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Before Study Evaluation of Interstate 4 (I-4) Florida's Regional Advanced Mobility Elements (FRAME) Project (Before Analysis)

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DISCLAIMER

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UNITS CONVERSION

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
AREA				
in^2	square inches	645.2	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	2.59	square kilometers	km^2
	WHEN YOU KNOW	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric	Mg (or "t")
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
TEMPERATURE (exact degrees)				
ºF	Fahrenheit	5 (F-32)/9	Celsius	ºC
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
FORCE and PRESSURE or STRESS				
lbf	pound force	4.45	newtons	N

lbf/in^2	pound force per square inch	6.89	kilopascals	kPa
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
AREA				
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	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
VOLUME				
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
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
FORCE and PRESSURE or STRESS				
N	newtons	0.225	pound force	lbf
kPa	kilopascals	0.145	pound force per square	lbf/in^2

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The primary objectives of this project were to evaluate the safety and mobility conditions along the I-4 corridor from Orlando to Tampa as a part of Interstate 4 (I-4) Florida's Regional Advanced Mobility Elements' (FRAME) integrated corridor management (ICM). Since UCF's main role will be to identify safety challenges on the project corridors and document how the I-4 FRAME project will address these challenges, this report has mainly focused on the corridor level and segment level analyses for freeways, and intersection and segment level analyses for arterials. For safety analyses, crash data are collected from the Signal Four Analytics (S4A) and State Safety Office Geographic Information System (SSOGIS) to ensure the maximum coverage of the crash information. During this crash data collection, crash numbers, crash types, different crash severities, work zone-related crashes, and weather information were collected and analyzed. From the perspectives of the crash rates, different crash types, and crash severities, the main safety challenges on the intersections and segments were identified. For mobility analyses, traffic data were collected and analyzed using Microwave Vehicle Detection System (MVDS) and National Performance Management Research Data Set (NPMRDS) data sources. Average travel time and speed and travel time reliability measures were used to analyze the mobility conditions of the studied area. Extensive analyses for safety and mobility evaluation have been performed and possible justification of such findings have been added. This study summarizes the overall safety and mobility evaluation before the new technologies are implemented and will be used to compare with safety and mobility issues after the technologies are implemented.</td></tr>
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EXECUTIVE SUMMARY

The Florida Department of Transportation (FDOT) created the Interstate 4 (I-4) Florida's Regional Advanced Mobility Elements (FRAME) project to address the safety and mobility issues along the I-4 from Tampa to Orlando. The I-4 FRAME project will deploy an advanced integrated corridor management system consisting of next-generation traffic incident management, work zone traffic management, road weather alerts, freeway back-of-queue warning, wrong-way driving, and speed harmonization message systems using vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) technologies. The United States Department of Transportation selected the I-4 FRAME project for its Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) grant. As part of the grant obligations, UCF has conducted before analysis on the emerging technologies in this report.

I-4 FRAME project spans three FDOT Districts (One, Five, and Seven), and Florida's Turnpike Enterprise. The project is expected to address the safety and mobility issues in the study area. In this report, the UCF research team has collected massive data from different sources on freeways, expressways, and arterials, conducted an extensive analysis for safety and mobility evaluations, developed appropriate performance measures, and identified the prevailing mobility and safety challenges.

To analyze the freeways, the report considered the corridor level and segment level. In the case of arterials, the study focused on the intersection and segment level analyses. Crash numbers and rates, crash types, different crash severities, work zone-related crashes, and weather information were collected and analyzed after collecting data from the Signal Four Analytics (S4A) and State Safety Office Geographic Information System (SSOGIS) for safety evaluation. Average travel time and speed, travel time reliability measures, and emergency response and events data

were analyzed for mobility evaluations. Finally, the safety and mobility challenges were identified and described. The data and results in this report will be used to evaluate the after improvement in safety and mobility after the technologies are implemented.

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CHAPTER 1: OVERVIEW

Interstate 4 (I-4) Florida's Regional Advanced Mobility Elements (FRAME) project is an intercity integrated corridor management (ICM) project running along the I-4 corridor between Tampa and Orlando. The project is expected to address the safety and mobility issues in the study area. The Transportation System Management and Operations (TSM&O) devices, and new V2X technologies, including next-generation traffic incident management, work zone traffic management, road weather alerts, freeway back-of-queue warning, wrong-way driving mitigation, and speed harmonization message systems, will be deployed. As part of the grant obligations, this study was conducted to help evaluate the existing transportation system before the project is implemented.

I-4 FRAME spans three FDOT Districts (One, Five, and Seven), and Florida's Turnpike Enterprise. In this report, the UCF research team conducted data collection and analysis for the before conditions for the freeways and arterials located in the study area. The research team has collected data from a variety of sources, conducted safety and mobility evaluations, developed appropriate performance measures, and identified the prevailing mobility and safety challenges.

The structure of this report is summarized as follows. In Section 2.1, the data sources are described. Sections 2.2 and 2.3 present the safety evaluation for freeways and arterials, respectively. Sections 2.4 and 2.5 present the mobility evaluation for freeways and arterials, respectively. Chapter 3 summarizes the overall before evaluation of this project.

CHAPTER 2: DATA COLLECTION

In this task the UCF research team identified the safety and mobility challenges on the freeways and arterials located in the study area. The main corridors with new devices to be installed include Interstate-4 (I-4), Florida Turnpike, Polk Parkway, and Selmon Expressway (SR-618). For arterials, the main corridors where new devices will be installed mainly include the intersections and their corresponding segments. The overview of the study area and the corridors are shown in Figure 1. The project will leverage vehicle-to-infrastructure and vehicle-to-vehicle technologies, with installing devices like RSU (Roadside Unit), CCTV (closed-circuit television) cameras, Bluetooth detectors, etc. on intersections, arterials, and freeways.

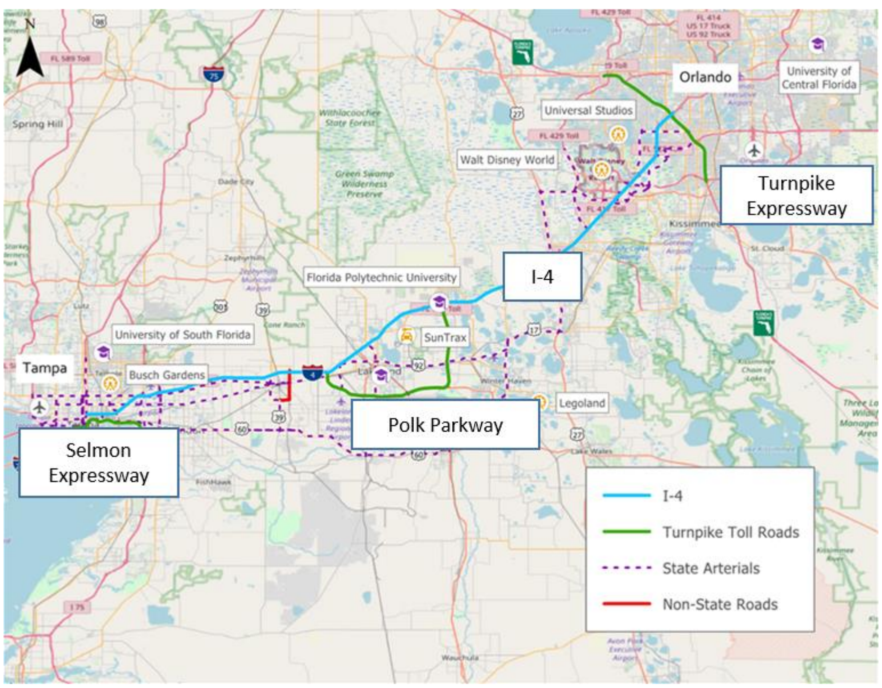


Figure 1 Overview of the Studied Area and Corridors

The main function of an RSU is to facilitate the communications between the vehicles and infrastructure. The vehicles equipped with OBU (On-Board Unit) can receive TIM (Traveler Information Message) broadcast by RSU. And an RSU can also gather basic safety messages

(BSM) information from OBU. Through the installations, the project aims to improve safety and alleviate traffic congestion from Tampa to Orlando.

The overview of the used data and sources are listed in Table 1. The crash data during 2017-2020 were collected from Signal Four Analytics (S4A) and State Safety Office Geographic Information System (SSOGIS). Traffic data was collected mainly from MVDS (Microwave Vehicle Detection System), Bluetooth, etc. The geometric data and weather data were also collected. The related variables are derived using the above-mentioned data sources. Both safety and mobility evaluations are conducted within the study area.

Table 1 Data Collection (Variables and Sources)

Data	Variables	Data Source(s)
Crash data	Time	S4A, SSOGIS
	Location	
	Crash type	
	Crash severity	
	Weather condition	
	Pedestrian-involved	
Geometric information	Roadway type	FDOT, manual collection
	Lane number	
Traffic data	Planning Time Index (PTI)	MVDS (INRIX), Bluetooth, and NPMRDS (INRIX)
	Throughput	
	Delay	
	Average speed	
	Average travel time	
	Travel time reliability	
Event data	Lane clearance time	SunGuide
	Notification duration	
	Verification duration	
	Open roads duration	
	Departure duration	
	Roadway clearance duration	
	Incident clearance duration	
Weather data	Adverse weather (i.e., fog)	NOAA (National Oceanic and Atmospheric Administration), OpenWeatherMap

In the following section, the research team carried out before analysis using mobility and safety data. The collected data sources, descriptions, mobility evaluation, and safety evaluation are summarized below.

2.1 Data Description

2.1.1 MVDS (Microwave Vehicle Detection System)

MVDS detector data was obtained from Regional Integrated Transportation Information System (RITIS). RITIS is a traffic data sharing, dissemination, and archiving system maintained by the Center for Advanced Transportation Technology Laboratory (CATT Lab) at the University of Maryland. RITIS has an online graphic user interface (GUI) for agencies to fully utilize the whole system. Data archived in RITIS include both infrastructure-based traffic data and data from third parties. The MVDS detector data are high-resolution traffic data which are collected from radar detectors and loop detectors. The details of MVDS data are summarized in Table 2.

Table 2 MVDS of RITIS

Variable	Temporal Coverage	Spatial Coverage	Aggregation Level
Time mean speed	Varies for different roadways	Freeways and expressways	From 30 seconds to 1 minute
Volume			
Occupancy			

2.1.2 NPMRDS (National Performance Management Research Data Set)

The NPMRDS is created as a tool for performance measurement for states and metropolitan planning organizations (MPOs). The downloaded NPMRDS data include speed, travel time of passenger cars and trucks. On the basis of the AVI or Bluetooth segments, the travel time of Traffic

Message Channel (TMC) segments is summed up at the five-minute interval and transformed into speed values. The details of NPMRDS data are summarized in Table 3.

Table 3 NPMRDS of RITIS

Variable	**Temporal Coverage**	**Spatial Coverage**	**Aggregation Level**
Speed	Varies for different roadways	Freeways and expressways	5 minutes
Travel time			

2.1.3 Crash Data

Crash data can provide comprehensive information for each crash, including the crash type, date and time, crash severity, the number of vehicles involved, etc. The crash data during 2017-2020 are collected from Signal Four Analytics (S4A) and State Safety Office Geographic Information System (SSOGIS) in this study.

2.1.4 HERE

Similar to NPMRDS, HERE is also provided by RITIS to offer travel time information of road segments. The aggregation level is one-minute, as shown in Table 4.

Table 4 HERE of RITIS

Variable	**Temporal Coverage**	**Spatial Coverage**	**Aggregation Level**
Speed	Varies for different roadways	Freeways, expressways, arterials, etc.	1 minute
Travel time			

2.2 Safety Evaluation of Freeways

Crash data can provide comprehensive information for each crash, including the type, time, severity, etc. In this task, the crash data from 2017 to 2020 were collected from S4A and SSOGIS within the study area. The roadway types in the research area are divided into mainline and ramp, since the crash characteristics vary in these two types of facilities. To perform the safety evaluation, all the crash data are analyzed at the corridor level and segment level, from the perspectives of crash number, crash severity. Different crash types, including weather-related crashes and work zone-related crashes are also analyzed.

2.2.1 Basemap Preparation

Basemap is prepared for processing all the data used in this study, as shown in Figure 2. To match detector and crash data to the corresponding segments, NPMRDS map is utilized as a primary route shape file. The NPMRDS map follows the Traffic Message Channel (TMC) standard to identify unique segments. Initially, the routes are divided into sub-segments using TMC standard. However, with the TMC standard, there are segments which had multiple detectors in one segment. Therefore, in order to measure the traffic features that can present the condition of a segment by using data from adjacent detectors, this study separated each segment based on the location of the detectors. Through the base map processing, detector data and crash data can be matched to each road segment.

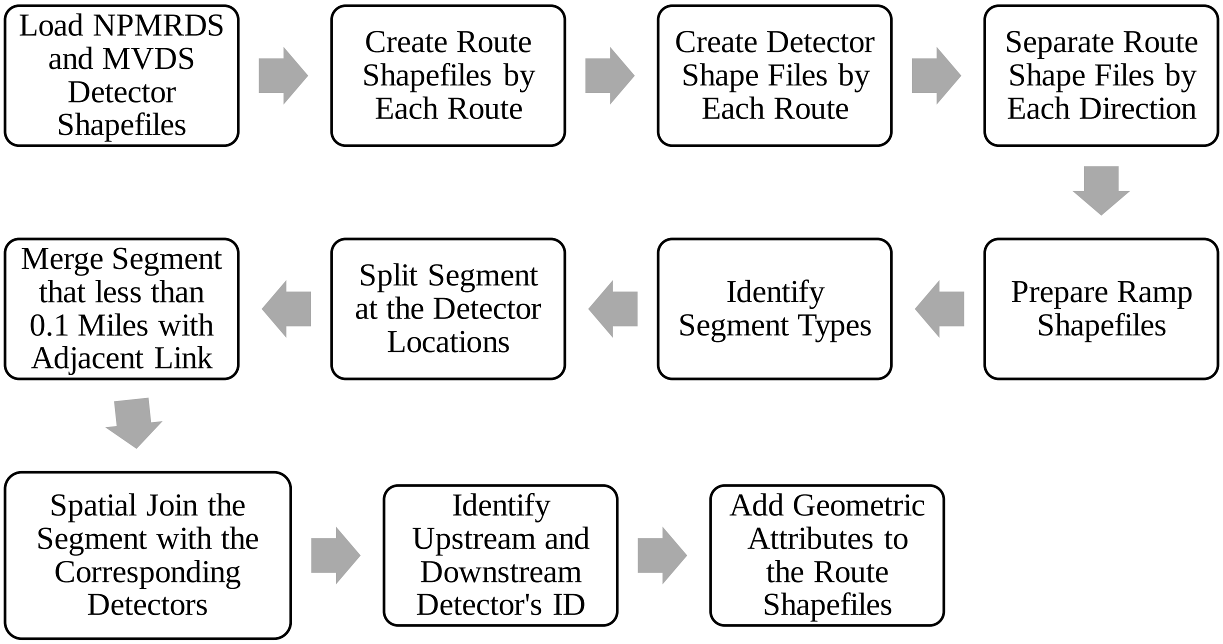


Figure 2 Steps for Preparing Basemap

After the basemap preparation, the studied corridors are split into short segments with the average mileage of around 0.30 miles to 0.41 miles for the normal mainline and ramp segments. Four main roads are studied, namely I-4, Polk Parkway, Selmon Expressway, and Turnpike Expressway. Selmon Expressway has two types of lanes, General Purpose Lane (GPL) and Reversible Lane (RVL). Hence, they are studied separately. However, the MVDS detectors are not available on Selmon Expressway, resulting in longer road segments compared with the other roads. Table 5 shows the detailed statistics for all the roads.

Table 5 Corridor (Segment) Summary Statistics

Road Name (Direction)	Number of Segments	Minimum Length (Miles)	Maximum Length (Miles)	Total Length (Miles)	Average Length (Miles)
I-4 EB	227	0.10	2.65	75.96	0.33
I-4 WB	227	0.10	2.62	76.20	0.34
Polk Parkway EB	80	0.10	0.80	23.75	0.30
Polk Parkway WB	80	0.10	0.80	23.79	0.30
Selmon_GPL EB	42	0.10	1.16	13.53	0.32
Selmon_GPL WB	37	0.10	1.37	13.38	0.36
Selmon_RVL EB	9	0.10	3.08	9.05	1.01
Selmon_RVL WB	6	0.11	3.34	6.80	1.13
Turnpike NB	49	0.10	1.15	18.40	0.38
Turnpike SB	44	0.11	1.02	17.99	0.41

2.2.2 Summary of Crash Data (Corridor Level)

Crash data from the year 2017 to 2020 were collected. Four main roads were analyzed, I-4, Polk Parkway, Selmon Expressway, and Turnpike Expressway. Selmon Expressway has two types of lanes, General Purpose Lanes (GPL) and Reversible Lanes (RVL). As shown in Table 6, crash numbers from the year 2017 to 2020 are shown by direction on the studied roads. Crashes on the ramps are designated as R, and crashes on the mainline are designated as M. Also, crashes that occurred in the eastbound direction are designated as E. Similarly, for westbound, northbound, and southbound directions, the crash directions are designated as W, N, and S, respectively. It is also shown that I-4 and the Turnpike Expressway have higher numbers of crashes compared to the other roads. Also, the numbers of crashes decreased in 2019 and 2020, which might result from the impact of the Covid-19 pandemic.

Table 6 Crash Numbers (Corridor Level, 2017-2020)

Road Name	Mainline(M)/Ramp(R)	Direction	2017	2018	2019	2020
I-4	M	E	1631	1707	1741	1309
		W	1633	1680	1530	1212
	R	E	387	394	255	199
		W	360	398	222	246
Polk Parkway	M	E	52	45	41	62
		W	29	31	51	29
	R	E	24	21	20	15
		W	19	17	9	2
Selmon Expressway (GPL)	M	E	60	98	107	73
		W	98	146	99	62
	R	E	15	19	13	5
		W	24	27	20	11
Selmon Expressway (RVL)	M	E	8	12	10	5
		W	16	12	18	8
	R	E	4	3	3	2
		W	1	5	5	2
Turnpike Expressway	M	N	317	412	447	265
		S	280	340	419	288
	R	N	162	150	93	59
		S	58	68	28	32

To better comprehend the crash data, Figure 3 is generated to show the tendency of crash occurrence per mile from 2017 to 2020. It is evident that I-4 and Turnpike Expressway experienced higher crash numbers per mile. For example, both I-4 eastbound and westbound directions experienced around 27 crashes per mile in the years 2017 and 2018. However, a sharp decrease in the crash number was observed for 2019 and 2020. Turnpike northbound direction had more crash occurrences than the southbound direction. In 2017 and 2018, the average crash numbers per mile in the northbound and southbound were 28 and 21, respectively. Other roads had lower risk than I-4 and the Turnpike Expressway. However, the westbound direction of Selmon Expressway GPL still possessed a higher risk (five crashes per mile) and Polk Parkway (two crashes per mile) with an average crash number of around 11 crashes per mile.

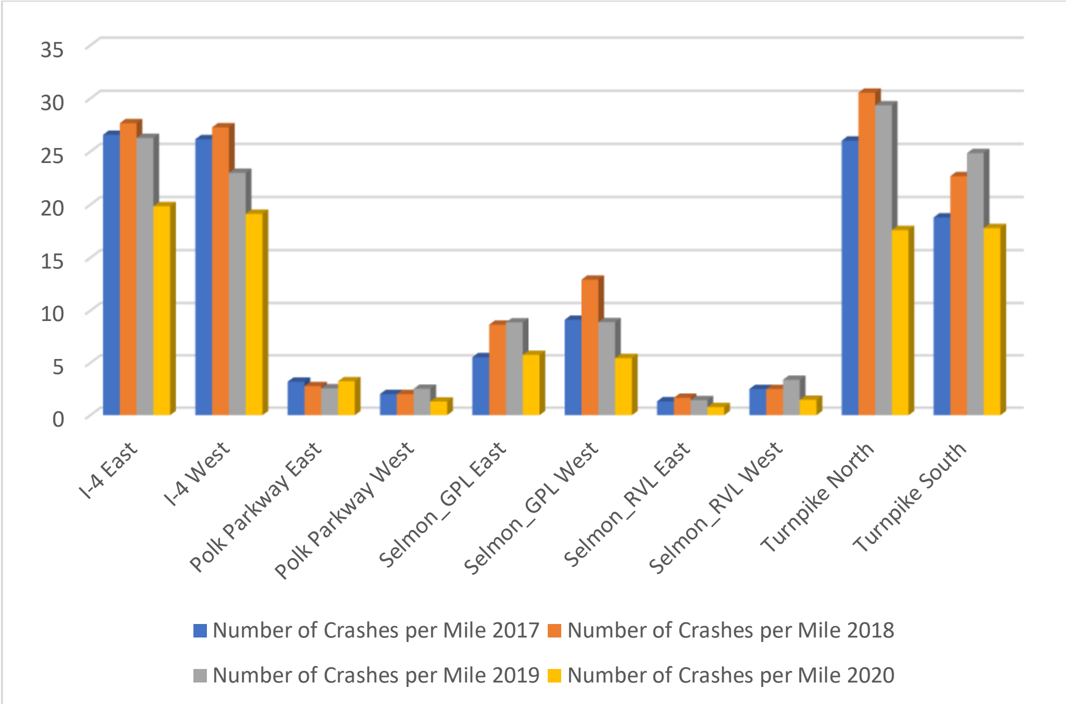


Figure 3 Numbers of Crashes per Mile from 2017 to 2020

In addition, crash rates were calculated. Crash rate is a measure that normalizes the frequency of crashes with the exposure, measured by traffic volume. Traffic volume is measured as vehicle-miles traveled (VMT) for the study period. The crash rate of a segment was estimated based on crash number and annual average daily traffic (AADT) using the following formula as referred by Golembiewski and Chandler (2011):

$$R = \frac{100000000 \times C}{365 \times N \times V \times L}$$

where C was the total number of crashes, N was the number of years, V was the AADT, and L was the length of the roadway segment in miles. AADT data were obtained from FDOT RCI data set and MVDS (FDOT, 2021). To explain the forumula used to obtain the crash rate for different freeways in different years, I-4 eastbound freeway can be considered. In 2017, the total number of crashes was 2018, AADT/Volume was 5062.4362 million and the length of the freeway (including mainline and ramp) was 75.9633 miles. Hence, applying the corresponding values in the formula, we obtained the crash rate = (100000000*2018)/(365*1*5062436214.15*75.9633)=0.0014 per 100 million vehicle miles travelled. Table 7 and

In Selmon Expressway, the crash rate varied from 0.0018 to 0.0294 per 100 million vehicle miles travelled. For Turnpike Expressway, crash rate varied from 0.0049 to 0.0089 per 100 million vehicle miles travelled. Turnpike Expressway northbound direction had higher crash number compared to the Turnpike Expressway southbound direction. Among all these roads, Turnpike Expressway had higher crash rates per 100 million vehicle miles travelled compared to other studied roads.

Table 8 show the calculated crash rates for all the studied roads. For I-4, the crash rate varied from 0.0011 to 0.0014 per 100 million vehicle miles travelled. I-4 eastbound direction had higher crash rate compared to the I-4 westbound direction. For Polk Parkway, the crash rate varied from 0.0008 to 0.0021 per 100 million vehicle miles travelled. Polk Parkway eastbound direction had higher crash rates than the westbound direction.

Table 7 Crash Rates on I-4 and Polk Parkway (Corridor Level, 2017-2020)

Road Name (Direction)	Year	Total Crash Number	Length (Miles)	Volume/AADT (in Million)	Crash Rate (per 100 Million Vehicle Miles Travelled)
I-4 EB	2017	2018	75.9633	5062.4362	0.0014
	2018	2101		5413.1962	0.0014
	2019	1996		5527.0484	0.0013
	2020	1508		4702.0840	0.0012
I-4 WB	2017	1993	76.1978	5365.3076	0.0013
	2018	2078		5817.0742	0.0013
	2019	1752		5622.6300	0.0011
	2020	1458		4777.4748	0.0011
Polk Parkway EB	2017	76	23.7541	413.3367	0.0021
	2018	66		481.1020	0.0016
	2019	61		505.1624	0.0014
	2020	77		419.0119	0.0021
Polk Parkway WB	2017	48	23.7918	428.2374	0.0013
	2018	48		491.7758	0.0011

	2019	60		522.2431	0.0013
	2020	31		437.4333	0.0008

In Selmon Expressway, the crash rate varied from 0.0018 to 0.0294 per 100 million vehicle miles travelled. For Turnpike Expressway, crash rate varied from 0.0049 to 0.0089 per 100 million vehicle miles travelled. Turnpike Expressway northbound direction had higher crash number compared to the Turnpike Expressway southbound direction. Among all these roads, Turnpike Expressway had higher crash rates per 100 million vehicle miles travelled compared to other studied roads.

Table 8 Crash Rates on Selmon and Turnpike Expressway (Corridor Level, 2017-2020)

Road Name (Direction)	**Year**	**Total Crash Number**	**Length (Miles)**	**Volume/AADT (in Million)**	**Crash Rate (per 100 Million Vehicle Miles Travelled)**
Selmon_RVL EB	2017	75	13.5315	862.0205	0.0018
	2018	117		967.0675	0.0024
	2019	120		976.9225	0.0025
	2020	78		767.7775	0.0021
Selmon_GPL WB	2017	122	13.3785	815.7750	0.0031
	2018	173		889.5050	0.0040
	2019	119		899.3600	0.0027
	2020	73		704.2675	0.0021
Selmon_RVL EB	2017	12	9.0519	56.3925	0.0064
	2018	15		54.3850	0.0083
	2019	13		52.3775	0.0075
	2020	7		35.7335	0.0059
Selmon_RVL WB	2017	17	6.8057	32.8135	0.0209
	2018	17		31.0615	0.0220
	2019	23		31.4995	0.0294
	2020	10		22.0460	0.0183
Turnpike NB	2017	479	18.4041	951.2191	0.0075
	2018	562		942.9955	0.0089

	2019	540		1202.2437	0.0067
	2020	324		993.7904	0.0049
Turnpike SB	2017	338	17.9915	951.9137	0.0054
	2018	408		1026.6443	0.0061
	2019	447		1183.1800	0.0058
	2020	320		990.3088	0.0049

2.2.2.1 Crashes with different severity levels

The crashes are divided into five severity levels according to the KABCO Injury Classification Scale and definitions from the Federal Highway Administration (FHWA) (FHWA, 2022b). In this system, K is designated as the fatal injury, or any injury that results in death within a 30-day period after the crash occurred. A is designated as the incapacitating injury, which is defined as disabling injury, such as broken bone, severed limb, etc. This injury type usually requires hospitalization and transporting to medical facility. B denotes the non-incapacitating evident injury, which is defined by non-disabling injury, such as laceration, scrape, bruise, etc. C denotes possible injury. And O denotes no injury. This crash type is usually referred to as Property Damage Only (PDO) crash.

Since detailed crash information is missing sometimes and also sometimes a single source does not provide all the crash information, this study has used two data sources, i.e., SSOGIS and S4A to get the KABCO system. First, the research team tried to obtain the KABCO information from SSOGIS data sources, if there was missing information, then S4A data source was used. Since the variables to extract the KABCO data are named differently in these two data sources, Table 9 shows which label indicate which severity level according to the KABCO system.

Table 9 Definition of Crash Severity in S4A and SSOGIS

KABCO Injury Classification Scale	Label in S4A	Label in SSOGIS
K (fatal injury)	Fatalities_30_Days	Traffic_Fatalities
A (incapacitating injury)	Incapacitating_Injuries	Serious_Injuries
B (non-incapacitating evident injury)	Non_Incapacitating Injuries	Nonfatal Injuries (more than two)
C (possible injury)	Possible_Injuries	Nonfatal Injuries (equal/less than two)
O (no injury)	None of above	None of above

Figure 4 shows the trend of numbers of fatal crashes in the studied roads. Only one crash happened on the eastbound ramp of the Selmon Expressway (GPL) in 2019. No fatal crash happened on Polk Parkway. Besides, eastbound direction of I-4 mainline had the highest number of fatal crashes. It is really difficult to draw a clear increasing or decreasing pattern for all the routes. Most of the routes experienced fluctuation patterns. The range of the fatal crash number per year on I-4 is one to five, and for Turnpike Expressway is one to three.

