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Large Truck Crash Analysis for Freight Mobility and Safety Enhancement in Florida

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Florida Department of Transportation

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DISCLAIMER

METRIC CONVERSION CHART

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	mega grams (or metric ton)	Mg (or t)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F−32)/9 or (F−32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	pound force	4.45	newton	N
lbf/in^2	pound force per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS TO SI UNITS

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
AREA				
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.314	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or t)	mega grams (or metric ton)	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newton	0.225	pound force	lbf
kPa	kilopascals	0.145	pound force per square inch	lbf/in²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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16. Abstract

This report summarizes the efforts and results of the research project "Large Truck Crash Analysis for Freight Mobility and Safety Enhancement in Florida", which was intended to gain more understanding of the patterns and contributing factors of large truck crashes in Florida, to recommend practical countermeasures to reduce crashes involving freight, and to enhance freight mobility and safety. A comprehensive statewide crash analysis was conducted focusing on large truck-involved crashes in the past ten years, between 2007 and 2016. Three different approaches were undertaken to analyze the crash data. A framework was developed to identify the critical reason for individual crashes, which provided insights into the potential causes or factors that lead to increasing risk of a crash. Disaggregate crash severity analysis was conducted to investigate the impacts of contributing factors on crash severity outcomes through random parameter ordered logit (RPOL) models. Spatial analysis was also conducted to illustrate the spatial pattern of large truck crashes and identify concentration or problematics areas, using an ArcGIS Spatial Analyst extension, the Kernel Density tool. Incorporating findings from the three major crash analysis efforts, a data-driven and evidence-based set of countermeasures was developed that target the behavioral factors and critical locations identified from those efforts. A group of selected systemic countermeasures were presented and discussed with some examples representing the common applications. Targeted countermeasures were then recommended for 35 priority locations identified in the state of Florida, including 15 hotspot areas ranked by kernel density and 20 high priority intersections ranked by high crash severity or high crash rate. Last but not least, an economic appraisal approach was recommended that considers the economic impacts of enhanced freight safety and mobility in the project evaluation process. The Large Truck Crash Reduction Benefit Estimator, a spreadsheet-based tool, was developed to facilitate the economic appraisal process.

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EXECUTIVE SUMMARY

This report summarizes the efforts and results of the research project "Large Truck Crash Analysis for Freight Mobility and Safety Enhancement in Florida", which was intended to gain more understanding of the patterns and contributing factors of large truck crashes in Florida, to recommend practical countermeasures to reduce crashes involving freight, and to enhance freight mobility and safety.

A comprehensive statewide crash analysis was conducted focusing on large truck-involved crashes in the past ten years, between 2007 and 2016. Crash data were acquired from Signal Four Analytics, including all police crash reports in the state of Florida. The database produced 243,017 crashes involving large trucks in the ten-year period. The Florida all-road GIS street basemap, referred to as Navteq data, was obtained and incorporated into the database, which provided complete and detailed coverage of the street network in Florida. Relevant FDOT roadway characteristics were obtained from the FDOT Statistics Office to supplement the network data.

Three different approaches were undertaken to analyze the crashes. One major effort focused on identifying the critical reasons for each crash, in order to provide some insights into the potential causes or factors that lead to increasing risk of a crash. A comprehensive framework was proposed for this purpose. It retrieves available information from the crash data and covers all possible elements including driver characteristics, vehicle conditions, roadway and environmental situation. Six categories of critical reasons were identified, including driving error, non-driving error, distraction or vision obstruction, vehicle defect, roadway condition, and weather condition. Each category was further broken down into several sub-categories that identified unique contributing factors. Based on the framework, critical reasons were identified for individual crashes, and detailed analysis for the critical reasons by crash type were conducted for trucks and non-trucks, respectively.

Major findings regarding critical reasons are highlighted as follows:

- Overall, driving error was the dominant critical reason, representing 92.3% of the crashes for trucks and 95.6% for non-trucks. Non-trucks were more likely to be associated with driving errors than trucks across all crash types.
- Collisions with pedestrian, bicycle, animals were the least likely to be associated with driving errors, compared with other crash types, especially for trucks.
- The next critical reason was vehicle defects and roadway conditions for trucks, each representing 2.9% of the crashes. Relatively, non-trucks were less likely to be assigned to vehicle defects (0.8%) and roadway conditions (1.7%) than trucks.
- Vehicle defects for trucks were particularly significant for non-collisions (15.3%) and collision with other non-fixed object (16.9%), while roadway conditions were particularly critical for collisions with pedestrian, bicycle, and animals (16.9%).

- Driver distraction and vision obstruction was another significant factor for collisions with pedestrian, bicycle, and animals, for both trucks (9.4%) and non-trucks (4.2%).
- Non-driving error showed minimal influence, especially for trucks. It should be noted that while trucks were more likely to be associated with asleep/fatigue, they were much less likely to be involved in DUI conditions than non-trucks.

The second major effort in this study focused on crash severity analysis. A random parameter ordered logit (RPOL) model structure was employed for this study, because of its capability in accommodating the ordered nature of severity level and in capturing potential heterogeneity of contributing factors among the crash events. Similarly, separate analyses were conducted for each crash type, given that it is reasonable to assume that different contributing factors and mechanisms are associated with different types of crashes. Six RPOL models were developed for non-collision crashes, collision with fixed object, collision with pedestrian, bicycle, and animals, collision with parked vehicle, collision with vehicle in motion, and collision with other non-fixed objects. Model results revealed interesting and distinct patterns among different types of crashes. Various factors were identified as significant contributors to crash severity, including crash attributes, driver condition and actions, vehicle conditions, and roadway and environmental factors. Model results showed that a variety of parameters, including speeds, vehicle configuration, vehicle body type, driver condition, driver action, and roadway conditions, exhibited random effects on crash severity outcome. In other words, these factors did not always show the same impacts on severity; instead, their impacts exhibited significant variations across the crash events. Further analysis is needed to identify the source of heterogeneity.

