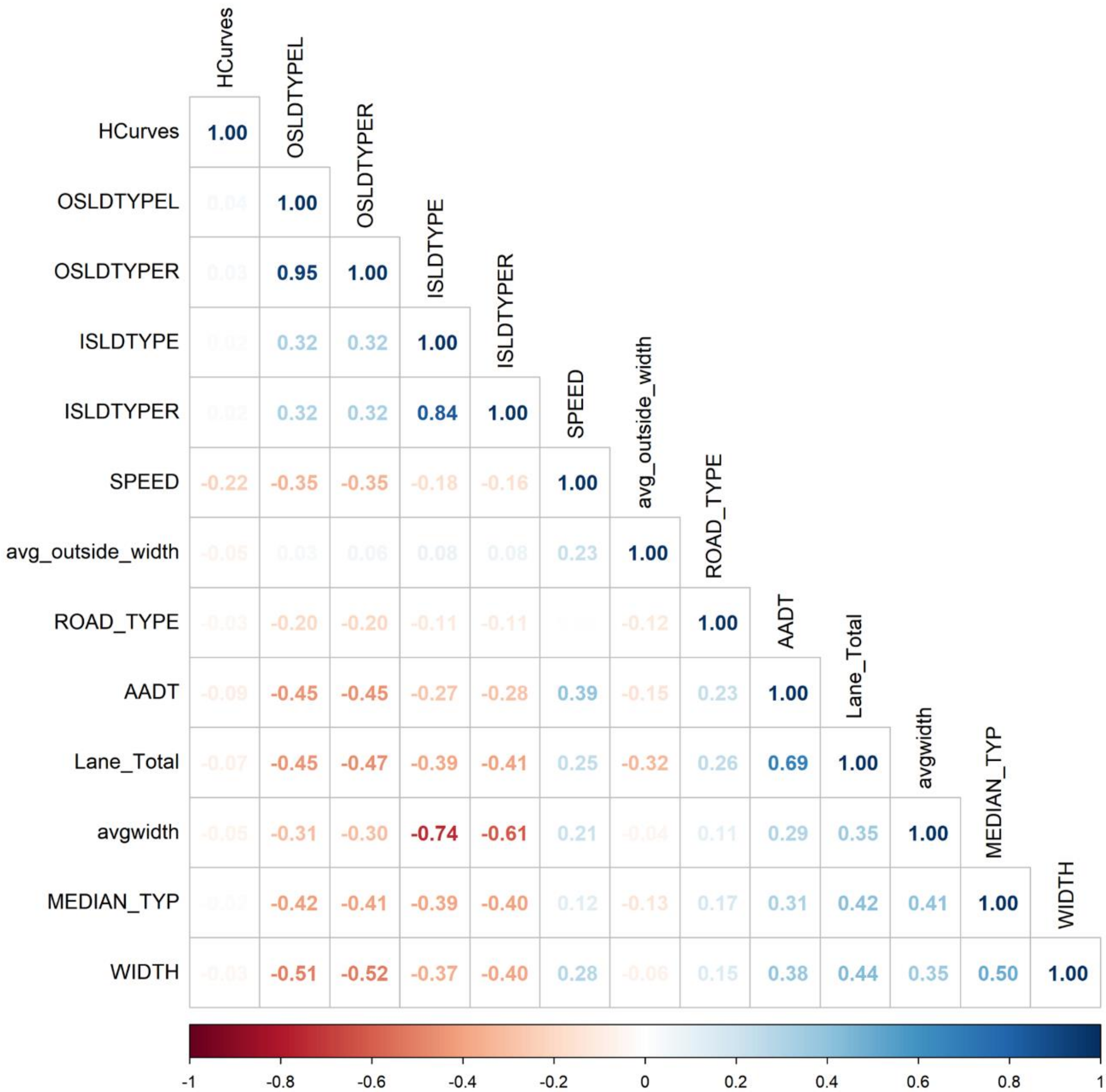


Figure 5.4: Correlation Matix for Urban Arterials

For rural collectors, as can be inferred from Figure 5.5, Average Outside Shoulder Type (Left and Right) and Median Width were excluded due to high correlation.

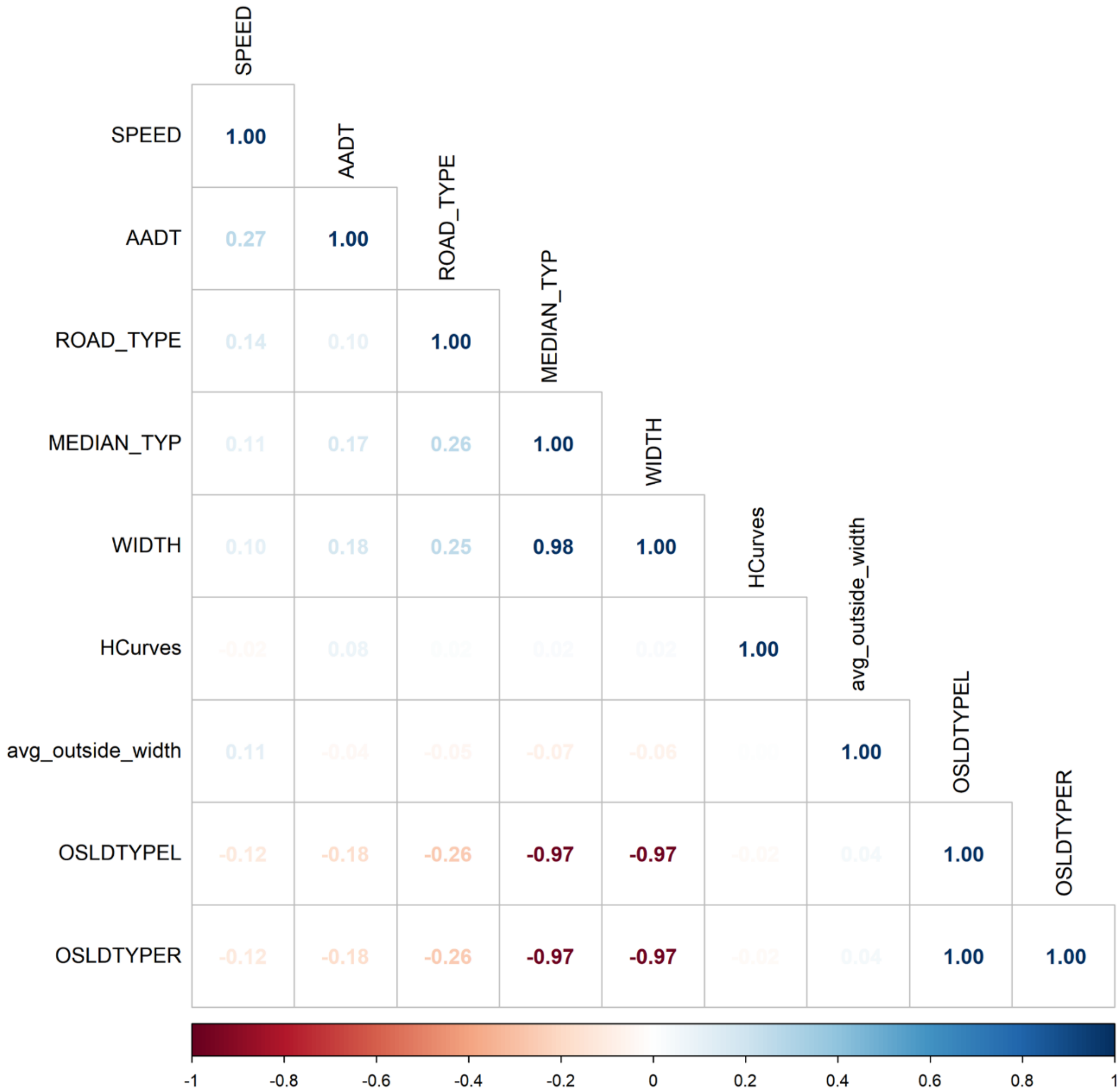


Figure 5.5: Correlation Matix for Rural Collectors

For urban collectors, as can be inferred from Figure 5.6, the following variables were excluded due to high correlation: Average Inside Shoulder Type (Left and Right), Average Outside Shoulder Type (Left and Right), Total Number of Lanes, and Median Width.

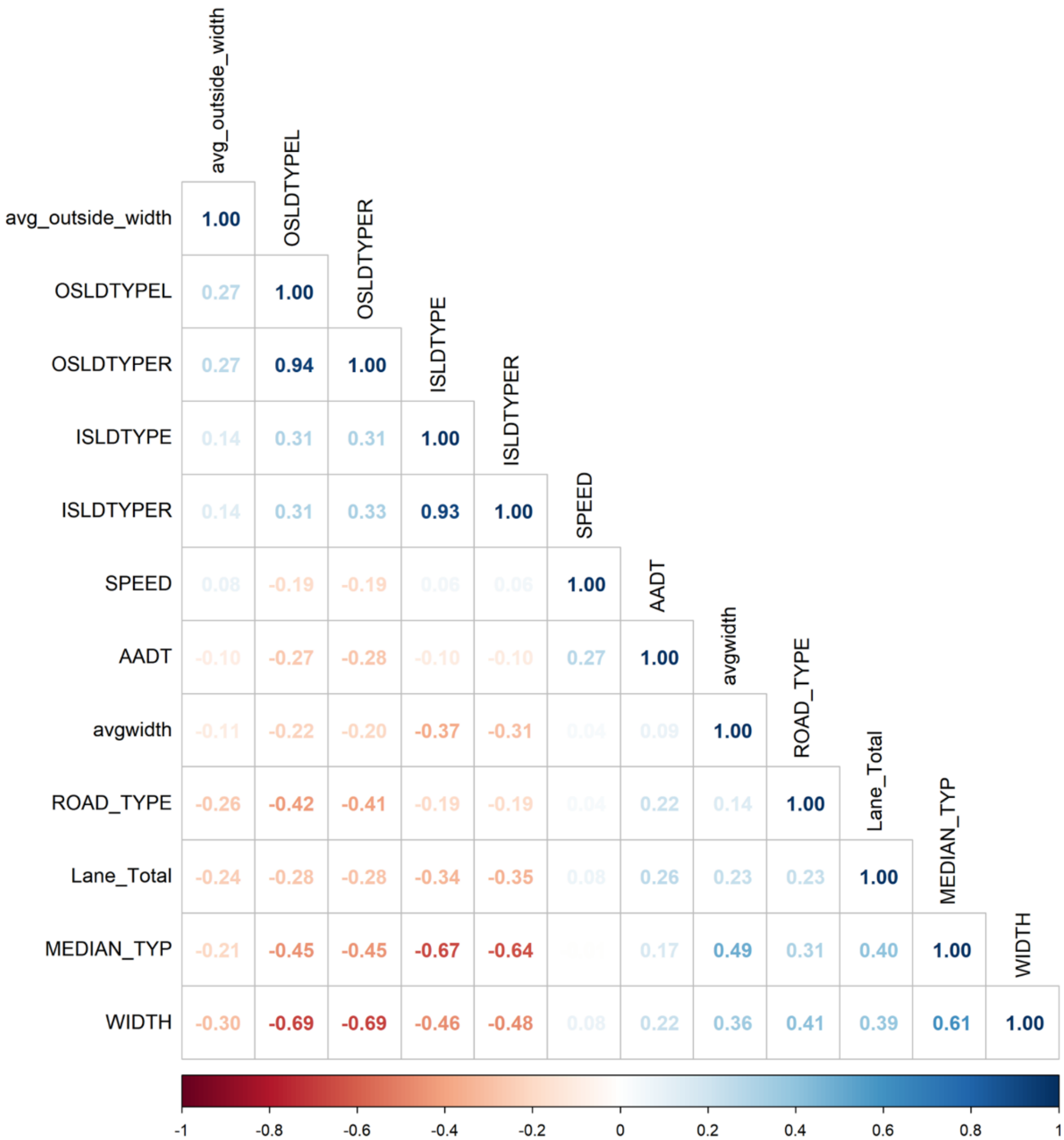


Figure 5.6: Correlation Matix for Urban Collectors

5.4 Safety Performance Functions

Tables 5.7 – 18 provide the model results for all six roadway classification categories, for both total crashes and FS crashes. The tables also summarize the coefficients, standard errors, Z-values, and P-values for the variables in the ZINB models. The model coefficients indicate the change in the frequency of head-on crashes because of a unit change in the variables. The variables with positive coefficients are associated with an increase in head-on crash frequency, while negative coefficients indicate a reduction in head-on crash frequency. Note that the base categories are shown in bold font. Also note that independent variables vary among the models due to the availability of the data.