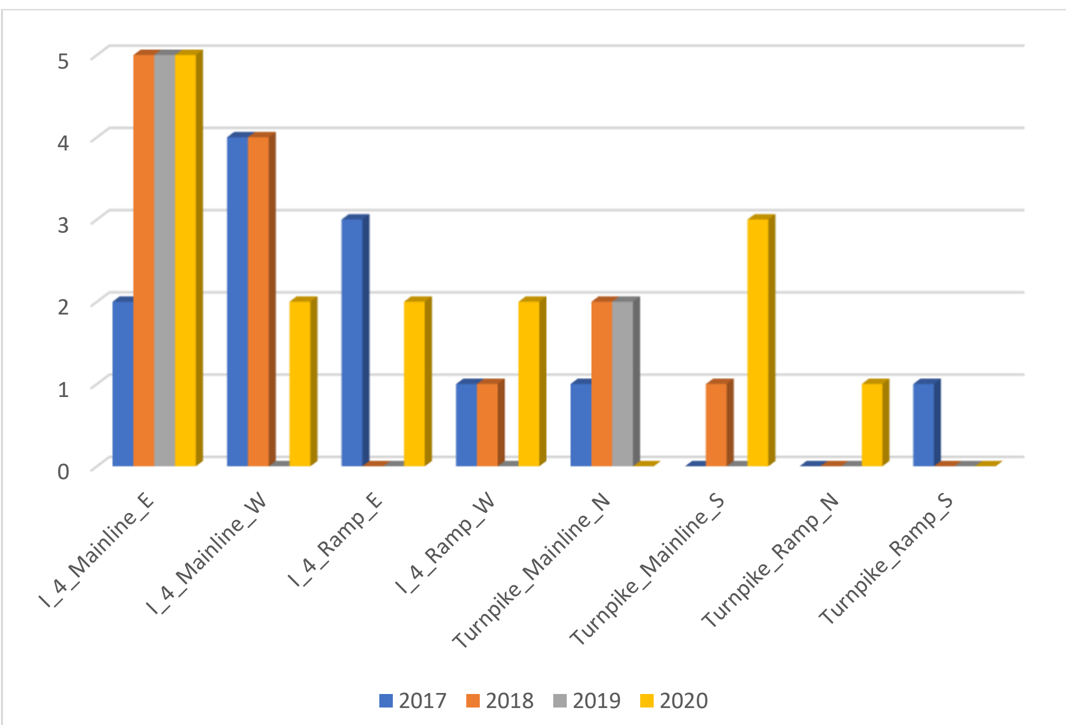


Figure 4 Numbers of Fatal Crashes from 2017 to 2020

As shown in Figure 5, number of crashes with incapacitating injury was the highest on the eastbound direction of I-4 mainline. There were no crashes with incapacitating injury on Selmon Expressway (RVL) and Polk Parkway ramps. Also, there was one crash with incapacitating injury per year in Selmon Expressway (GPL) ramp and westbound Polk Parkway mainline. Hence, these roads are not shown in the figure. Although there are some fluctuations, for most of the roads, the numbers of crashes with incapacitating injuries decreased from 2017 to 2020. Particularly, a sharp decrease is observed in the year 2020. The range of crash number with this crash type on I-4, Turnpike Expressway, Polk Parkway, and Selmon Expressway (GPL) varies from two to 43, zero to 10, zero to five, and one to four, respectively.

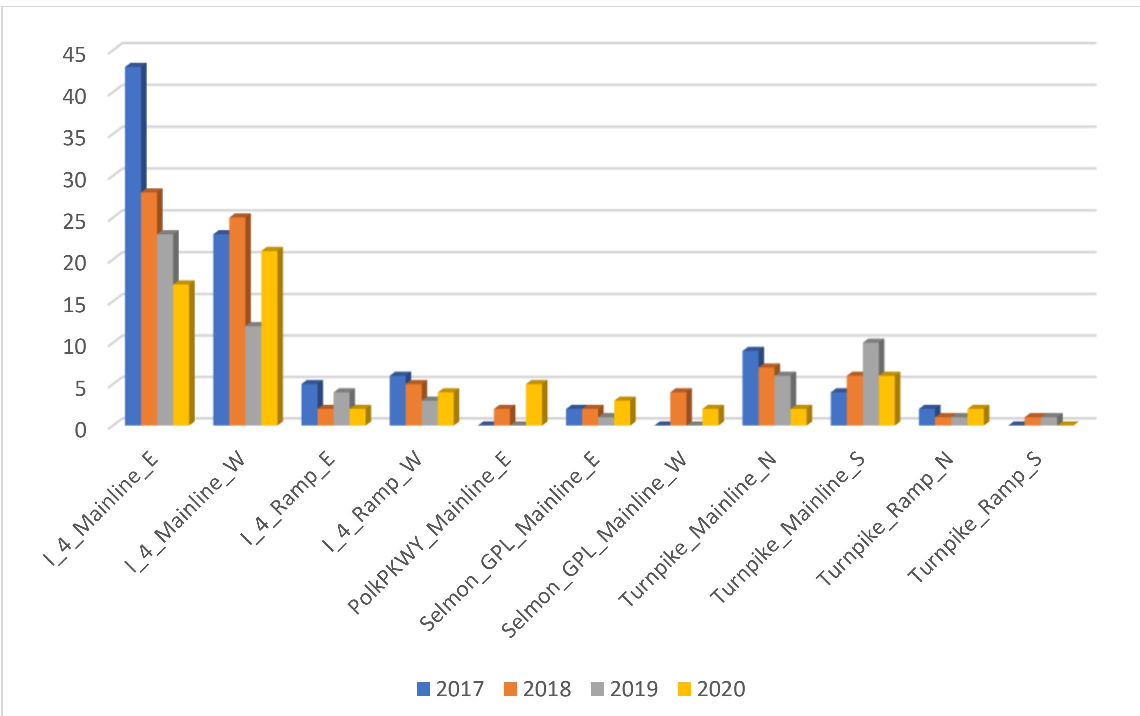


Figure 5 Numbers of Crashes with Incapacitating Injury (2017-2020)

As shown in Figure 6, the number of crashes with non-incapacitating evident injury was the highest on the eastbound direction of the I-4 mainline. Almost for all the roads, the numbers of crashes with non-incapacitating evident injuries were sharply reduced in 2020. This is probably due to the impact of the Covid-19 pandemic. The range of the numbers of crashes with non-incapacitating injury on I-4, Polk Parkway, Turnpike Expressway, and Selmon Expressway (GPL) on each direction varied from 15 to 130, zero to six, one to 37, and zero to 11, respectively.

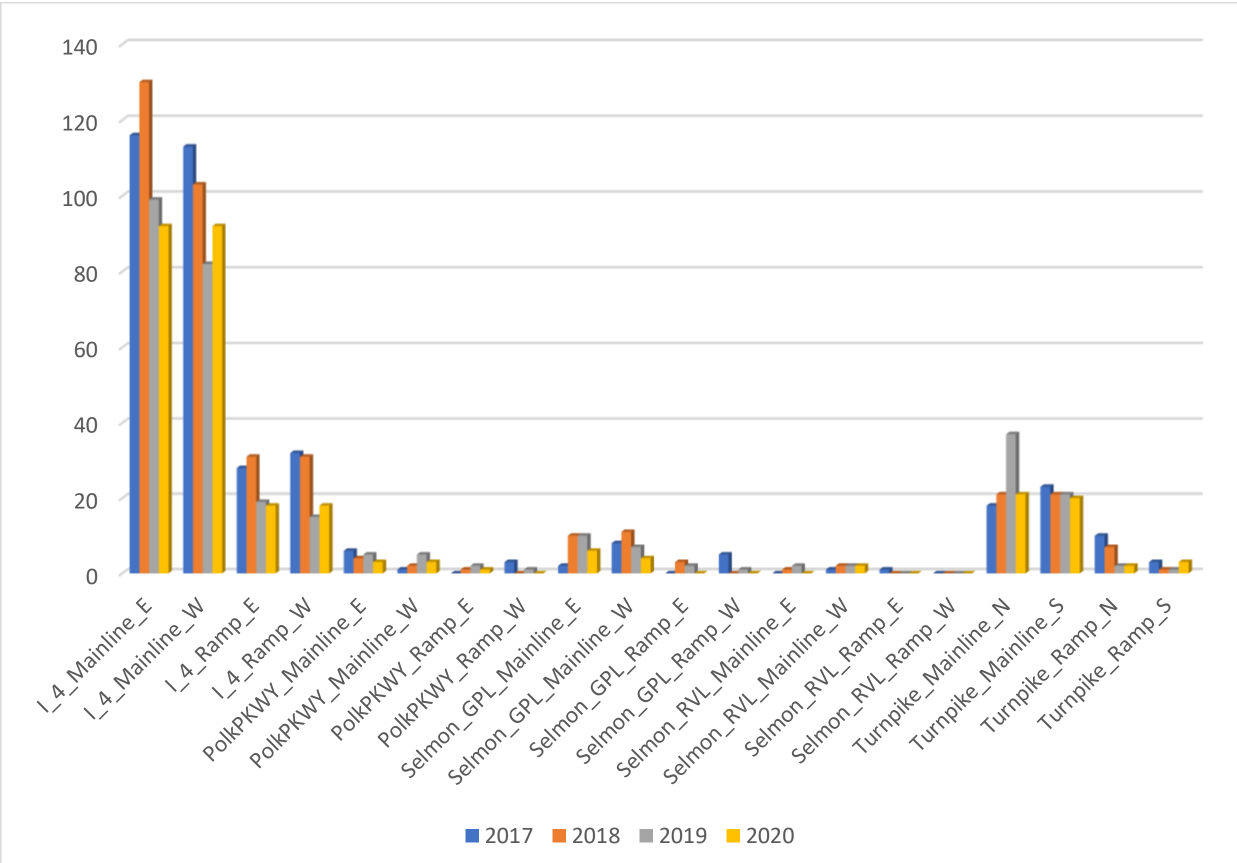


Figure 6 Numbers of Crashes with Non-incapacitating Injury (2017-2020)

Figure 7 shows that each of the studied roads has experienced crashes with possible injury, particularly I-4 and Turnpike Expressway. Both the eastbound and westbound I-4 possessed equally risk in terms of possible injury risk. However, Polk Parkway and Selmon Expressway had very low numbers of crashes with possible injury crashes compared to other roads.,. Crash numbers of this type fluctuated from 2017 to 2019. However, one common pattern was a decline in the crash number in the year 2020.

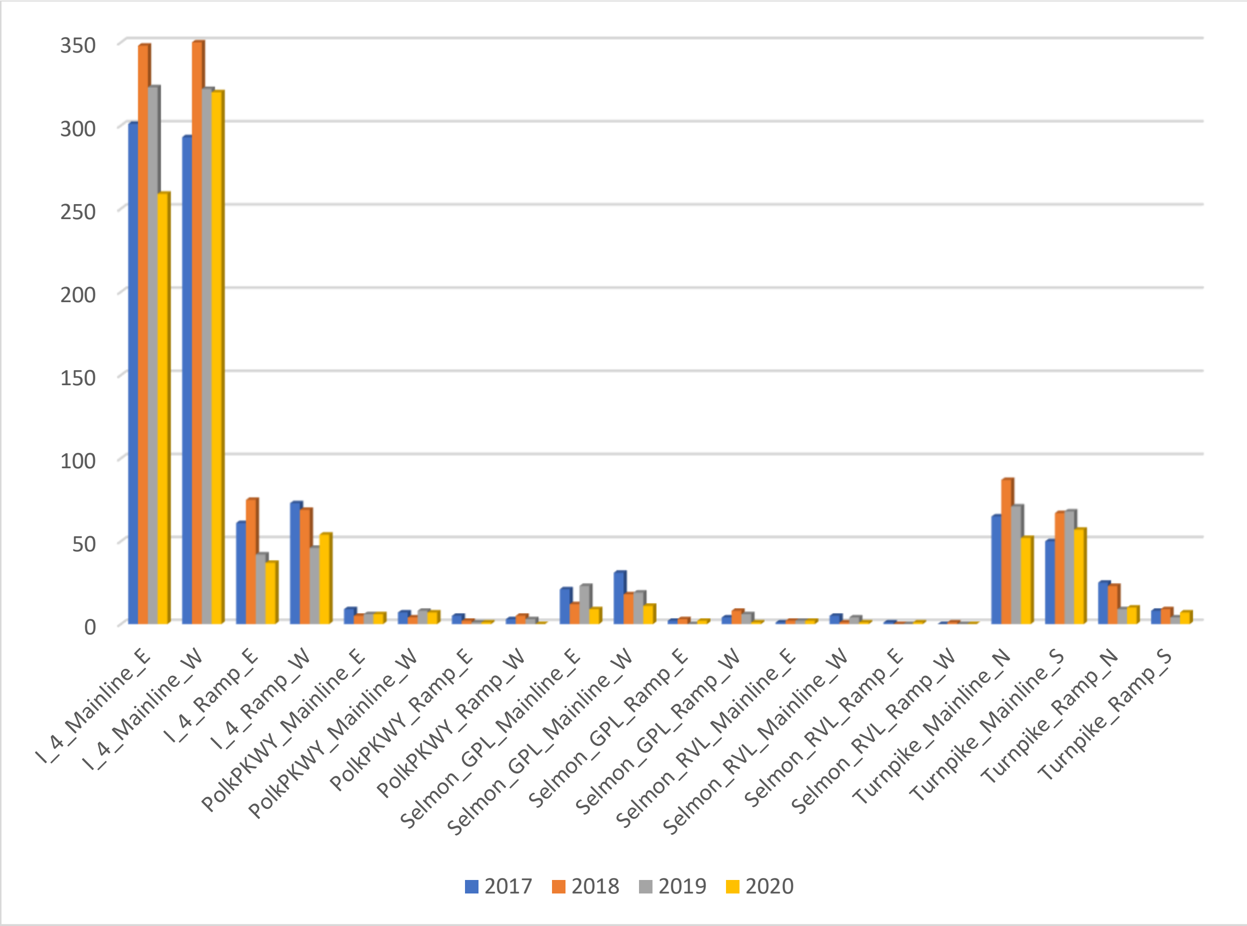


Figure 7 Numbers of Crashes with Possible Injury (2017-2020)

High disparity in the PDO crashes on all the roads are evidently visible from Figure 8. Again, a clear sharp decline was observed in the year of 2020 on all the roads. The ranges of PDO crash numbers on I-4, Turnpike Expressway, Polk Parkway, Selmon Expressway (GPL), and Selmon Expressway (RVL) varied from 140 to 1291, 22 to 331, two to 48, two to 19, and one to 12 respectively. Polk Parkway, and Selmon Expressway (RVL) had very few numbers of crashes compared with other roads.

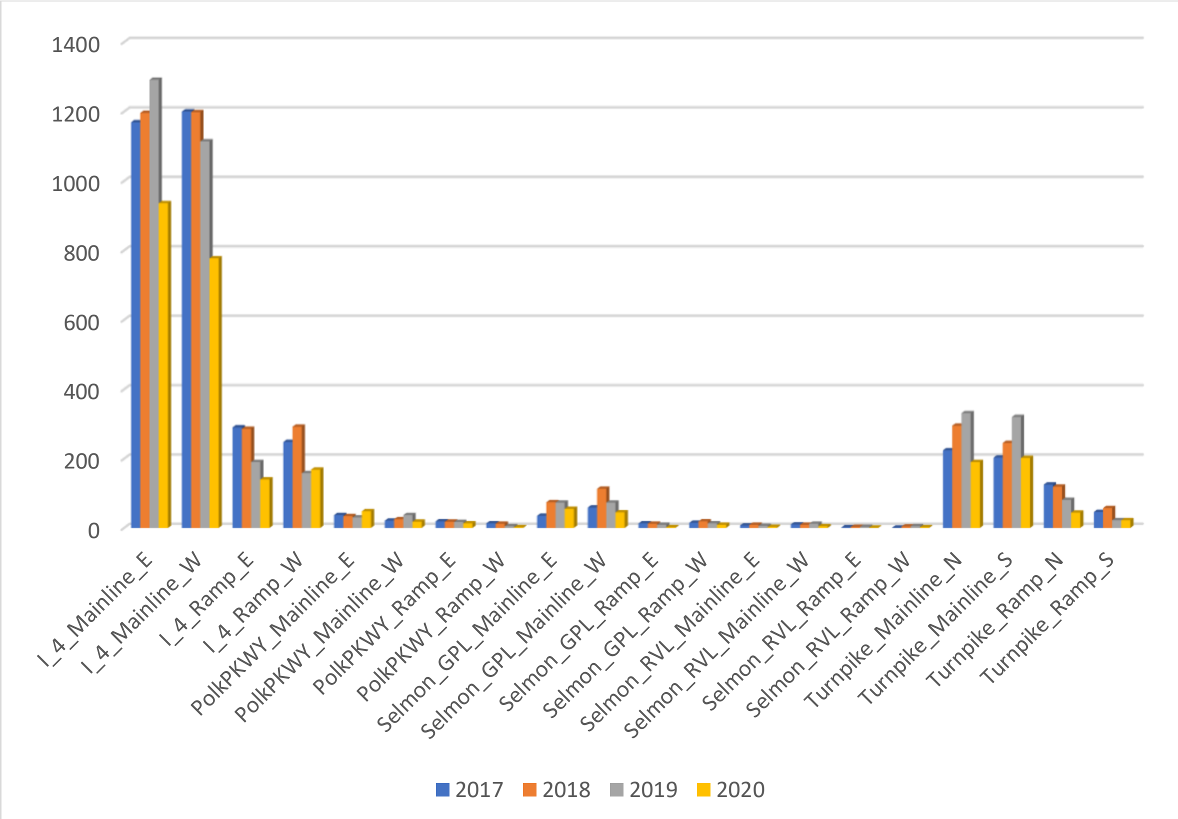


Figure 8 Numbers of PDO Crashes (2017-2020)

2.2.2.2 Crashes with different types

Analyses were also conducted using the different crash types. Based on the crash types in SSOGIS and S4A, the following crash types were identified: angle, head on, off-road, other, rear end, rollover, and sideswipe. The crash numbers with major types such as off-road, rear end, rollover, and sideswipe on I-4 mainline road are shown in Figure 9. Among them, rear end was the dominant type. Sideswipe and off-road crashes also posed threat for road safety, as the two crash types were also playing important roles. Steady decreases in almost all types of crashes were observed from the year 2017 to 2019, and a sharp decrease was observed during the year 2020.

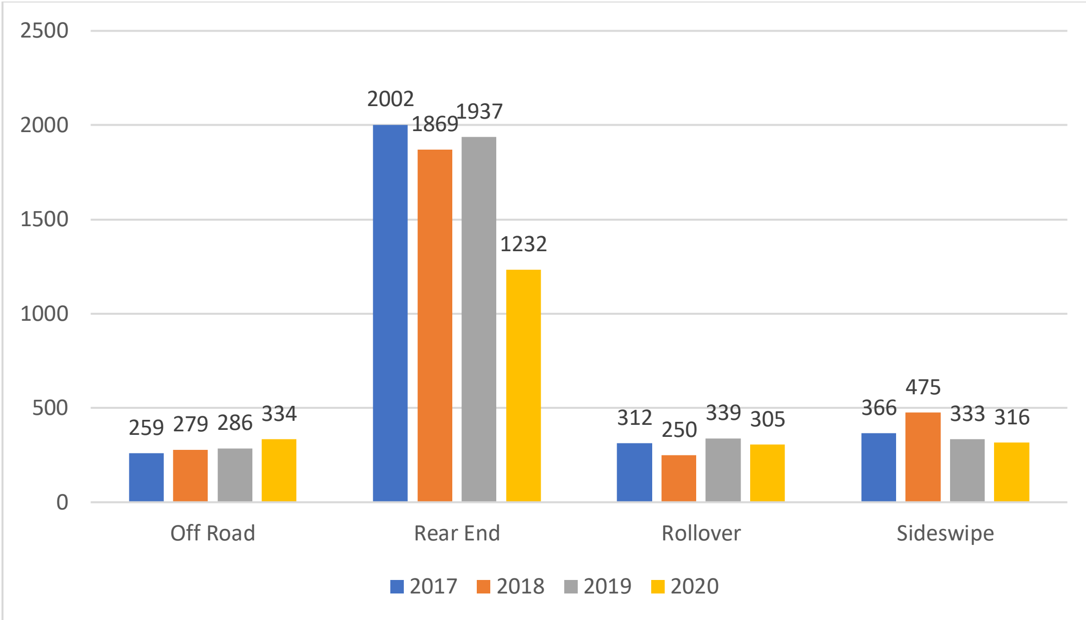


Figure 9 Major Types of Crashes on I-4 Mainline

As shown in Figure 10, off-road crash was the dominant crash type on Polk Parkway. The second dominant type was rear end. It should be mentioned that the number of off-road crashes had an unusual peak in 2020. Due to the Covid-19 situation, traffic volume has fallen sharply, and the drivers tend to speed. This is the possible reason for such an increase in off road crashes.

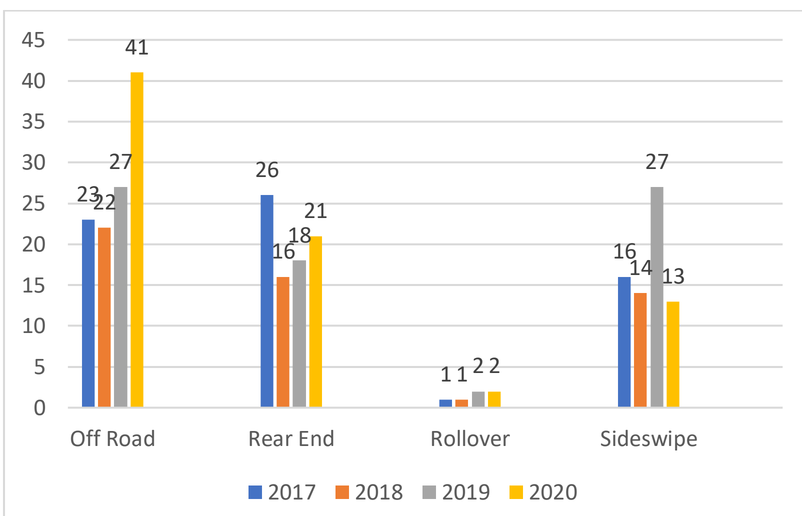


Figure 10 Major Types of Crashes on Polk Parkway Mainline

As shown in Figure 11, for Selmon Expressway (GPL) mainline road, rear end road crashes were the most likely to occur. From 2017 to 2019, the numbers of off-road crashes and sideswipe crashes increased. From 2019 to 2020, there was a sharp decrease in almost all the crash types. Impact of the global Covid-19 pandemic was the possible reason for such finding.

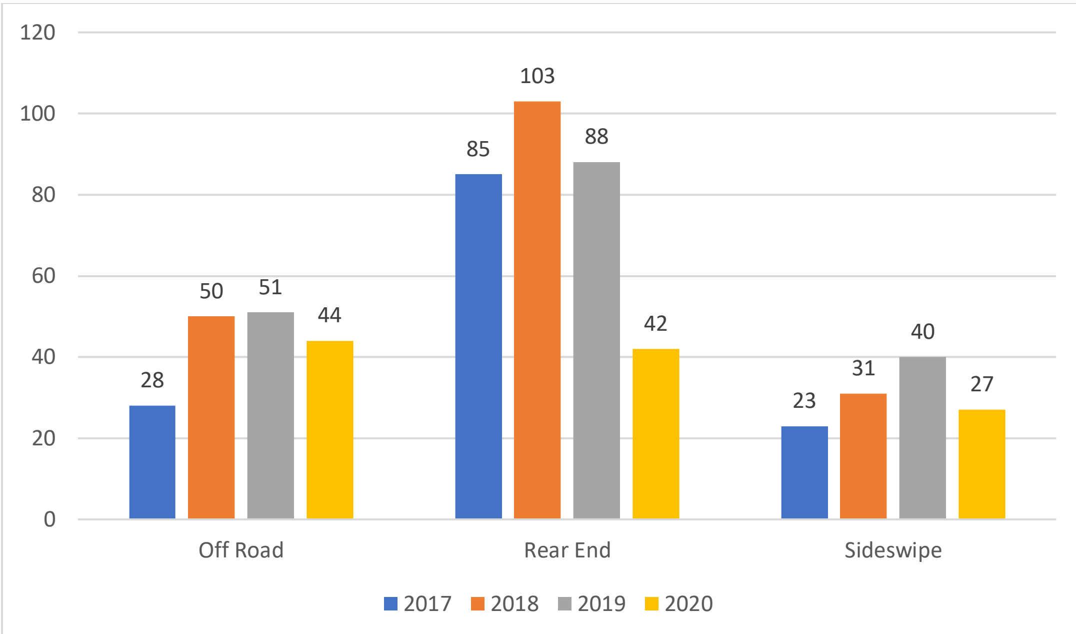


Figure 11 Major Types of Crashes on Selmon Expressway (GPL) Mainline

As shown in Figure 12, Selmon Expressway (RVL) (mainline) had lower crash numbers compared to other roads. It was due to its shorter length compared to all other roads. However, on this road, off road, rear end, and sideswipe crashes were the most likely to happen. Also, in the year 2020, this road experienced an unusually low number of crashes.

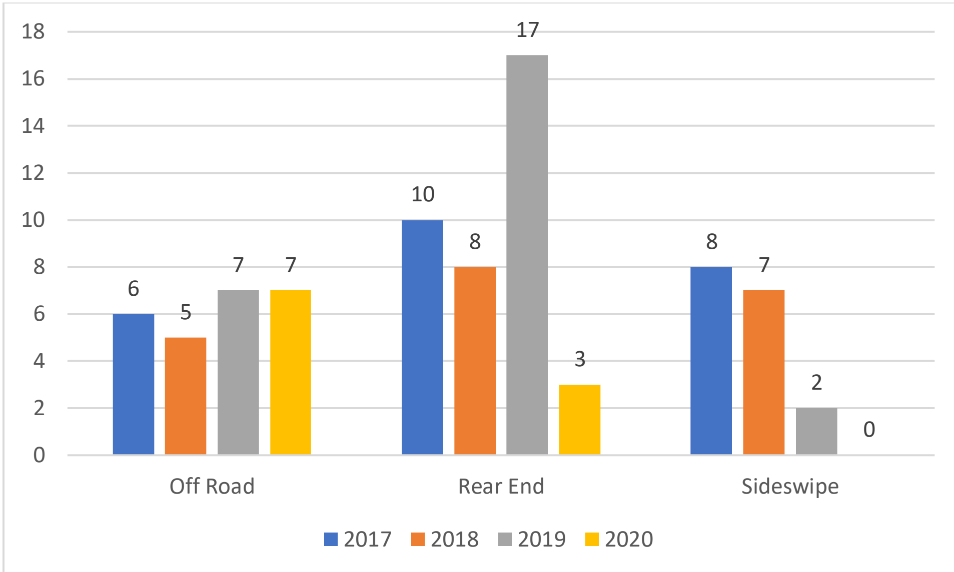


Figure 12 Major Types of Crashes on Selmon Expressway (RVL) Mainline

As shown in Figure 13, rear end crash was the dominate crash type on Turnpike Expressway. Off-road and sideswipe crashes were the next two dominant types to occur. There was a gradual increasing trend for off-road crashes and rear end crashes from 2017 to 2019. And there was a decreasing trend for rear end and sideswipe crashes from 2019 to 2020.

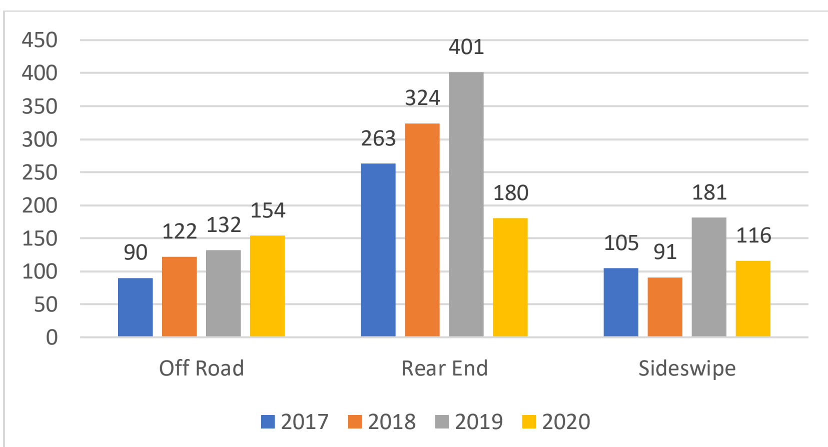


Figure 13 Major Types of Crashes on Turnpike Expressway Mainline

Since rear end, sideswipe, and off-road crashes were most frequent crash types in almost all of the roads, further analyses were done to get a relative comparison of these crashes in different roads. As shown in Figure 14, a huge disparity was evidently visible for the rear end crashes on I-4 and other roads. Turnpike Expressway and Selmon Expressway (GPL) had the next highest numbers of crash type. However, all other roads had relatively small numbers of rear end crashes.

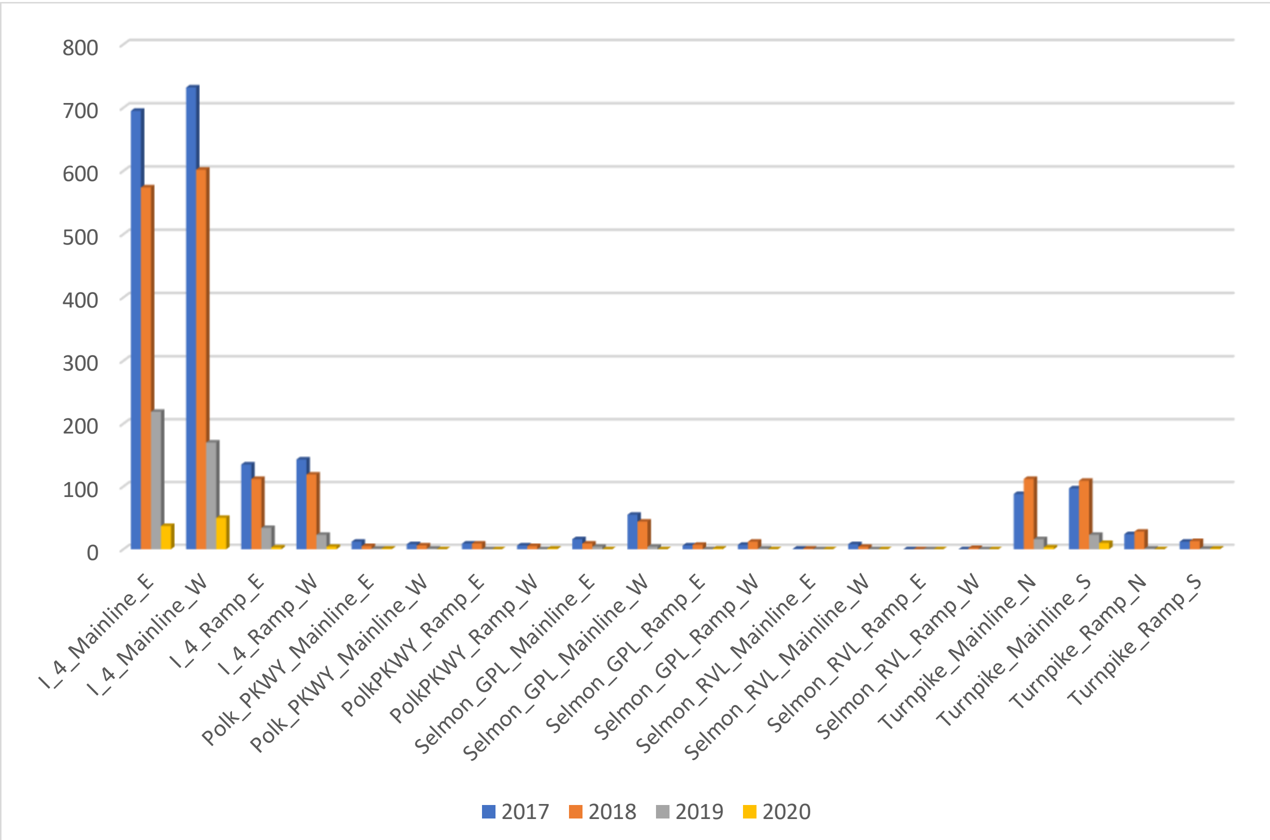


Figure 14 Numbers of Rear-end Crashes (2017-2020)

As shown in Figure 15, I-4 and Turnpike Expressway had the highest number of off-road crashes among all the roads. All the other roads possessed relatively smaller risk in terms of off-road crash occurrence.