The third major effort focused on the spatial pattern of the crashes, in order to identify crash concentration or problematic areas. ArcGIS Spatial Analyst extension, the Kernel Density tool, was used to analyze the spatial clustering of large truck crashes. Density maps for each district were developed, and the top ten locations in each district were identified. Each location was accompanied with a zoomed-in street map to show the details and a brief description about the location and the surrounding land uses. The spatial analysis provided a general understanding of the areas with high crash density, which served as the foundation for more detailed investigation at the roadway level.

Incorporating findings from the three major crash analysis efforts, a data-driven and evidence-based set of countermeasures was developed that targets the behavioral factors and critical locations identified from those efforts. The countermeasures were developed following the traditional "3Es" approach, namely engineering, enforcement, and education. A combination of systemic and targeted countermeasures was recommended. The systemic approach relies on a broader view of treatments, targeting a greater geography and range of risk factors. Systemic approaches may involve prioritizing where investments may be made, which is common in the infrastructure/engineering solutions. In the case of enforcement and education, they imply a more general application of the treatment, like agency-wide enforcement programs and area-wide media coverage. Targeted countermeasures were aimed at the specific factors and locations identified in the severity analysis and spatial analysis.

A group of selected systemic countermeasures were presented and discussed with some examples representing the common applications. Targeted countermeasures were then recommended for 35 priority locations identified in the state of Florida, including 15 hotspot areas by kernel density ranking, and 20 high priority intersections by high crash severity or high crash rate. Each high priority location was characterized through location maps, and the most notable critical reasons were highlighted. Based on the charts of occurrence of critical reasons, the most notable reasons for large truck crashes at the hotspot areas and some intersections were driving error, driver distraction or vision obstruction, and the roadway condition. Targeted countermeasures were selected and ranked by cost level for each notable critical reason.

Last but not least, an economic appraisal approach was recommended that considers the economic impacts of enhanced freight safety and mobility in project evaluation process. An economic appraisal deals with the identification and measurement of project costs and the size and distribution of the benefits created by the project. The proposed approach followed the standard benefit-cost analysis procedure recommended by the U.S. Department of Transportation (USDOT). The analysis considered five categories of crash costs, including medical costs, emergency services, property damage, lost productivity, and monetized quality-adjusted life years (QALYs). It calculated project-level safety benefits given the expected risk reduction (based on crash modification factors of the countermeasures to be implemented) and unit cost per crash by truck type and severity level.

This project presents a significant effort in analyzing large truck-involved crashes in the state of Florida. It provides a comprehensive understanding of the patterns and contributing causes of large truck crashes. The findings and recommendations will facilitate investment and policy decisions in reducing truck crashes and promoting freight safety, which have direct impacts and significant benefits in terms of reductions in the societal and environmental costs associated with truck crashes, improvement in transportation system performance and freight transportation productivity, and enhanced economic outcomes in the state. This study also lays the foundation for further investigation of large truck crashes, focusing on specific segments of interest or employing enhanced methods.

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1. INTRODUCTION

Truck movement plays a vital role in fueling the nation's economic prosperity and the well-being of all Americans. In 2017, about $700 billion worth of goods were carried by truck in the U.S. (ATA, 2018), and over 85 percent of Florida communities relied exclusively on trucks to move their goods (FTA, 2018). Large truck crashes impose enormous amounts of loss on the society. In addition to increased congestion and property damages, they put roadway users at high risk of injury and fatality. These crashes also result in impacts on industry prosperity, such as delay-related cost, additional operations costs, and productivity loss. According to the Federal Motor Carrier Safety Administration (FMCSA), large trucks were involved in about 411,000 crashes in 2014 in the United States, with approximately 1% of the crashes resulting in at least one fatality, and the cost of commercial vehicle crashes was estimated to be over $99 billion annually (FMCSA, 2014a).

Commercial vehicle movement is an Emphasis Area in Florida's Strategic Highway Safety Plan; likewise, Florida Transportation Plan goals include providing a safe transportation system and improving freight mobility. The primary goal of this study was to enhance freight mobility by removing crashes as an inhibitor so transportation safety and economic viability are improved in Florida. The specific objectives of this project were:

- Conduct a statewide crash analysis focusing on crashes involving large trucks in the past ten years, and investigate the impacts, occurrences, and severity of crashes involving freight mobility;
- Develop practical countermeasures to reduce crashes involving freight mobility, and recommend response strategies to offset impacts of crashes on productivity loss and operation costs while enhancing freight mobility safety; and
- Recommend a better economic appraisal approach that accounts for the impacts of freight incidents on the economic viability.

A comprehensive understanding of the patterns and contributing causes of large truck crashes will facilitate investment and policy decisions in reducing truck crashes and promoting freight safety. It will lead to improvement in transportation system performance and freight transportation productivity and enhanced economic outcomes in the state.

The remainder of this report lays out as follows: The next chapter describes the background and objectives of this project, followed the chapter that summarizes the literature review in terms of crash analysis methods, data sources, contributing factors and countermeasures. Chapter 3 describes the data acquisition and preparation process, followed by Chapter 4, which presents descriptive analysis that reveal the general characteristics of the large truck crashes. Chapter 5, 6 and 7 presents the process and results for the critical reason analysis, crash severity analysis, and spatial analysis, respectively. Chapter 8 focuses on the countermeasure development. Chapter 9 describes the recommended economic appraisal approach and the Large Truck Crash Reduction Benefit Estimator tool developed to facilitate the process.

2. LITERATURE REVIEW

A comprehensive literature review was conducted in the aims of establishing an understanding of the current knowledge in large truck crash analysis, including data analysis methodology, major findings, and recommended counter measures.