5.4.1 Rural Freeways

5.4.1.1 Model for Total Crashes

The models were developed based on 46 segments, totaling 41.82 miles. Table 5.7 provides the model results for total crashes on rural freeways. Because none of the variables were found to be statistically significant, CMF values were not estimated.
Although an increase in AADT correlates with a notable increase in crash frequency, this variable is not statistically significant. Compared to straight tangent sections, horizontal curves were found to have fewer crashes, although not statistically significant. Similarly, increase in the average outside shoulder width was found to reduce head-on crashes. Median width was found to have no impact on head-on crashes.

Table 5.7: Model Results for Rural Freeways: Total Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-18.95	15.26	-1.24	0.21	
Horizontal Curve	**Tangent Section**					
	Horizontal Curve	-0.08	1.30	-0.06	0.95	-
Median Type	**Vegetation**					-
	Other	-14.56	1503.00	-0.01	0.99	-
Continuous Variables						
Natural Logarithm of AADT		3.73	3.34	1.12	0.26	-
Average Outside Shoulder Width (ft)		-0.02	0.11	-0.14	0.89	-
Average Median Width (ft)		0.00	0.01	0.01	1.00	-

Note: Bold categories indicate base variables. CMF values not estimated for variables not statistically significant.

5.4.1.2 Model for FS Crashes

The FS models were developed based on 46 segments, totaling 41.82 miles. Table 5.8 provides the model results for FS crashes on rural freeways. Similar to the model for total crashes, none of the variables were found to be statistically significant; therefore, CMF values were not estimated.

AADT was found to increase FS crash frequency. Compared to the straight tangent sections, horizontal curves were found to have fewer FS crashes. An increase in the average outside shoulder width was found to reduce FS head-on crashes, while median width was found to have no impact on FS head-on crashes.

Table 5.8: Model Results for Rural Freeways: FS Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-18.59	14.90	-1.25	0.21	
Horizontal Curve	**Tangent Section**					
	Horizontal Curve	-0.09	1.29	-0.07	0.95	-
Median Type	**Vegetation**					-
	Other	-17.97	8266.00	0.00	1.00	-
Continuous Variables						
Natural Logarithm of AADT		3.65	3.27	1.12	0.26	-
Average Outside Shoulder Width (ft)		-0.01	0.11	-0.13	0.90	-
Average Median Width (ft)		0.00	0.01	0.01	0.99	-

Note: Bold categories indicate base condition. CMF values not estimated for variables not statistically significant.

5.4.2 Urban Freeways

5.4.2.1 Model for Total Crashes

The models were developed based on 211 segments, totaling 142.48 miles. Table 5.9 provides the model results for total crashes on urban freeways. Among continuous variables, the natural logarithm of AADT was found to have a significant positive association with total crash frequency at 5% level of significance, implying that higher traffic volumes lead to more head-on crashes. The average median width and speed limit were found to have no impact on total head-on crash frequency. While the average outside shoulder width was found to have a slightly negative association with total crashes, the variable is not statistically significant.

Table 5.9: Model Results for Urban Freeways: Total Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-8.38	3.92	-2.14	0.03	
Inside Shoulder Type (Right)	**No Shoulder**					
	Paved	0.72	1.70	0.19	0.85	-
	Paved (Warning Device)	0.16	1.04	-0.11	0.91	-
	Curb & Gutter	-0.17	24.32	0.00	1.00	-
Horizontal Curve	**Tangent Section**					
	Horizontal Curve	0.07	0.31	0.27	0.79	-
Continuous Variables						
Natural Logarithm of AADT***		1.42	0.64	2.23	0.03	4.15
Average Median Width (ft)*		0.00	0.00	1.40	0.16	1.00
Average Outside Shoulder Width (ft)		-0.01	0.02	-0.29	0.78	-
Speed Limit (mph)		0.00	0.03	0.14	0.89	-

Note: Bold categories indicate base condition. ***Variable, **Variable, and *Variable are significant at 5%, 10%, and 20% level of significance, respectively. CMF values estimated only for significant variables.

5.4.2.2 Model for FS Crashes

The models were developed based on 211 segments, totaling 142.48 miles. Table 5.10 provides the model results for FS crashes on urban freeways. In terms of continuous variables, the natural logarithm of AADT was found to show a positive association with FS crash frequency, but the variable is not significant at a 20% level of significance. Average median width, average outside shoulder width, and speed limit were found to show non-significant associations with FS crash frequency. Among the categorical variables, horizontal curve segments were found to experience more FS crashes compared to the tangent sections. Compared to the absence of inside shoulder, paved shoulder with a warning device and curb and gutter were found to reduce FS head-on crashes, while just paved inside shoulders were found to increase FS crashes. However, this variable is not statistically significant.

Table 5.10: Model Results for Urban Freeways: FS Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-5.26	4.63	-1.14	0.26	
Inside Shoulder Type (Right)	**No Shoulder**					
	Paved	0.19	2.18	-0.09	0.93	-
	Paved (Warning Device)	-0.17	1.23	-0.27	0.79	-
	Curb & Gutter	-5.49	141.52	-0.01	0.99	-
Horizontal Curve	**Tangent Section**					
	Horizontal Curve	0.08	0.40	0.27	0.79	-
Continuous Variables						
Natural Logarithm of AADT		0.83	0.75	1.10	0.27	-
Average Median Width (ft)		0.00	0.00	0.64	0.53	-
Average Outside Shoulder Width (ft)		-0.02	0.03	-0.65	0.52	-
Speed Limit (mph)		0.00	0.04	0.27	0.79	-

Note: Bold categories indicate base condition. CMF values not estimated for variables not statistically significant.

5.4.3 Urban Arterials

5.4.3.1 Model for Total Crashes

The models were developed based on 1,176 urban arterial segments, totaling 1,077.92 miles. Table 5.11 provides the model results for total crashes on urban arterials.

All the continuous variables were found to be statistically significant. The natural logarithm of AADT was found to exhibit a significant positive association with total head-on crash frequency, indicating that higher traffic volumes lead to more head-on crashes. Note that the AADT variable is statistically significant at a 5% level of significance. Speed limit was found to be statistically significant at a 20% level of significance, but not significant at a 95% or 99% level of significance. The CMF for speed limit was estimated to be 0.99, implying that a unit increase in the posted speed limit would result in a 1% reduction in total head-on crash frequency on urban arterials.

The CMF for average inside shoulder width was estimated to be 0.95 at a 20% level of significance. This implies that a 1-ft increase in the average inside shoulder width would result in a 5% reduction in total head-on crashes. Similarly, the CMF for average outside shoulder width was estimated to be 0.98 at a 5% level of significance. This implies that a 1-ft increase in the average outside shoulder width would result in a 2% reduction in total head-on crashes. Similarly, the CMF for average median width was estimated to be 0.99 at a 5% level of significance, implying that a 1-ft increase in average median width would result in a 1% reduction in total head-on crashes.

Among the categorical variables, only inside right shoulder type was found to be statistically significant. Compared to the absence of inside right shoulder, paved shoulder with a warning device was found to reduce total head-on crashes by 53% (i.e., CMF = 0.47). Similarly, constructing curb and gutter on the inside right shoulder would result in a 43% reduction in total head-on crashes (i.e., CMF = 0.57).

Compared to the straight tangent sections, horizontal curves were found to slightly reduce total head-on crashes; however, the reduction is not statistically significant. When the left outside shoulder type is considered, compared to the absence of shoulder, raised curb, paved, and lane/gravel and valley gutter were found to experience fewer total head-on crashes while paved with a warning device and curb and gutter were found to experience more crashes. However, note that these conditions are not statistically significant at 20% level of significance.

When road type is considered, compared to two-way undivided sections, both the two-way divided and the one-way streets were found to increase total head-on crashes. However, these conditions are not statistically significant at a 20% level of significance. When median type is considered, raised traffic separator, vegetation, and curb and vegetation categories were found to be associated with increased total head-on crash frequency, and paved medians were found to reduce total head-on crash frequency, although not statistically significant.

Table 5.11: Model Results for Urban Arterial: Total Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-2.45	0.79	-3.09	0.00	
Median Type	**Undivided**					
	Paved	-0.04	0.78	-0.05	0.96	-
	Raised Traffic Separator	0.55	0.79	0.70	0.49	-
	Vegetation	0.44	0.81	0.54	0.59	-
	Curb & Vegetation	0.44	0.81	0.54	0.59	-
	Other	0.06	0.82	0.07	0.94	-
Road Type	**Two Way Undivided**					
	Two Way Divided	0.18	0.16	1.11	0.27	-
	One Way	0.19	0.24	0.78	0.43	-
Horizontal Curve	**Tangent Section**					
	Horizontal Curve	-0.01	0.12	-0.10	0.92	-
Outside Shoulder Type (Left)	**No Shoulder**					
	Raised Curb	-0.26	0.84	-0.31	0.75	-
	Paved	-0.04	0.78	-0.05	0.96	-
	Paved with warning Device	0.13	0.77	0.17	0.87	-
	Lane /Gravel & Valley Gutter	-0.11	0.80	-0.14	0.89	-
	Curb & Gutter	0.25	0.78	0.32	0.75	-

Note: Bold categories indicate base condition. ***Variable, **Variable, and *Variable are significant at 5%, 10%, and 20% level of significance, respectively. CMF values estimated only for significant variables.

Table 5.11: Model Results for Urban Arterial: Total Crashes (continued)

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-2.45	0.79	-3.09	0.00	
Outside Shoulder Type (Left)	**No Shoulder**					
	Raised Curb	-0.26	0.84	-0.31	0.75	-
	Paved	-0.04	0.78	-0.05	0.96	-
	Paved with warning Device	0.13	0.77	0.17	0.87	-
	Lane /Gravel & Valley Gutter	-0.11	0.80	-0.14	0.89	-
	Curb & Gutter	0.25	0.78	0.32	0.75	-
Inside Shoulder Type (Right)	**No Shoulder**					
	Raised Curb	0.27	0.44	0.61	0.54	-
	Paved	0.04	0.18	0.25	0.80	-
	Paved with warning Device*	-0.76	0.48	-1.58	0.11	0.47
	Curb & Gutter***	-0.56	0.21	-2.65	0.01	0.57
Continuous Variables						
Natural Logarithm of AADT***		0.89	0.19	4.73	0.00	2.45
Speed Limit (mph)*		-0.01	0.01	-1.56	0.12	0.99
Average Inside Shoulder Width (ft)*		-0.06	0.04	-1.47	0.14	0.95
Average Outside Shoulder Width (ft)***		-0.02	0.01	-1.95	0.05	0.98
Average Median Width (ft)***		-0.01	0.01	-2.86	0.00	0.99

Note: Bold categories indicate base condition. ***Variable, **Variable, and *Variable are significant at 5%, 10%, and 20% level of significance, respectively. CMF values estimated only for significant variables.