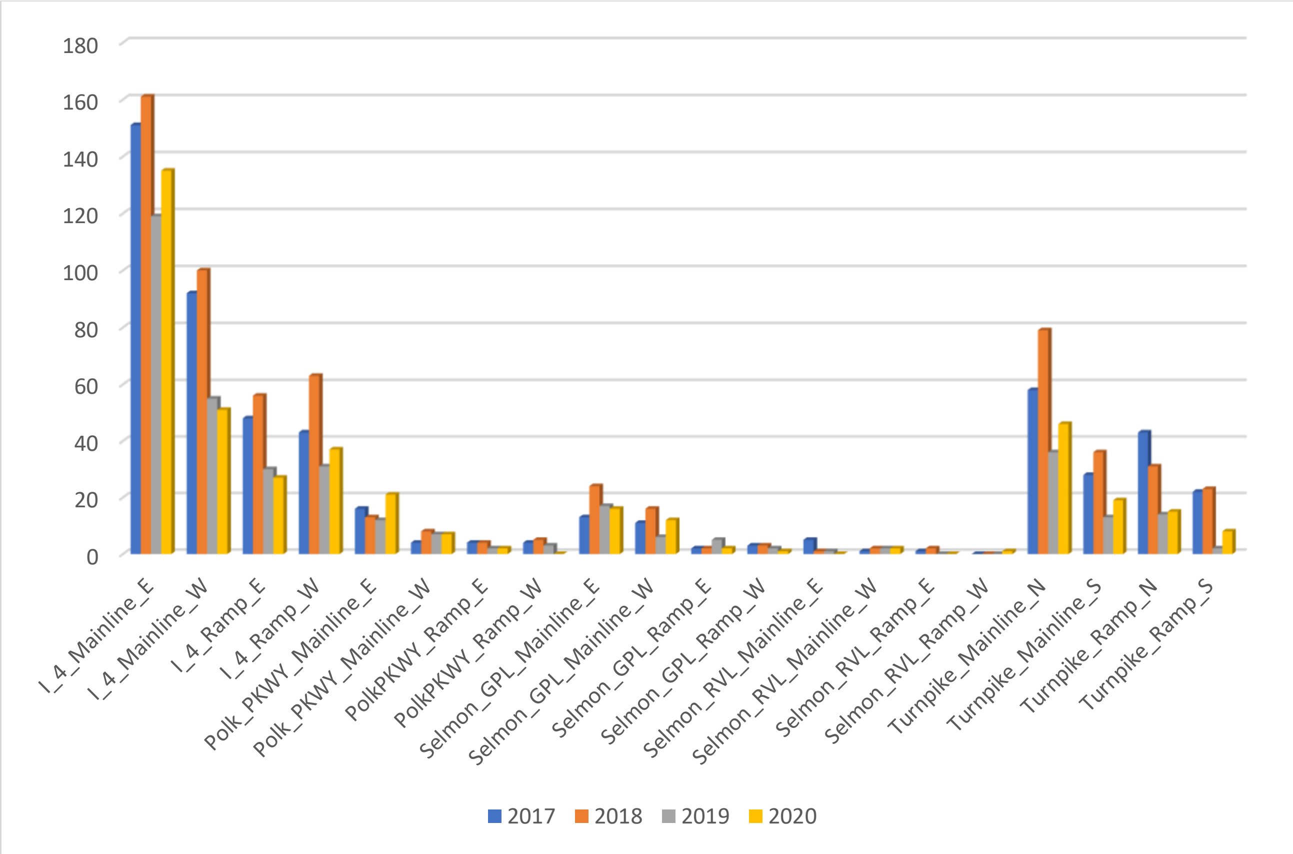


Figure 15 Numbers of Off-road Crashes (2017-2020)

As shown in Figure 16, sideswipe crashes presented an almost similar scenario as the rear end crashes. I-4 and Turnpike Expressway had the highest numbers of sideswipe crashes. Mainline of Selmon Expressway (GPL) also had a significantly higher number of such crashes. However, the crash number on other roads were very small compared to the mentioned roads.

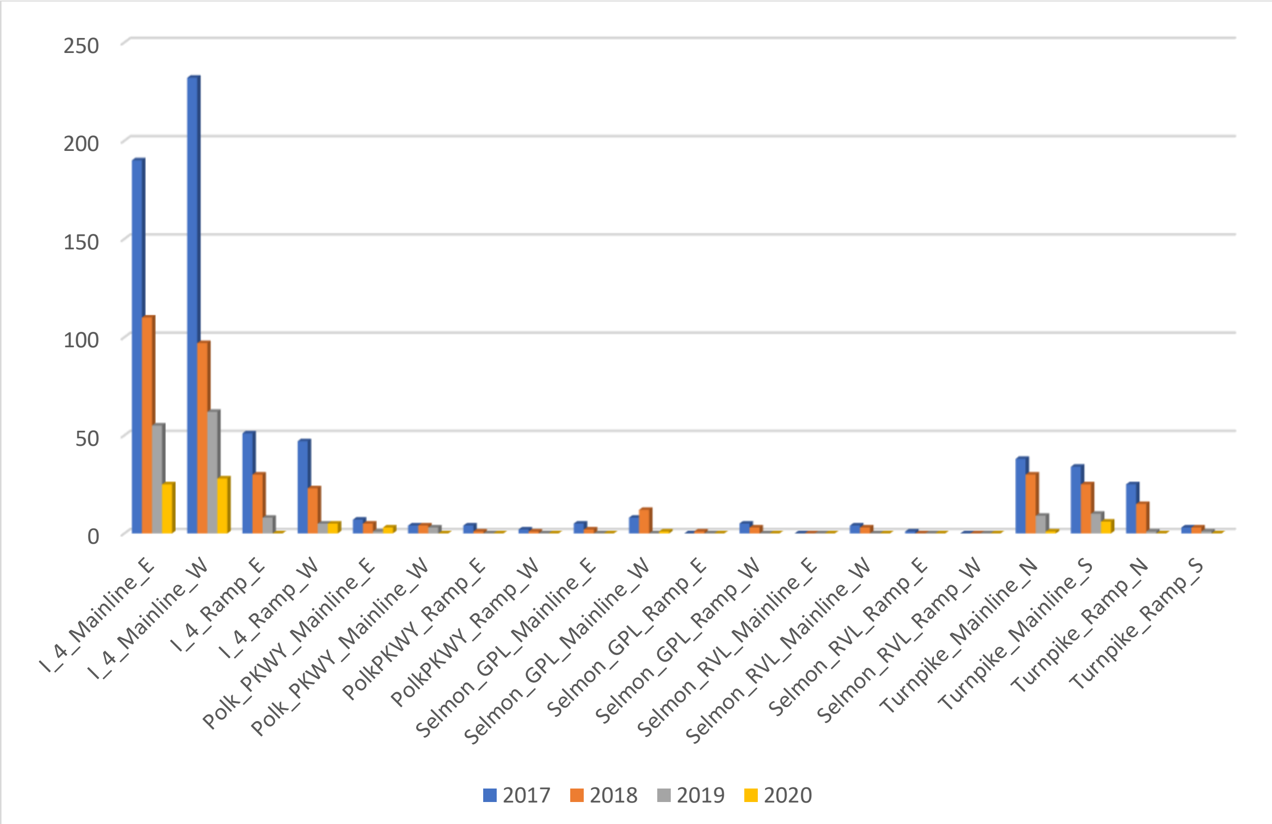
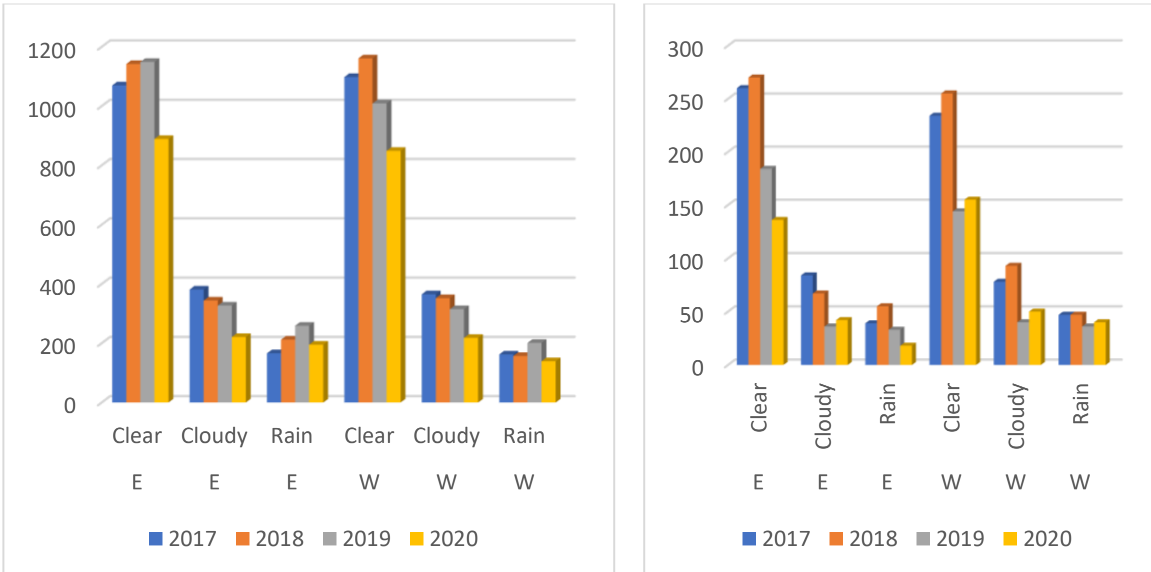


Figure 16 Numbers of Sideswipe Crashes (2017-2020)

2.2.2.3 Crashes with different weather conditions

Different weather conditions may impact crash occurrence. Hence, the study also analyzed crashes under different weather conditions, i.e., clear, rain, cloudy, fog, smog, smoke, etc. These weather types were extracted from crash reports. To maintain the uniformity, SSOGIS data were used to fill up the gap/unfilled data of the S4A data. These analyses were also performed for the data from year 2017-2020.

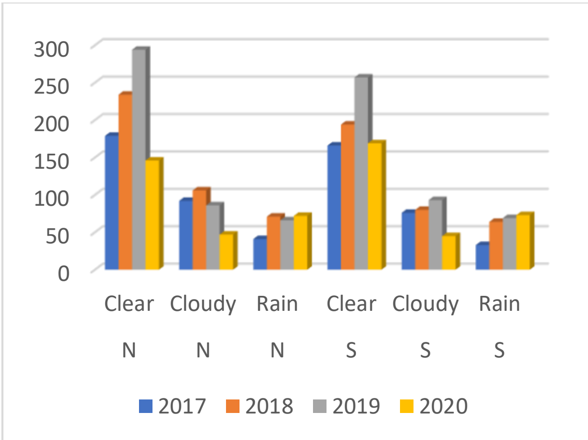
From Figure 17, it is evident that occurrence of crashes under more favorable conditions was high for both the mainline and the ramp of the I-4. For example, most of the crashes occurred in clear weather conditions. Crash numbers under cloudy conditions were higher than crash numbers under the rainy condition.



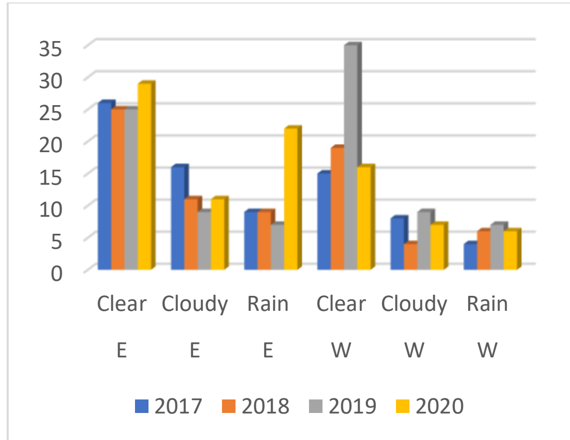
(a) Mainline (b) Ramp

Figure 17 Crash Numbers under Different Weather Conditions

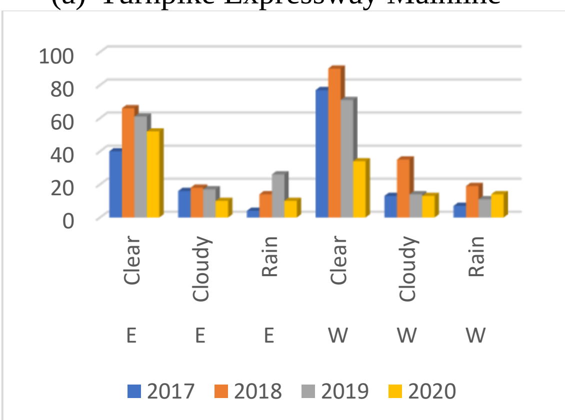
Conditions of other roads were also analyzed. Figure 18 clearly proves that the findings from the I-4 mainline and ramp remained true for other roads.



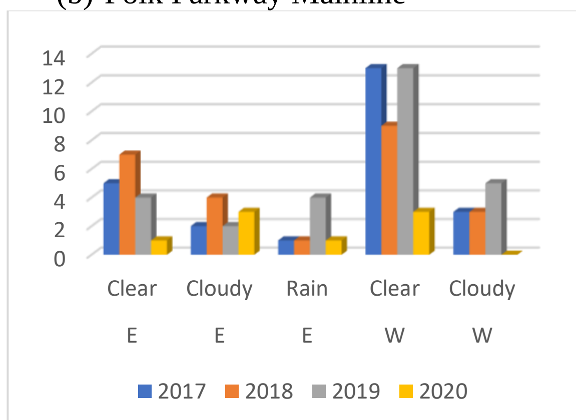
(a) Turnpike Expressway Mainline



(b) Polk Parkway Mainline



(c) Selmon Expressway (GPL) Mainline

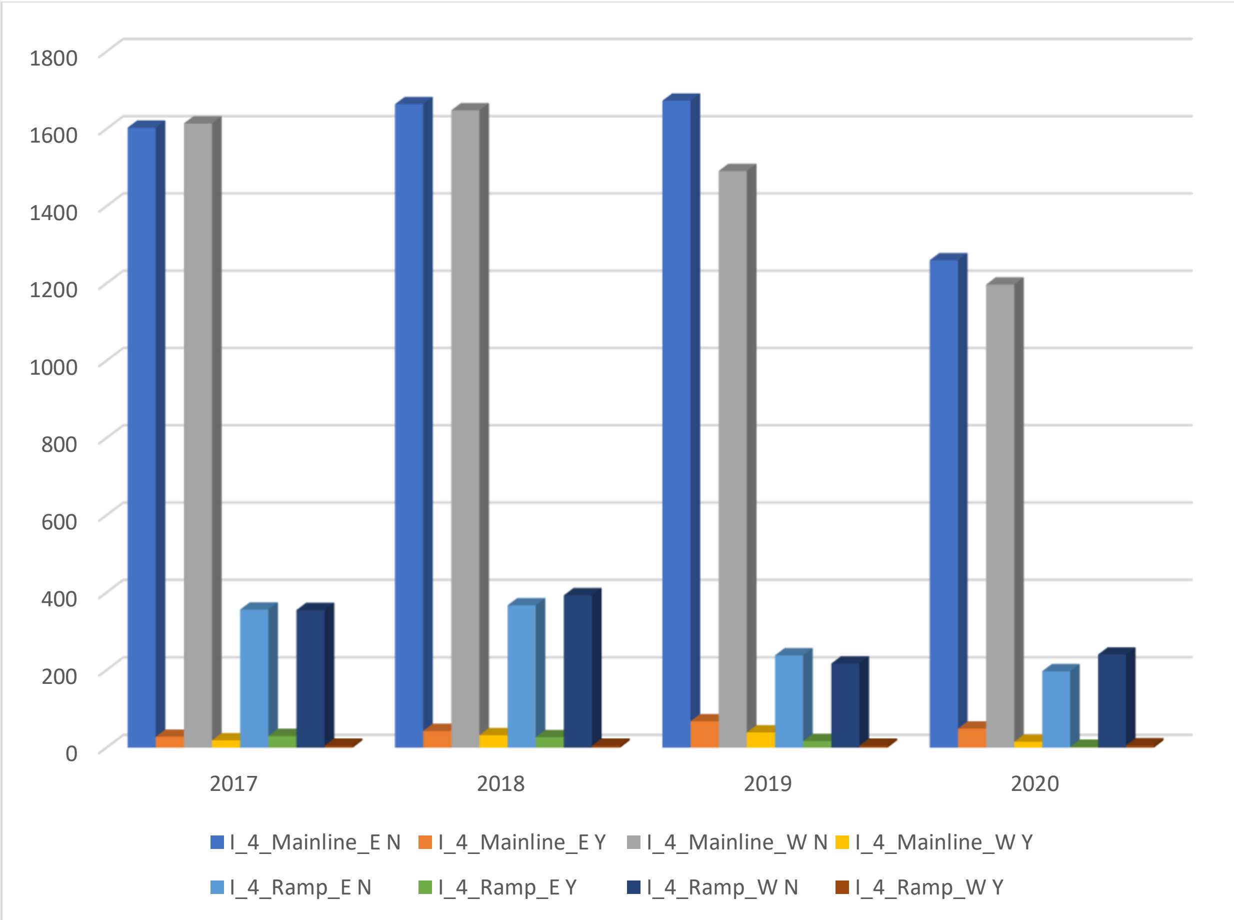


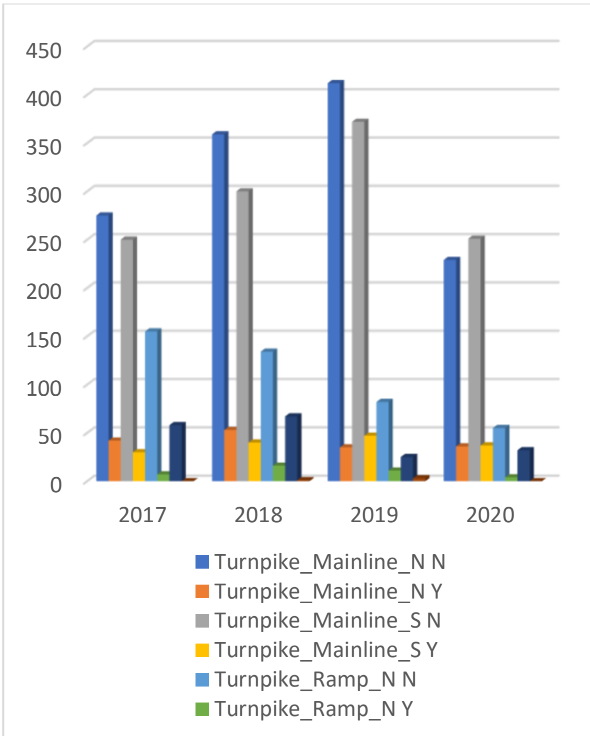
(d) Selmon Expressway (RVL) Mainline

Figure 18 Number of Crashes under Different Weather Conditions

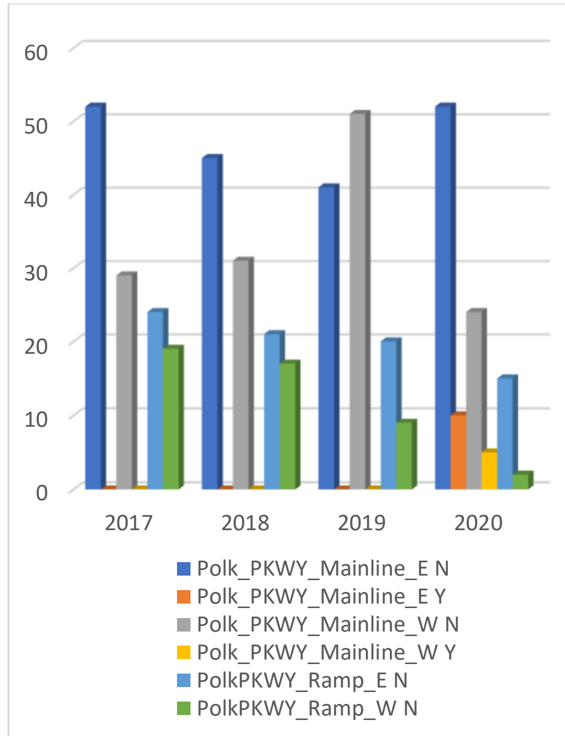
2.2.2.4 Work zone-related crashes

Analyses on work zone-related crashes were also performed since this information bears special significance to the policy makers and research community. As shown in Figure 19, Y indicates that the crash is related to work zone and N indicates that the crash is not related to work zone. Figure 19 shows that most of the crashes on I-4 mainline and ramp were non-work zone related crash. To better understand the scenario, all the other roads were analyzed.

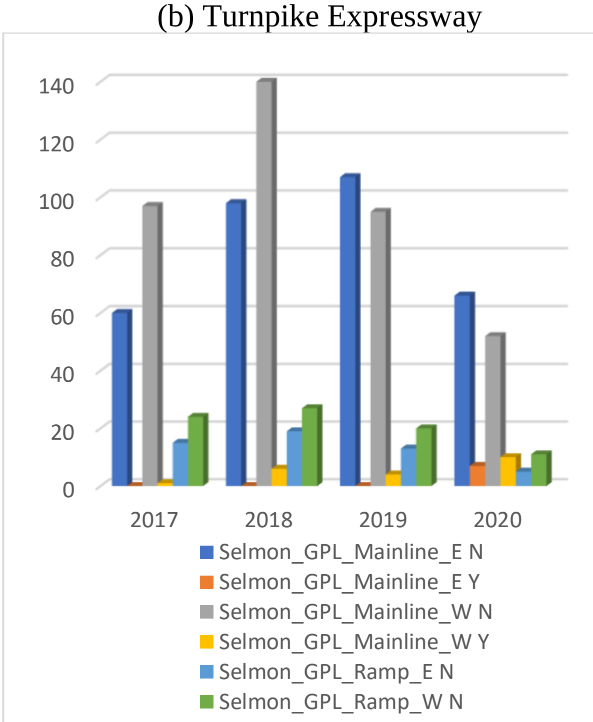

1800
1600
1400
1200
1000
800
600
400
200
0
2017
2018
2019
2020
I_4_Mainline_E N
I_4_Mainline_E Y
I_4_Mainline_W N
I_4_Mainline_W Y
I_4_Ramp_E N
I_4_Ramp_E Y
I_4_Ramp_W N
I_4_Ramp_W Y
(a) I-4



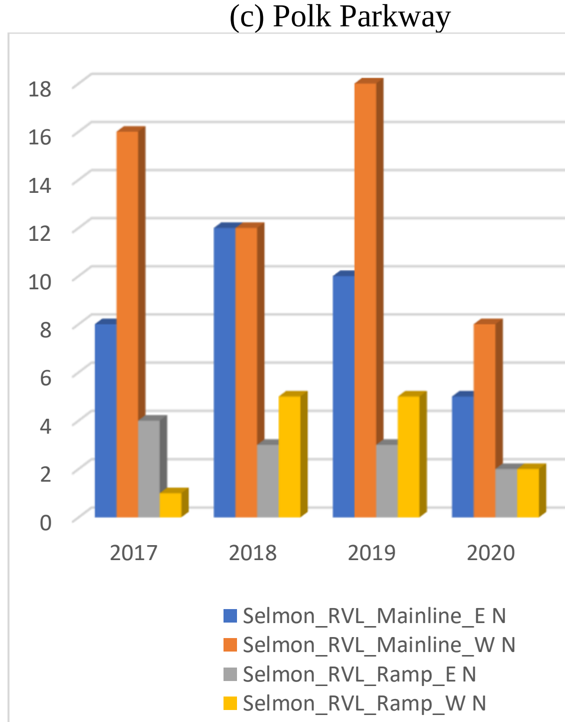
(b) Turnpike Expressway



(c) Polk Parkway



(d) Selmon Expressway (GPL)



(e) Selmon Expressway (RVL)

Figure 19 Work Zone-related Crash Numbers

2.2.3 Summary of Crash Data (Segment Level)

2.2.3.1 Crashes at the segment level

It is important for policy makers and practitioners to know the specific road segments with high frequency of crash occurrence. Particularly when there is a need to apply safety countermeasures, relevant authorities might be interested to know more details about the crash records on each particular segment. Hence, crash analyses at the segment level were conducted. The total numbers of the crashes on each segment during 2017 to 2020 are shown in Figure 20. These crash numbers represent the crashes occurred on a particular segment considering both directions of the considered freeways and expressways. Four colors are used to display different levels of crash numbers in the studied roads. If the sum of the crash numbers of the considered four years in any particular segment is between 0 to 40, the road segment is colored as “green”. Similarly, the road segment with crash numbers between 41 to 80 is marked as “yellow”, 81 to 120 as “orange”, and more than 120 crash is marked as “red.

From the analyses, it is obvious that I-4 possessed the highest risk for segment-level crashes among all the studied roads, and particularly the connecting segments near I-275, Gardenview Parkway, Old Lake Wilson Road, Kissimmee Vineland Road, and Universal Boulevard. In terms of crash risk at the segment level, Turnpike Expressway possessed the next higher risk among all the considered roads. In particular, the segments close to Central Florida Gateway, Beachline Expressway, South Orange Blossom Trail, I-4, and Pearl Lake Park showed the highest risk of crashes per segment. For Polk Parkway and Selmon Expressway, the numbers of crashes per segment were very low compared with I-4 and Turnpike Expressway.

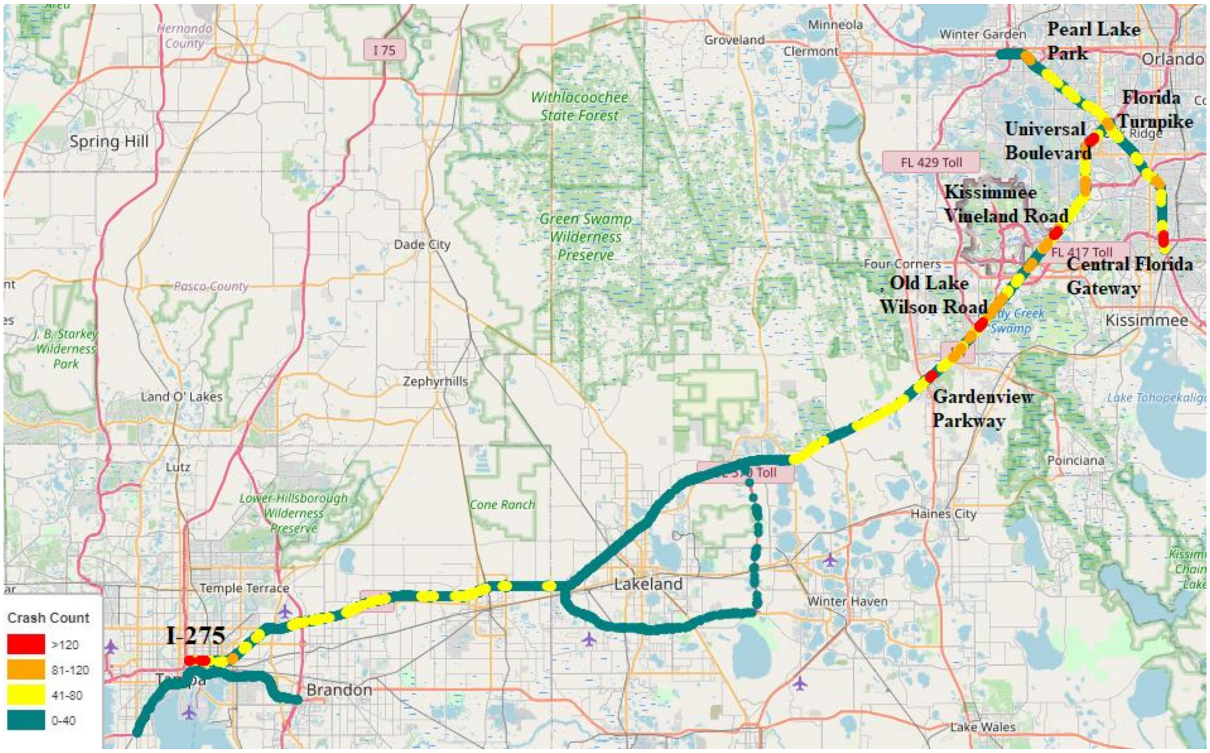
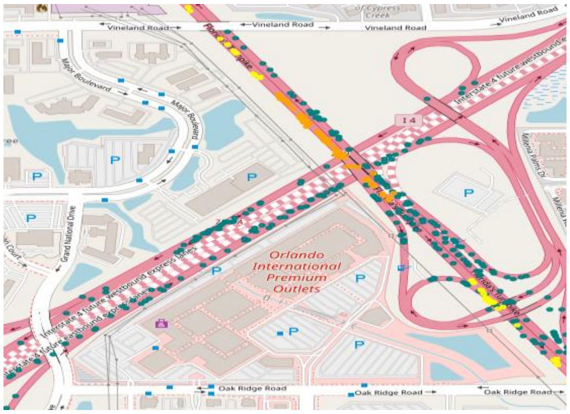
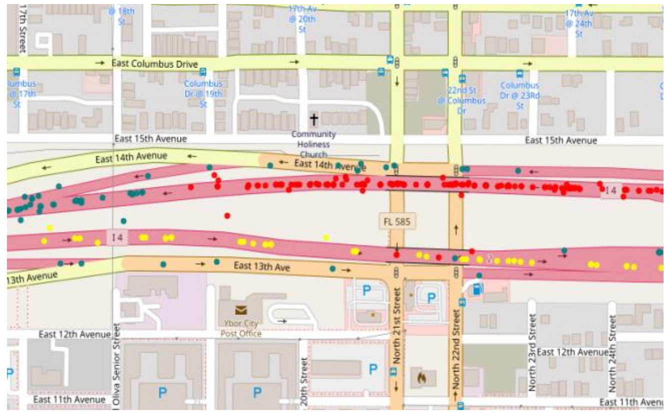


Figure 20 Crash Numbers on the Studied Roads (Segment Level)

To investigate the road segments that had relatively higher crash numbers, Figure 21 shows a few hotspots (road segments) where crashes occurred very frequently. It should be noted that since the analyses were made direction wise on mainline and ramp segments, there may be different colors shown in close proximity. However, this does not necessarily mean different colors appear on the same road segment.