In general, there were two main types of crash analysis in the literature, one at aggregate level focusing on a segment of roadway in terms of the frequency of crash occurrence (by severity type or other characters), the other at disaggregate level investigating individual crashes regarding the correlations between crash characteristics (severity level, location, and crash type, etc.) and other factors related to the vehicles, the drivers, and the roadway and weather conditions.

2.1. Aggregate (Segment-Level) Crash Analysis

Aggregate crash analysis focuses on the probability or risk of crash occurrence for a particular roadway segment (usually of 0.3 to 0.75 miles in length). The risk is usually measured as crash frequency or crash rate.

- Crash Frequency: an integer value indicating the total number of crashes within a pre-defined period of time.
- Crash Rate: a floating number reflecting the total number of crashes within the unit of exposure (such as freight volume measured in ton-miles).

2.1.1. Crash Frequency Analysis

Taking into account that crash frequencies are whole numbers, count data models have been widely used in the literature (Daniel et al., 2002; Schneider et al., 2009; Dong et al., 2015) Count data models could assume a variety of probability distributions, such as Poisson (P), Poisson lognormal (PLN), and Negative Binomial (NB). The key advantage of NB models over Poisson models is that they allow for over-dispersion, a statistical situation where the observations' variance is higher than the mean. Over-dispersion is quite prevalent in crash data and therefore will result in more accurate estimates.

Daniel et al. (2002) employed Poisson and negative binomial (NB) models to study the effects of various factors on truck crashes on signalized roadways. In terms of contributing factors, various interaction and roadway geometry characteristics were investigated. A two-year New Jersey accident database was developed for this study, including accidents involving trucks of 20,025 and 21,561 observations in 1998 and 1999, respectively. Full Poisson regression model was run for both ordinary least-squares and maximum likelihood methods. The results indicated that truck crash accidents were highly affected by the number of signalized intersections, segment length, average annual daily traffic (AADT), length of horizontal curve, length of vertical curve, number of lanes, number of signals within the segment, crest curve grade rate, and pavement width.

Using a negative binomial (NB) model, Schneider et al., (2009) studied truck crashes affected by horizontal curvature on rural two-lane collector and arterial horizontal curves in Ohio. The impacts of highway geometric features (e.g. shoulder width, curve radius, curve length) and traffic parameters (passenger and trucks AADTs) on the frequencies of truck involved crashes were examined. Two datasets containing 15,390 observations of single- and multi-vehicle crashes on horizontal curves between 2002 and 2006 were provided by the Ohio Department of Public Safety and the Ohio Department of Transportation Roadway Inventory. In order to obtain better estimation, Markov chain Monte Carlo (MCMC) technique and a Gibbs sampling technique were applied to the NB model. Results showed that significant increase in truck crashes was associated with the increase in the value of the horizontal curve, truck and passenger AADTs, and the degree of curvature.

Dong et al. (2014) developed various structures of Poisson models and assessed their performance on crash frequency estimation. In the study, crash frequencies were classified by crash type: car only crashes, car-truck crashes, and truck only crashes. The study used data from the Tennessee Roadway Information System (TRIMS) from 2005 to 2009, which included 6,790 crashes and 245 intersections. Three different model structures were tested: univariate model (UVPLN), where the three dependent variables were modeled independently, multivariate Poisson model (MVP), where the three variables were modeled jointly in a Poisson distribution and the expected value of crash frequency was a linear function of the explanatory variables, and multivariate Poisson log-normal model (MVPLN), where it follows a Poisson probability distribution but the expected value of crash frequency followed an exponential function. The results showed that the MVPLN model has superior performance in goodness-of-fit compared to the other approaches. In terms of the contributing factors, traffic volume, truck percentage, lighting conditions, and intersection design had significant impacts on crash frequency. In addition, contributing factors seem to have different impacts from one crash type to another.

Dong et al. (2015) developed a Bivariate Negative Binomial (BNB) model to predict crash frequencies for 1,310 highway segments in Tennessee. The term bivariate refers to the fact that two types of crash frequencies are jointly modeled: car-truck crashes, and truck-only crashes. Various data sources were employed, including the state crash record information system and the road inventory records from the Tennessee Department of Transportation (TDOT). The final sample data included 1,787 truck involved crashes through a 4-year period, from 2004 to 2007. In order to treat the excessive number of zeros in the dataset, both zero-inflated (BZINB) and regular BNB models were tested. Results showed superior goodness-of-fit for the BZINB structure compared to the BNB model. In terms of contributing variables, large truck AADT, segment length, geometric design, lighting conditions, and posted speed limits showed significant impacts on both crash types. For car-truck crashes, passenger car AADT, number of lanes, and different speed limit indicators were significant contributors, while international roughness index (IRI) was significant for truck-only crashes.

2.1.2. Crash Rate Analysis

For crash rate analysis, censored regression models have been introduced. Specifically, Left-Censored Tobit Regression models have shown favorable performance in predicting crash rates (Bin Islam and Hernandez, 2016).

Bin Islam and Hernandez (2016) developed a random-parameter tobit regression to estimate crash rates. Crash rate, defined as crash frequency divided by the measure of exposure, is a continuous censored variable used as a safety index for a segment. Two different measures of exposure were considered in this study: million truck-miles traveled and ton-miles of freight. In order to consider crash heterogeneity, both fixed and random parameter models were tested for each dependent variable. Random variables included constants, number of vehicles involved, and number of people not fatally injured. A total of four separate models were developed. Data for this study came from the Fatality Analysis Report System (FARS), Bureau of Transportation Statistics (BTS), and FHWA travel reports. In general, it was revealed that factors related to crash mechanism, temporal and spatial characteristics, road and environmental attributes, vehicle configuration, and driver/passenger attributes had significant contribution to the models. For both exposure units, random-parameter models showed better performance compared to fixed models.