5.4.3.2 Model for FS Crashes

The models were developed based on 1,176 urban arterial segments, totaling 1,077.92 miles. Table 5.12 provides the model results for FS crashes on urban arterials. The natural logarithm of AADT was found to exhibit a significant positive association with FS crash frequency, indicating that higher traffic volumes lead to more FS head-on crashes, and this variable is statistically significant at a 5% level of significance. The speed limit was found to be not statistically significant at a 20% level of significance. The CMF for average inside shoulder width was estimated to be 0.94 at a 20% level of significance. This implies that a 1-ft increase in the average inside shoulder width would result in a 6% reduction in FS head-on crashes. The average outside shoulder width was found to reduce FS crashes, but it is not statistically significant. The CMF for average median width was estimated to be 0.98 at a 5% level of significance, implying that a 1-ft increase in average median width would result in a 2% reduction in FS head-on crashes.

Compared to the absence of inside right shoulder, curb and gutter shoulder type was found to reduce FS head-on crashes by 32% at a 20% level of significance (i.e., CMF = 0.68). Similarly, paved and paved with a warning device on the inside right shoulder were found to reduce FS crashes, but these conditions are not statistically significant.

Compared to the straight tangent sections, horizontal curves were found to reduce FS crashes; however, the reduction is not statistically significant. Compared to two-way undivided sections, one-way streets were found to decrease FS crashes and two-way divided streets were found to increase FS crashes. However, these conditions are not statistically significant at a 20% level of significance. When median type is considered, paved, raised traffic separator, vegetation, and curb and vegetation categories were found to be associated with increased FS crash frequency, although they are not statistically significant.

Table 5.12: Model Results for Urban Arterial: FS Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-2.48	0.79	-3.12	0.00	
Median Type	**Undivided**					
	Paved	0.18	0.84	0.21	0.83	-
	Raised Traffic Separator	0.70	0.86	0.82	0.41	-
	Vegetation	0.60	0.88	0.68	0.49	-
	Curb & Vegetation	0.42	0.88	0.47	0.64	-
	Other	0.05	0.88	0.05	0.96	-
Road Type	**Two Way Undivided**					
	Two Way Divided	0.17	0.18	0.93	0.35	-
	One Way	-0.35	0.32	-1.11	0.27	-
Horizontal Curve	**Tangent Section**					-
	Curved	-0.09	0.14	-0.68	0.50	-
Outside Shoulder Type (Left)	**No Shoulder**					
	Raised Curb	-0.64	0.93	-0.69	0.49	-
	Paved	-0.23	0.84	-0.27	0.79	-
	Paved with warning Device	0.25	0.80	0.31	0.75	-
	Lane /Gravel & Vally Gutter	-0.26	0.87	-0.30	0.77	-
	Curb & Gutter	-0.13	0.84	-0.15	0.88	-
Inside Shoulder Type (Right)	**No Shoulder**					
	Raised Curb	0.52	0.50	1.04	0.30	-
	Paved	-0.08	0.18	-0.42	0.68	-
	Paved with warning Device	-0.57	0.59	-0.97	0.33	-
	Curb & Gutter*	-0.39	0.26	-1.49	0.14	0.68
Continuous Variables						
Natural Logarithm of AADT***		0.63	0.21	2.96	0.00	1.88
Speed Limit (mph)		0.01	0.01	0.97	0.33	-
Average Inside Shoulder Width (ft)*		-0.06	0.04	-1.46	0.15	0.94
Average Outside Shoulder Width (ft)		-0.01	0.01	-0.89	0.38	-
Average Median Width (ft)***		-0.02	0.01	-2.64	0.01	0.98

Note: Bold categories indicate base condition. ***Variable, **Variable, and *Variable are significant at 5%, 10%, and 20% level of significance, respectively. CMF values are estimated only for significant variables.

5.4.4 Urban Collectors

5.4.4.1 Model for Total Crashes

The models for urban collectors were developed based on 1,594 segments, totaling 786.06 miles. Table 5.13 provides the model results for total head-on crashes on urban collectors.

The natural logarithm of AADT was found to exhibit a significant positive association with total head-on frequency, indicating that higher traffic volumes lead to more head-on crashes, and this variable is statistically significant at a 5% level of significance. The CMF for average outside shoulder width was estimated to be 0.97 at a 5% level of significance. This implies that a 1-ft increase in the average inside shoulder width would result in a 3% reduction in total head-on crashes on urban collectors. The average inside shoulder width was found to increase total head-on crashes, but it is not statistically significant. Similarly, number of through lanes was found to increase total head-on crashes, but it is not statistically significant.

Compared to two-way undivided sections, both one-way streets and two-way divided streets were found to increase total head-on crashes. However, one-way is statistically significant at a 10% level of significance, with a CMF of 1.81. In other words, compared to two-way undivided sections, one-way streets increase head-on crashes by 81%.

Compared to undivided roadway segments, raised traffic separator, vegetation, curb and vegetation, and other median types were found to be associated with reducing total head-on crash frequency. Note that all of these conditions except raised traffic separator are statistically significant. The CMFs for vegetation and curb and vegetation are 0.49 and 0.26, respectively. This implies that compared to undivided sections, having vegetation in the median reduces total head-on crashes by 51%, and having curb and vegetation in the median reduces total head-on crashes by 74%. Only a paved median was found to be associated with increasing total head-on crash frequency, but this condition is not statistically significant.

Table 5.13: Model Results for Urban Collector: Total Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-4.19	0.63	-6.69	0.00	
Median Type	**Undivided**					
	Paved	0.13	0.15	0.88	0.38	-
	Raised Traffic Separator	-0.28	0.31	-0.91	0.37	-
	Vegetation*	-0.72	0.50	-1.45	0.15	0.49
	Curb & Vegetation***	-1.36	0.63	-2.16	0.03	0.26
	Other**	-0.97	0.55	-1.75	0.08	0.38
Road Type	**Two Way Undivided**					
	Two Way Divided	0.07	0.15	0.48	0.63	-
	One Way **	0.59	0.33	1.79	0.07	1.81
Continuous Variables						
Natural Logarithm of AADT***		1.05	0.16	6.44	0.00	2.86
Lane total		0.07	0.09	0.77	0.44	-
Average Inside Shoulder Width (ft)		0.06	0.10	0.56	0.58	-
Average Outside Shoulder Width (ft)***		-0.03	0.01	-3.29	0.00	0.97

Note: Bold categories indicate base condition. ***Variable, **Variable, and *Variable are significant at 5%, 10%, and 20% level of significance, respectively. CMF values are estimated only for significant variables.

5.4.4.2 Model for FS Crashes

This model was developed based on 1,594 segments, totaling 786.06 miles. Table 5.14 provides the model results for FS head-on crashes on urban collectors.

The natural logarithm of AADT was found to exhibit a significant positive association with FS head-on crash frequency, indicating that higher traffic volumes lead to more FS crashes, and this variable is statistically significant at a 5% level of significance. The average outside shoulder width was found to reduce FS crashes, while the average inside shoulder width was found to increase crashes. Note that these two conditions are not statistically significant. The total number of through lanes was also found to reduce FS crashes, but it is also not statistically significant.

Compared to two-way undivided sections, both one-way streets and two-way divided streets were found to reduce FS crashes. However, neither are statistically significant.

Compared to undivided roadway segments, raised traffic separator, vegetation, curb and vegetation, and other categories were found to be associated with reducing FS head-on crash frequency. Note that all of these conditions except the other category are statistically significant. Only paved median was found to be associated with increasing FS crash frequency, but this condition is not statistically significant.

Table 5.14: Model Results for Urban Collector: FS Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-5.43	0.88	-6.21	0.00	
Median Type	**Undivided**					
	Paved	0.12	0.26	0.47	0.64	-
	Raised Traffic Separator	-0.49	0.50	-0.98	0.33	-
	Vegetation	-0.36	0.69	-0.52	0.60	-
	Curb & Vegetation	-0.19	0.47	-0.40	0.69	-
	Other*	-1.56	1.10	-1.42	0.16	0.21
Road Type	**Two Way Undivided**					
	Two Way Divided	-0.08	0.20	-0.41	0.68	-
	One Way	-0.30	0.53	-0.56	0.58	-
Continuous Variables						
Natural Logarithm of AADT***		1.24	0.22	5.56	0.00	3.47
Lane total		0.11	0.12	0.87	0.38	-
Average Inside Shoulder Width (ft)*		0.13	0.08	1.58	0.11	1.14
Average Outside Shoulder Width (ft)		-0.01	0.01	-1.27	0.21	-

Note: Bold categories indicate base condition. ***Variable, **Variable, and *Variable are significant at 5%, 10%, and 20% level of significance respectively. CMF values are estimated only for significant variables.

5.4.5 Rural Arterials

5.4.5.1 Model for Total Crashes

This model was developed based on 136 segments, totaling 131.79 miles. Table 5.15 provides the model results for total head-on crash frequency on rural arterials.

The natural logarithm of AADT was found to exhibit a significant positive association with total head-on crash frequency, indicating that higher traffic volumes lead to more head-on crashes, and this variable is statistically significant at a 5% level of significance. The CMF for average outside shoulder width was estimated to be 0.93 at a 20% level of significance, this implies a 1-ft increase in average outside shoulder width would result in 7% reduction of total head-on crashes on rural arterials. The speed limit variable was found to be statistically significant at a 20% level of significance, and it would increase the head-on crashes by 1% for each 1-mph increase in posted speed limit. Average median width and total number of through lanes were found to reduce total head-on crashes, but these variables are not statistically significant.

Compared to the straight tangent sections, horizontal curves were found to slightly reduce total head-on crashes; however, the reduction is not statistically significant. When the right inside shoulder type is considered, compared to the absence of shoulder, raised curb, paved, paved with waring device, and curb and gutter were found to experience fewer total head-on crashes. However, these conditions are not statistically significant at a 20% level of significance.

Table 5.15: Model Results for Rural Arterial: Total Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-8.95	3.21	-2.79	0.01	
Horizontal Curve	**Tangent Section**					
	Horizontal Curve	-0.36	0.43	-0.85	0.39	-
Inside Shoulder Type (Right)	**No Shoulder**					
	Raised Curb	-0.19	1.35	-0.14	0.89	-
	Paved	-1.24	1.33	-0.93	0.35	-
	Paved with Warning Device	-0.52	1.46	-0.36	0.72	-
	Curb & Gutter	-0.49	1.05	-0.47	0.64	-
Continuous Variables						
Natural Logarithm of AADT***		2.26	0.69	3.30	0.00	9.60
Average Outside Shoulder Width (ft)*		-0.07	0.04	-1.62	0.11	0.93
Speed Limit (mph)*		0.01	0.03	1.27	0.20	1.01
Average Median Width (ft)		-0.02	0.02	-1.14	0.25	-
Total Number of Through Lanes		0.14	0.33	0.43	0.67	-

Note: Bold categories indicate base condition. ***Variable, **Variable, and *Variable are significant at 5%, 10%, and 20% level of significance, respectively. CMF values are estimated only for significant variables.