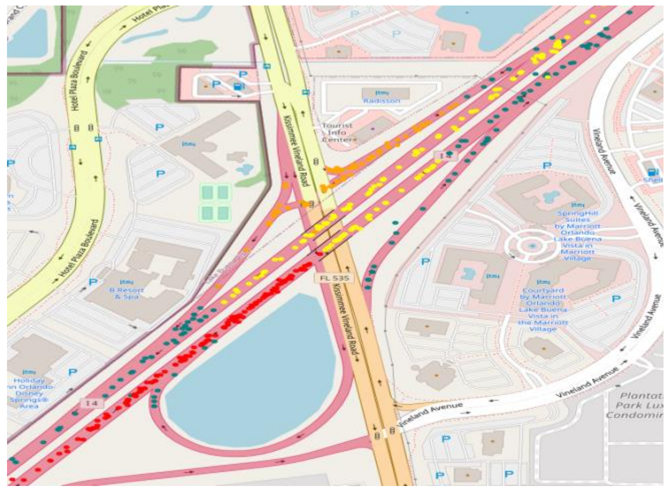


(a) I-4 and Florida Turnpike Connecting Roads

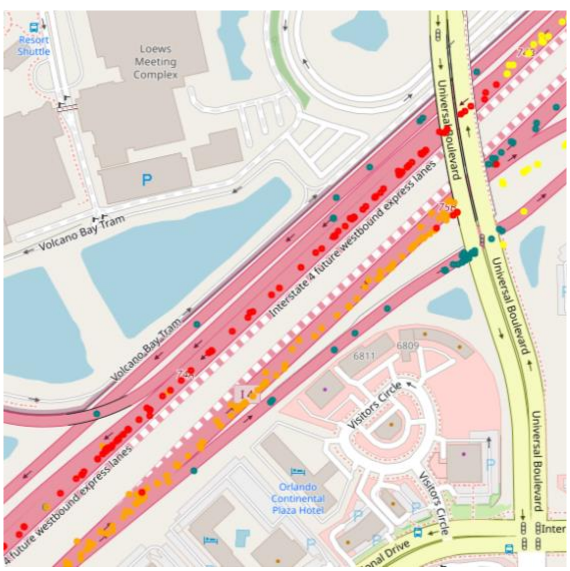


(b) I-4 and East 15th Avenue

(c) I-4 and Old Lake Wilson Road



(d) I-4 and Kissimmee Vineland Road



(e) I-4 and Universal Boulevard

(f) Turnpike Expressway and FL 417

Figure 21 Crash Hotspots on the Studied Roads

Further analyses were conducted to understand the yearly variations among the segments that have high crash numbers. Table 10 shows the variations in the number of crashes per road segment. The range of crashes in a single year for these segments on I-4 and Turnpike Expressway varied from 13 to 117, and 10 to 52, respectively.

Table 10 Crash Number Variations of Top Five Dangerous Segments

Primary Road Name	Secondary Road Name	Crash Number (2017)	Crash Number (2018)	Crash Number (2019)	Crash Number (2020)	Total Crash Number
I-4 Mainline (EB)	Garden View Parkway	13	23	63	23	122
I-4 Mainline (EB)	Kissimmee Vineland Road	70	84	69	20	243
I-4 Mainline (WB)	Universal Boulevard	32	48	38	24	142
I-4 Mainline (WB)	Old Lake Wilson Road	35	33	47	19	134
I-4 Mainline (WB)	I-275	106	117	110	30	363
I-4 Ramp (WB)	I-275	34	30	13	56	133
Turnpike Expressway (NB)	Central Florida Gateway	40	52	23	10	125

2.3 Safety Evaluation of Arterials

Based on crash data and AADT (Annual Average Daily Traffic) information, safety evaluation was conducted. The facilities in the study area were divided into intersections and road segments, since the crash characteristics vary for these two types of facilities. To perform the safety evaluation, analyses based on total crash number, crash types, and crash severities were carried out.

2.3.1 Basemap Preparation

A basemap was prepared using the ArcGIS software. The procedures of basemap preparation and safety evaluation are shown in Figure 22. Firstly, based on the project scope, the key intersections and arterials were selected as the research target. The intersections were loaded in the ArcMap based on the latitude and longitude. AADT information of the studied arterials from the year 2017 to 2020 was collected from the FDOT RCI dataset. Based on the availability of the AADT information, 395 intersections were screened and finally identified as research targets. The crashes for the studied segments were collected from S4A and SSOGIS. Both of the data sources were merged and cleaned. Finally, the processed crash data were loaded in the basemap and matched with the selected intersections using a buffer zone with a radius of 250 ft. Namely, a zone with 250 ft radius was drawn from the center of each intersection, which was considered as the intersection influential zone. Crashes within an intersection influential area were considered as crashes on this intersection (Alarifi, Abdel-Aty and Lee, 2018). On the other hand, the roadway portion between the two intersections, excluding the intersection influential zones was considered as a road segment. AADT information was mapped to the road segments for further calculation. In total, 365 road segments were identified as the research target, and the crashes on these segments were obtained and defined as the segment crashes. It should be noted that intersection crashes which were in the immediate vicinity of an intersection (within 250 ft) were excluded from the segment crashes (Rahman *et al.*, 2019).

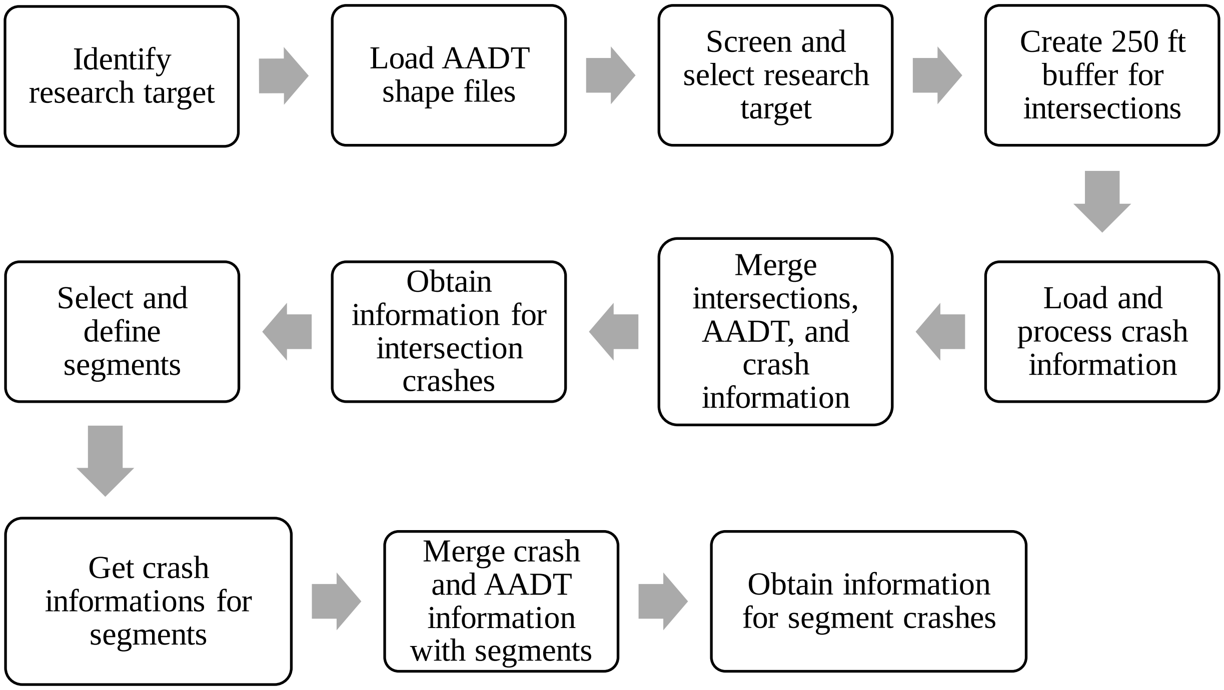


Figure 22 Safety Evaluation Procedure

2.3.2 Summary of Crash Data (Intersection)

To identify the safety challenges of the intersections, crash rates were calculated to determine relative safety level among similar roadways, segments, or intersections. The crash rate takes into account of exposure data, typically like traffic volumes or vehicle-miles traveled (VMT). The benefit of a crash rate analysis is that it provides a more effective comparison of similar locations with safety issues, which allows for prioritization for the critical locations when considering safety improvements with limited resources .

To calculate the crash rate for an intersection, the following formula was used (Golembiewski and Chandler, 2011):

$$CR = \frac{1000000 \times C}{365 \times N \times V}$$

where CR is the crash rate for the intersection expressed as crashes per million entering vehicles (MEV), C is the total number of intersection crashes, N is the number of years, and V is the total entering AADT at the intersection.

First, the crash rates were calculated for the intersections from 2017 to 2020. Crash rates were grouped into different ranges i.e., no crash (0), $0 < CR < 0.5$ (between 0 and 0.5), and so on. Finally, the percentages of the intersections within each range were summed up and reported, as shown in Figure 23. This helps to understand the patterns of crash rate for all intersections. For example, from the figure, it can be observed that there was no crash at around 5.06% of the intersections in the year 2017. More than one fourth of the intersections had a crash rate between $0.5 \leq CR < 1$. Overall, 27.34%, 23.42% and 17.03% of the intersections had crash rates within the ranges of $0 < CR < 0.5$, $0.5 \leq CR < 1$, and $1 \leq CR < 1.5$, respectively. From the perspective of the yearly trend, it is evident that fluctuating patterns were observed in many ranges.

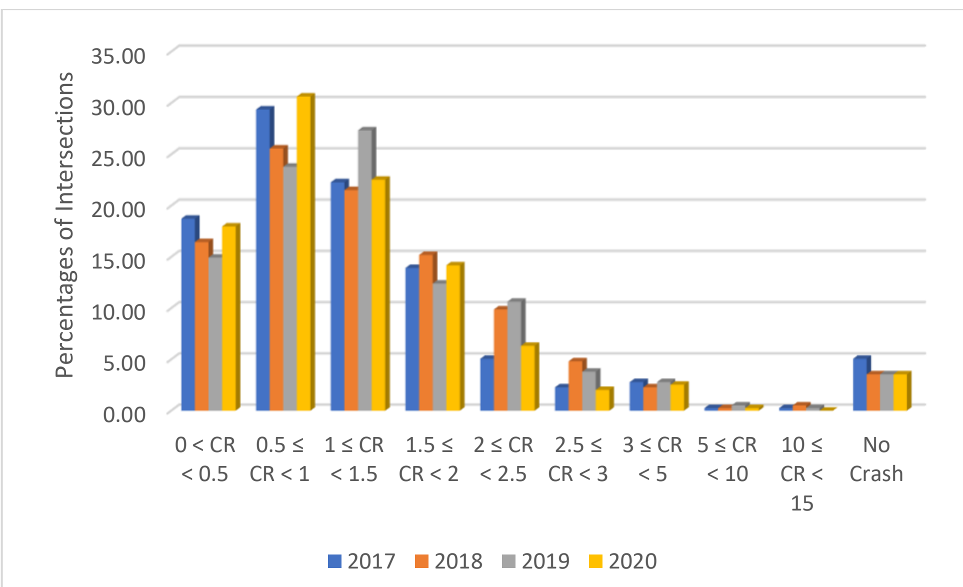


Figure 23 Percentages of Intersections Grouped on Different Crash Rate (CR) Ranges (2017-2020)

Additional analyses were conducted for crash severity levels. The crashes were divided into five severity levels according to the KABCO injury classification scale and definitions from the Federal Highway Administration (FHWA) (FHWA, 2022b). In this system, K is designated as the fatal injury or any injury that results in death within a 30-day period after the crash occurred. A is designated as the incapacitating injury, which is defined as disabling injury, such as broken bone, severed limb, etc. This injury type usually requires transporting and hospitalization to medical facility. B denotes the non-incapacitating evident injury, which is defined by non-disabling injury, such as laceration, scrape, bruise, etc. C denotes possible injury. And O denotes no injury. This crash type is usually referred to as Property Damage Only (PDO) crash.

Because detailed crash information is missing and a single source might not provide all the crash information, this study used two data sources, i.e., SSOGIS and S4A, to obtain KABCO crash severity scale. First, the research team obtained the KABCO information from SSOGIS data sources; if there was any missing information, then S4A data source was used. Because the variables to extract the KABCO data are named differently in these two data sources, Table 11 shows how the labels were used to obtain the severity scale.

Table 11 Definition of Crash Severity in S4A and SSOGIS

KABCO Injury Classification Scale	Label in S4A	Label in SSOGIS
K (fatal injury)	Fatalities_30_Days	Traffic_Fatalities
A (incapacitating injury)	Incapacitating_Injuries	Serious_Injuries
B (non-incapacitating evident injury)	Non_Incapacitating Injuries	Nonfatal Injuries (more than two)
C (possible injury)	Possible_Injuries	Nonfatal Injuries (equal/less than two)
O (no injury)	None of above	None of above

As shown in Figure 24, the average crash rates of fatal crashes increased from 2017 to 2019 and then decreased from 2019 to 2020. The underlying reason why fatal crash rate in 2020 was higher might be the effects of COVID-19. As there were fewer vehicles on roads, drivers were more likely to overspeed, which may have resulted in a higher rate of fatal crashes compared to 2017 and 2018 (Islam *et al.*, 2022). The average crash rate was 0.075 (in MEV) over four years.

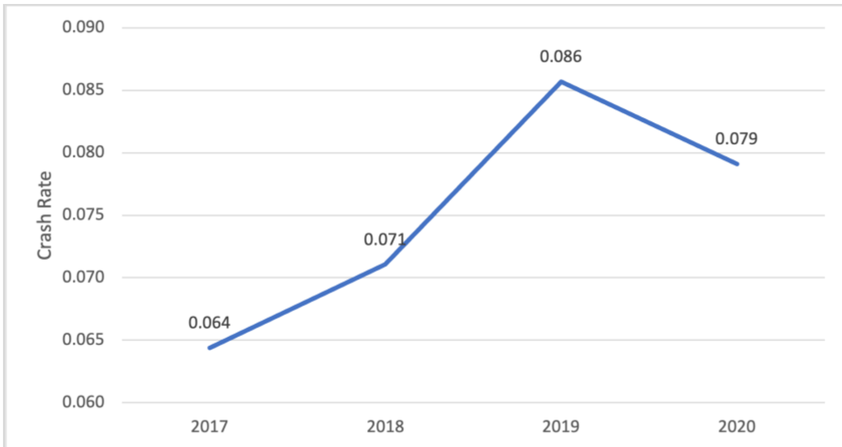


Figure 24 Crash Rates of Fatal Crashes (per MEV, 2017-2020)

Figure 25 shows the percentages of intersections with fatal crashes from the year 2017 to 2020. In 2017, 9.11% fatal crashes occurred within intersections. From 2017 to 2019, there was a decreasing trend in the percentage of intersections involving fatal crashes; however, in 2020, more intersections experienced fatal crashes compared to 2019, which is consistent with the findings from Figure 24.

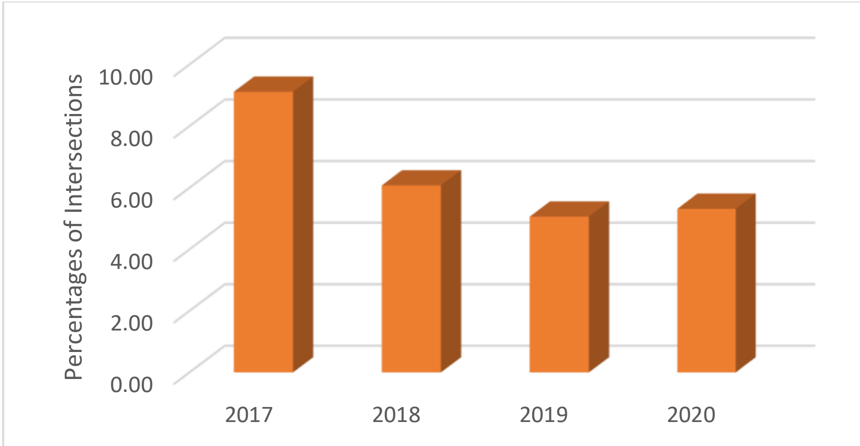


Figure 25 Percentages of Intersections with Fatal Crashes (2017-2020)

As shown in Table 12, the crash rates of the three severity levels did not experience large fluctuations from 2017 to 2020. Crashes with possible injury were more compared with crashes of other two severity levels. As shown in Figure 26, around 24.81% intersections had type A crashes, 8.48% of intersections had type B crashes, and 60.06% of intersections had type C of crashes.

Table 12 Crash Rates for Type A, B, and C Crashes (in MEV, 2017–2020)

	Crash Severity		
Year	**Incapacitating injury (A)**	**Non-incapacitating evident injury (B)**	**Possible injury (C)**
2017	0.097	0.076	0.168
2018	0.103	0.072	0.168
2019	0.103	0.068	0.165
2020	0.094	0.074	0.159
Average	0.099	0.073	0.165

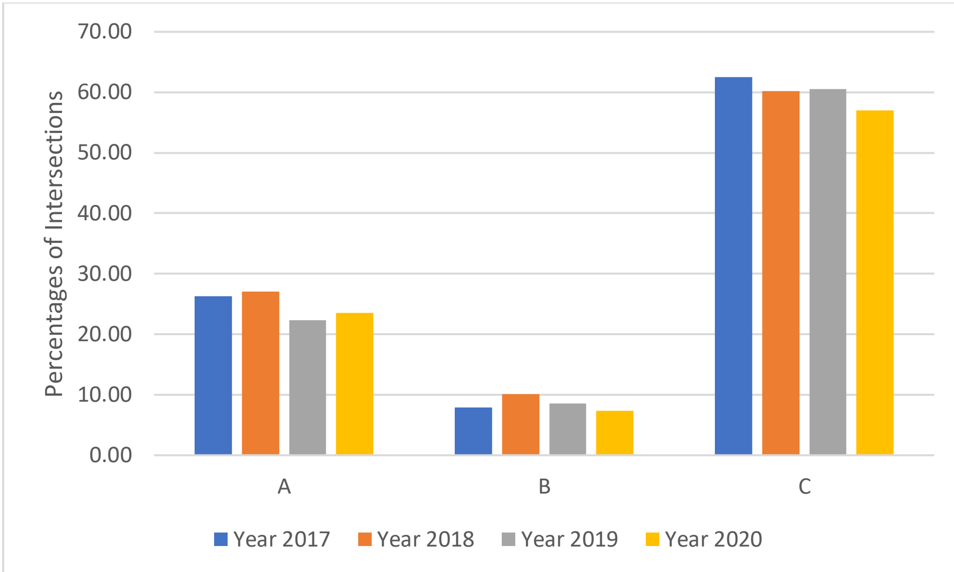


Figure 26 Percentages of Intersections with A, B, and C Crashes (2017–2020)

For PDO crashes, as shown in Figure 27, it is evident that around 2% to 6% of the intersections had no PDO crashes from 2017 to 2020. This indicates that almost all the intersections experienced PDO crashes. Hence, to better understand the scenario, crash rates were calculated for PDO crashes. On average 30.70%, 21.84%, and 20.25% of the studied intersections experienced PDO crashes in the range of $0.5 \leqslant CR < 1$, $1 \leqslant CR < 1.5$, and $0 < CR < 0.5$ crash rate, respectively. This implies that most of intersections had lower crash rates; 0.32% and 0.19% of the intersections experienced higher crash rates i.e., in the range of $5 \leqslant CR < 10$, and $10 \leqslant CR < 15$, respectively. The average crash rate of those intersections having PDO crashes were also calculated. The average crash rates were 1.03, 1.19, 1.19, and 1.04 (in MEV) from 2017 to 2020 respectively.

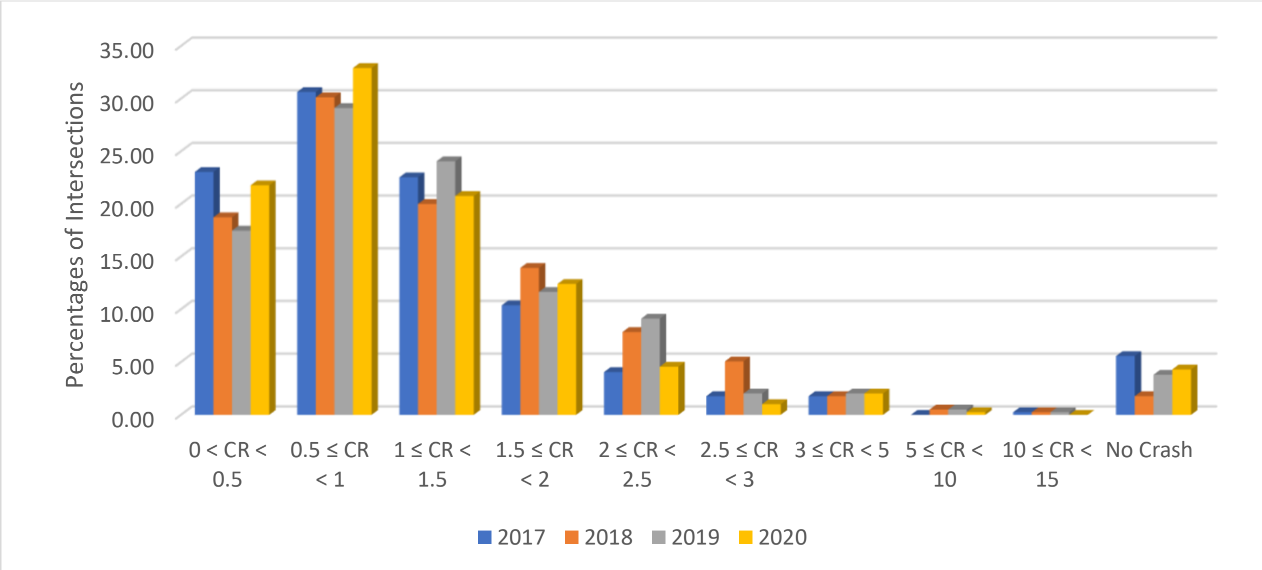


Figure 27 Percentages of Intersections Grouped on Different Crash Rate Range for the PDO Crashes (2017-2020)

In the next phase of the analysis for intersections, different crash types were considered. Based on the crash types in SSOGIS and S4A, the following crash types were identified: rear-end, sideswipe, left-turn, angle, head-on, off-road, others, unknown, right-turn, pedestrian, head-on, bicycle, rollover, and animal. The percentages of intersections with these crash types are shown in Figure 28. Among them, rear-end crashes occurred in most of the intersections; on average 86.58% of the intersections experienced rear-end crashes. Sideswipe and left-turn crashes also posed threat to road safety, and they also had higher percentages 70.57% and 65.82% respectively. A steady increase in the proportion of intersection with these types of crashes was observed from the year 2017 to 2019, and a slight decrease was observed during the year 2020.

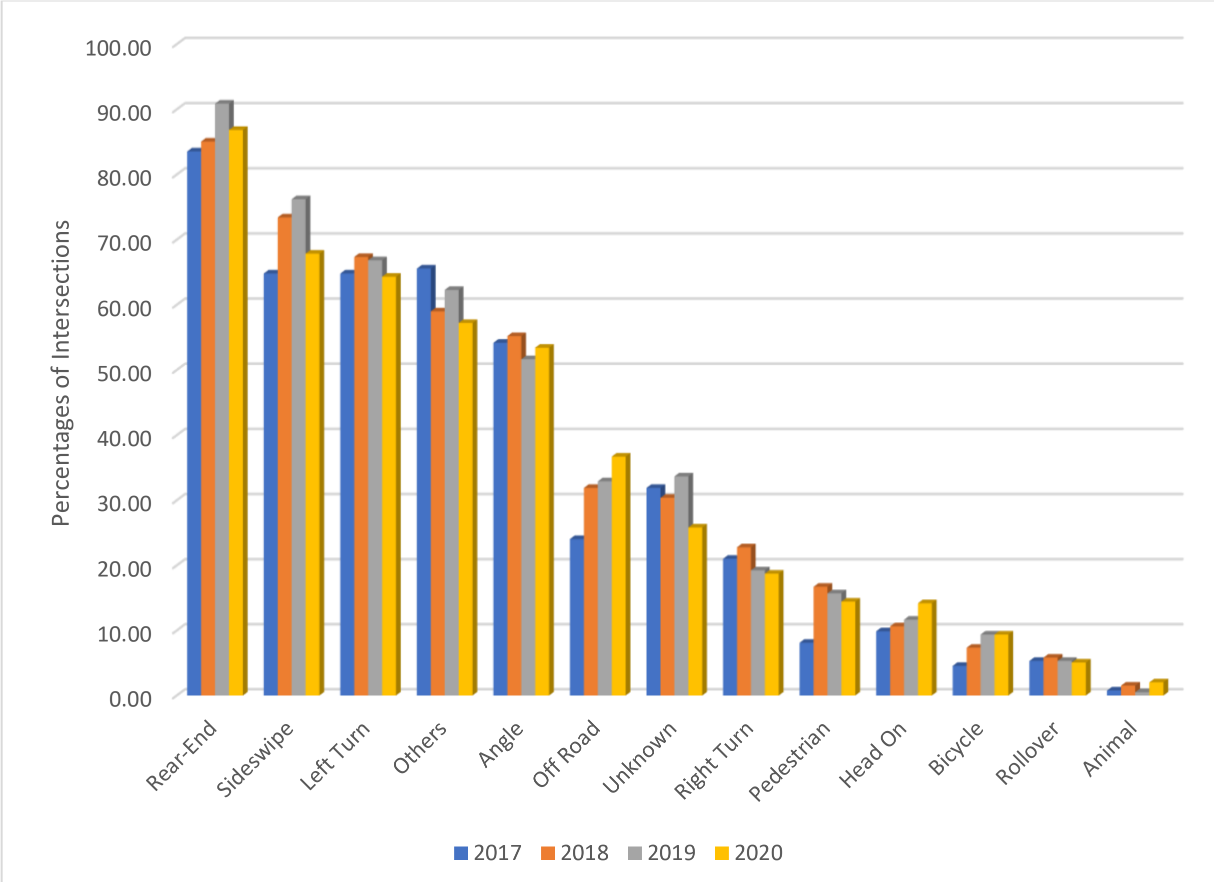


Figure 28 Percentages of Intersections with Different Types of Crashes (2017-2020)

From Figure 28, coverages of the different crash types on the studied intersections are evident. However, to better understand the major crash types on those intersections, further average crash rate values in different years of those intersections having these types of crashes are shown the Table 13. From Table 13, it is evident that rear-end, sideswipe and left turn crashes are the major crash types on the studied intersections with average crash rate values of 0.596, 0.247, and 0.246, respectively.

Table 13 Average Crash Rates for Major Types of Crashes (per MVM, 2017-2020)

Year/Crash Type	Rear-end	Sideswipe	Left-Turn	Angle	Head On	Off road	Right Turn	Pedestrian and Bicyclists
2017	0.603	0.218	0.245	0.168	0.081	0.123	0.0982	0.081
2018	0.640	0.259	0.245	0.189	0.089	0.136	0.103	0.084
2019	0.628	0.278	0.242	0.185	0.080	0.138	0.100	0.085
2020	0.512	0.234	0.250	0.212	0.085	0.140	0.099	0.088
Average	0. 596	0.247	0.246	0.189	0.084	0.134	0.100	0.085

Since rear-end, sideswipe, and left-turn crashes were major crash types in those intersections, further analyses were done based on crash rate to better understand the safety challenge. In addition, pedestrians and bicycles crashes were also considered in crash rate analyses as they are vulnerable road users.

Figure 29 shows that on average 12.15% of the intersections did not have any rear-end crashes. Majority of the intersections having rear-end crashes experienced the crash rate less than 2. Also, 45.32%, 28.99% and 10.99% of the intersections had crash rates in the range of $0 < CR < 0.5$, $0.5 \leqslant CR < 1$ and $1 \leqslant CR < 1.5$ respectively.