While total crash numbers/rates provide general information regarding the safety performance of a specific segment, researchers/planners are interested in obtaining more detailed information (yet at aggregate level), leading to breakdown of crash rates/numbers based on different attributes (e.g. crash type, crash severity, crash location, etc.). In particular, crash severity is of interest for planners since it provides a more detailed safety index for the specific location. For instance, it will be much more informative for decision makers if they know the rates of fatal/injury/PDO crashes separately rather than all combined in one number. Although univariate models could be separately developed for any of the aforementioned rates, they tend to overlook the unobserved correlation between the observations. This is where multivariate models are applied with highly promising outcomes. Statistical analysis confirms superior performance of correlated multivariate models that consider frequencies/rates of different crash attributes simultaneously. In particular, the efficiency of Multivariate Poisson Lognormal (MVPLN) or Multivariate Tobit models has been emphasized in the literature Dong et al. (2014).

In summary, aggregate (segment-level) crash analysis has been widely practiced in terms of large truck crash analysis. Both crash frequencies (Poisson and NB structures) and crash rates (Tobit structures) have been documented in the literature. A few studies also employed more complex structures to account for heterogeneity, zero-inflation, and unobserved correlation between different crash severities.

2.2. Disaggregate (Crash-Level) Crash Analysis

Disaggregate analysis investigate individual crashes instead of the aggregates at segment level. Therefore, the analysis can take into consideration the individual crash level attributes, such as driver characteristics, and vehicle conditions, etc. Disaggregate analysis could focus on many crash attributes, such as, crash location (e.g. intersection vs. non-intersection, on-ramp vs. off-ramps, etc.), crash type (rear-end, head-on, etc.), land use (urban vs. rural), severity, weather conditions, and temporal factors (weekend vs. weekday, time-of-day, etc.). Among the attributes, crash severity was the most popular one.

In terms of modeling techniques, discrete choice models were widely used in the literature, including binary, multinomial, mixed and ordered response models depending on the dependent variable. Both normal (probit) and Gumble (Logit) distributions have provided reasonable fit to the crash data in existing studies.

Truck-car injury severity in rear-end accidents on divided roadways was studied by Duncan et al. (1998). Using accidents data from the Federal Highway Administration's Highway Safety Information System (HSIS), a total of 562 observations of truck-car crashes in North Carolina between 1993 and 1995 were extracted. Ordered probit model was applied, with and without interaction effects among the variables. A set of vehicle, occupant, roadway, and environmental variables was considered as independent variables. Results showed that darkness, wetness, being drunk, being female, and speed limit, etc. increased the probability of injury severity, while existence of snow and ice on road, congestion, presence of child, etc. decreased the injury severity.

Khattak et al. (2002) conducted a study on single-vehicle large track crash severities with an emphasis on the distinction between rollover and non-rollover situations. Three discrete choice models were developed, a binary probit model to estimate the probability of a rollover event, an ordered probit model with 5 levels to study the injury severity level, and a separate ordered probit model to predict injury severity given a single vehicle rollover crash. Using the HSIS data from North Carolina from 1996 to 1998, a subsample of 5,163 single-vehicle large truck crashes was extracted, out of which 1,503 cases were identified as rollovers. Results showed that trailer length, make and model, dangerous driving behavior (e.g. reckless driving, alcohol/drug abuse, speeding, passing violation, etc.), turning maneuvers, and curved segments significantly increased the probability of a rollover event. In terms of severity, number of truck occupants, defective brakes, dangerous driving behavior particularly violating traffic control signs or signals, and post-crash fire had significant contribution to more severe injuries. Results also confirmed that the combination of rollover and post-crash fire was the most dangerous factor in injury severity.

Khorashadi et al. (2005) analyzed injury-severity in large-truck crashes by developing two multinomial logit (MNL) models, for rural and urban areas, respectively. Four injury classes were identified, including no injury, complaint of pain, visible injury, and severe/fatal injury. The study used data from the Traffic Accident Surveillance and Analysis System (TASAS) maintained by the California Department of Transportation (Caltrans) and included a total of 6,300 rural and 11,072 urban crashes in a four-year period (1997-2000). Considering the disaggregate nature of the study, several factors including driver (liability, gender, etc.), vehicle (vehicle age, type, occupancy, function, etc.), environmental (crash location, etc.), roadway geometry (terrain, number of lanes, median type, road lighting, etc.), crash attributes (collision type, primary collision factor, etc.) as well as traffic conditions (Time of day, etc.) were analyzed. Pseudo-elasticities were computed and analyzed to assess the direct impacts of these factors on the severity level separately. As expected, significant differences were observed between rural and urban areas. Several likelihood ratio tests were also conducted on the models, comparing the MNL with nested structure and comparing the rural/urban sub-models with a total combined model. In both cases, the two MNL sub-models outperform the alternatives.

Blower et al. (2010) investigated post-crash inspection results for 1,001 medium and heavy trucks in the Large Truck Crash Causation Study (LTCCS) crash database. A concept known as "Critical reason" (CR) was applied, which recorded the specific driver, vehicle, or environmental reason for the event that precipitated the actual crash, in order to test two major hypotheses: First, whether trucks with defects and out-of-service conditions were more likely to cause a crash; and Second, whether defects in particular systems were more likely to be involved in crashes that could be directly prevented using those systems (if they were not defective). In addition to t-test comparisons, a binary logit model was developed to evaluate the impacts of several potential factors on the critical reason. Results showed that trucks with an out-of-service brake condition were more likely to cause a crash by 1.8 times. Similarly, hours-of-service and log out-of-service violations increased crash odds by 2.0 and 2.2 times, respectively. In particular, it was inferred that the odds of Brake-Relevant (BR) crashes increases by 1.8 times in presence of break service violations.