5.4.5.2 Model for FS Crashes

This model was developed based on 136 segments, totaling 131.79 miles. Table 5.16 provides the model results for FS crash frequency on rural arterials.

The natural logarithm of AADT was found to exhibit a significant positive association with FS frequency, indicating that higher traffic volumes lead to more FS head-on crashes, and this variable is statistically significant at a 5% level of significance. The CMF for average outside shoulder width was estimated to be 0.94 at a 20% level of significance; this implies that a 1-ft increase in the average outside shoulder width would result in a 6% reduction in FS head-on crashes. The speed limit variable was found to be statistically significant at a 20% level of significance, indicating that a 1-mph increase in posted speed limit was found to increase FS head-on crashes by 3%. Average median width and total number of through lanes were found to reduce FS crashes, but these variables are not statistically significant.

Compared to the straight tangent sections, horizontal curves were found to slightly reduce FS crashes; however, the reduction is not statistically significant. When the right inside shoulder type is considered, compared to the absence of shoulder, raised curb, paved, and curb and gutter found to experience fewer FS crashes. However, note that these conditions are not statistically significant at a 20% level of significance.

Table 5.16: Model Results for Rural Arterial: FS Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-11.95	3.74	-3.19	0.00	
Horizontal Curve	**Tangent Section**					
	Horizontal Curve	-0.56	0.47	-1.20	0.23	-
Inside Shoulder Type (Right)	**No Shoulder**					
	Raised Curb	-12.14	459.24	-0.03	0.98	-
	Paved	-12.95	604.51	-0.02	0.98	-
	Paved with warning Device	0.47	1.61	0.30	0.77	-
	Curb & Gutter	-0.27	1.21	-0.22	0.82	-
Continuous Variables						
Natural Logarithm of AADT***		3.03	0.79	3.86	0.00	20.76
Average Outside Shoulder Width (ft)*		-0.06	0.04	-1.62	0.11	0.94
Speed Limit (mph)*		0.03	0.03	1.27	0.20	1.04
Average Median Width (ft)		-0.01	0.02	-0.39	0.69	-
Total Number of Through Lanes		-0.40	0.43	-0.93	0.35	-

Note: Bold categories indicate base condition. ***Variable, **Variable, and *Variable are significant at 5%, 10%, and 20% level of significance respectively. CMF values are estimated only for significant variables.

5.4.6 Rural Collectors

5.4.6.1 Model for Total Crashes

This model was developed based on 207 segments, totaling 206.11 miles. Table 5.17 provides the model results for total head-on crash frequency on rural collectors.

Among all of the continuous variables, only the natural logarithm of AADT was found to exhibit a significant positive association with total head-on crash frequency, indicating that higher traffic volumes lead to more head-on crashes, and this variable is statistically significant at a 5% level of significance. Average outside shoulder width was found to slightly reduce total head-on crash frequency, but this is not statistically significant. Speed limit was found to increase total head-on crash frequency, but it is not statistically significant.

Compared to undivided roadway sections, paved medians were found to increase total head-on crash frequency, although this is not statistically significant. Compared to two-way undivided sections, two-way divided sections were found to decrease total head-on crashes. However, this is not statistically significant at a 20% level of significance.

Table 5.17: Model Results for Rural Collector: Total Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-8.63	2.01	-4.29	0.00	
Median Type	**Undivided**					
	Paved	0.12	0.70	0.17	0.86	-
Road Type	**Two Way Undivided**					
	Two Way Divided	-9.12	81.94	-0.11	0.91	-
Continuous Variables						
Natural Logarithm of AADT***		1.77	0.53	3.32	0.00	5.86
Average Outside Shoulder Width (ft)		-0.01	0.03	-0.48	0.63	-
Speed Limit (mph)		0.03	0.03	1.23	0.22	-

Note: Bold categories indicate base condition. ***Variable, **Variable, and *Variable are significant at 5%, 10%, and 20% level of significance respectively. CMF values are estimated only for significant variables.

5.4.6.2 Model for FS Crashes

This model was developed based on 207 segments, totaling 206.11 miles. Table 5.18 provides the model results for FS crash frequency on rural collectors.

The natural logarithm of AADT was found to exhibit a significant positive association with total head-on crash frequency, indicating that higher traffic volumes lead to more FS head-on crashes, and this variable is statistically significant at a 5% level of significance. Average outside shoulder has no impact on FS crash frequency, and this variable is also not statistically significant. The speed limit was found to increase FS crash frequency by 6% with a one-unit increase in speed limit, at a 5% level of significance.

Compared to undivided segments, paved medians were found to increase FS head-on crash frequency, although this is not statistically significant. Compared to two-way undivided sections, two-way divided sections were found to reduce FS crashes. However, this is not statistically significant.

Table 5.18: Model Results for Rural Collector: FS Crashes

Variable	Category	Estimate	Std. Error	Z value	P value	CMF
Intercept		-9.25	2.24	-4.13	0.00	
Median Type	**Undivided**					
	Paved	0.33	0.68	0.49	0.62	-
Road Type	**Two Way Undivided**					
	Two Way Divided	-10.43	170.14	-0.06	0.95	-
Continuous Variables						
Natural Logarithm of AADT***		1.52	0.55	2.74	0.01	4.56
Average Outside Shoulder Width (ft)		0.00	0.03	-0.15	0.88	-
Speed Limit (mph)***		0.05	0.03	1.95	0.05	1.06

Note: Bold categories indicate base condition. ***Variable, **Variable, and *Variable are significant at 5%, 10%, and 20% level of significance respectively. CMF values are estimated only for significant variables.

5.5 Chapter Summary

This discussed CMFs developed for total and FS head-on crashes for the following roadway facility types: rural freeways, urban freeways, rural arterials, urban arterials, rural collectors, and urban collectors.

Tables 5.19 and 5.20 list the CMFs for total and FS head-on crashes, respectively.

Table 5.19: Summary of CMFs for Total Head-On Crashes

		Rural Freeways	Urban Freeways	Rural Arterials	Urban Arterials	Rural Collectors	Urban Collectors
Median Type	**Undivided**	-	-	-	-	-	-
	Vegetation	-	-	-	-	-	0.49
	Curb & Vegetation	-	-	-	-	-	0.26
	Other	-	-	-	-	-	0.38
Road Type	**Two Way Undivided**	-	-	-	-	-	-
	One Way	-	-	-	-	-	1.81
Inside Shoulder Type (Right)	**No Shoulder**	-	-	-	-	-	-
	Paved with Warning Device	-	-	-	0.47	-	-
	Curb & Gutter	-	-	-	0.57	-	-
Continuous Variables							
Natural Logarithm of AADT		-	4.15	9.60	2.45	5.86	2.86
Speed Limit (mph)		-	-	1.01	0.99	-	-
Average Inside Shoulder Width (ft)		-	-	-	0.95	-	-
Average Outside Shoulder Width (ft)		-	-	0.93	0.98	-	1.06
Average Median Width (ft)		-	1.00		0.99	-	-

Note: Bold categories indicate base condition. CMF values are estimated only for significant variables.

Table 5.20: Summary of CMFs for FS Head-On Crashes

		Rural Freeways	Urban Freeways	Rural Arterials	Urban Arterials	Rural Collectors	Urban Collectors
Median Type	**Undivided**	-	-	-	-	-	-
	Other	-	-	-	-	-	0.21
Road Type	**Two Way Undivided**	-	-	-	-	-	-
Horizontal Curve	**Tangent Section**	-	-	-	-	-	-
	Horizontal Curve	-	-	-	-	-	-
Inside Shoulder Type (Right)	**No Shoulder**	-	-	-	-	-	-
	Curb & Gutter	-	-	-	0.68	-	-
Continuous Variables							
Natural Logarithm of AADT		-	-	20.76	1.88	4.56	3.47
Speed Limit (mph)		-	-	0.94	-	1.06	-
Average Inside Shoulder Width (ft)		-	-	1.04	0.94	-	1.14
Average Median Width (ft)		-	-	-	0.98	-	-

Note: Bold categories indicate base condition. CMF values are estimated only for significant variables.

CHAPTER 6
NEAR-TERM AND LONG-TERM ACTION PLANS

This chapter discusses potential near-term and long-term action plans to mitigate head-on crashes in FDOT District 7. The proposed countermeasures focus on the 4E's of traffic safety identified in the 2021 Florida Strategic Highway Safety Plan (SHSP): Engineering, Education, Enforcement, and Emergency Services (FDOT, 2021). Site-specific countermeasures are also presented.

6.1 Near-Term Action Plans

Actions that can be implemented in the near future to mitigate head-on crashes involve countermeasures with respect to the 4E's of traffic safety and evaluation processes. These strategies may be executed fairly quickly. While engineering countermeasures may be warranted, education and enforcement mitigation strategies should also be considered, especially for crash hot-spot locations. The following subsections discuss suggested near-term strategies.

6.1.1 Engineering Countermeasures

Near-term engineering countermeasures primarily consist of roadway features that can be implemented at relatively low to moderate cost to reduce opposite-direction and RwD crashes resulting in fatal and serious injury head-on collisions. Countermeasure categories associated with head-on crashes include horizontal curves, centerline treatments, shoulder treatments, median treatments, intersections, and lighting.

Crash modification factors (CMFs) for engineering countermeasures were obtained, where available, from the CMF Clearinghouse (https://www.cmfclearinghouse.org/), provided by the FHWA. The Clearinghouse also provides a quality score for each CMF, reflecting the scored quality of the respective study.

A CMF less than 1.0 indicates an expected reduction in crashes when a particular countermeasure is implemented. Conversely, a CMF greater than 1.0 indicates an expected increase in crashes when a particular countermeasure is implemented. Crash reduction factors (CRFs) represent the expected percentage increase or decrease in crashes correlated with each CMF. A positive CRF is the percentage crash reduction that might be expected after implementing a given countermeasure, whereas a negative value indicates a percentage increase in the number of crashes.

The following subsections discuss potential countermeasures that may be implemented in the near future to reduce the overall number of head-on crashes or reduce the number of head-on crashes resulting in fatal or serious injury. Table 6.1 presents the highest scoring CMFs and corresponding CRFs currently available for engineering countermeasures. Figures 6.1 through 6.8 present examples of engineering countermeasures discussed in the following subsections.