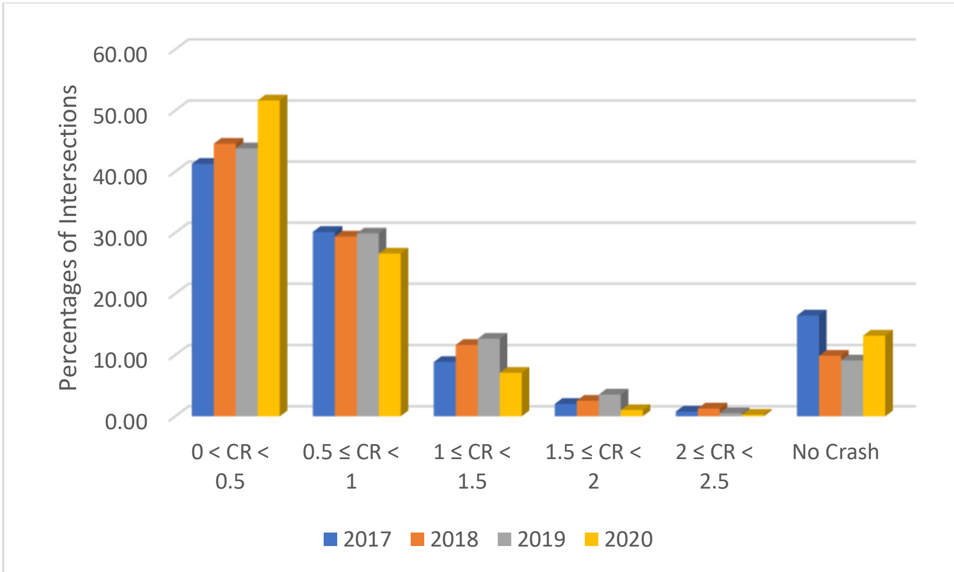


Figure 29 Percentages of Total Intersections Grouped on Different Crash Rate (CR) Range for the Rear-end Crashes (2017-2020)

From Figure 30 it is evident that on average 29.43% of intersections did not encounter sideswipe crashes. The majority of the intersections (65.06%) experienced sideswipe crashes in a low crash rate range i.e., 0 < CR < 0.5.

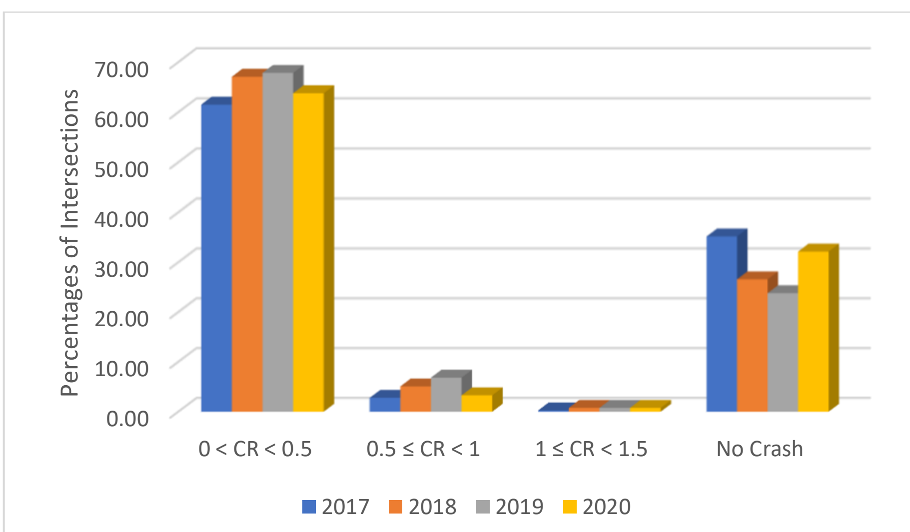


Figure 30 Percentages of Intersections Grouped on Different Crash Rate (CR) Range for the Sideswipe Crashes (2017-2020)

Figure 31 shows that on average 34.18% of intersections did not have left-turn crashes. The majority of the intersections (58.67%) experienced left-turn crashes with low crash rate range, i.e., 0 < CR < 0.5. Crash rate ranging from 0 to 1 showed a slight increase from 2017 to 2018, and then gradual decreased from 2019 to 2020.

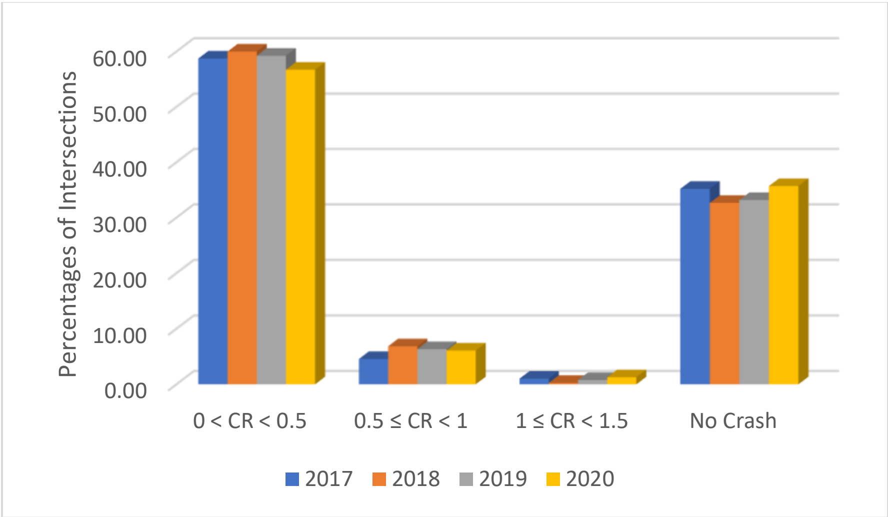


Figure 31 Percentages of Intersections Grouped on Different Crash Rate (CR) Range for the Left-turn Crashes (2017-2020)

Pedestrians and bicyclists are the most vulnerable road users (VRUs). VRU safety is very important to ensure a safer road system. Hence, this study also considered pedestrian crashes and bicyclist crashes on the studied intersections. As shown in Figure 32, although around 78% intersections did not experience any pedestrian and bicyclist crashes, still a high percentage (around 22%) of total intersections experienced pedestrian crashes. Reducing this number would be a great step to ensure a safer road system. Annually, for all the intersections, the average number of pedestrian crashes is 55, and the average number of bicyclist crashes is around 31.

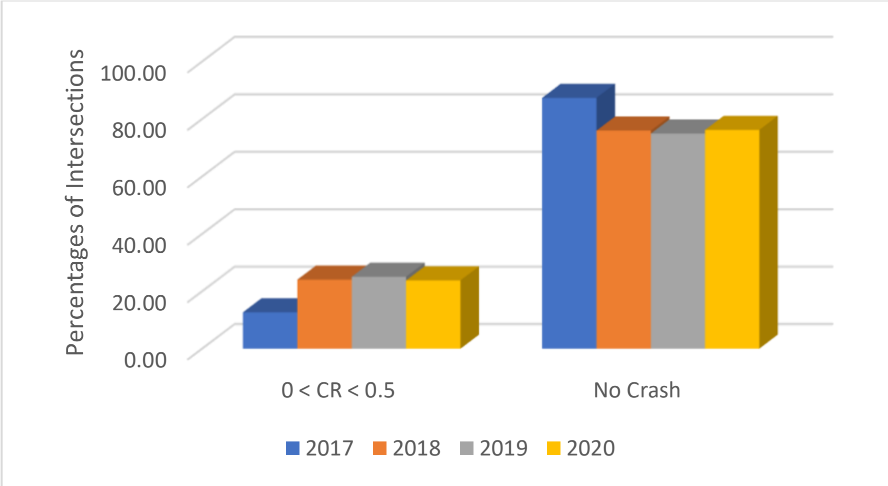


Figure 32 Percentages of Intersections Grouped on Different Crash Rate (CR) Range for the Pedestrian and Bicyclist Crashes (2017-2020)

Finally, intersections having fatal, pedestrians and Bicyclist Crashes need special focus considering the damages made by these crash types and severities. In addition, it is also important to investigate whether the safety conditions of those intersections are improving after deploying TSM&O devices and technologies. Hence, the study has listed all those intersections having fatal, pedestrian and bicyclist crashes with their geographic identifying locations in Table A-1 in Appendix A. It is evident that 196 intersections either experienced fatal crashes, or pedestrian crashes, or bicyclist crashes or any combination of any of these crashes. Those intersections had the same types of crashes in more than two years period or combination of any crashes, i.e., fatal, pedestrian, bicyclist crashes. Particularly intersection number 13, 21, 46, 160, 163, 165, 172, 173, 188, 199, 201, 202, 218, 380, and 397 pose the most risks as it had experienced all these three crashes. Apart from these, intersection number 62, 66, 95, 97, 107, 157, 166, 167, 168, 170, 182, 183, 186, 191, 193, 194, 198, 216, 217, 238, 241, 254, 258, 277, 287, 290, 297, 298, 305, 307, 311, 325, 338, 345, 377, and 385 were found to be high risk intersections as they either experienced at least two of these crash types or they experienced same crashes at least for 3 years.

2.3.3 Summary of Crash Data (Segment)

It is important for policymakers and practitioners to know the specific road segments with higher crash risk, particularly when there is a need to apply safety countermeasures. The relevant authorities might be interested to know more details about the crash records on each particular segment. Hence, crash analyses at the segment level were conducted. After processing the data and basemap, 365 segments were considered on some major arterials in the studied area. The crash rate was calculated for each segment for the years 2017 to 2020 as base criteria to evaluate the future safety challenges.

Crash rate for segment is calculated as per the formula of FHWA (FHWA, 2022a). The formula is as follows:

$$CR = \frac{100{,}000{,}000 \times C}{365 \times N \times V \times L}$$

where CR is the crash rate for a particular segment, C is the total number of crashes, N is the number of years, V is the AADT, and L is the length of the roadway segment in miles. CR is expressed in Million Vehicle Miles (MVM). It is the measure of exposure of the total number of vehicles traveling on the road segment during the specified time period.

First, the crash rates, considering the total number of crashes, were calculated for all the segments from the year 2017 to 2020. The average crash rate of all the considered segments were 5.17, 5.78, 5.95, and 5.96 (crash frequency per MVM) for 2017 to 2020, respectively. As only around 1.6% of segments had no crash, crash rates were grouped into different ranges to better understand in which range most of the segments were experiencing crashes. From Figure 33, it is evident that around 46% of segments are at risk of higher crash rate (greater than 3) i.e., 17.67%, 16.51%, and 11.92% segments experienced crashes in the range of 3 ⩽ CR < 5, 5 ⩽ CR < 10, CR ⩾10 respectively. It is hard to find a yearly pattern within each crash rate range as it fluctuated over the periods. Lower percentages of road segments experienced low crash rates, and high percentages of segments experiencing high crash rate range are alarming in the sense that it poses a great risk to the road users in most of those segments.

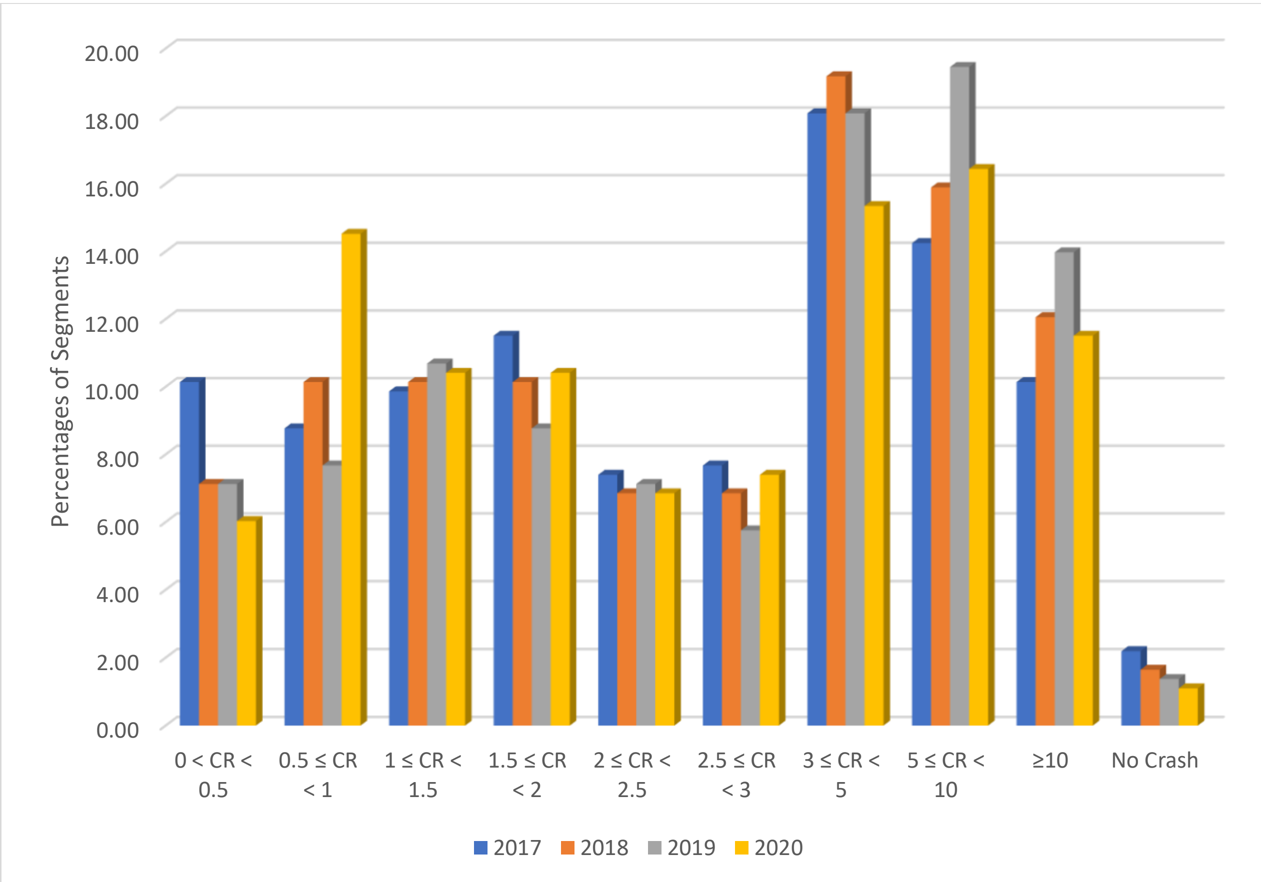
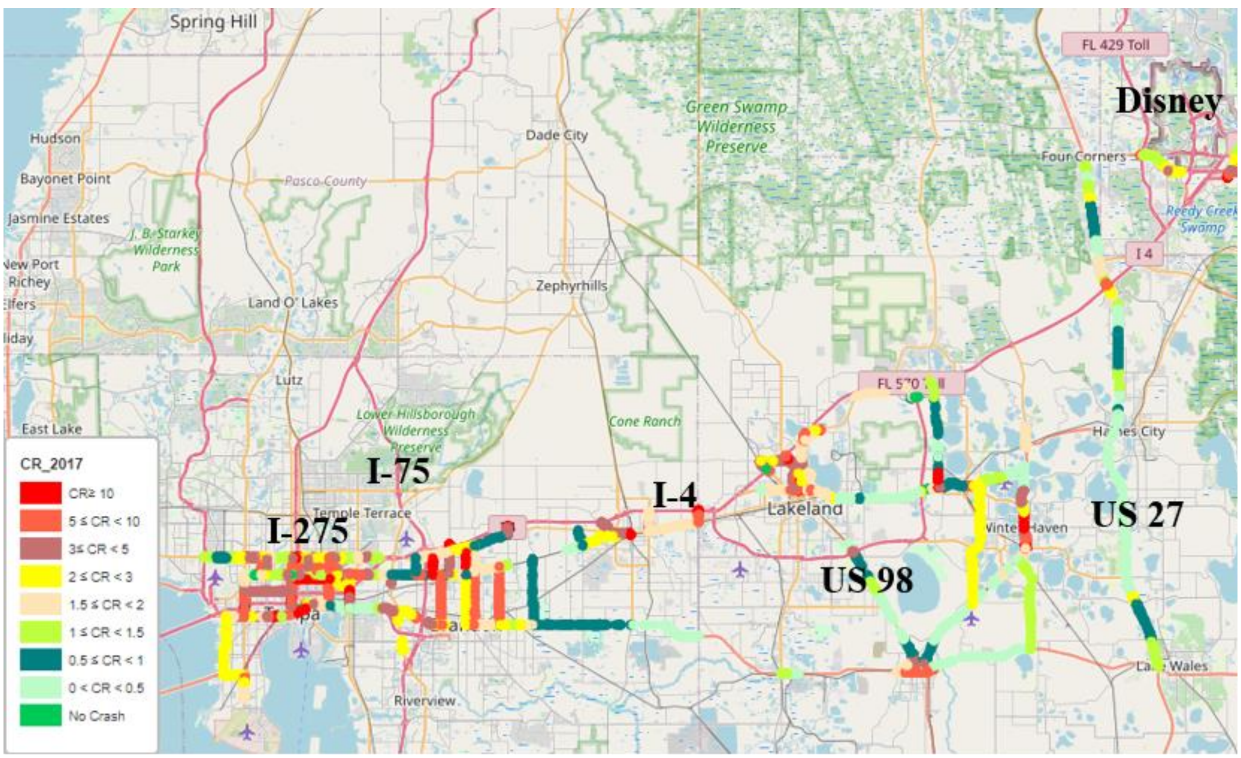
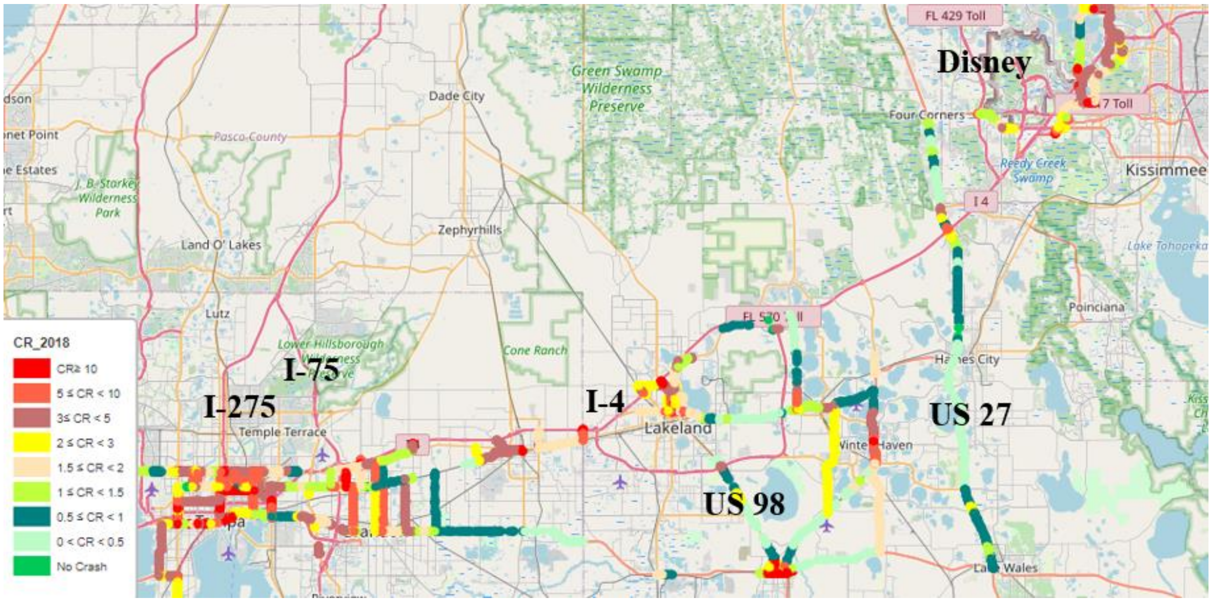


Figure 33 Percentages of Segments Grouped on Different Crash Rate (CR) Range for the Total Crashes (2017-2020)

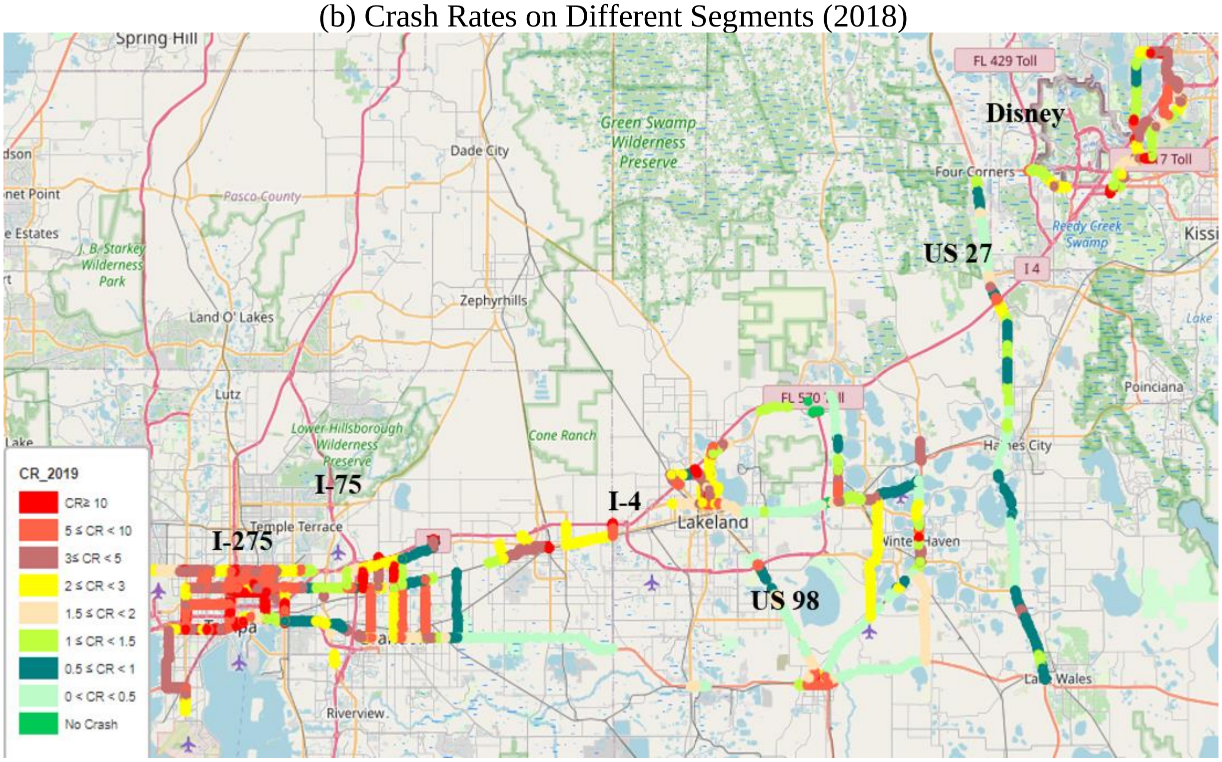
To visualize the most risk-prone segments, crash rates are shown on the map from 2017 to 2020 in Figure 34. The crash-prone segments are marked with darker colors (red and close to red colors), i.e., CR≥10 as red, 3 ≤ CR < 5 as medium light shade of red, etc. Less crash-prone segments as marked with green or close to green colors, i.e., no crash as green, 0 < CR < 0.5 as very soft lime green, 0.5 ≤ CR < 1 as cyan-green color, etc. And medium crash-prone segments are presented with yellow or close to yellow color i.e., 1.5 ≤ CR < 2 as Green Yellow, 2 ≤ CR < 2.5 as very light shade of brown, and 2.5 ≤ CR < 3 as yellow. It is evident that segments near I-275, the arterials close to I-4 and I-75 connecting point, US-98, and surrounding arterials of Disney were found to be the most crash-prone segments.



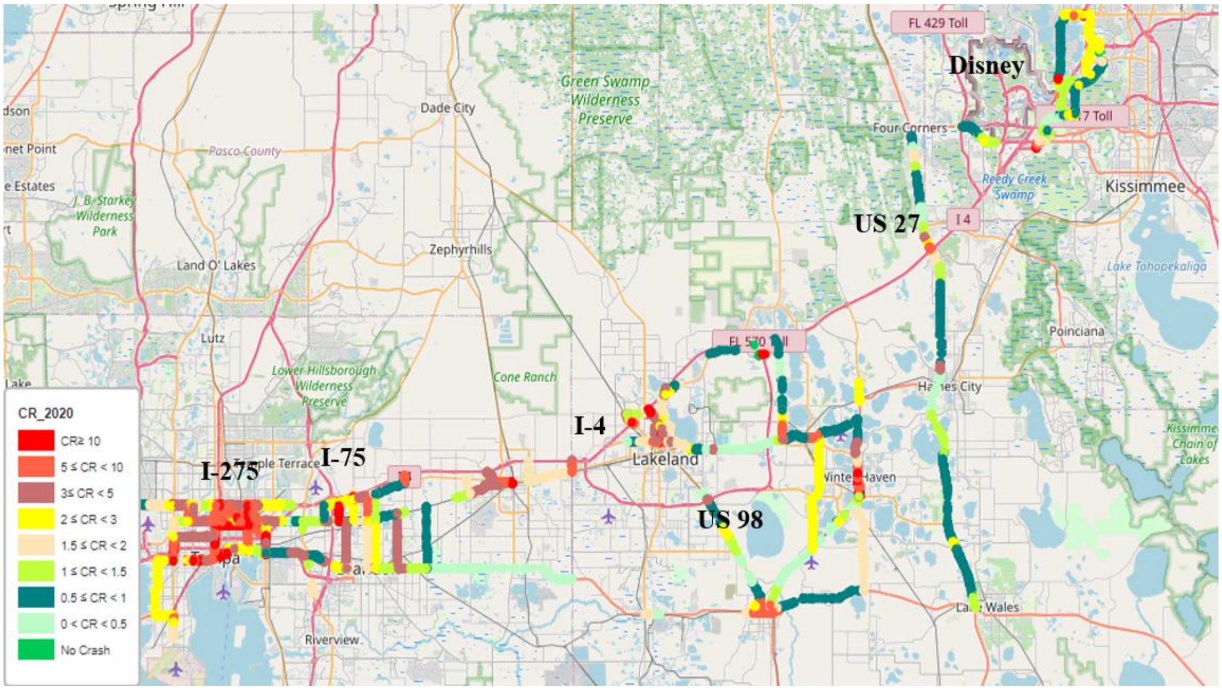
(a) Crash Rates on Different Segments (2017)



(b) Crash Rates on Different Segments (2018)



(c) Crash Rates on Different Segments (2019)



(d) Crash Rates on Different Segments (2020)

Figure 34 Crash Rates on Different Segments (2017-2020)

Next, safety challenges were identified based on the crash severity. In this analysis, first the percentages of total segments with fatal crashes were obtained. From Figure 35, it is observed that on average 14% of segments of the study area experienced fatal crashes. It was maximum in 2019 (16.16%) and dropped slightly in 2020 (14.25%).

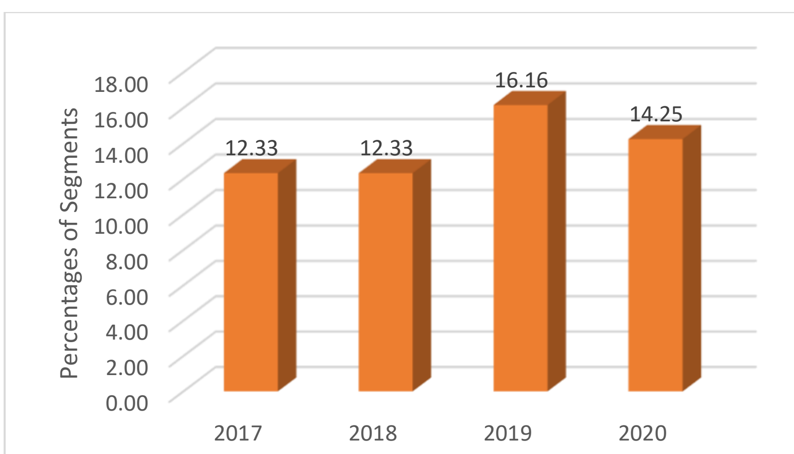


Figure 35 Percentages of Segments experiencing Fatal Crashes (2017-2020)

Figure 36 shows the A, B, and C crash severities from the year 2017 to 2020. On average 35.41%, 13.49%, and 71.71% of total segments had A, B and C crash severities, which was very high. A and C crash severities decreased gradually from 2017 to 2020, except a slight increase of C crashes in 2018. B crashes gradually increased from 2017 to 2019 and dropped slightly in 2020.