Lemp et al. (2011) developed a heteroskedastic ordered probit (HOP) model in large truck crash severity analysis. The main advantage of a heteroskedastic structure is that it provides higher levels of flexibility by allowing the variance (standard deviation) to vary for each observation and therefore leading to more accurate coefficient estimates. Data from the LTCCS, General Estimates System (GES), and vehicle inventory were used for a three-year period (2001 to 2003). Two different sample datasets were constructed: A crash-level injury (922 observations), and a vehicle-level injury (1,894 observations). Two separate HOPs were developed and the results were compared to conventional ordered probit (OP) models. Overall, the better performance of HOP models indicated the importance of heteroskedasticity in crash severity analysis. In addition, the models showed significant impacts of crash, driver, roadway, weather conditions, and vehicle attributes on injury severity.

Zhu and Srinivasan (2011a) provided a comprehensive analysis of injury-severity factors in large truck crashes using a nationally distributed sample of 953 crashes in the LTCCS database. Two disaggregate ordered probit models were developed and compared: One used the severity index from the police accident reports (PAR), and the other defined by researchers from the LTCCS data (RES). Three variable categories were applied including car-level, truck-level, and crash-level attributes. Considering the existing differences and similarities between the two models, researchers recommended more accurate assessment of injury severity in both police reports and LTCCS data. Furthermore, missing data (which is reflected through several dummy variables) showed significant contribution to the models, which pointed out the need for more comprehensive post-crash data collection.

In a similar study, Chang and Chien (2013) developed a non-parametric classification tree structure in order to relax some of the underlying assumptions and constraints of the parametric models. A sample of 1,620 observations was collected from the 2005-2006 truck-involved accident data from national freeways in Taiwan. Accordingly, variables such as alcohol drinking, seatbelt usage, crash type, vehicle type, number of vehicles involved, and crash location were among the significant factors. In particular, a drunk driver not using a seatbelt provided the highest probability of a fatal accident.

Chen and Chen (2011) developed disaggregate crash-level mixed logit models in order to assess critical factors in single-vehicle and multi-vehicle incidents on rural highways. A 10-year detailed accident data (1991-2000) on rural highways in the state of Illinois were extracted from the HSIS database, leading to a final subsample of 6,891 single and 12,850 multi-vehicle crash observations. A comprehensive set of contributing factors at driver, vehicle, accident, temporal, and environmental level were explored. In general, results showed significant differences between single-vehicle and multi-vehicle crashes. In particular, some variables only affected one type of crash (e.g. improper lane usage on SV model and right turn maneuvers on MVs) while some variables showed opposite impacts on the two models (e.g. female driver, fatigued driver, snow/slush road surface, etc.). Finally, likelihood ratio tests confirmed that mixed logit models had better fit compared to fixed-parameter MNL models as well as a higher performance of separate single-vehicle and multi-vehicle models compared to a total combined structure.

Islam et al. (2014) analyzed injury severities for single-vehicle and multi-vehicle crashes in both rural and urban areas. A total of four disaggregate crash-level mixed logit models were developed. Crash severity groups are classified in three categories major, minor, and possible/no injury. Police report data were used from 2010 to 2012, providing a cleaned sample dataset of 8,171 crashes. Various contributing factors including driver, vehicle, temporal, roadway, environmental, accident, and land use characteristics were examined in the model. Pseudo-elasticities were also computed which can directly assess the impact of one particular factor on crash severity (irrespective of other coefficients). From a general point of view, the four developed models differ significantly, i.e. one variable can be significant in one model and totally insignificant in others, or another variable can have completely opposite signs in different models. The authors consequently inferred that policy makers should provide specific recommendations based on crash type and location in order to increase overall highway safety in an efficient manner.

Using the Trucks in Fatal Accidents (TIFA) database, Linchao and Fratrovic (2016) analyzed vehicle damages in 3,633 fatal accident cases involving large trucks across the United States. The main essence of the paper was to identify major crash causing factors and differentiate them between rural/urban areas. An ordered response variable was constructed for vehicle damage including no damage, minor damage, functional damage, and disabling damage. Consequently, two generalized ordered logit models (urban vs. rural) were developed. The advantage of a "generalized" structure is that it relaxes the parallel-line assumption, therefore allowing the coefficients to vary across different levels and providing better overall goodness-of-fit. Several variables were tested in the model, mainly categorized as driver, vehicle, or roadway/environmental attribute. Results showed that some explanatory variables had similar signs for both rural and urban (e.g. high speed, downhill locations, steering, some two-way roads, angle, and front-to-front crashes increase vehicle-damage in both cases) crashes, while factors such as braking, work zones, front-to-rear, and left turns had opposite impacts.

Vachal (2016) developed a binary logit model to explore large truck crash severity in rural areas in North Dakota. A simplified binary variable was constructed for crash severity, with fatal and disabling crash recognized as "serious" and others categorized as "non-serious". Data came from police reported injury crashes on rural roads from 2009 to 2014 with truck involvement, leading to a final sample of 2,811 crashes. It was inferred that alcohol/drug abuse, head-on and rollover events were influential factors in serious injuries. Furthermore, passenger vehicles were more likely to be exposed to serious injuries. Weather conditions and sideswipe collisions showed reduced likelihood on serious injuries.

In terms of disaggregate studies, crash severity was the most prevalent topic and different studies employed different definitions (classifications) of crash severity. Few studies, have delved into deeper levels such as occupant-level injury, which consider multiple injuries that happened in a crash. Applications of discrete choice models such as multinomial, binary, and ordered probit models have been well documented.

2.3. Disaggregate vs. Aggregate Approach

Both methodologies have been widely applied in the literature. There is a general consensus that disaggregate models provide better fit to the data since they use information of higher resolution and are more likely to provide more accurate predictions. However, one major issue remains. Disaggregate methods highly depend on crash-specific data obtained from police reports, most of which are not easily available before actual crash occurrence. Therefore, although disaggregate approaches provide valuable information at theoretical level based on a more behavioral foundation, their application in practice will be difficult due to large number of variables that need to be known. For prediction purposes, planners are usually looking for more parsimonious models that rely on easily accessible segment-level information such as roadway, traffic and weather conditions. A recent research work revealed that aggregate models could provide reasonable fit to the data provided that an efficient modeling structure along with appropriate variables were to be applied (Anastasopoulos and Mannering, 2011). In addition, disaggregate analysis allows for consideration of multi-level heterogeneity (correlations at different levels other than crash level, e.g. corridor levels), which could not be explored in aggregate methods.