6.1.1.1 Horizontal Curves

Potential horizontal curve countermeasures to reduce head-on crash occurrence include:

- *Improve horizontal curve delineation on 2-lane undivided roadways:* Enhancing horizontal curves through chevrons, horizontal arrows, or advance warning signs, as well as the improvement of existing signs using fluorescent yellow sheeting, can help to reduce RwD crashes, especially opposite-direction head-on crashes and single-vehicle-run-off-road (SVROR) crashes during nighttime conditions (CMF = 0.75).
- *Install chevron signs on horizontal curves:* Chevron signs help motorists better recognize the degree of horizontal curvature on approach and adjust their driving actions accordingly (see Figure 6.1). This low-cost countermeasure can be used to reduce head-on, nighttime, non-intersection, run-off-road, and sideswipe crashes on 2-lane undivided rural roadways with a maximum Annual Average Daily Traffic (AADT) of 14,790 vehicles/day (CMF = 0.78).
- *Install new fluorescent curve signs or upgrade existing curve signs to fluorescent sheeting:* Fluorescent signs provide improved visibility, and can be used to reduce head-on, non-intersection, run-off-road, and sideswipe crashes (CMF = 0.82) on 2-lane undivided roadways, especially at night (CMF = 0.66) (see Figure 6.1).
- *Install High-Friction Surface Treatment (HFST):* This moderate- to high-cost countermeasure can help to keep vehicles in their lane, thus, reducing crash occurrence through horizontal curves (CMF = 0.15) (see Figure 6.2). Note: A recent study on the effectiveness and durability of HFST on rigid and flexible pavement projects in District 7 showed notable overall crash reductions.
- *Install Sequential Dynamic Curve Warning Systems (SDCWS) at locations with high crash frequency:* SDCWS are a moderate-cost countermeasure to reduce vehicle operating speeds and improve curve delineation (see Figure 6.3). Although the evaluation of the effectiveness of this countermeasure is ongoing, recent studies have found that the percentage of vehicles exceeding the posted and advisory speed limits was also lower after installing the SDCWS, and results were generally consistent across all time periods after implementation (FHWA, 2016). A CMF value for this countermeasure was not available.

6.1.1.2 Centerline Treatments

Potential centerline countermeasures to reduce head-on crash occurrence include:

- *Install centerline rumble strips on 2-lane undivided roadways:* Centerline rumble strips (see Figure 6.4(a)) are a relatively low-cost countermeasure used to help prevent lane departures and reduce opposite-direction head-on crash occurrence (CMF 0.63).
- *Install centerline buffer area on 2-lane undivided roadways:* Adding a paved buffer area between opposing lanes on 2-lane roadways can reduce the likelihood of head-on crash occurrence (see Figure 6.4(b)). A 2-ft centerline buffer area can reduce opposite-direction head-on crashes by 35 percent (CMF = 0.65), and this reduction increases with each additional foot of buffer area (NCHRP, 2022).

6.1.1.3 Shoulder Treatments

Potential shoulder countermeasures to reduce head-on crash occurrence include:

- *Install shoulder audible and vibratory treatments (AVTs) on 2-lane undivided roadways:* Overcorrection by vehicles that inadvertently veer onto the shoulder can contribute to head-on crash occurrence. AVTs, such as shoulder rumble strips, are a relatively low-cost countermeasure to help keep vehicles in the lane and reduce the potential for a head-on crash with an approaching vehicle (CMF = 0.68) (see Figure 6.5).
- *Install edge line audible and vibratory treatments (AVTs) on 2-lane undivided rural roadways:* Edge line rumble stripes are a low-cost countermeasure that can be used to help vehicles stay in the travelway and reduce run-off-road crashes on 2-lane undivided rural roadways, resulting in fatal to possible injury (CMF 0.67) (see Figure 6.5).
- *Widen edge lines from 4 inches to 6 inches on 2-lane rural roadways:* Widening edge line pavement stripes is a low-cost countermeasure to help prevent lane departures on 2-lane roadways and reduce head-on crash occurrence (CMF = 0.64) (see Figure 6.6). Note: 6-inch edge lines are currently the standard for all state roadways in Florida.
- *Install SafetyEdge^{SM} during all paving or resurfacing projects:* SafetyEdge^{SM} (FHWA, 2012) is an effective countermeasure for helping drivers that drift off the travelway, onto the shoulder, to return to the road safely, thus reducing the potential of losing control of the vehicle and colliding with on-coming traffic (FHWA, 2017). The SafetyEdge^{SM} is constructed with a low-cost paver attachment that enables the pavement edge to be paved and compacted to a finished 30-degree angle. Compacted backfill material is then installed on the shoulder and graded flush with the paved road surface, as shown in Figure 6.7(a) (FHWA, 2017). Over time, as the backfill material settles or erodes, the exposed angled SafetyEdge^{SM} provides a traversable surface, allowing vehicles to safely re-enter the travelway (see Figure 6.7(b)). With conventional paving techniques (i.e., graded backfill to the pavement edge), a vertical or near-vertical drop-off can develop at the pavement edge and cause tire-scrubbing, which may lead to loss of control of the vehicle (FHWA, 2017). This countermeasure can reduce head-on crashes by 19 percent on 2-lane rural roads (CMF = 0.81).

6.1.1.4 Median Treatments

Potential median countermeasures to reduce head-on crash occurrence include:

- *Install median barrier on multilane divided highways:* This moderate-cost countermeasure is used to minimize injury severity from cross-median head-on crashes on multilane facilities, such as principal arterials, by as much as 96 percent (CMF = 0.04). The CMF was developed based on the presence of a median barrier and includes all barrier types.
- *Install cable barriers:* Installing cable barriers is an effective moderate-cost countermeasure for reducing head-on crashes on divided highways (CMF = 0.56) (see Figure 6.8).
- *Regularly perform vegetation maintenance in medians:* Controlling vegetation growth, especially in curves, allows the driver to see the length of the required stopping sight distance for the associated speed (FHWA, 2008).

6.1.1.5 Intersections

Although the majority of head-on crashes in District 7 occurred on roadway tangent segments, and not at an intersection, a number of fatal and serious injury crashes have occurred at 4-way and T-intersections. However, few countermeasures for reducing head-on crashes at non-signalized intersections have been studied by the research community. The following options are presented as only possible countermeasures for reducing head-on crashes and/or injury severity at these locations:

- Installing warning beacons and signs at approaches to side streets.
- Adding warning beacons on top of signs at or near intersections.
- Installing stop signs bordered with solar powered flashing light-emitting diodes (LEDs).
- Providing clear pavement markings on all approaches.
- Installing High-Friction Surface Treatment (HFST) at intersection approaches.

6.1.1.6 Lighting

Dark or poor lighting conditions are associated with head-on crash occurrence and crash severity. To reduce the number of fatal and serious injury head-on crashes during nighttime conditions, the following countermeasures are recommended:

- *Install lighting on roadways without street lighting:* This moderate-cost countermeasure can reduce nighttime crashes and injury severity, in general, by as much as 28 percent (CMF = 0.72).
- *Install lighting at T-intersections and side streets on rural 2-lane roadways:* Installing a single luminaire at 3-leg and 4-leg rural intersections is a moderate-cost countermeasure that can reduce nighttime head-on crashes on 2-lane rural roadways by as much as 71 percent (CMF = 0.29).
- *Install street lights at crash hot-spot locations, as warranted.*

6.1.1.7 Speed Management Strategies

- *Lowering posted speed*: In hot-spot areas, where speed has been a contributing factor in head-on crashes, an engineering speed study can be conducted to determine if lowering the posted speed is warranted. This countermeasure will require a transition period, accompanied by information devices, such as variable message signs or posted signs, to inform the motoring public and allow motorists to adjust to the new speed limit. Nevertheless, lowering the posted speed to a speed limit that is not reasonable for the roadway classification or geometry may be ineffective in reducing actual traveling speeds.
- *Speed management strategies for low-speed facilities*: Several strategies outlined in the FDOT Design Manual may be implemented in the near term to achieve desired operating speeds on low-speed facilities and arterials and collectors when consistent with the context classification of the roadway (FDOT, 2024). These strategies include: speed feedback signs, posted speed pavement markings, Rectangular Rapid Flashing Beacons (RRFBs) and Pedestrian Hybrid Beacons (PHBs).

6.1.1.8 Roadside Objects

Removing or shielding roadside objects within the right-of-way or clear zone can reduce the potential of a head-on crash when a vehicle leaves the roadway. Head-on crash locations should be evaluated to determine if addressing roadside objects is warranted. Refer to the FDOT Design Manual for roadside safety requirements.

6.1.1.9 Combination Treatments

Several combined countermeasures on 2-lane roadways have been proven to be effective in reducing the number of head-on crashes and/or reducing the injury severity associated with head-on crashes. Combination treatments include:

- *Install centerline and shoulder rumble strips:* The combination of both centerline and shoulder rumble strips can reduce the occurrence of head-on crashes on 2-lane undivided rural roadways by nearly 37 percent (CMF 0.63).
- *Widen both center lines and edge lines from 4 inches to 5 inches on 2-lane rural roadways:* Research indicates that this low-cost countermeasure may have little impact on the total number of opposite-direction head-on crashes, but may reduce fatal and serious injury crashes by as much as 24 percent (CMF = 0.76) on 2-lane rural roadways (NCHRP, 2022). Note: 6-inch pavement stripes are currently the standard for all state roadways in Florida.

Because appropriate countermeasures to reduce head-on crashes are site-specific, more than one mitigation strategy may be warranted at any particular location. For example, an effective strategy at a location with several recorded head-on crashes may include a combination of speed reduction measures and improved lighting. Sites prone to head-on crash occurrence should be evaluated to determine the most effective combination treatment.

6.1.2 Education Countermeasures

Education efforts can be targeted to census block groups (CBGs) with a high number of head-on crash occurrences, identified hot spot locations, countywide, or Districtwide. Near-term education efforts may include:

- Brochures distributed to motorists when renewing a vehicle registration or driver license.
- Safety announcement emails to registered drivers using emails on file at the Florida Department of Highway Safety and Motor Vehicles (FLHSMV), if available.
- Public safety announcements using television or radio.

Educational programs on the potential hazards of distracted driving and speeding on two-lane roadways may better inform the public and promote safety. These programs should be tailored to the specific needs and characteristics of the affected areas. However, educational efforts may be more effective when combined with additional countermeasures.

6.1.3 Enforcement Countermeasures

Speed has been associated with head-on crash severity by a number of previous studies. However, enforcing speed limits presents challenges for authorities. Potential near-term countermeasures to encourage drivers to slow their speed include:

- *Driver feedback speed signs*: A speed feedback sign, as shown in Figure 6.9, is a relatively low-cost countermeasure that can be installed quickly to help inform drivers of their traveling speed, and encourage them to slow down. Speed feedback signs should be considered at hot-spot locations where speed has been a factor in head-on crash occurrence. Other locations on 2-lane roadways, where speed feedback signs may be used as a proactive measure, include horizontal curve approaches, sag vertical curve sections, and non-signalized intersection approaches.
- *Law enforcement decoy vehicles*: In most jurisdictions, the availability of law enforcement officers to enforce speed limits is often limited. One option to consider is periodic placement of decoy vehicles in areas where speeding is an issue. This action may encourage motorists to recognize their traveling speed and slow down. Note that the use of decoy vehicles may be subject to a number of restrictions, including location, availability, and jurisdictional policy.

6.1.4 Emergency Services

The type of response and actions needed by emergency services are generally incident-specific. In many cases, the need for traffic control, rescue units, life-flight helicopters, and ambulance services must be assessed onsite following a crash. However, emergency services need can be anticipated when a head-on crash is reported. Near-term action plans may include:

- Coordination with first responder agencies on identified head-on crash hot spot locations to help the agencies plan accordingly for potential response needs.

6.1.5 Evaluation Processes

Near-term evaluation processes include head-on crash analyses and site evaluations, as follows:

- *Crash analyses*: As a part of this research effort, crash analyses were performed on head-on crashes that occurred in years 2018–2022. Additional crash analyses are recommended for years 2023 – 2025 in hot spot areas, especially if engineering countermeasures have been implemented.
- *Site evaluation*: Site conditions should be examined for crash sites with a high number of head-on crash occurrences, as well as hot spot areas, to determine appropriate engineering countermeasures.