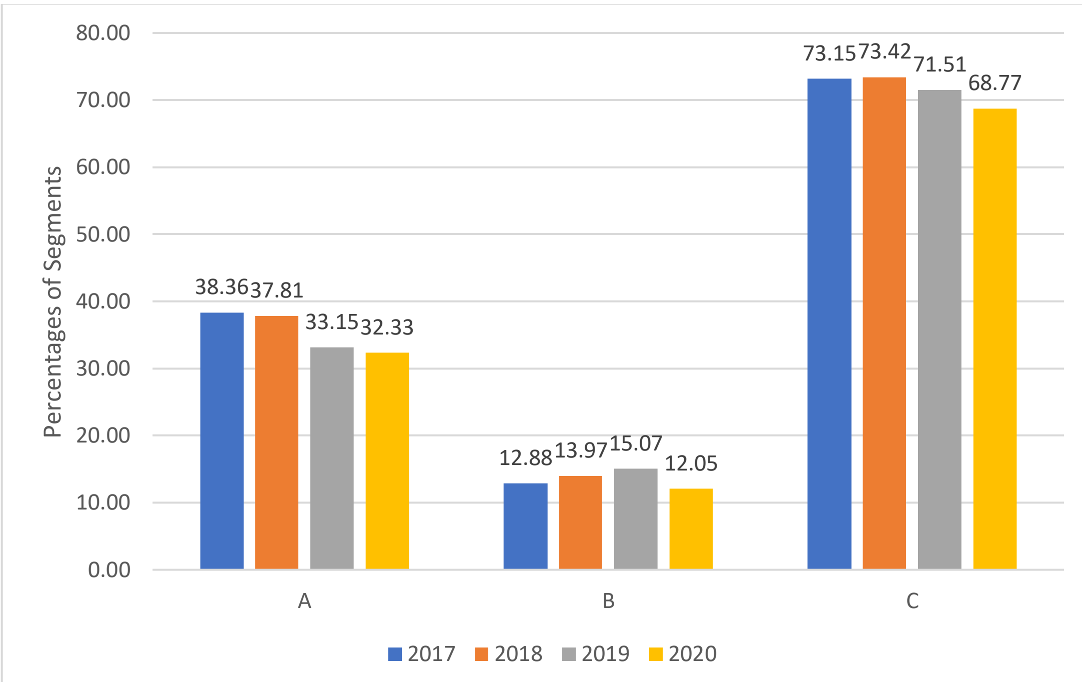


Figure 36 Percentage of Segments with Different Severity Levels (2017-2020)

Figure 37 shows that on average only 2% of segments had no PDO crashes throughout the study period. This implies that PDO crashes happened on almost all the segments. Most alarming is that 54.38% of the segments had higher crash rate, i.e., in the range of $2 \leq CR < 3$, $3 \leq CR < 5$, $5 \leq CR < 10$ and $CR \geq 10$. The average values of the crash rates for all the segments were found to be 15.355, 14.954, 13.921, and 10.630 (per MVM) in the year 2017, 2018, 2019, and 2020 respectively.

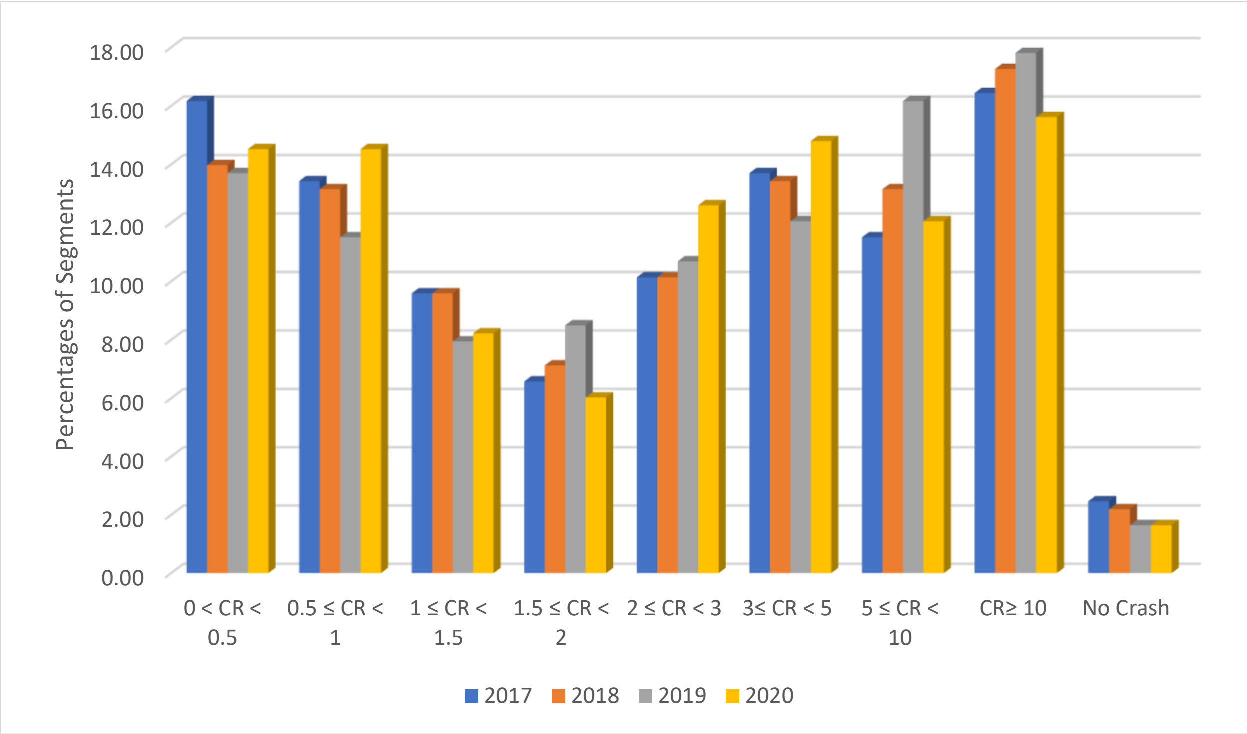


Figure 37 Percentages of Segments Grouped on Different Crash Rate (CR) Range for PDO Crashes (2017-2020)

Finally, the analyses for the different crash types of these segments were done. The following crash types were identified in the study area, rear-end, sideswipe, left-turn, angle, head-on, off-road, others, unknown, right-turn, pedestrian, head-on, bicycle, rollover, and animal. The crash rates for major types of crashes are shown in Table 14. As shown in Figure 38, for rear-end, sideswipe, left-turn, and pedestrian and bicyclist crashes, there is a common trend that crash rates increased from 2017 to 2019, and then decreased in 2020, probably due to the impact of COVID-19.

Table 14 Average Crash Rates for Major Types of Crashes (per MVM, 2017-2020)

Year/ Crash Type	Rear-end	Sideswipe	Left-Turn	Pedestrian and Bicyclist
2017	2.739	1.910	0.741	0.061
2018	2.807	2.101	0.858	0.145
2019	2.613	2.255	0.992	0.180
2020	2.541	1.329	0.694	0.165
Average	2.675	1.899	0.821	0.138

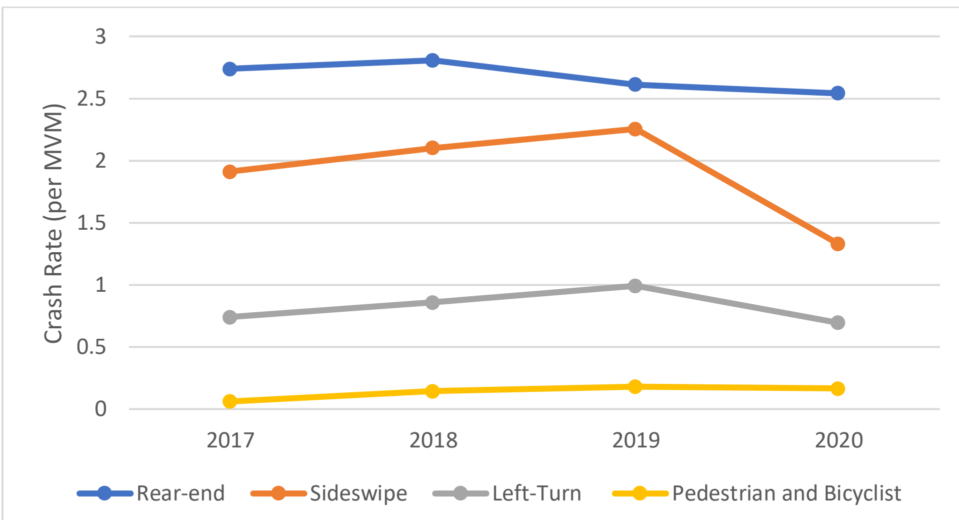


Figure 38 Crash Rates for Different Types of Crashes (2017-2020)

The percentages of the road segments experiencing these crash types are shown in Figure 39. On average, 92.53%, 81.23% and 67.33% of the segments had rear-end, sideswipe, and left-turn crashes respectively, from 2017 to 2020.

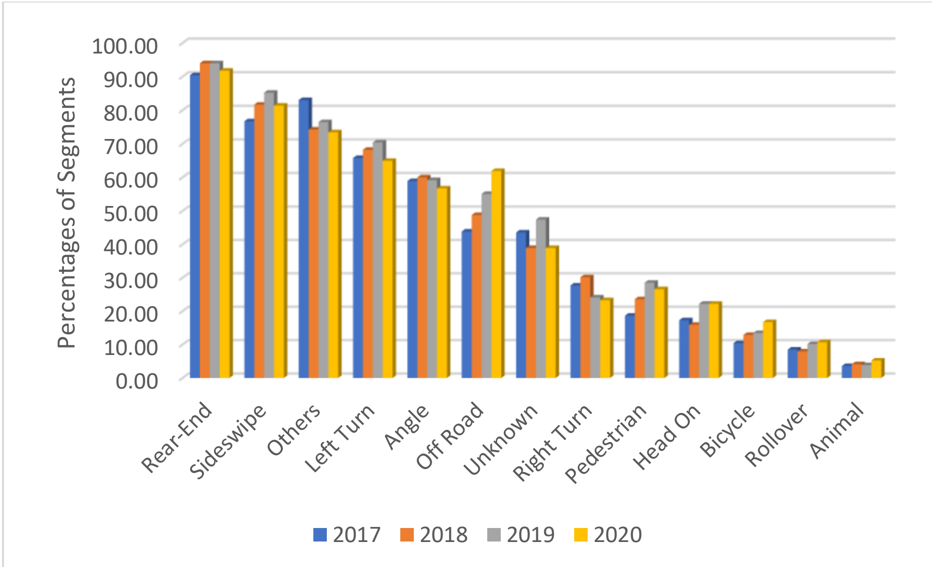


Figure 39 Percentages of Segments having Different Types of Crashes (2017-2020)

Since these three types of crashes were predominant, further analyses were done to better illustrate the different crash rate ranges for those crash types. Figure 40 shows that around 24% of segments had the crash rates of rear-end crashes between 0.5 and 1. Although the number of segments not having rear-end crashes decreased from 2017 to 2019, it suddenly rose in 2020.

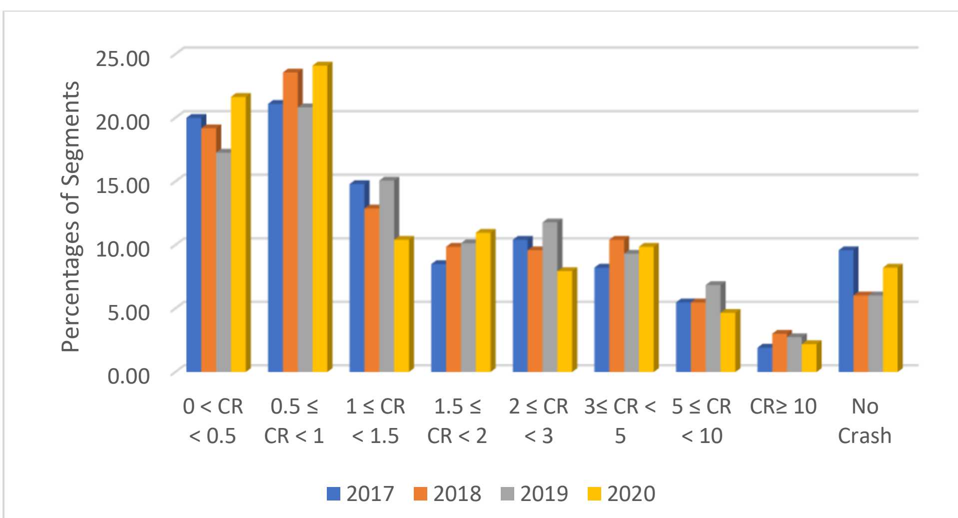


Figure 40 Percentages of Segments Grouped on Different Crash Rate (CR) Range for the Rear-end Crashes (2017-2020)

Figure 41 shows that 18.77% of segments did not experience sideswipe crashes. Most of these segments had low crash rates, i.e., 45.82% of the segments had crash rates in the range of 0 < CR < 0.5 and 16.37% of the segments had crash rates in the range of 0.5 ⩽ CR < 1. Still, around 6% of the segments experienced higher sideswipe crash rates (higher than 3 (per MVM)).

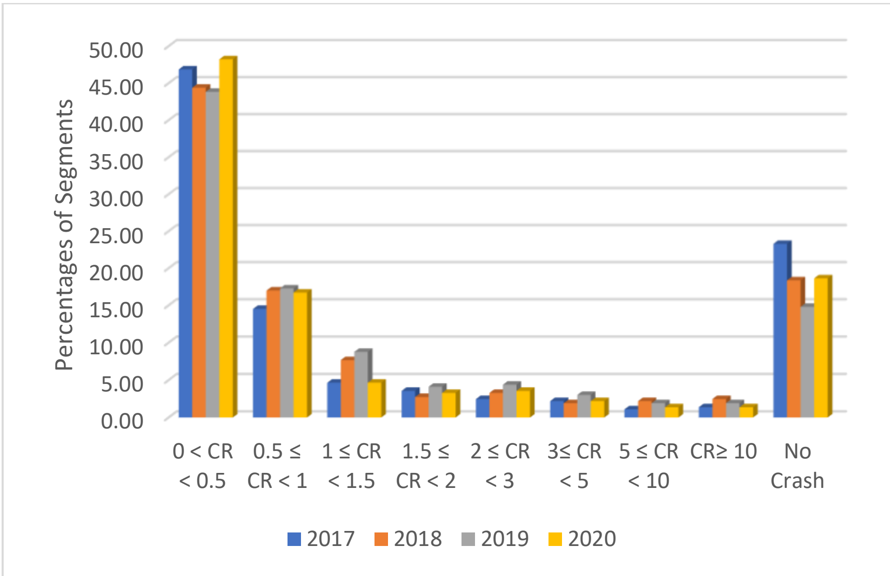


Figure 41 Percentages of Segments Grouped on Different Crash Rate (CR) Range for the Sideswipe Crashes (2017-2020)

From Figure 42, around 41% and 14% of the segments experienced left-turn crashes in the range of 0 < CR < 0.5 and 0.5 ⩽ CR < 1, respectively. There were no left-turn crashes on around 33% of the segments. Around 4% of the segments experienced left-turn crashes in the higher crash rate range.

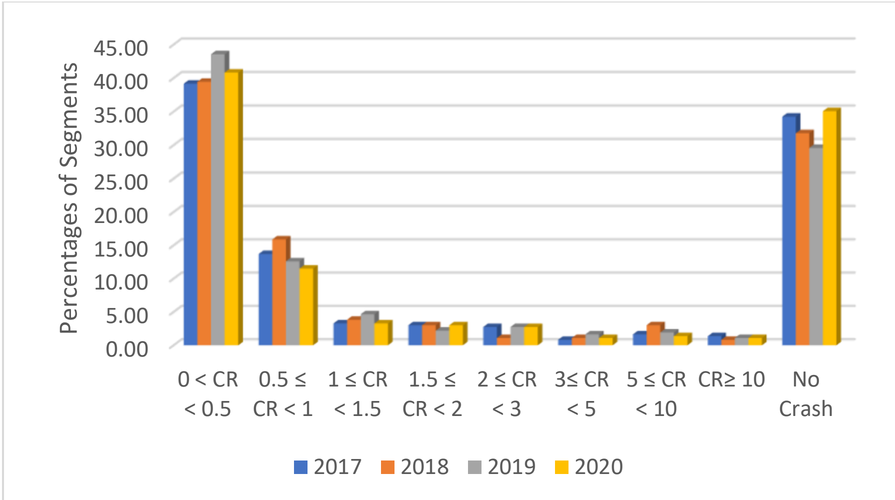


Figure 42 Percentages of Segments Grouped on Different Crash Rate (CR) Range for the Left-turn Crashes (2017-2020)

Finally, pedestrian and bicyclist crash rates were calculated, as shown in Figure 43. Around 69% of the segments did not experience any pedestrian or bicyclist crashes. Around 26.10% of the segments had pedestrian and bicyclist crashes in the range of 0 < CR < 0.5, and there was a gradually increasing trend from 2017 to 2020. Despite the advancement of safety research and vigilant presence of law enforcement, the increased crash rate is alarming. More focused research to investigate the underlying causes is required. Another safety challenge in this regard is that there were few segments with extremely high pedestrian and bicycle crash rates. Those challenges need to be addressed by adopting proper measures i.e., deployment of pedestrian-cyclist CV application.

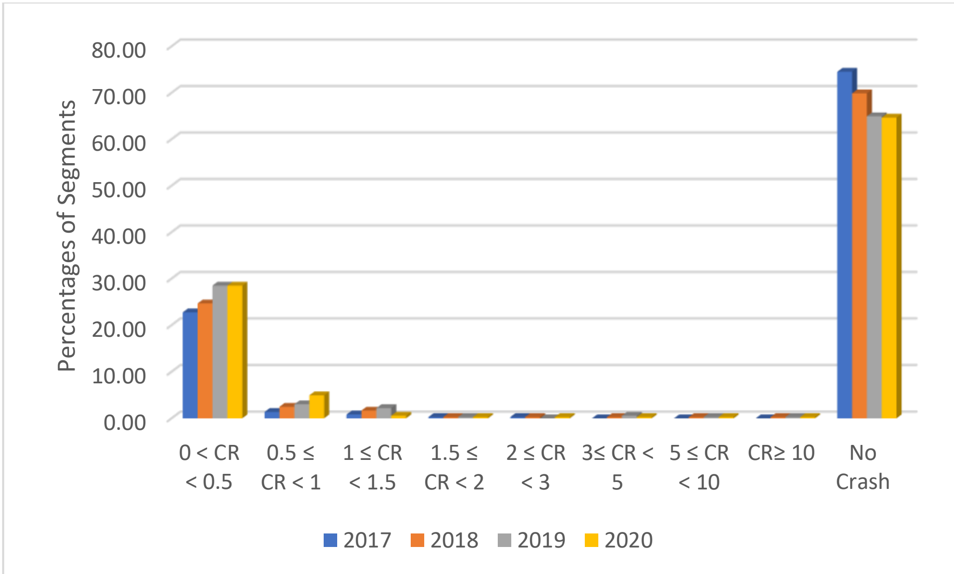


Figure 43 Percentages of Segments Grouped on Different Crash Rate (CR) Range for the Pedestrian and Bicycle Crashes (2017-2020)

Finally, as the study is considering fatal crashes, pedestrian crashes and bicyclist crashes with high importance, an attempt was made to analyze those crashes in segment levels. These three types of crashes were analyzed yearly on segment level, and it was found that 262 of total segments experienced either fatal crashes, pedestrian crashes, bicyclist crashes or any of their combinations. To show it in the map of the study area, a yearly weight was assigned for each segment for each crash. For example, in segment 1, there were no fatal crashes from 2017 to 2020. Hence, the weight for fatal crashes is 0 out 4 (each year has 1 weight). If in segment 1, there were pedestrian crashes in 2017 and 2020, the weight for pedestrian crashes was assigned 2. Similarly if there was only one bicyclist crash in 2019 in segment 1, the weight for bicyclist crashes is 1. Thus, the total weight in segment 1 is the sum of fatal crashes weight, pedestrian crashes weight, and bicyclist crashes weight i.e., 3. The maximum weight was found for segment number 138, and it was 10, i.e., fatal crashes (2019, 2020), pedestrian crashes (2017, 2018, 2019, 2020) and bicyclist crashes (2017, 2018, 2019, 2020). Thus, weights for all the segments experiencing fatal, pedestrian or bicyclist crashes were calculated and shown in the Figure 44. More weight indicates more risk-prone segments for fatal, pedestrian and bicyclist crashes. For visualization, weights of all segments were further grouped into three categories i.e., low weight (greater than or equal to 0 and less than 4); medium weight (greater than or equal to 4 and less than 8); and high weight (greater than or equal to 8 and less than 12). Low weight segments are marked with yellow color, medium weight segments are marked with cadmium orange color, and high weight segments are marked with red color in Figure 44. Arterial segments near Tampa Heights, FL-655, CR-655, and International Drive were found to be most unsafe.

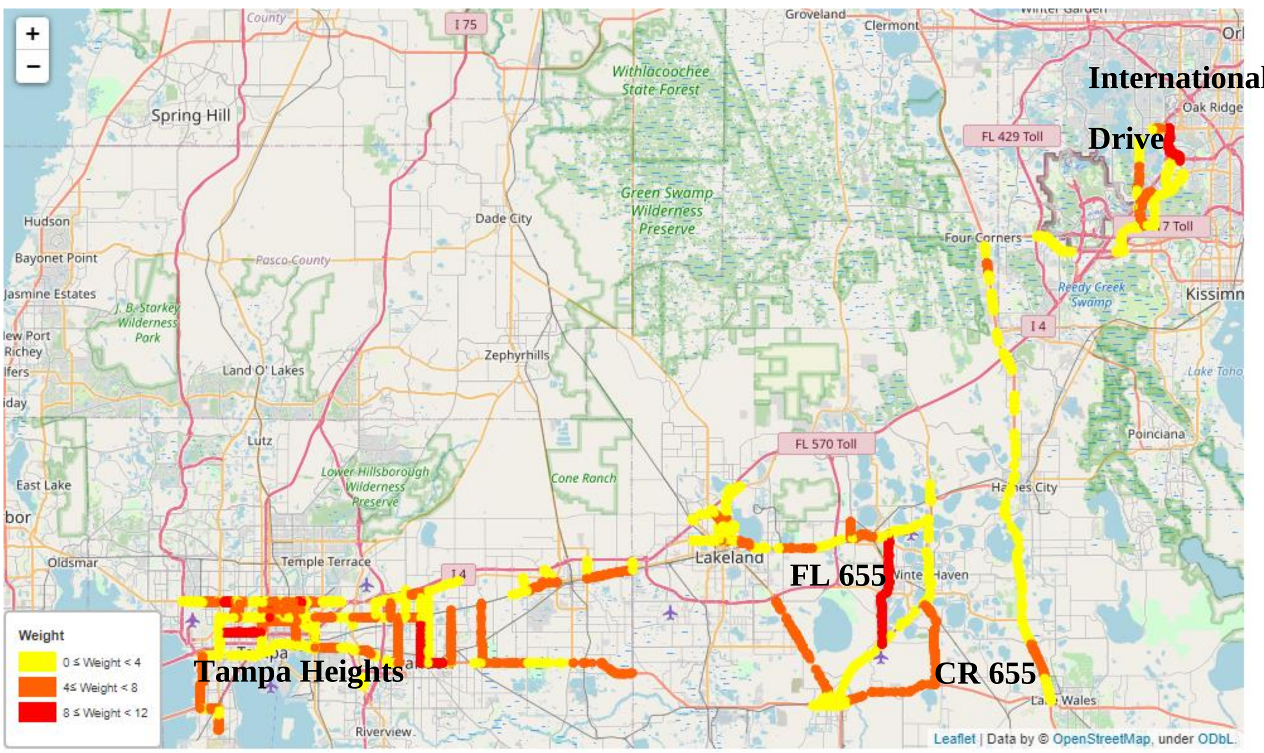


Figure 44 Segments Experiencing Fatal Pedestrian and Bicyclist Crashes (2017-2020)

2.4 Mobility Evaluation for Freeways

The mobility evaluation is carried out using travel time reliability (TTR) measures (Lyman and Bertini, 2008). This section illustrates the details of these measures along with emergency response and event analyses for freeways.

2.4.1 Travel Time Reliability Measures

- Travel time index (TTI): the ratio of actual average travel time to free flow travel time (FHWA, 2017). It is used for measuring the congestion degree on the road. The equation is shown as below.

$$\text{Travel time index (TTI)} = \frac{Average\ travel\ time}{Travel\ time_{85th\ percentage\ speed\ during\ overnight}}$$

- Buffer time index (BTI): the difference between 95th percentile travel time and average travel time, divided by the average travel time (FHWA, 2017). The buffer time index is a measure of trip reliability by expressing the amount of extra buffer time needed to be on time for 95% of trips (Dowling *et al.*, 2015). The equation is shown below.

$$\text{Buffer time index (BTI)} = \frac{95^{th}\ percentile\ travel\ time - average\ travel\ time}{Average\ travel\ time}$$

- Planning time index (PTI): total time needed to plan for an on-time arrival 95% of the time, computed as 95th percentile travel time divided by free flow travel time.

$$\text{Planning time index (PTI)} = \frac{95^{th}\ percentile\ travel\ time}{Travel\ time_{85th\ percentage\ speed\ during\ overnight}}$$

- Congestion index (CI): the difference between the 85th percentile speed during the overnight period and actual speed, divided by the 85th percentile speed during the overnight period.

Congestion index (CI) $=\frac{85th\ percentage\ speed\ during\ overnight\text{-}actual\ speed}{85th\ percentage\ speed\ during\ overnight}$ when CI > 0;

Congestion index (CI) = 0 when $CI \leq 0$.

- Delay (travel time delay): delay is defined as the additional travel time experienced by a driver, passenger, or pedestrian in comparison to free flow condition. The total delay on a road segment is measured by the average travel time delay experienced by each vehicle times the volume.

$$\text{Total delay} = \sum \left(average\ travel\ time\ \text{-}\ travel\ time_{85th\ percentage\ speed\ during\ overnight}\right) * volume$$

The TTR measures are calculated using MVDS and NPMRDS data. For those measures, the free flow travel time, defined as the travel time under the 85th percentile speed during the overnight period (10 pm to 5 am (next day)) , is calculated for each segment during each year (FDOT, 2011; Fan and Gong, 2017). The flow chart shown in Figure 45 summarizes the integration between the two data sources. Traffic parameters such as average speed and volume during each hour are derived on each road segment using the readings from MVDS data. For instance, for one road segment, the average speed is calculated using average values from the upstream and downstream MVDS detectors. The travel time is calculated as the length of the road segment divided by speed. Other parameters, like 95th percentile travel time are also calculated. After acquiring these parameters, different TTR measures are calculated accordingly.

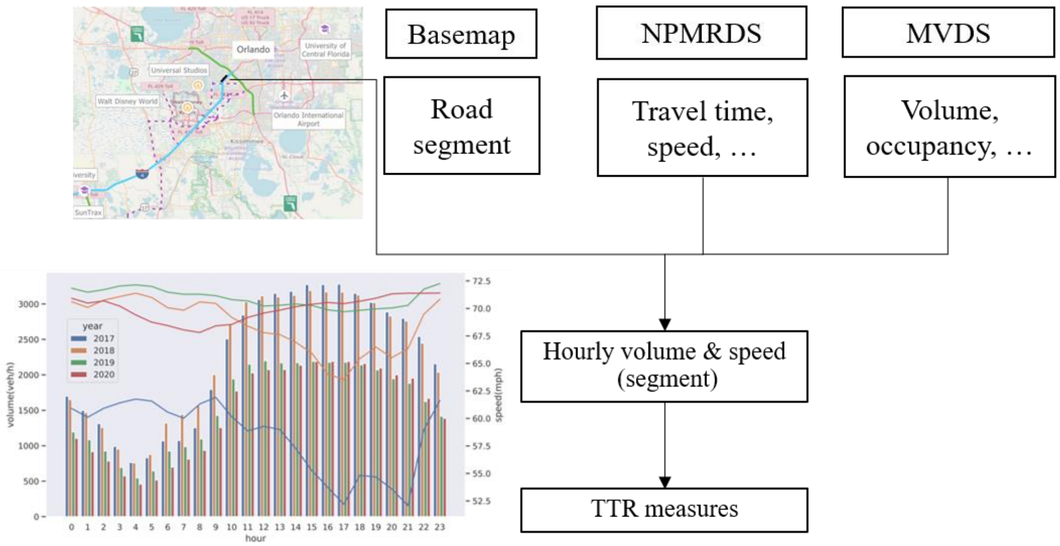
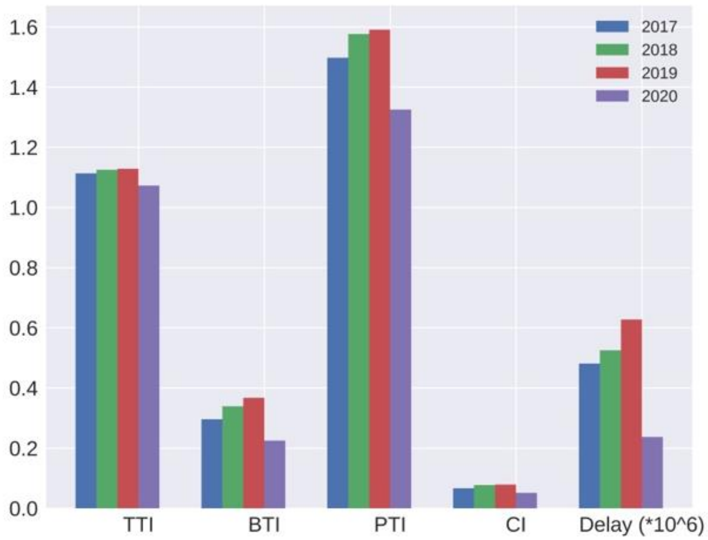


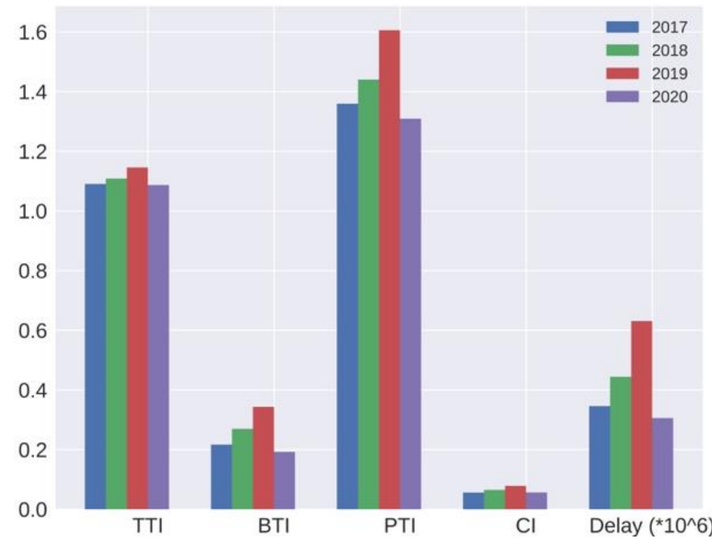
Figure 45 Calculation of the TTR Measures (Segment Level)

2.4.2 Summary of TTR Measures (Segment Level)

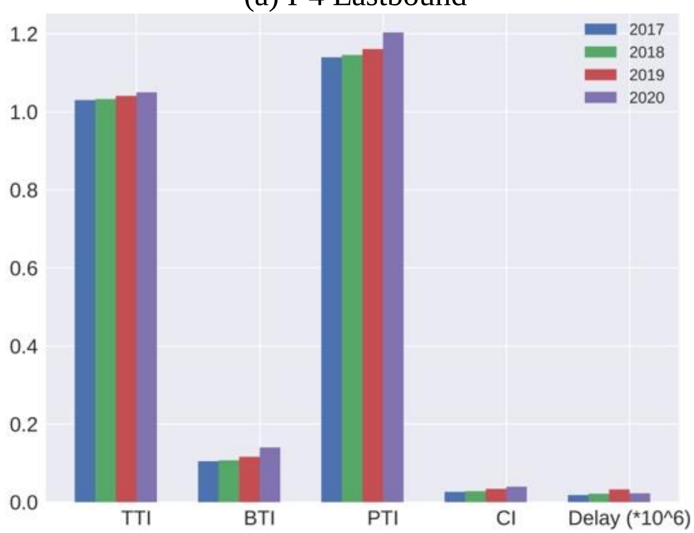
The TTR measures during 2017-2020 for all the corridors (segment level) are summarized below. The values of TTI, BTI, PTI, and CI measures are calculated on all segments, and then the average values are calculated. As shown in Figure 46, in 2020, due to Covid-19 pandemic, the reliability values decreased (the mobility levels increased) on I-4, Selmon Expressway, and Turnpike Expressway. Specifically, for I-4, the values for TTI, BTI, and CI values were similar between the eastbound and westbound directions, as shown in Figure 46a and Figure 46b. The total delay for each segment per year ranged from 237,000 minutes to 631,000 minutes. For Polk Parkway, as shown in Figure 46c and Figure 46d, both directions experienced similar TTI, PTI, and CI values during 2017-2019. Then in 2020, all the TTR values increased, except for the delay values in the eastbound direction. The possible reason for the decreasing delay value was the decrease of vehicle volume in 2020 (due to the COVID-19 pandemic). For Selmon Expressway, as shown in Figure 46e and Figure 46f, the eastbound direction experienced good mobility with similar TTR values during 2017-2020. For the westbound direction, 2018 had the most congested level from the perspective of all measures. For the Turnpike Expressway northbound direction, as shown in Figure 46g, the year 2017 had the highest values of TTI, BTI, and PTI. However, 2018 had the highest CI index (0.037) and delay value (75,000 minutes per segment). For the Turnpike Expressway southbound direction (Figure 46h), the year 2018 was the most congested among the four years. Overall, I-4 is the most congested among all the studied roads.