2.4. Methodology Advancement

This section discusses some prevalent analytical issues that may lead to biased and inconsistent inferences in crash analysis, and also intends to shed light on model enhancements to address these issues, mostly based on literature from general crash studies, which may also be applied for truck crash analysis.

2.4.1. Zero-state Segments

When it comes to segment-level analysis, it is quite common to encounter segments with no crash reported during the study period. This could either 1) be due to the stochastic nature of crash events, which lead to a value of zero during the finite study period, or 2) it could reflect high levels of safety at the foresaid segment leading to a very low crash risk. In either case, such zero-sate segments need to be carefully analyzed as their attributes will probably provide benchmark standards for reducing crash risks on similar roadway segments (Kumara and Chin 2003; Anastasopoulos 2016; Dong et al., 2015).

With the above being said, zero-state observations were usually treated distinctively compared to other road segments. When analyzing crash frequencies, this was usually addressed through zero-inflated structures (Lee and Mannering 2002; Anastasopoulos 2016). In view of crash rates, left-censored Tobit models have been widely accepted (Anastasopoulos et al. 2008; Dong et al. 2014 ;Bin Islam and Hernandez, 2016).

2.4.2. Heterogeneity and Unobserved Correlations

One simplifying assumption in crash modeling (or more generally, in predictive analytics of any type) is that the sample observations are homogenous against different factor impacts. However, recent studies have documented the presence of heterogeneity among different observations (Hakkanen and Summala 2001; Ma et al. 2008; Anastasopoulos 2016). For instance, the impact of traffic volume on injury severity might differ from one crash type to another (crash-level heterogeneity). In such cases, the model structure can be enhanced by applying random-parameter models instead of fixed-effect structures. The concept of random parameters will allow the analyst to consider flexible variable impacts across different observations in the study sample. Application of mixed-logit models or random-parameter count data is a perfect example of how to address heterogeneity (Chin and Quddus 2003; Kumara and Chin 2003; Anastasopoulos and Mannering 2009; El-Basyouny and Sayed 2009; Malyshkina et al. 2009; Venkataraman et al. 2011; Anastasopoulos et al. 2012; Venkataraman et al. 2013).

In view of crash analysis, heterogeneity is not limited to crash level. One popular form of heterogeneity occurs when unobserved correlation exists between different subcategories of data (e.g. among different crash types or corridor types) rather than between each and every single observations. This type of heterogeneity was usually addressed through multi-level models where different levels of correlation could be defined and measured (Ma et al. 2008; Anastasopoulos 2016).

2.4.3. Endogeneity

Endogeneity happens when there is a mutual cause-effect relationship exists between an explanatory variable and the dependent variable. Some specific cases of endogeneity has been reported in crash analysis studies. The endogenous relationship between the presence of exclusive left turn lanes and frequency of left lane crashes, or between warning sign locations and crash frequencies well fit in this concept. However, only few research works have tried dealing with endogeneity issue in crash frequency analysis, all of which reported several complexities in their model structures (Carson and Mannering 2001; Kim and Washington 2006).

2.4.4. Functional Form

Although most studies tended to consider a linear relationship in their crash analysis, instances of non-linear modeling techniques have been reported (Miaou and Lord 2003; Bonneson and Pratt 2008). Results showed that non-linear models might provide a better estimation of the relationship between crash frequency and explanatory variables, however the models were too complicated and required intricate estimation techniques.

2.4.5. Small Sample Size and Low Sample Mean

When it comes to crash data, it is not uncommon to encounter small sample sizes (due to high costs associated with data collection) or low sample means because of small number of observed crashes. Speaking of statistical theories, both conditions will cause problems when coming to model estimation. In particular, a small sample size will question the efficiency of the well-known maximum likelihood approach for model estimation. In such cases, application of alternate methods such as the Bayesian estimation approach is recommended (Pande and Abdel-Aty, 2009; Ahmed et al., 2012; Yu and Abdel-Aty, 2013a, 2013b, 2014).

2.5. Methodology Summary

In general, the methodologies applied in large truck crash studies are very similar to what has been used in general crash analysis studies, while general crash studies have seen more recent efforts in exploring advanced model structures. As illustrated in Figure 1, at aggregate level count data model and tobit regression are the most common methods used to analyze crash frequency and crash rate, respectively.