Table 6.1: Crash Modification Factors (CMFs) for Head-On Crash Countermeasures

Countermeasure		Project Cost	CMF	CMF Clearinghouse ID / Source	CRF
Centerline	Install centerline rumble strips.	Low	0.63	3355	37
Centerline	Install centerline buffer area (2 feet).	Moderate	0.65	NCHRP (2022)	35
Shoulders	Widen edge line pavement stripes from 4 inches to 6 inches on 2-lane rural roadways.	Low	0.64	4737	36.5
Shoulders	Install shoulder rumble strips.	Low	0.68	10449	32
Shoulders	Install edge line rumble strips on 2-lane undivided roadways.	Low	0.67	3394	33
Shoulders	Install SafetyEdge^{SM}.	Low	0.81	9217	18.7
Shoulders	Widen unpaved shoulders to >5 feet on 2-lane rural roadways.	High	0.21	5404	79
Shoulders	Widen 6-ft paved shoulders to 8 feet on 2-lane rural roadways.	High	0.87	5168	13
Medians	Widen existing 10-ft median on rural divided highways to: • 20 feet • 40 feet • 60 feet • 80 feet	High	0.84 0.60 0.43 0.31	4523 4534 4545 4555	16 40 57 69
Medians	Install median barrier on multilane divided highways.	Moderate	0.04	7042	96
Medians	Install cable median barrier.	Moderate	0.56	9395	44
Horizontal Curves	Improve horizontal curve delineation on 2-lane undivided roadways	Low	0.75	10614	25.4
Horizontal Curves	Install chevron signs on horizontal curves.	Low	0.78	2440	22
Horizontal Curves	Install new fluorescent curve signs or upgrade existing curve signs to fluorescent sheeting. • For nighttime conditions	Low Low	0.82 0.66	2432 2435	18 34
Horizontal Curves	Install high friction surface treatment (HFST)	Moderate	0.515	10333	48.5
Lighting	Install street lighting.	Moderate	0.72	7780	28
Lighting	Install lighting at rural intersections.	Moderate	0.29	9029	71
Combinations	Install centerline and shoulder rumble strips.	Low	0.63	6853	36.8
Combinations	Widen both center lines and edge lines from 4 inches to 5 inches on 2-lane rural roadways.	Low	0.76	NCHRP (2022)	24
Other	Install alternating / periodic passing lanes on rural 2-lane undivided highways.	High	0.65	4082	35

Note: Project Cost Source: NCHRP (2022); CMF = Crash Modification Factor; CRF = Crash Reduction Factor.

(a) Curve warning sign with advisory speed

(b) Chevron signs with retroreflective strips on sign posts

Figure 6.1: Examples of Curve Signs (FHWA, 2016)

(a) HFST installation

(b) HFST after installation

Figure 6.2: High-Friction Surface Treatment (HFST) (Merritt et al., 2020)

Figure 6.3: Sequential Dynamic Curve Warning Systems (SDCWS) (FHWA, 2016)

(a) Centerline rumble strips
(FHWA, 2023)

(b) Centerline buffer area
(FHWA, 2022a)

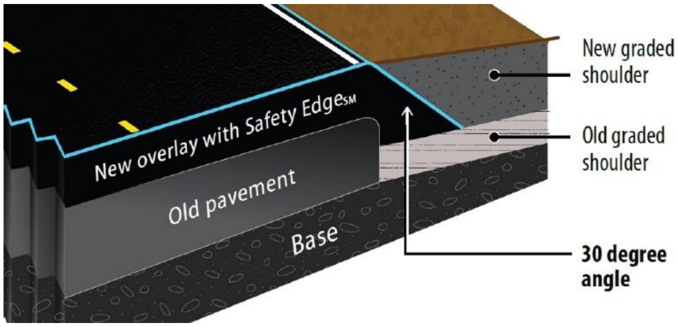
Figure 6.4: Examples of Centerline Countermeasures

(a) Shoulder rumble strips
(FHWA, 2023)

(b) Edge line rumble strips
(FHWA, 2018)

Figure 6.5: Examples of Shoulder Rumble Strips

Figure 6.6: Wider Edge Line Example (FHWA, 2021b)



(a) SafetyEdge^{SM} after installation.

(b) SafetyEdge^{SM} after backfill settles or erodes.

Figure 6.7: SafetyEdge^{SM} Examples (FHWA, 2017)

Figure 6.8: Cable Median Barrier (Schmaltz, 2016)

Figure 6.9: Driver Feedback Speed Sign (Radarsign^{TM}, 2023)

6.2 Long-Term Action Plans

Long-term action plans for mitigating head-on crashes generally consist of high-cost strategies that require a greater degree of design and planning prior to implementation, as well as continued research efforts. In addition to considering near-term countermeasures, new facilities and future roadway improvements should be designed and planned to reduce the potential risk of head-on crashes, especially in hot spot areas. The following subsections discuss suggested countermeasures to consider.

6.2.1 Engineering Countermeasures

Long-term engineering actions focus on countermeasures to be considered during the design and planning of new or improved roadways. In addition to near-term strategies for reducing head-on crashes and injury severity, several high-cost mitigation strategies for long-term safety goals may include passing lanes, lower posted speeds, widening shoulders, widening medians, and adding lighting. Table 6.1 presents the CMFs, and corresponding CRFs, currently available for high-cost engineering countermeasures.

6.2.1.1 Passing Lanes

- Installing alternating / periodic passing lanes on rural 2-lane undivided highways: Adding periodic passing lanes on rural 2-lane roadways is a high-cost countermeasure that can reduce head-on injury crashes by up to 35 percent (CMF = 0.65).

6.2.1.2 Speed Management Strategies

- *Lower speed limits*: For new facilities, lower posted speed limits can be considered during the planning phase. Consideration should be based on findings from engineering speed studies conducted on similar facilities or locations, as well as the propensity of head-on crash occurrence at the study sites. Posted speed limits should also be reasonable for the roadway classification and design geometry.
- *Speed management strategies for low-speed facilities*: Consider speed management strategies outlined in the FDOT Design Manual to achieve desired operating speeds for new low-speed facilities and programed improvements.

6.2.1.3 Horizontal Curves

- Horizontal curve geometry: Evaluate the existing curves in District 7 to determine length, radius, super elevation, etc. This effort can help to identify deficiencies and implement appropriate curve correction measures and/or the potential countermeasures.

6.2.1.4 Shoulders

A majority of head-on crashes occur when vehicles leave their respective travelway, especially on 2-lane roadways. To help drivers stay in the lane and reduce the risk of colliding with on-coming traffic, the following high-cost shoulder countermeasures should be considered:

- Widen unpaved shoulder width to greater than 5 feet on 2-lane rural roadways: (CMF = 0.21).
- Widen 6-ft paved shoulder width to 8 feet on 2-lane rural roadways: (CMF = 0.87).

6.2.1.5 Medians

Proven median countermeasures to reduce head-on crashes on 2-lane or multilane highways include:

- Increasing median width on rural divided highways: Converting an existing 10-ft median on rural highways to 20 ft, 40 ft, 60 ft, and 80 ft can reduce the number of cross-median head-on crashes by up to 16 percent (CMF = 0.84), 40 percent (CMF = 0.60), 57 percent (CMF = 0.43), and 69 percent (CMF = 0.31), respectively.

6.2.1.6 Intersections

New intersections and planned intersection improvements should consider the potential of head-on crash occurrence during the planning and design phases. To reduce the risk of head-on crashes at intersections, the following assessments should be conducted:

- Assess the need for lighting at 4-way and T-intersections (3-leg), especially in rural areas.
- Assess the need for additional or improved pavement markings on all approaches.

6.2.1.7 Lighting

Lighting should be considered for new facilities and planned roadway improvements, especially for locations outside of urban areas, to reduce potential head-on crashes. Recommended lighting installation locations include:

- Lighting on rural 2-lane highways at approaches to curves, hillcrests, and sag tangent sections.
- Lighting at T-intersections and side streets, especially in rural areas.

6.2.1.8 Wrong-Way Driving (WWD)

Wrong-way driving (WWD) often results in head-on crashes. Locations, such as intersections and divided highways, should be evaluated for the potential of WWD incidents. Countermeasures to mitigate WWD crashes are typically site-specific, based on a number of factors, such as location, roadway characteristics, and target driving group. Potential countermeasures may include:

- Red-Rectangular Rapid Flashing Beacons (Red-RRFBs).
- Red flush-mount internally illuminated raised pavement markers (iiRPMs).
- LED lights around WRONG WAY signs.

In addition, Section 3.12 lists several potential countermeasures to mitigate WWD crashes on arterials, which often result in head-on collisions.

6.2.2 Education Countermeasures

A long-term educational campaign should expand on near-term initiatives, with greater planning and coordination among various agencies. To be effective in reducing future head-on crashes, a long-term educational program must be wide in scope and persistent. Not only should the focus be on the general motoring public, but also on new and inexperienced drivers, especially teenage and young adult drivers. In addition to near-term education efforts, long-term education initiatives may include:

- Adding additional safety components to the driver license exam to alert new/beginner drivers of potential roadway characteristics with a higher risk of head-on crash occurrence, such as hillcrest and sag roadway sections, curves, and 2-lane roadways.
- Coordinating with driver education/training course providers to educate new and inexperienced drivers on the potential risk of head-on crashes and promote awareness of roadway factors associated with head-on crash occurrence and injury severity.
- Consider establishing *Crash Awareness Days* or a *Crash Awareness Month* to remind the public of safety measures, such as avoiding head-on crashes, minimize distracted driving, lowering speeds during wet/inclement weather conditions, and current safety laws, such hands-free driving. *Crash Awareness Days* could also be promoted at local high schools and colleges, as an aggressive attempt to educate teenage and young adult drivers. Radio and television could also reach a larger audience.

6.2.3 Enforcement

At locations where speed is a contributing factor in head-on crash occurrence, more aggressive actions may be needed to enforce speed limits. In addition to near-term countermeasures, long-term actions may include:

- Regular presence of speed enforcement officers.
- Photo radar technology: Automated speed enforcement cameras may be installed in areas where speeding is a contributing factor in head-on collisions (see Figure 6.9). These devices automatically detect and record speeding vehicles and issue tickets to the address associated with the vehicle registration. Careful consideration should be taken in determining the placement of these devices. In addition, the use of photo enforcement devices may be limited or restricted, based on location and local or jurisdictional policies.

Figure 6.9: Photo Radar Camera Example (Keller, 2022)

6.2.4 Emergency Services

Long-term action plans should involve continued coordination with first responder agencies, especially as hot spot head-on crash locations change over time. This allows each emergency service agency to better prepare for crash response needs, as well as the needs of the community.