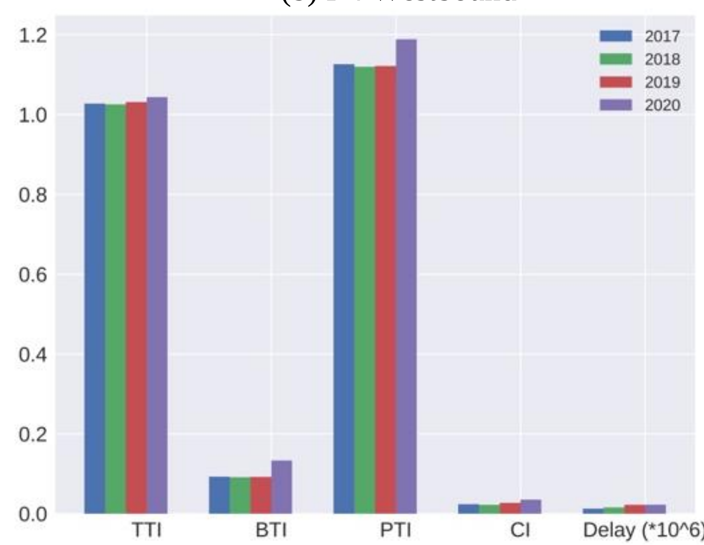
(a) I-4 Eastbound



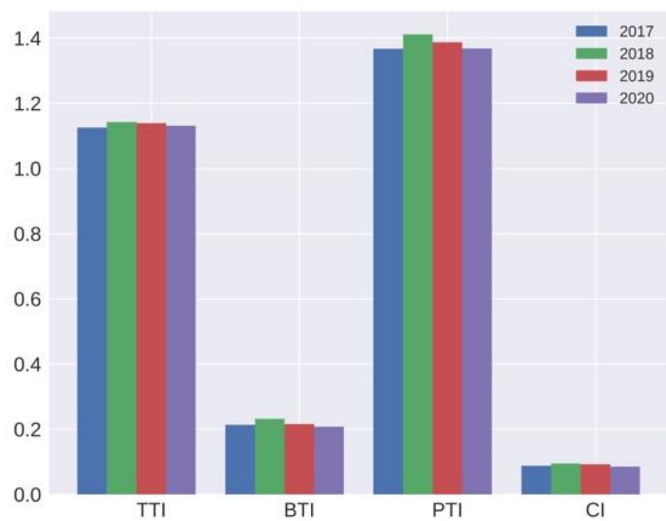
(b) I-4 Westbound



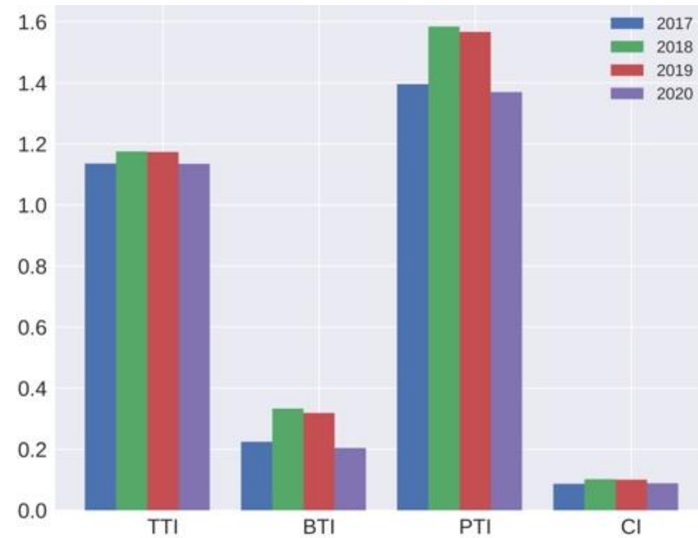
(c) Polk Parkway Eastbound



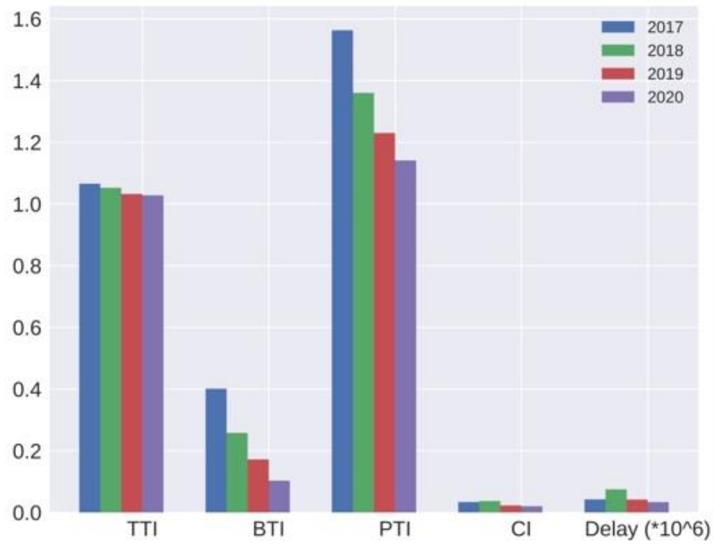
(d) Polk Parkway Westbound



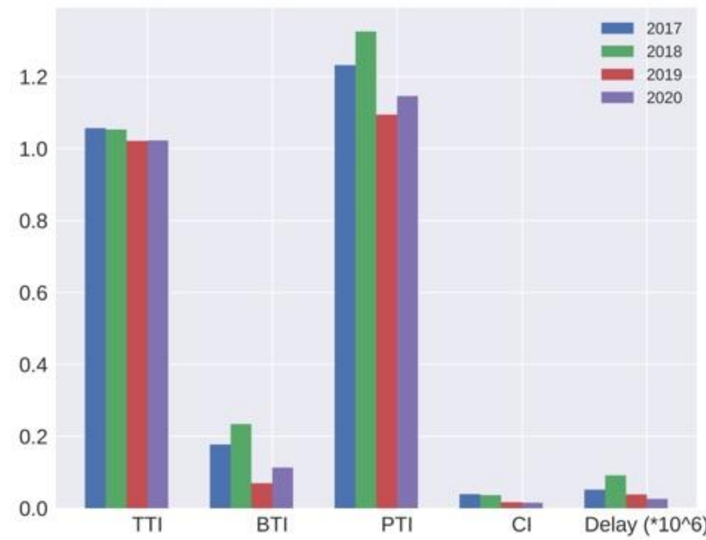
(e) Selmon Expressway Eastbound



(f) Selmon Expressway Westbound



(g) Turnpike Expressway Northbound

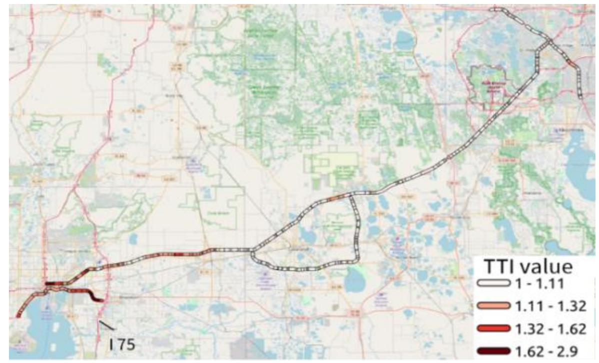


(h) Turnpike Expressway Southbound

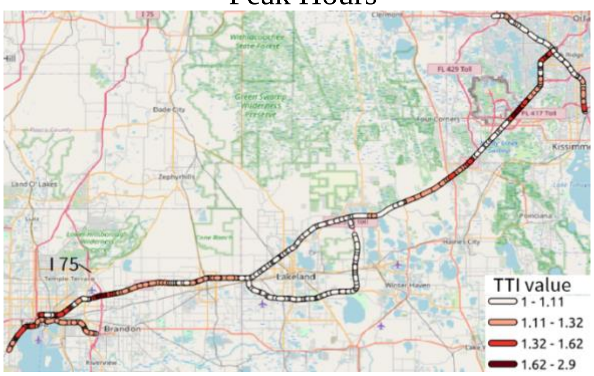
Figure 46 TTR Measures (2017-2020, Segment Level)

Two peak periods are used for further analysis. The AM peak period are defined as from 7 am to 10 am, PM peak period are defined as from 4 pm to 7 pm. TTI is a typical measure to show the variation of the mobility feature of the road segments. The average TTI values for all segments during the peak hours on workdays from 2017 to 2020 are plotted in Figure 47. During the AM peak hours, on eastbound direction (for I-4, Polk Parkway, and Selmon Expressway)/northbound direction (for Turnpike Expressway) direction, as shown in Figure 47 (a), the segments close to I-4 and US 27 had high congestion level (high TTI values). And the segments close to I-4 and FL 417 were also congested. The road segments between Turnpike Expressway and FL 417 were congested. The other corridors show lighter color, which means the TTI values were low, and traffic mobility was good. For westbound/southbound direction (Figure 47 (b)), the segments close to downtown Tampa on both I-4 and Selmon Expressway had high TTI values. During PM peak hours, for eastbound/northbound direction (Figure 47 (c)), the road segments between I-4 and I-75, I-4 and FL 417 were congested. The whole Selmon Expressway had high congestion level. For westbound/southbound direction (Figure 47 (d)), the segments between I-4 and I-275, I-4 and FL 528, I-4 and FL 417, Selmon Expressway and US 92, and Turnpike Expressway and FL 528 had high congestion level. Overall, the road segments in PM peak hours were more congested than in AM peak hours. It should be noted that there are some missing values (or insufficient data supply) on specific segments due to detectors failure.

(a) Eastbound/Northbound direction, AM Peak Hours



(b) Westbound/Southbound, AM Peak Hours



(c) Eastbound/Northbound, PM Peak Hours

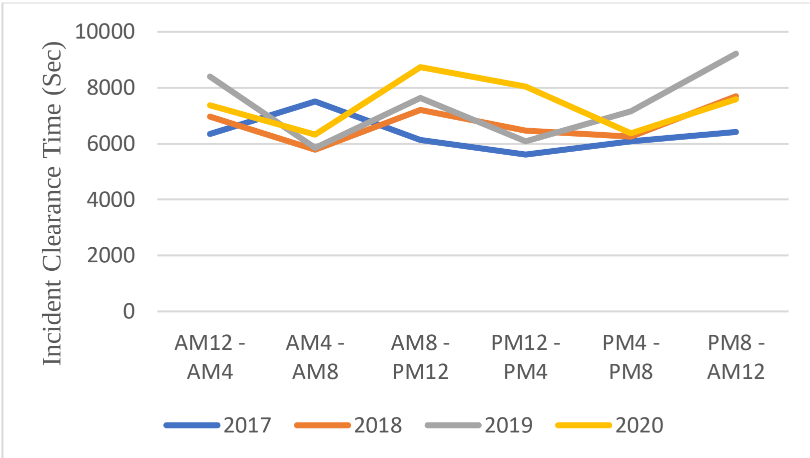
(d) Westbound/Southbound, PM Peak Hours

Figure 47 TTI Values (AM/PM Peak Hours, Workday, Average during 2017-2020)

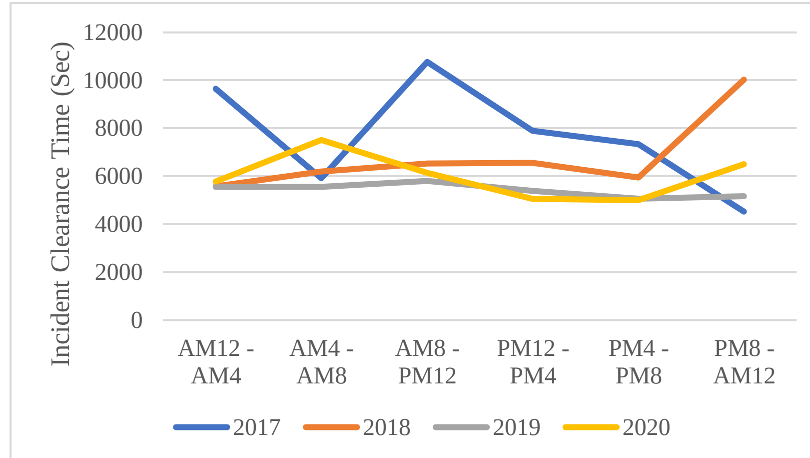
2.4.3 Emergency Response and Event Analyses

The Highway Capacity Manual (HCM) defined incident duration time as the combination of four phases, i.e., detection time, response time, clearance time, and recovery time. HCM manual defined the detection time is the time between incident occurrence and its identification, response time is the time between incident detection and arrival of the first responder on the scene, clearance time is the time required for the incident response team to clear the incident scene, and recovery time is the time between incident clearance and the recovery of the facility to its normal operating capacity (National research council. Transportation research board, 1994). The study analyzed the incident clearance time from different perspectives i.e., based on different time of a day, different days of a week, and different months of a year for all the four studied freeways.

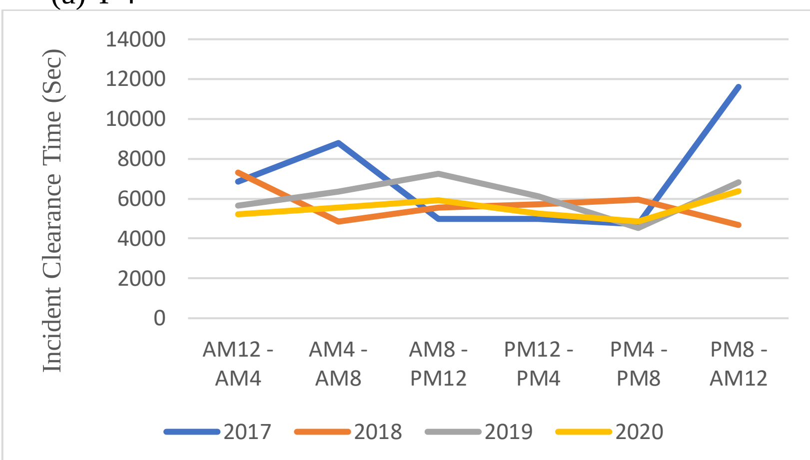
Figure 48 shows that variations of incident clearance time for different times in a day for all the freeways considered in the studied area. I-4 required highest time during 12 am to 4 am with an average of 7280 seconds to clear the road after a crash occurred. With each year, there was an increase in time to clear the roads in I-4 and in the year 2020, it took maximum time with an average of 7407 seconds. Turnpike Expressway required highest time during 8 am to 12 pm with an average of 7314 seconds to clear the road after a crash occurred. From 2017 to 2019, there was a decreasing trend in incident clearance time for Turnpike Expressway, and in the 2020, there was a slight increase. Overall, maximum incident clearance time was found in the year 2017 with an average of 7690 seconds for Turnpike Expressway. Polk Parkway required highest time during 4 am to 8 am with an average of 6389 seconds to clear the road after a crash occurred. A fluctuating pattern was found for Polk Parkway among the years, and the maximum incident clearance time was found in 2017 with an average of 6992 seconds. Selmon Expressway required highest time during 4 am to 8 am with an average of 7908 seconds to clear the road after a crash occurred. Selmon Expressway took maximum time with an average of 7473 seconds in 2020 among all the four years.



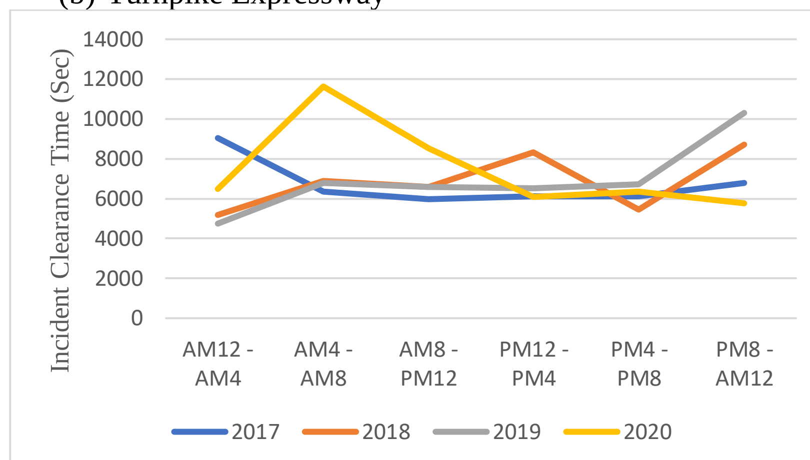
(a) I-4



(b) Turnpike Expressway



(c) Polk Parkway

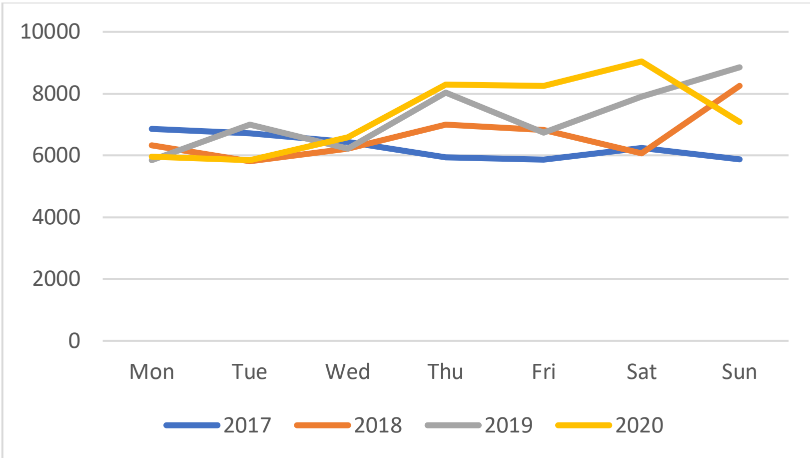


(d) Selmon Expressway

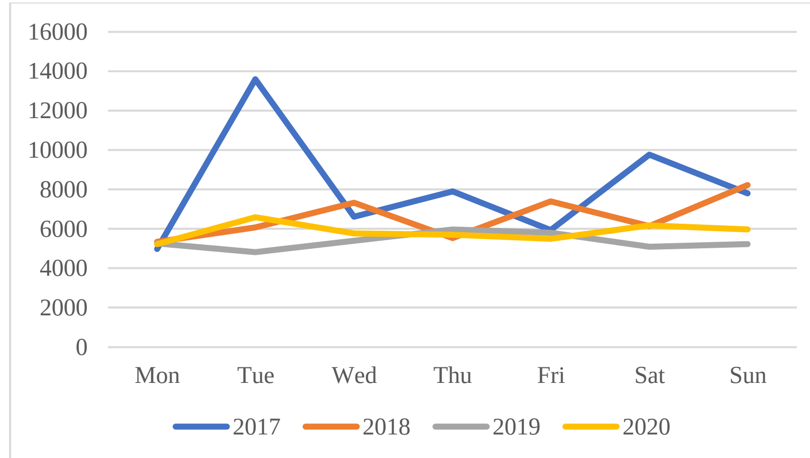
Figure 48 Incident Clearance Time in Different Time of A Day

Figure 49 shows variations of incident clearance time for different days in a week for all the freeways considered in the studied area. All the freeways had higher incident clearance time on the weekend than on the weekdays except for the Selmon Expressway. For the I-4, Thursday had higher clearance time among weekdays, with an average value of 7319 seconds over the four years. Tuesday had the highest clearance time on the Turnpike Expressway, with an average value of 7774 seconds. For the Polk Parkway, Monday took higher clearance time among weekdays, with an average value of 6397 seconds. Friday had the highest clearance time required on the Selmon Expressway, with an average value of 7578 seconds. Among weekends, Sunday was found to take more time to clear the roads than Saturday for all freeways except Selmon Expressway.

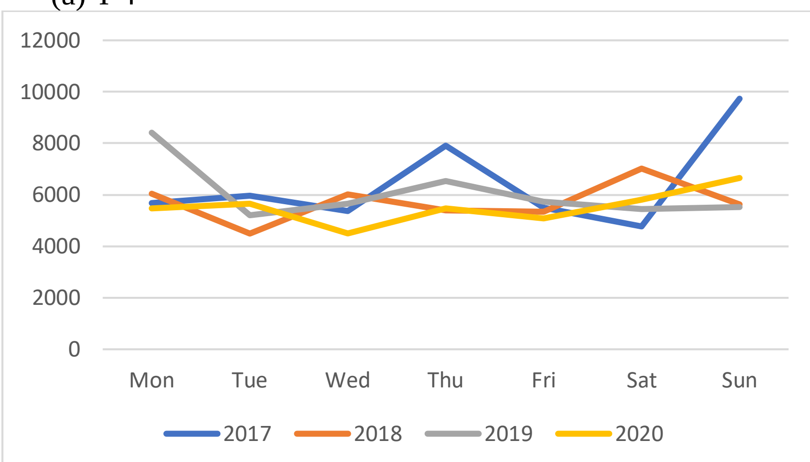
Figure 50 shows variations of incident clearance time for different months in a year for all the freeways considered in the studied area. February and September to November were found to have highest incident clearance time for the I-4. June and December were found to have higher incident clearance time for the Turnpike Expressway. September to November and January had higher incident clearance time for Polk Parkway. February and November were found to have higher incident clearance time for the Selmon Expressway.



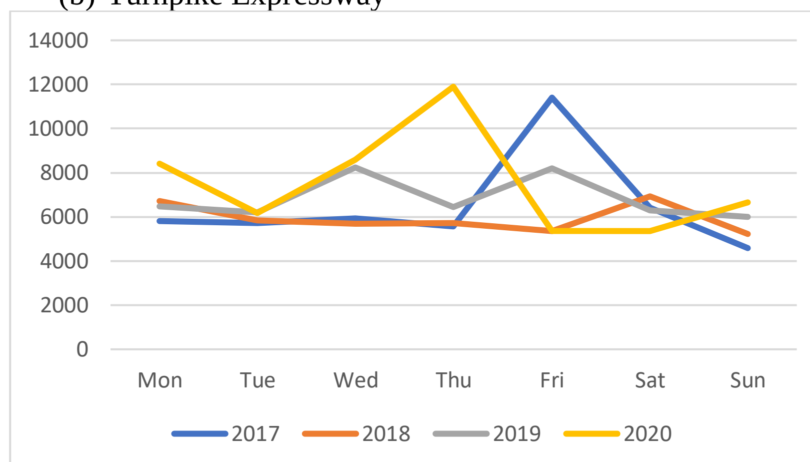
(a) I-4



(b) Turnpike Expressway

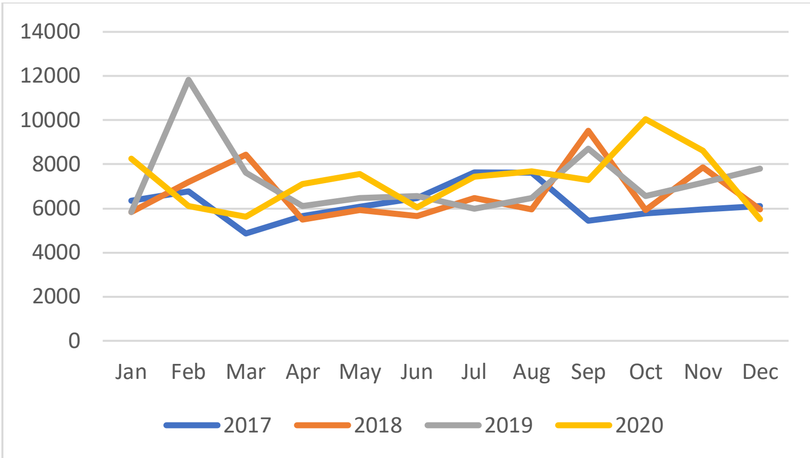


(c) Polk Parkway

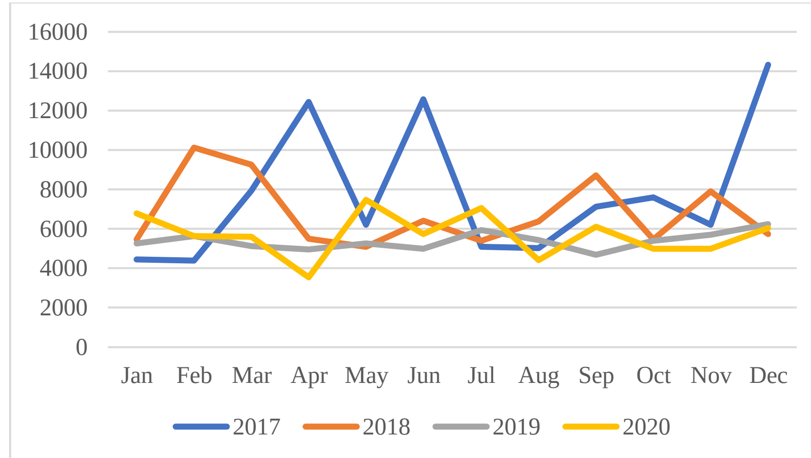


(d) Selmon Expressway

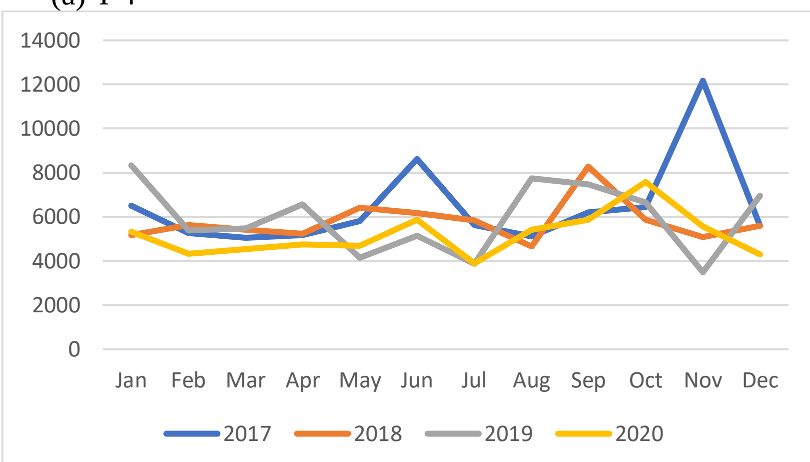
Figure 49 Incident Clearance Time in Different Days of A Week



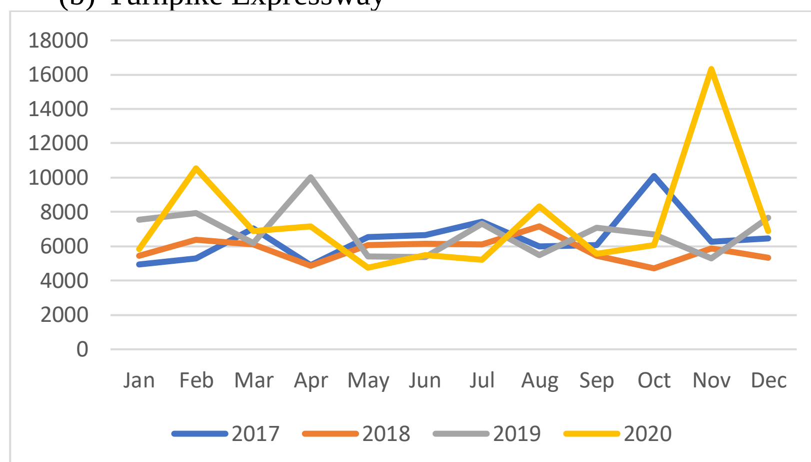
(a) I-4



(b) Turnpike Expressway



(c) Polk Parkway



(d) Selmon Expressway

Figure 50 Incident Clearance Time in Different Months of A Year

2.5 Mobility Evaluation for Arterials

The mobility evaluation is carried out using travel time reliability (TTR) measures, based on NPMRDS data. Numerous studies have used measures such as travel time index (TTI), buffer time index (BTI), etc. to evaluate the travel time reliability (Lyman and Bertini, 2008). This section describes the details of these measures.