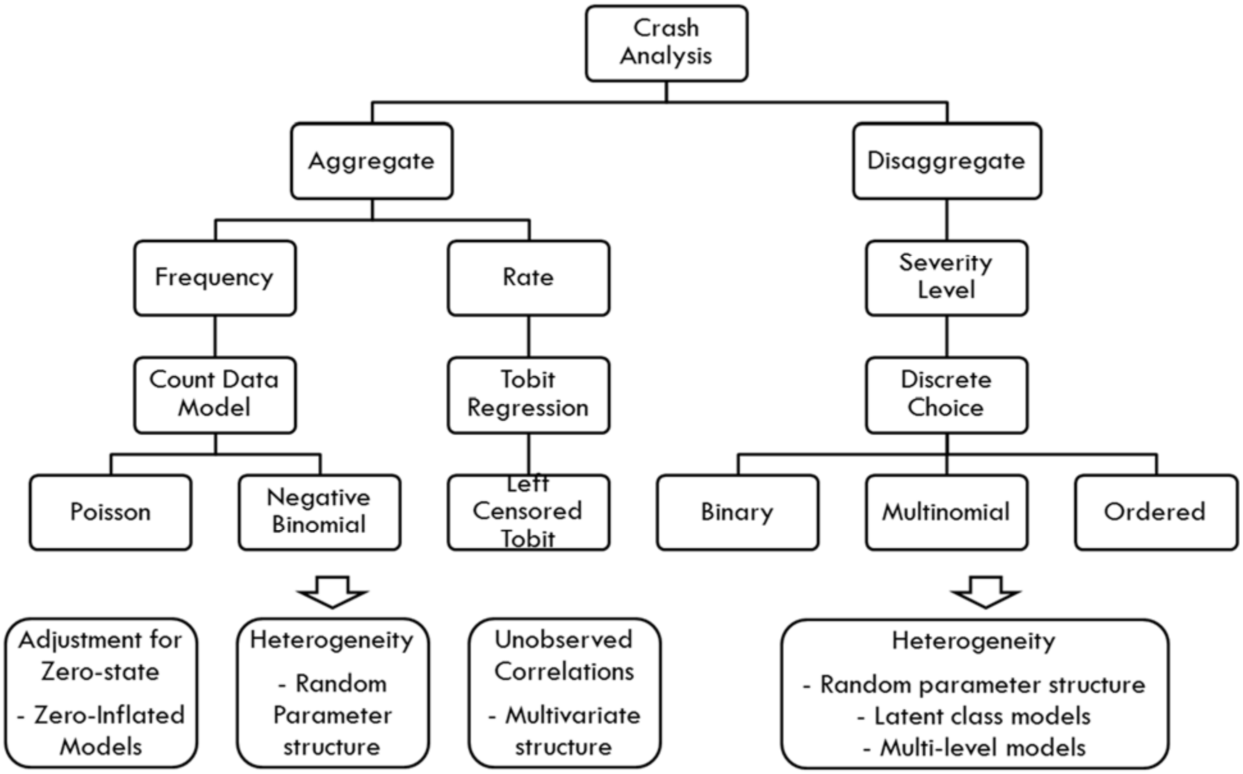


Figure 1 Modeling methodology in crash analysis studies.

For disaggregate level analysis, the models include variety of structures such as ordered, binary, and multinomial with respect to the variables being analyze. Application of mixed (random-parameter) models enables the analyst to incorporate impacts of heterogeneity into the model. In terms of injury severity, some studies compared the efficiency of different severity classifications in their predictions (Kononen et al. 2011).

While discrete choice structures are classified as parametric models, some researchers also tested the application of non-parametric models to avoid restrictions and assumptions involved with parametric structures (Pande et al. 2010; Chang and Chien 2013; Kashani and Mohaymany 2011). In particular, methods such as classification and regression tree (CART), genetic algorithm, and neural networks have reflected promising performance as well as interesting outcomes.

For both aggregate and disaggregate analysis, heterogeneity and unobserved correlation are among the prevalent concepts for model enhancement. Treatments are also similar: either using random parameter structures to explain heterogeneity, or using multivariate structures to account for unobserved correlations. Few studies have used alternate methods such as latent class models (LCL).

Table 1 below shows a brief summary of crash studies included in the literature review.

Table 1 Summary of Relevant Studies in Crash Analysis

Study	Location	Purpose	Methodology	Data set	Major Findings
Hakkanen and Summala, (2001)	Finland	Identifying major factors that lead to crash liability for truck drivers	Descriptive Statistics	337 two-vehicle truck accidents (1991-1997) Plus a survey of 251 long-haul truck drivers.	Younger driver and evening hours were significant predictors of being principally responsible. The probability of being principally responsible for the accident increased by a factor of over three if the driver had a chronic illness. Prolonged driving preceding the accident, accident history or traffic offence history did not have a significant effect.
Daniel et al., (2002)	New Jersey	Developing a frequency model for truck crashes at signalized intersections	Poisson/negative Binomial Models	More than 40,000 truck accidents in 1998-1999 on US 1 New Jersey	Interchange density was likely to increase number of crashes along a roadway.
Khattak et al. (2002)	North Carolina	Injury severity estimation and contributing factors for Single-Vehicle Crash and Single-Vehicle Rollover	Descriptive Statistics and Binary Probit Model	HSIS[1] data collected from 1996-1998 for 5,163 single-vehicle truck police-reported crashes in North Carolina.	Recommended countermeasures related to truck-driver behavior and roadway geometry
Toth et al (2003)	Nation-wide	LTCC methodology investigation and contributing factors study	Descriptive Statistics	LTCCS[2] data by the NHTSA[3] and the FMCSA[4], including 967 injury and fatal large truck crashes between 2001 and 2003 form 24 cities in 17 States.	All LTCCS data categorized in different types. LTCCS tabulated based on different characteristics (e.g. number of cases by type of crash, number of involved vehicles by first harmful event and involved vehicle type, number of involved vehicles by body type, Number of Cases by Maximum Injury Level, etc.)
McCartt et al. (2004)	Northern Virginia	Study of contributing factors of ramp-related on urban interstate roadways	Descriptive Statistics	Data from FARS[5] and GES[6] from 1993 to 1998 for Northern Virginia urban interstate roadways including 1,150 motor vehicle crashes.	Contributions of different parameters such as drivers' fault, crash location (entering-exiting the ramp), and crash types were highlighted. Ramp related countermeasures were recommended.
Khorashadi et al. (2005)	California	Injury severity estimation	Multinomial Logit Model	Data from TASAS[7] for California from 1997-2000 including 17,372 urban and 6,300 rural passenger-vehicle and large-truck observations.	Exploring contributing variables affect driver injury severity in terms of differences with risk factors in urban and rural roads for both passenger-vehicle and large-truck driver injuries

Table 1 Summary of Relevant Studies in Crash Analysis (Continued)