6.2.5 Research Actions

Long-term solutions to reduce head-on crashes will require a comprehensive research effort. Performance measures (i.e., CMFs) available through the CMF Clearinghouse are based on previous studies conducted in a number of states. However, factors associated with head-on crashes in Florida may differ from these previous studies. Accurate CMFs, specific to factors associated with Florida head-on crashes, need to be developed. A long-term research program should be established to include:

- Periodic crash analyses to determine head-on crash trends and identify crash hot spots
- Future before-and-after crash analyses to evaluate engineering countermeasures and establish Florida-specific CMFs

6.3 Hot Spot Locations

Locations identified from crash analyses as hot spots are presented in a separate Excel® file accompanying this report. The Excel® file includes a total of 459 state highway segments, spanning 185.19 miles, that exist within the identified hot spot regions in FDOT District 7. This information is provided to assist agency personnel with determining specific countermeasures at each location. The supplemental Excel® file includes the following variables:

- Roadway ID
- Begin Milepost

- End Milepost
- Segment Length
- Median Type (if divided)
- Speed Limit
- Functional Classification
- AADT
- Number of Lanes
- Surface Width
- Roadway Type
- Inside Shoulder Type – Left
- Inside Shoulder Type – Right
- Outside Shoulder Type – Left
- Outside Shoulder Type – Right
- Outside Shoulder Type – Center
- Average Inside Shoulder Width
- Average Outside Shoulder Width
- Presence of Horizontal Curve
- Recommended Countermeasure: Chevrons
- Recommended Countermeasure: Rumble Strips

6.4 Chapter Summary

To reduce the number of head-on crashes, this research effort conducted a comprehensive study on factors contributing to head-on crash occurrence and injury severity. This report, Deliverable 4, presented recommended near-term and long-term action plans to mitigate head-on crashes in District 7.

Actions plans were developed with respect to the 4E's of traffic safety: Engineering, Education, Enforcement, and Emergency Services, with Engineering the lead 'E'. Near-term action plans focus on relatively low- to moderate-cost strategies that may implemented in the near future. Long-term action plans consist of high-cost strategies that require more planning and design efforts.

Low- to moderate-cost engineering countermeasures that may be implemented in the near term include:

- Audible and Vibratory Treatments (i.e., centerline, shoulder, and edge line rumble strips)
- Widen edge lines from 4 inches to 6 inches
- SafetyEdge^{SM}
- Median barriers
- Improving curve delineation
- Chevron signs on horizontal curves
- New fluorescent curve signs or fluorescent sheeting on existing sign
- Sequential Dynamic Curve Warning Systems (SDCWS)
- Improve pavement friction and skid resistance
- High-Friction Surface Treatment (HFST)

- Street or intersection lighting
- Wider center lines and edge lines

High-cost engineering countermeasures that should be considered with long-term action plans include:

- Widen unpaved and paved shoulders,
- Widen existing median, and
- Alternating / periodic passing lanes.

Potential Education, Enforcement, and Emergency Services action plans, and recommendations for continued research in Florida were also presented. Since head-on crashes often result in fatal or serious injury, mitigation efforts to minimize this crash type could not only improve safety for the motoring public, but also save lives.

CHAPTER 7
CONCLUSIONS

While head-on crashes generally constitute a small proportion of total crash occurrences, they often result in fatal and incapacitating injuries. As a result, many agencies are exploring strategies to mitigate head-on crashes and resulting injury severity. This research examined head-on crashes that occurred in Florida Department of Transportation's District 7 during the years 2018–2022. A total of 4,309 head-on crashes within the five-year study period were analyzed. A comprehensive literature review of previous studies related to head-on crash occurrence and injury severity was conducted. Proven countermeasures were also researched and presented.

Crash data were analyzed using descriptive statistics, police crash reports, and spatial analyses to determine contributing factors associated with head-on crashes, as well as crash patterns and trends. Primary roadway factors associated with the head-on crashes analyzed include: straight roadway segments, no physical barriers present (i.e., guard rails, cable, or concrete barriers), roadways with vegetation medians, locations with reflective pavement markers (RPMs) installed, and dark unlighted areas.

A total of 505 police crash reports were reviewed for head-on crashes that resulted in fatal and serious (FS) injuries to explore crash patterns. Site evaluations were conducted for each of the reported head-on crashes to identify roadway factors associated with these FS crashes.

Hot spots were determined using an optimized hot spot analysis of crash data and geographical data. Model results revealed 215 hot spots, all located in Hillsborough County in District 7. Locations identified from crash analyses as hot spots are presented in a separate Excel® file accompanying this report.

Crash modification factors were developed based on a cross-sectional analysis of crash data and roadway characteristics. Findings revealed that a curb and gutter inside shoulder offers the greatest reduction in FS head-on crashes for urban arterials (CMF = 0.68). Compared to undivided roadways, a median offers the greatest reduction in FS crashes for urban collectors (CMF = 0.21).

Near-term and long-term action plans to mitigate head-on crashes in FDOT District 7 were also presented. The proposed countermeasures focus on the 4E's of traffic safety: Engineering, Education, Enforcement, and Emergency Services.

Understanding the factors associated with head-on crashes is essential for determining appropriate countermeasures to reduce head-on crash occurrence and injury severity. Findings from this research can assist FDOT and other transportation agencies in developing effective mitigation strategies.

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APPENDIX A:
STREET-LEVEL ANALYSIS OF HEAD-ON CRASHES

Table A.1: Citrus County Fatal and Serious Injury Head-On Crash Counts

County	Fatal Crashes	Serious Injury Crashes	Total
Citrus	**17**	**34**	**51**
Citrus Ave N		1	1
County Road 488		1	1
County Road 488 (W Dunnellon Rd)		1	1
County Road 490 (W Homosassa Trail)	1		1
County Road 491 (S Lecanto Highway)	1		1
County Road 495	2	1	3
County Road 495 (N Citrus Ave)		1	1
County Road 581 (Pleasant Grove Rd)	1		1
County Road 581 (S Pleasant Grove Rd)		1	1
CR-488 (W Dunnellon Rd)		1	1
CR-486 (W Norvell Bryant Hwy)		1	1
CR-491 (S Lecanto Highway)		1	1
East Withlacoochee Trail		1	1
Gulf To Lake Hwy E		1	1
N Croft Avenue		1	1
N Knoll Rd		1	1
N Lecanto Highway		1	1
N Suncoast Blvd		1	1
S Florida Ave		1	1
S Lecanto Hwy		1	1
Se Kings Bay Dr		1	1
SR-200 (N Carl G Rose Hwy)	1		1
State Road 200		1	1
State Road 200 (N Carl G Rose Hwy)		1	1
State Road 200 (N Carl G Rose Hwy)	1		1
State Road 44	1	3	4
State Road 44 (E Gulf To Lake Hwy)	1		1
State Road 44 (East Gulf-To-Lake Highway)	1		1
State Road 44 (Gulf To Lake Highway)	1		1
State Road 44 (West Gulf To Lake Highway)	1		1
State Road 48 (E Bushnell Rd)		1	1
Turkey Oak Drive		1	1
US Highway 19 (North Suncoast Blvd)		1	1
US Highway 19 (State Road 55)	1		1
US Highway 19 (State Road 55/N Suncoast Blvd)	1		1
US Highway 41		2	2
US Highway 41 (North Florida Avenue)	1		1
US Highway 41 (S Florida Avenue)	1		1
US Highway 41 (South Florida Ave)		1	1

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.1: Citrus County Fatal and Serious Injury Head-On Crash Counts (cont'd)

County	Fatal Crashes	Serious Injury Crashes	Total
Citrus	**17**	**34**	**51**
US-19		1	1
US-41		1	1
W Dunnellon Rd (CR-488)		1	1
W Grover Cleveland Blvd		1	1
W Halls River Rd		1	1
W Homosassa Trail	1		1

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.2: Hernando County Fatal and Serious Injury Head-On Crash Counts

County (Roadway Streets)	Fatal Crashes	Serious Injury Crashes	Total
Hernando	**13**	**35**	**48**
Barclay Ave		1	1
Commercial Way		1	1
Corporate Blvd	1	1	2
County Line Road		1	1
County Road 491 (Citrus Way)		1	1
County Road 493 (Sunshine Grove Rd)	1		1
County Road 541		1	1
County Road 570 (Wiscon Road)	1	1	2
County Road 576 (Ayers Road)		1	1
County Road 597		1	1
Countyline Rd		1	1
CR-574 (Spring Hill Dr)		1	1
CR-476 (Lake Lindsey Rd)		1	1
CR-578 (County Line Rd)		1	1
CR-585 (Anderson Snow Rd)	1		1
Fordham St		1	1
Hayman Road		1	1
Jacobson Road		1	1
Mariner Blvd		4	4
NB SR-589	1		1
Sharon Ct		1	1
Shoal Line Boulevard		1	1
Spring Hill Drive		1	1
SR-50 (Cortez Blvd)		1	1
State Road 50		2	2
State Road 50 (Cortez Blvd)	1		1
State Road 50 (Cortez Blvd)	3	2	5
State Road 589 (Suncoast Pkwy)	1		1
US-19 (COMMERCIAL WAY)		1	1
US-19 (SR-55)		1	1
US-41 (SR-45)		1	1
US Highway 19		2	2
US Highway 41 (Broad Street)		1	1
US Highway 41 (North Broad Street)	1		1
US Highway 41 (S Broad Street)	1		1
US Highway 41 (State Road 45)	1		1
US Highway 98 (Mckethan Road)		1	1

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.3: Hillsborough County Fatal and Serious Injury Head-On Crash Counts

County (Roadway Streets)	Fatal Crashes	Serious Injury Crashes	Total
Hillsborough	**61**	**112**	**173**
15th St N		1	1
50th St N		1	1
Adamo Dr	1		1
Alexander St N	1		1
Anderson Rd	1		1
Avenue SE		1	1
Bell Shoals Rd		1	1
Big Bend Rd		1	1
Bloomingdale Ave		1	1
Bloomingdale Ave		1	1
Boyette Rd	1	1	2
Busch Blvd E		1	1
Countryway Blvd		1	1
County Line Rd	1		1
County Rd 640 (Lithia Pinecrest Rd)	1		1
County Road 672	2		2
CR-39 S	1		1
CR-579		1	1
CR-579 N		1	1
CR-582 (Bearss Ave W)		1	1
CR-587 (Gunn Hwy)		2	2
CR-672 (Balm Rd)		1	1
CR-672 (Big Bend Rd)		1	1
CR-579 (Morris Bridge Rd)	1		1
Deb Silas Way		1	1
Dover Rd N		1	1
Dover Road South		1	1
E Bird St		1	1
E Fowler Ave		1	1
E Sligh Ave		1	1
East Bay Rd		1	1
Fishhawk Blvd		1	1
Fletcher Ave W	1	1	2
Fowler Ave E		1	1
Gandy Blvd W		1	1
George J Bean Pkwy	1		1
Glenshire Dr		1	1
Grady Ave N		1	1
Harney Rd		2	2

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.3: Hillsborough County Fatal and Serious Injury Head-On Crash Counts (cont'd)

County (Roadway Streets)	Fatal Crashes	Serious Injury Crashes	Total
Hillsborough	**61**	**112**	**173**
Heather Lakes Blvd		1	1
Hillsborough Ave E		1	1
Hillsborough Ave		1	1
Hutchison Rd		1	1
H.W. E		1	1
H.W. S	1	1	2
Hwy 301 (SR-43)		1	1
I-275 NB (SR-93)	1		1
Interstate 275	1		1
Interstate 4 (SR-400)	1		1
James L Redman Pkwy		1	1
Keysville Rd E	1		1
Kings Bl		1	1
Knights Griffin Rd	1	1	2
Lakewood Dr		2	2
Lee Roy Selmon Exp	1		1
Lithia Pinecrest Rd	1		1
Manhattan Ave N		1	1
Mcintosh Rd		1	1
Morris Bridge	1		1
Morris Bridge Rd		1	1
N 22nd St		1	1
N 50th St		1	1
N Armenia Ave		1	1
N Boulevard	1		1
N Himes Ave	1		1
N Valrico Rd		1	1
NB US Highway 301 (State Road 43)		1	1
NB US Highway 301 (State Road 43)	1		1
North St		1	1
Nundy Ave		1	1
Palm River Rd	1	1	2
Park Rd	1		1
Parke East Blvd		1	1
Patterson Rd	2	1	3
Paul Buchman Highway (SR-39)	1		1
Rhodine Rd		2	2
Rowlett Park Dr		1	1
Rowlett Park Dr N		1	1