Two data sources, NPMRDS and HERE from RITIS are used to calculate the travel time at the road segment level. The AM peak hours are defined from 7 am to 10 am, and PM peak hours are from 4 pm to 7 pm. Off peak hours are defined as 10 am to 3 pm. And nighttime hours are from 7 pm to 6 am (the next day). The average travel time (in seconds) for these time slots is shown in Table 15. It can be found that data from NPMRDS and HERE have slight differences. As HERE have more coverage, and higher updating frequency, this study used HERE for further analysis.

Table 15 Average Travel Time (Segment Level, 2017-2020)

Year	Peak	Workday		Weekend	
		Average Travel Time *(NPMRDS)	Average Travel Time* (HERE)	Average Travel Time* (NPMRDS)	Average Travel Time* (HERE)
2017	**AM Peak**	182.172	163.063	164.495	144.842
	Off Peak	186.999	167.372	180.280	160.360
	PM Peak	205.747	182.528	178.409	159.231
	Nighttime	162.616	141.520	161.688	139.190
2018	**AM Peak**	194.670	173.100	174.635	152.779
	Off peak	197.552	176.412	193.541	167.273
	PM Peak	216.699	190.539	192.297	166.607
	Nighttime	172.302	149.530	171.406	146.894
2019	**AM Peak**	193.332	176.667	168.515	149.675
	Off Peak	197.229	179.342	190.210	163.600
	PM Peak	217.580	193.062	187.483	162.295
	Nighttime	168.571	147.387	167.133	143.431
2020	**AM Peak**	172.441	158.763	157.631	137.943
	Off peak	180.537	165.931	174.495	148.513
	PM Peak	189.332	168.536	172.099	146.401
	Nighttime	156.278	137.399	156.084	133.371

*In seconds

2.5.1 Travel Time Reliability Measures

The travel time from HERE on workdays during 2017 to 2020 are shown in Figure 51. It can be found that the average travel time on all road segments increased from 2017 to 2019, and then decreased sharply in 2020. This indicates higher vehicle speed on the road due to COVID-19.

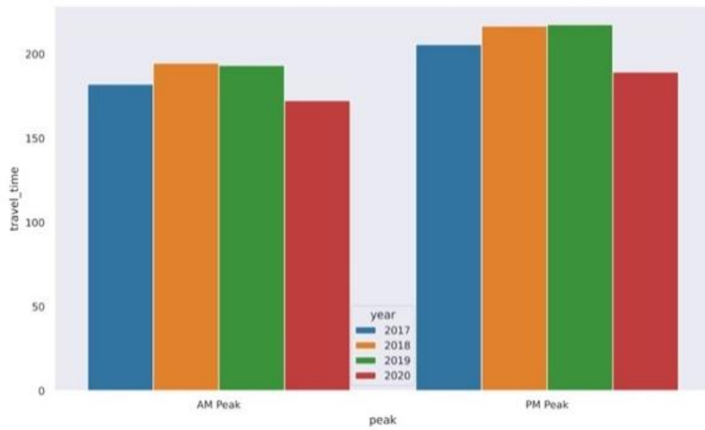


Figure 51 Average Travel Time on Workdays (HERE, 2017-2020)

The traffic congestion level can be measured by Travel Time Index (TTI). TTI is the ratio of average travel time to the speed-limit travel time. The speed-limit travel time is estimated based on segment length and speed limit. TTI represents the percentage of extra travel time spent during the congested traffic condition. The equation for TTI is shown as follows:

$$\text{TTI} = \frac{Average\ Travel\ Time}{Travel\ Time_{speed\ limit}}$$

The TTI values during AM and PM peak hours on workdays from 2017 to 2020 are calculated.

Planning Time Index (PTI) is also selected to assess the travel time reliability according to the FWHA's recommendation. The PTI is defined as the ratio of the 95th percentile travel time to the speed-limit travel time. The equation for PTI is shown as follows:

$$\text{PTI} = \frac{95th\ percentile\ Travel\ Time}{Travel\ Time_{speed\ limit}}$$

The above measures are calculated at the segment level. The basemap is used. For each segment, values for both directions on the road segments are calculated, and then taken average.

2.5.2 Summary of TTR Measures (Segment Level)

As shown in Figure 52, during the AM peak hours on workdays, the TTI values range from 1.364 to 1.433. The PM peak hours have a higher congestion level than AM peak hours, with higher TTI values (from 1.464 to 1.659). It can be found that during 2017 and 2020, the congestion level decreased year by year. Particularly a noticeable change is observed in the year 2020 compared to the previous years, and it might be due to the effect of COVID-19 pandemic.

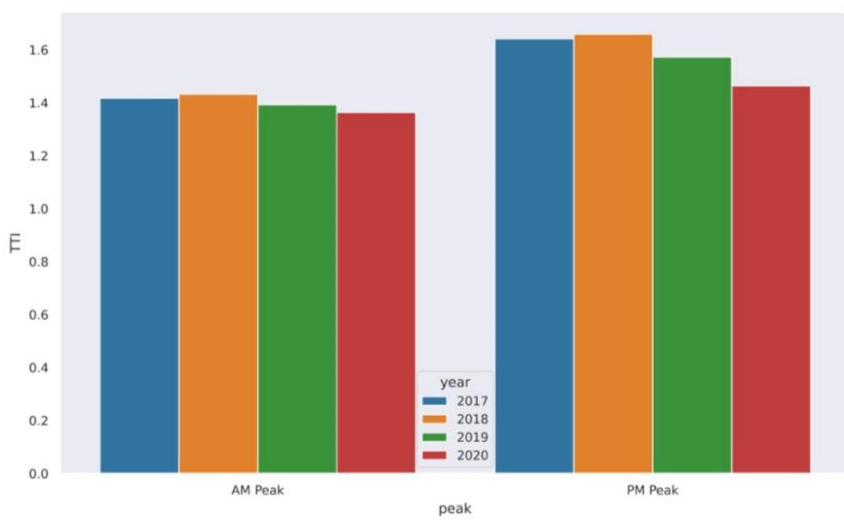


Figure 52 TTI during AM and PM Peak Hours (Workdays, 2017-2020)

As shown in Figure 53, during the AM peak hours, the PTI values range from 1.786 to 1.878. The PM peak hours had a more congested level than that of AM peak hours, with higher PTI values (more than 2).

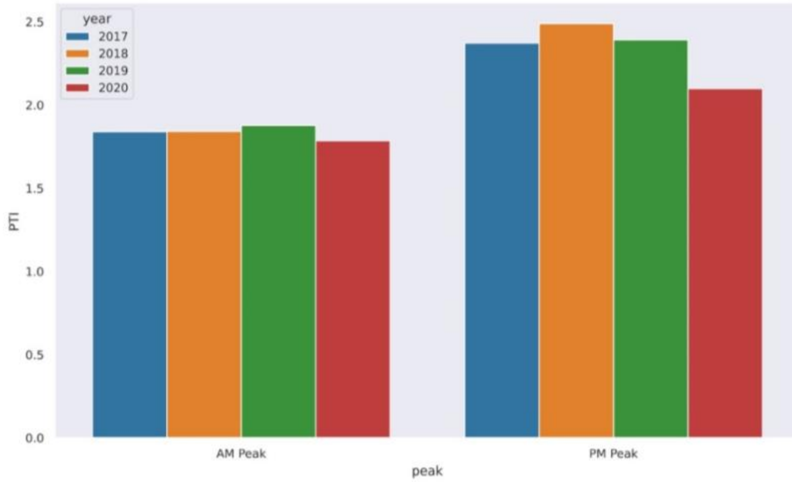


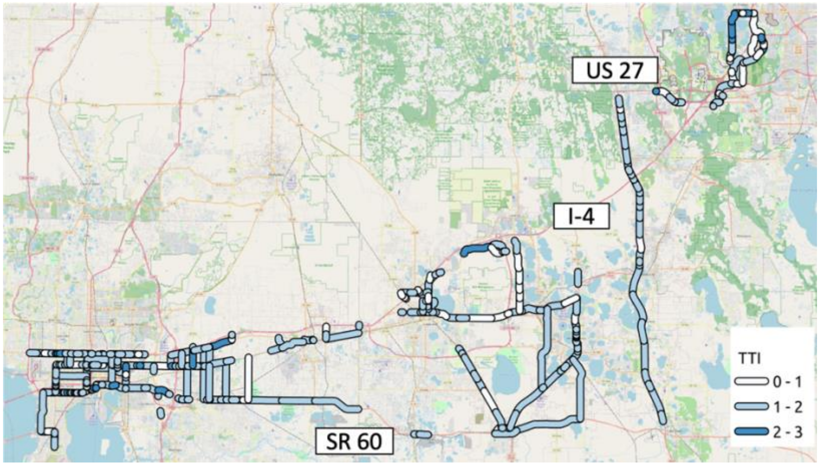
Figure 53 PTI during AM and PM Peak Hours (Workdays, 2017-2020)

Table 16 lists the average values of TTI and PTI during AM and PM peak hours from 2017 to 2020.

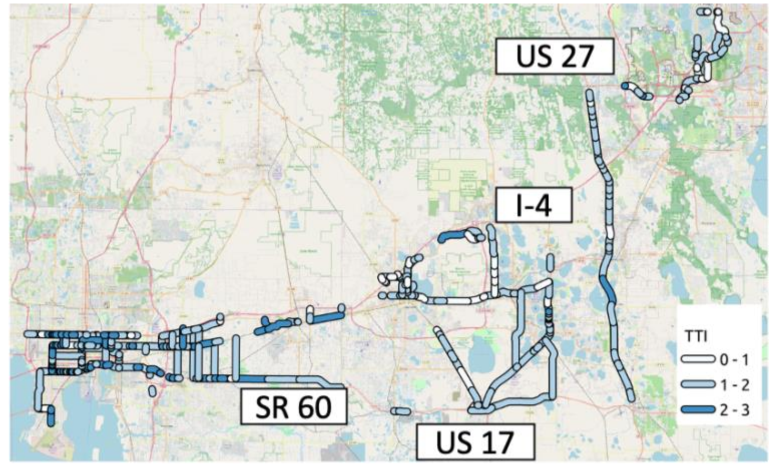
Table 16 TTI and PTI during AM and PM Peak Hours (2017-2020)

	TTI		**PTI**	
	AM Peak	**PM Peak**	**AM Peak**	**PM Peak**
2017	1.418	1.642	1.840	2.373
2018	1.433	1.659	1.842	2.490
2019	1.393	1.573	1.878	2.392
2020	1.364	1.464	1.786	2.099

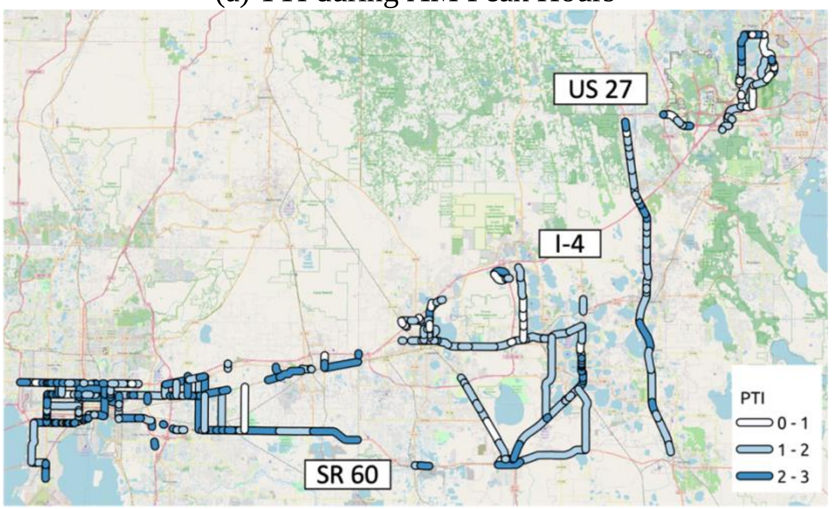
Figure 54 shows the average values during 2017 and 2020 for each road segment. The darker colors denote higher values. From the perspective of TTI, it can be found that downtown Tampa and downtown Orlando experienced more congested conditions, compared with other roads for AM peak hours. For PM peak hours, there were also similar patterns, with more congested roads like US 17 and some diverging roads for I-4. From the perspective of PTI values, the downtown Tampa area showed congested conditions during AM peak hours. For PM peak hours, SR 60, US 17, downtown Tampa, and downtown Orlando area had relatively higher PTI values.



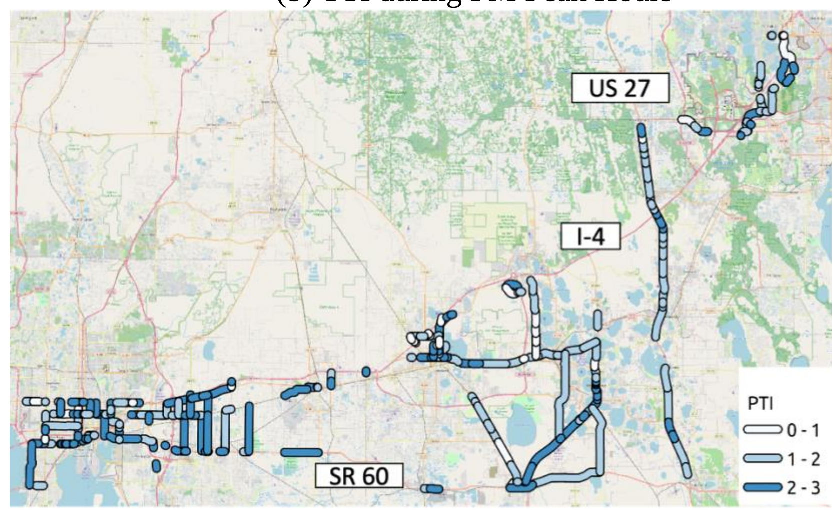
(a) TTI during AM Peak Hours



(b) TTI during PM Peak Hours



(c) PTI during AM Peak Hours



(d) PTI during PM Peak Hours

Figure 54 TTI and PTI (Workdays, 2017-2020)

CHAPTER 3: CONCLUSIONS

Interstate 4 (I-4) Florida's Regional Advanced Mobility Elements (FRAME) project is expected to address the safety and mobility issues on the freeways and arterials along I-4 between Tampa and Orlando. As the part of the grant obligations, this study was conducted to help to evaluate the existing transportation system before the project is implemented. In this report, the UCF research team collected massive data from different sources on freeways, expressways, and arterials, and conducted an extensive analysis for safety and mobility evaluations

According to the requirements of the I-4 FRAME project, two main aspects are selected, including safety and mobility. Since UCF's main role will be to identify safety challenges on the project corridors and document how the I-4 FRAME project will address these challenges, this report has mainly focused on the corridor level and segment level analyses for freeways and intersection and segment level analyses for arterials. For safety analyses, crash data were collected from the S4A and SSOGIS to ensure the maximum coverage of the crash information. During this crash data collection, crash numbers, crash types, different crash severities, work zone-related crashes, and weather information were collected and analyzed. From the perspectives of the crash rates, different crash types, and crash severities, the main safety challenges on the intersections and segments were identified. For mobility analyses, traffic data were collected and analyzed using MVDS and NPMRDS data sources. Average travel time and speed and travel time reliability measures were analyzed to analyze the mobility conditions of the studied area. Extensive analyses for safety and mobility evaluation have been performed and possible justification of such findings have been added. This report summarizes the overall safety and mobility evaluation before the new technologies are implemented and will be used to compare with safety and mobility issues after the technologies are implemented.

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PROJECT SCHEDULE

Project Title	Before Study Evaluation of Interstate 4 (I-4) Florida’s Regional Advanced Mobility Elements (FRAME) Project (Before Analysis)
Research Agency	University of Central Florida
Principal Investigator	Mohamed Abdel-Aty

- Task 1: Data Collection
- Task 2: Data Analysis and Safety Challenge Identification
- Task 3: Draft Final and Closeout Teleconference
- Task 4: Final Report

	Anticipated Timeframe (in Months)	2021				2022							Estimated Completion (%)
		Apr	July	Aug	Dec	Jan	Feb	Mar	Jun	Aug	Oct	Nov	100
		1	4	5	9	10	11	12	15	17	19	20	
Task 1	4												100
Task 2	7												100
Task 3	8												100
Task 4	1												100

Appendix A: Intersections with Fatal Pedestrian and Bicyclist Crashes

Table A-1 Intersections Experiencing Fatal, Pedestrian and Bicyclist Crashes

Intersection Number	Latitude	Longitude	Fatal Crashes	Pedestrian Crashes	Bicyclist Crashes
2	28.03825881	-82.10422288	2020	No	No
4	28.01473608	-82.13789971	2019	No	No
7	27.91563759	-82.34863484	No	2019	No
8	27.92271412	-82.34989648	No	2018	2018
11	27.94938328	-82.35412539	2018	No	No
13	27.98144192	-82.36011334	2020	2017	2017
15	27.9501773	-82.40161359	2019	No	No
16	27.95203419	-82.40161717	No	2019, 2020	No
17	27.96175058	-82.4017816	No	2018, 2020	No
18	27.96487472	-82.40164971	No	2018, 2019	No
19	27.96734098	-82.40162375	No	2019	No
21	27.97044759	-82.40163255	2018	2018, 2019	2018
23	27.97775268	-82.4140197	2018	No	No
25	27.98887305	-82.41403273	2018	No	No
28	27.95391111	-82.50555611	No	No	2018
29	27.9593471	-82.50549788	No	No	2018
32	27.95729679	-82.50552194	2020	No	No
34	27.9494608	-82.45774061	No	2018	No
35	27.95243859	-82.45904964	No	2017, 2020	No
39	27.94869081	-82.45739552	No	2018	No
40	27.95949988	-82.45948749	No	2017	No
42	27.95634625	-82.45950345	No	2019	No
43	27.96686833	-82.45944734	2019	2017	No

Table A-1 Intersections Experiencing Fatal, Pedestrian and Bicyclist Crashes (Contd.)

Intersection Number	Latitude	Longitude	Fatal Crashes	Pedestrian Crashes	Bicyclist Crashes
46	27.97093669	-82.45943769	2019	2018, 2019	2018
47	27.89363692	-82.50630696	2017	No	No
50	27.87266907	-82.50640191	No	2019	No
57	28.40689722	-81.45586771	No	2018	No
61	28.35455618	-81.49449196	2020	No	No
62	28.37068473	-81.50324953	2019	2018, 2019, 2020	No
63	28.37415752	-81.50384691	No	2020	No
64	28.38187281	-81.50540739	No	2017, 2020	No
66	28.38964073	-81.50628726	2018	2017, 2018	No
67	28.39132437	-81.50616027	No	2017	No
73	27.94663485	-82.45841835	No	No	2017
74	27.94723004	-82.45678155	No	2017, 2018	No
82	27.95228182	-82.44905841	No	2018	No
83	27.98128503	-82.49298659	No	2019, 2020	No
84	27.98128505	-82.49855935	No	2019	No
86	27.98149528	-82.50531424	No	2018	No
88	27.98135822	-82.48876779	No	2020	No
89	27.98129528	-82.48465263	No	2019	No
91	27.98142486	-82.4616025	No	2019	No
95	27.98146282	-82.45323538	2018, 2019	2019	No
96	27.98145455	-82.41403299	No	No	2018
97	27.98146627	-82.42222661	2017	2019	No
98	27.98151315	-82.40158605	No	2020	No
99	27.98136181	-82.38245618	2017	No	No
100	27.98164131	-82.38595036	No	2019	No
102	27.98142214	-82.37306181	2020	2017	No

Table A-1 Intersections Experiencing Fatal, Pedestrian and Bicyclist Crashes (Contd.)

Intersection Number	Latitude	Longitude	Fatal Crashes	Pedestrian Crashes	Bicyclist Crashes
103	27.98129249	-82.33507573	No	2018	No
104	27.9812512	-82.32873005	2020	No	No
106	27.98134748	-82.31872743	No	No	2018
107	27.98154039	-82.31053309	2017, 2018	2017, 2018, 2019	No
110	27.98157965	-82.29823146	No	No	2017
111	27.98150819	-82.29412786	No	No	2018
112	27.9816094	-82.28591407	No	2019	No
127	27.94479199	-82.52637505	No	2018	No
129	27.94476872	-82.51406708	2020	2019, 2020	No
133	27.94477995	-82.49329603	2020	No	No
134	27.94476298	-82.48509262	No	2018, 2019	No
135	27.94474598	-82.48292052	No	2020	2018
136	27.94465533	-82.47260897	No	2020	No
137	27.94461978	-82.46858838	No	2019	No
139	27.94552773	-82.46391919	No	2020	No
140	27.9470349	-82.45967431	No	2018, 2019	No
141	27.94736478	-82.45877877	No	2020	No
143	27.94796795	-82.45709485	No	2018	2018
145	27.94856629	-82.4554003	No	2018	No
148	27.95030117	-82.45034539	2017	No	No
156	27.95535258	-82.41552758	No	2020	No
157	27.95212954	-82.37476775	2017, 2018	2018	No
160	27.94392189	-82.33546524	2017	2019	2018
163	27.93941114	-82.32387196	2018	2017, 2018	2018
164	27.93763995	-82.3185822	No	2019	No
165	27.93761705	-82.3144425	2020	2018	2017
166	27.93771412	-82.31033199	No	2017	2017, 2018

Table A-1 Intersections Experiencing Fatal, Pedestrian and Bicyclist Crashes (Contd.)

Intersection Number	Latitude	Longitude	Fatal Crashes	Pedestrian Crashes	Bicyclist Crashes
167	27.9376563	-82.3062096	No	2017, 2018, 2020	No
168	27.93764179	-82.28583224	2019	2018	No
170	27.9376442	-82.27755164	No	2018	2017, 2018
172	27.93774636	-82.26103662	2018, 2019	2018	2018
173	27.93781156	-82.25273712	2018	2018, 2020	2017
175	27.93773488	-82.23638368	2018, 2020	No	No
176	27.93775245	-82.2280183	No	2020	No
178	27.93750485	-82.1703676	2020	No	No
179	27.99638372	-82.54545366	No	No	2017
180	27.99627815	-82.53377738	No	No	2017
181	27.99618199	-82.52366836	2020	2018	No
182	27.99612269	-82.51347727	No	2017, 2018, 2020	No
183	27.99604896	-82.50649715	2020	2017, 2020	No
185	27.99605945	-82.50095436	No	2017	No
186	27.996197	-82.488552	No	2019, 2020	2018
187	27.99619472	-82.48438413	No	2018, 2019	No
188	27.99594887	-82.47617793	2018	2018	2018
191	27.99618683	-82.45947957	No	2018, 2019	2018
192	27.9960924	-82.45415905	No	2018	No
193	27.99609622	-82.45113965	2017	2017, 2018, 2020	No
194	27.99608445	-82.44292463	2017, 2019	2017, 2018, 2019, 2020	No
195	27.99610356	-82.43882342	No	2020	No
196	27.99610831	-82.43471394	No	2018, 2020	No
197	27.99602793	-82.42652418	No	2018	No
198	27.99607965	-82.42239792	No	2017, 2020	2017
199	27.99607393	-82.41400079	2017	2017	2018

Table A-1 Intersections Experiencing Fatal, Pedestrian and Bicyclist Crashes (Contd.)

Intersection Number	Latitude	Longitude	Fatal Crashes	Pedestrian Crashes	Bicyclist Crashes
201	27.99612456	-82.3848989	2018	2017, 2020	2018
202	27.99631192	-82.37306965	2018	2017, 2018	2017
203	27.99549898	-82.33519924	No	2018	No
204	27.998666	-82.31883	No	2019	No
205	28.00181727	-82.30246919	No	2019	2017
207	28.0065773	-82.27774014	No	2017, 2018	No
208	28.01605046	-82.24461588	2020	No	No
214	28.02723393	-82.05572333	No	2019, 2020	2018
215	27.8933898	-82.5269518	No	2018	No
216	27.89347513	-82.51842109	No	2019, 2020	2017, 2018
217	27.98143263	-82.45115228	2018, 2019	2018, 2019, 2020	No
218	27.98143868	-82.44282111	2019	2019, 2020	2018
219	27.98153473	-82.43477901	No	2018, 2019	No
220	28.34673557	-81.64827879	2020	No	No
221	28.34005867	-81.59697702	No	2018	No
222	28.3355277	-81.59165171	No	2017	No
224	28.33245269	-81.57681221	2017, 2019	No	No
231	27.93765802	-82.12112508	2019	No	No
234	28.33282604	-81.5209068	No	No	2018
238	28.44993863	-81.47794215	No	2018, 2019, 2020	2017
241	28.4498861	-81.48808321	No	2018, 2019, 2020	No
245	28.00729464	-82.30243319	2019	No	No
250	27.99677779	-81.89936138	No	2020	No
251	27.99474585	-81.7380301	No	2019	No
252	28.05493587	-81.94086497	No	2019, 2020	No
254	28.25454981	-81.65855318	2018	2020	No
256	28.05468006	-81.99413722	No	2018	No

Table A-1 Intersections Experiencing Fatal, Pedestrian and Bicyclist Crashes (Contd.)

Intersection Number	Latitude	Longitude	Fatal Crashes	Pedestrian Crashes	Bicyclist Crashes
257	28.29258237	-81.6646414	2017	No	No
258	27.89482876	-81.97362191	2020	2018	No
262	28.04933443	-81.92570338	No	2018	No
263	27.92520654	-81.85199125	No	2018	No
265	27.90389281	-81.83342922	No	2019	No
266	28.07703574	-81.95327964	No	No	2018
269	28.05884756	-81.78867847	No	2018	No
271	28.047807	-81.85855764	No	2020	No
272	27.92375012	-81.82162668	No	2019	No
275	28.04782395	-81.90805102	No	2020	No
276	28.01100444	-81.73085274	No	2020	No
277	28.06973455	-81.95330956	2018	2018, 2020	No
278	27.90396018	-81.84343573	No	2018	No
284	28.05474254	-81.99018156	No	2019	No
285	28.06977525	-81.95735747	No	2020	No
287	28.054986	-81.94807028	2019	2019	No
289	28.22530781	-81.64546951	No	2017, 2020	No
290	27.96742135	-81.87940577	2017	2017	No
291	27.98285961	-81.75146896	No	2020	No
297	27.92708615	-82.05523939	2018, 2020	No	No
298	28.01876111	-81.6324065	2018, 2019	2020	No
299	28.06240193	-81.95326525	No	2017	No
305	27.91348705	-81.60319904	2018	2020	No
306	28.06240746	-81.95727473	No	2018	No
307	27.90389833	-81.8404895	2019	2017, 2019, 2020	No
311	28.04393952	-81.73486315	No	2018	2017
312	27.96351252	-81.62537746	No	2018	No

Table A-1 Intersections Experiencing Fatal, Pedestrian and Bicyclist Crashes (Contd.)

Intersection Number	Latitude	Longitude	Fatal Crashes	Pedestrian Crashes	Bicyclist Crashes
318	28.03470079	-81.73298871	No	2020	No
320	28.13811031	-81.63776534	2017	No	No
321	28.31068317	-81.66754663	No	2020	No
322	28.04775412	-81.89567964	2019	No	No
323	28.32160024	-81.6692919	2017, 2020	No	No
325	28.05765127	-81.81336691	No	2019	2017
327	28.06105843	-81.77606328	No	2018, 2019	No
328	27.97886189	-81.6308074	No	2020	No
330	28.05484998	-81.96550335	No	2018	No
331	27.95696937	-81.62187969	2017	No	No
336	27.98668275	-81.74725021	No	2019	No
338	27.90849507	-81.84339496	2020	2017, 2020	No
342	27.90390834	-81.83037904	No	2020	No
343	28.05487509	-81.9612921	No	2020	No
345	27.95284676	-81.86979291	2020	2018	No
356	28.08061823	-81.9737838	2017	No	No
357	28.08058392	-81.95733673	No	2019	No
361	27.97554278	-81.88511509	2018	No	No
362	28.02231664	-81.73309631	No	2017	No
365	28.03315737	-81.732962	No	2019	No
367	28.07598557	-81.99167396	No	2019, 2020	No
371	28.23002025	-81.64829913	No	2019	No
373	28.09318503	-81.72965433	2018	No	No
377	28.05689308	-81.81738774	2020	2018, 2020	No
378	28.05497373	-81.9542324	No	2019	No

Table A-1 Intersections Experiencing Fatal, Pedestrian and Bicyclist Crashes (Contd.)

Intersection Number	Latitude	Longitude	Fatal Crashes	Pedestrian Crashes	Bicyclist Crashes
379	28.0846569	-81.96963242	No	2019	No
380	28.08060044	-81.96543147	2018	2018	2017, 2018
383	28.08204151	-81.9531894	2019	No	No
385	28.05491393	-81.95731671	No	2018, 2020	2017
386	28.08053605	-81.99430849	No	No	2018
394	27.9447027	-82.47678296	No	2019	No
395	27.9446888	-82.47473975	No	2018, 2019	No
396	27.94478424	-82.48915643	No	2017	No
397	27.99619987	-82.49241079	2017, 2019	2019, 2020	2018