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.3: Hillsborough County Fatal and Serious Injury Head-On Crash Counts (cont'd)

County (Roadway Streets)	Fatal Crashes	Serious Injury Crashes	Total
Hillsborough	**61**	**112**	**173**
S 22nd St		1	1
S Manhattan Ave		1	1
S West Shore Blvd	1	2	3
SB Interstate 275 (State Road 93)	1		1
SB I-275 (SR-93)		1	1
SB US-301		1	1
Shell Point Rd E	1		1
South Mobley Rd		1	1
SR-45 (Hwy 41 S)		1	1
SR-580 (Busch BL W)		1	1
SR-597 Dale Mabry Hwy N		1	1
SR-60 (E Brandon Blvd)	1		1
SR-674		2	2
SR-39 (Paul Buchman Highway)	1		1
SR-39 (Paul Buchman Hwy)	1	1	2
SR-43 (S 301 Hwy)		1	1
SR-574		1	1
SR-574 (Dr MLK Jr Blvd)		1	1
SR-574 (Dr MLK Jr Blvd)		1	1
SR-60 (Adamo Drive)		1	1
SR-60 W		1	1
S.T. S		1	1
State Road 574		1	1
State Road 580		1	1
State Road 597 (Dale Mabry Hwy)	1		1
State Road 60	2		2
State Road 674	1		1
State Road 674 (SR-674)	1		1
Street NB		1	1
Sydney Rd	1		1
Symmes Rd	1	1	2
Turkey Creek Rd		1	1
US HWY 301 (State Road 41)	1		1
US-301 (State Road 43)		1	1
US HWY 301	1		1
US HWY 92		1	1
US-41 SB	1		1
US-301		1	1
US-301 (SR-43)	3	1	4

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.3: Hillsborough County Fatal and Serious Injury Head-On Crash Counts (cont'd)

County (Roadway Streets)	Fatal Crashes	Serious Injury Crashes	Total
Hillsborough	**61**	**112**	**173**
US-92 (SR-600)	1		1
US Highway 301	2		2
US Highway 301	1		1
US-301		2	2
US-301 (SR-41)	1		1
US-301 (SR-41)	1		1
US301 (SR-43)		1	1
US-301 (SR-43)		1	1
US-301 State Road 43	1		1
US-41		1	1
US-92	1	1	2
US-92 (E Hillsborough Ave)	1		1
Valrico Rd N	1		1
Veterans Expwy (State Road 589)		1	1
W Baker St		1	1
W Bloomingdale Ave		1	1
W Columbus Dr		3	3
W Dr Martin Luther King Jr Blvd	1		1
W Hillsborough Ave		1	1
W Knights Griffin Rd		1	1
W Pine St		1	1
W Rembrandt Dr		1	1
W Waters Ave	1		1
State Road 580 WB (Hillsborough Ave)		1	1
Webb Rd		1	1
West Shore Blvd		1	1
Willow Rd		1	1
Windhorst Rd E		1	1
Windhorst Rd W	1		1
Windsor Wy		1	1

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.4: Pasco County Fatal and Serious Injury Head-On Crash Counts

County	Fatal Crashes	Serious Injury Crashes	Total
Pasco	**33**	**128**	**161**
21st Street		1	1
3401 Paul S Buchman Hwy		1	1
7th Street		1	1
8515 Little Road		1	1
Aripeka Road		1	1
Baileys Bluff Road		1	1
Blanton Road		2	2
Boyette Rd		1	1
Cecelia Dr		1	1
Chancy Rd		1	1
Collier Pkwy		1	1
County Rd 1 (Little Rd)		1	1
County Rd 41 (Blanton Rd)		1	1
County Rd 587 (Decubellis Rd)		1	1
County Road 1 (Little Road)		1	1
County Road 35a (Old Lakeland Highway)		1	1
County Road 41 (CR-41 Blanton Road)		1	1
County Road 41 (Blanton Road)		1	1
County Road 41 (Fort King Road)		1	1
County Road 524 (Ridge Road)		1	1
County Road 535 (Chancey Road)	1		1
County Road 54	1	1	2
County Road 54 (Eiland Blvd)	1		1
County Road 54 (Wesley Chapel Blvd)		1	1
County Road 577 (Curley Rd)		1	1
County Road 578 (County Line Rd)	1		1
County Road 579 (Handcart Rd)		1	1
County Road 579a (Prospect Rd)	1		1
County Road 581 (Bellamy Brothers Blvd)		2	2
County Road 581 (Bellamy Brothers Blvd)		1	1
County Road 587 (Decubellis Road)		1	1
County Road 587 (Decubellis Road)		1	1
County Road 587 (Moon Lake Road)	1		1
County Road 77 (Rowan Road)	1		1
County Road 77 (Seven Springs Blvd)	1	1	2
CR 535 (Old Lakeland Highway)		1	1
CR-1 (Little Rd)	1		1
CR-1 (Little Rd)		1	1
CR-35ALT (Old Lakeland Highway)		1	1

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.4: Pasco County Fatal and Serious Injury Head-On Crash Counts (cont'd)

County	Fatal Crashes	Serious Injury Crashes	Total
Pasco	**33**	**128**	**161**
CR-54		1	1
CR-54 (Eiland Blvd)		2	2
CR-577 (Curley Rd)		1	1
CR-579 (Morris Bridge Rd)		1	1
CR-579 (Prospect Rd)		1	1
CR-587 (Massachusetts Ave)		1	1
Dayflower Blvd		1	1
Denton Ave	1		1
Denton Ave		1	1
East County Line Rd		1	1
East Rd	1	1	2
Ehren Cutoff CR-583		1	1
Eiland Blvd	1	1	2
Eiland Blvd		1	1
Embassy Blvd	1		1
Florida Ave		1	1
Fort King Rd		1	1
Happy Hills Rd		1	1
Holiday Lake Dr		1	1
Hudson Ave		1	1
HWY 54		1	1
I-75		1	1
I-75 (SR-93) SB MM 275		1	1
Interstate 75 (State Road 93)	1		1
Interstate 75 NB MM 281		1	1
Jasmine Blvd		1	1
Kiefer Rd		1	1
Kitten Trail		2	2
Lake Patience Rd		1	1
Leonard Road		1	1
Little Ranch Road		1	1
Main St		1	1
Majestic Boulevard		1	1
Oakstead Blvd.		1	1
Old Pasco Rd		2	2
Osteen Rd		1	1
Palm St		1	1
Panorama Ave		1	1
Parkway Blvd		1	1

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.4: Pasco County Fatal and Serious Injury Head-On Crash Counts (cont'd)

County	Fatal Crashes	Serious Injury Crashes	Total
Pasco	**33**	**128**	**161**
Perrine Ranch Rd		2	2
Ridge Rd		1	1
River Rd		1	1
Rockledge Ave		1	1
San Angela Dr		1	1
Seven Springs Blvd and Jenner Ave		1	1
Shady Hills Rd		2	2
Shady Hills Rd		2	2
SR-52		1	1
SR-471	1		1
SR-54	1	1	2
SR-56		2	2
Starkey Boulevard		1	1
State Road -54		1	1
State Road 52	1		1
State Road 39		1	1
State Road 41 (Gall Blvd)		1	1
State Road 52	3	5	8
State Road 54	4	9	13
State Road 56	1	1	2
State Road 575	1		1
State Road 589 (Suncoast Pkwy)		1	1
Trinity Blvd		1	1
US Highway 41 (State Road 45)	1		1
US-19 (State Road 55)		2	2
US Highway 19		1	1
US HWY 98		1	1
US HWY.98	1		1
US-19		1	1
US-41 (State Road 45)		1	1
US-98 (State Road 35)	1		1
US-98 (State Road 700)		1	1
US-98 (Old Lakeland Hwy)		1	1
US Highway 19		1	1
US Highway 19 (State Road 55)		2	2
US Highway 301		1	1
US Highway 301 (SR-35)	1		1
US Highway 41 (State Road 45)	1		1
US Highway 98		1	1

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.4: Pasco County Fatal and Serious Injury Head-On Crash Counts (cont'd)

County	Fatal Crashes	Serious Injury Crashes	Total
Pasco	**33**	**128**	**161**
US Hwy 98 (State Road 35)	1		1
US-301		1	1
US-301 (SR-35)	1		1
US-41 (State Road 45)		1	1
US-41 (State Road 45)		1	1
US-98		1	1
US-98 (State Road 35)		1	1
Zimmerman Road		1	1

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.5: Pinellas County Fatal and Serious Injury Head-On Crash Counts

County	Fatal Crashes	Serious Injury Crashes	Total
Pinellas	**15**	**57**	**72**
10th Ave NE		1	1
110th Ave N		1	1
13th Ave N		1	1
22nd Ave N		1	1
22nd Ave S		3	3
22nd St S		1	1
34th St S		1	1
38th Ave N		1	1
49th St N		2	2
4th St S		1	1
53rd St S		1	1
54th Ave N		1	1
54th Ave N.		1	1
5th Ave N	1		1
62nd Ave		1	1
62nd Ave S		1	1
62nd St N		1	1
66th St N	2		2
94th Ave N		1	1
9th Ave N		1	1
9th St N		1	1
Belleair Rd	1		1
Burlington Ave N		1	1
Clearwater Largo Rd	1		1
County Road 202 (54th Ave N)		1	1
County Road 681 (28th Street N)		1	1
County Road 752 (Tampa Road)	1		1
CR-138 (Gulfport Blvd S)		1	1
CR-611 (N McMullen Booth Rd)	1		1
CR-752 (Tampa Rd)		1	1
CR-1 N	1		1
Dr MLK St N		1	1
Dr Martin Luther King Jr St S		1	1
Drew St	1		1
East Bay Dr		1	1
Gateway Centre Blvd N		1	1
Gulf Blvd	1	1	2
Gulf To Bay Blvd		1	1
Gulfport Blvd S		1	1

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).

Table A.5: Pinellas County Fatal and Serious Injury Head-On Crash Counts (cont'd)

County	Fatal Crashes	Serious Injury Crashes	Total
Pinellas	**15**	**57**	**72**
Hibiscus Ave S		1	1
Howard Frankland Bridge NB I-275		1	1
Indian Rocks Rd		1	1
Interstate 275		1	1
Interstate 275 (SR-93) SB MM 28		1	1
Interstate 275 SB (I-275)	1		1
Jamaica Way		1	1
Keene Rd	1		1
Main St		1	1
McMullen Booth Rd (CR-611)		1	1
N Betty Ln		2	2
Nursery Road		1	1
Palm Harbor Blvd (US Alt 19)		1	1
Park Blvd N		1	1
Park St N		1	1
S Fort Harrison Ave	1		1
S Gulfview Blvd		2	2
SR-688 (Ulmerton Rd)		1	1
SR-694 (Gandy Blvd)		1	1
SR-693 (66th St N)	1		1
State Road 686 (Roosevelt Blvd) EB		1	1
US 19 N (SR-55)		1	1
US Highway 19 N	1	2	3
US-19-ALT		1	1

Note: Highlighted cells indicate locations with two or more total fatal and/or serious injury head-on crashes during the study period (2018–2022).