Study	Location	Purpose	Methodology	Data set	Major Findings
Starnes (2006)	Nationwide	Investigation of empirical approaches using LTCC dataset	Descriptive Statistics	LTCCS	Expanded LTCCS variables based on crash-level (i.e number of vehicles and number of trucks involved, crashes by truck type/ vehicle type, etc.), vehicle-level (i.e. number of involved vehicles, by vehicle body type, by general/specific accident type, etc.), and driver-level (i.e. number of drivers by driver age, crash type, and involved vehicle body type, driver's seat air bag status by crash type and involved vehicle type, etc.) categories.
Hanowski et al. (2007)	Southwestern Virginia	Study of contributing factors (light vehicle vs. heavy vehicle)	Descriptive Statistics	1- FMCSA data. 2- Two naturalistic (video and non-video (sensor)) datasets from Southwestern Virginia, including 251 critical truck incidents.	Probability of being involved in crash for light vehicle (LV) drivers more than three times of heavy vehicle (HV) drivers. Moreover, distinct primary contributing factors for LV (Aggressive driving) and HV (poor driving techniques)
Anastasopoulos et al. (2008)	Indiana	Crash rate estimation (Accidents per 100 million VMT)	Tobit Model	Vehicle accident data from interstate highways in Indiana from 1995 to 1999.	Significant association between pavement condition, roadway geometrics, traffic characteristics AND vehicle accident rates
McKnight and Bahouth (2009)	Nationwide	Study of contributing factors	Descriptive Statistics	LTCCS	Results showed rollover causes could be classified into four major groups, including speed, attention, control, and non-driving factors, with high speed being the single largest factor in rollover cases (responsible for more than 45 percent of the sample crashes).
Olson et al. (2009)	Nationwide	Study of contributing factors of crash probability	Descriptive Statistics Using odds Ratios and Population Attributed Risk	Two Naturalistic data sets including 203 CMV[8] drivers and 55 trucks from seven trucking fleets operating at 16 locations.	1- Engaging 70 percent of crashes, 46 percent of near-crash and 60 percent of critical events in non-driving related tasks. 2- Fulfilling complicated non-driving related task will extremely increase the risk of crash. 3- Tasks found as risky functions were also associated with high eyes off forward road times. 4- Talking on a cell phone was not found to increase risk.
Schneider et al. (2009)	Ohio	Investigation of roadway geometry effects on truck crash frequency on horizontal curve	Negative Binomial Model Applying Bayes' Methods	15,390 crash data on rural two-lane collector and arterial horizontal curves in Ohio between 2002 and 2006, from crash reports and the Ohio DOT Roadway Inventory files.	1- Truck crashes highly affected by horizontal curves and the volume of passenger vehicles 2- Results reflect superior performance of the presented model's predictions compared with the initial model.

Table 1 Summary of Relevant Studies in Crash Analysis (Continued)

Study	Location	Purpose	Methodology	Data set	Major Findings
Anastasopoulos and Mannering (2009)	Indiana	Crash frequency estimation	Negative Binomial Model	Vehicle accident data from interstate highways in Indiana from 1995 to 1999.	1- Potential of random-parameters count models in providing a better perspective of influential factors. 2- Variety of factors found to significantly influence the number of crashes occurrence (e.g. effects of friction, road segment length, AADT)
Blower et al. (2010)	Nation wide	Study the role of mechanical deficits on crash probability	Test Statistic, Binary Logistic Regression	LTCCS	1- Truck conditions in LTCCS not represented properly. 2- The importance of identifying truck systems defects on crash reduction.
Hickman et al. (2010)	Nation wide	Risk of cellphone distractions and related tasks on crash, near-crash, crash-relevant conflicts.	Descriptive Statistics	Two naturalistic data including CMVs and OBSM[9] Systems, for commercial trucks (3-axle and tractor trailer/tanker) and buses, include 13,431 and 13,306 observation respectively.	Talking/listening on a cell phone while driving did not impact significantly the odds of involvement in a safety-critical event, texting, dialing, reaching objects showed significant impact.
Zhu and Srinivasan (2011a)	Nation wide	Injury severity estimation (truck drivers vs. car drivers)	Ordered-probit model	LTCCS and PAR[10]	Higher severity reported for driver distraction, alcohol use, and emotional factors and effects of missing data
Lemp et al. (2011)	Nation wide	Study of contributing factors and Injury severity estimation (considering LCVs)	Heteroskedastic Ordered Probit (HOP) and Logit Models	LTCCS and GES micro data from April 2001 to December 2003 [which provides crash data for all vehicle involved crash types and estimates of non-injury and injury crash outcomes for each truck category], VIUS[11] from 2002 [for VMT], crash datasets.	Different characteristics of Long-combination vehicles (LCVs) in terms of crash risk and severity injury. (i.e. number of trailers increase the risk of fatalities and sever injuries, however, the risk decreases by truck length and gross vehicle weight rating (GVWR)).
Zhu and Srinivasan (2011b)	Nation wide	Injury severity estimation at Occupant-level (i.e. drivers, occupants involved in large truck crash)	Exploratory Analysis and Heteroskedastic Ordered-probit Model	LTCCS	Effects of person, driver, vehicle, and crash-characteristics on the injury severities of persons involved in large-truck crashes. (e.g illegal drugs, car drivers' familiarity with the vehicle and the roadway, the use of seat-belts (both for car-drivers and car-passengers in the event of crashes with large trucks) were recognized as the strong predictors of injury severity)

Table 1 Summary of Relevant Studies in Crash Analysis (Continued)

Study	Location	Purpose	Methodology	data set	Major Findings
Chen and Chen (2011)	Illinois	Injury severity estimation (Single-Vehicle and Multi-Vehicle Crashes on Rural Roads)	Mixed Logit Model	HSIS data for Illinois, from 1991-2000 included 19,741 truck-involved accidents.	Distinct trends of single- and multi-vehicle accidents involving trucks. (i.e. some variables have significant impact either on single or multi vehicle accidents (16 variables recognized) or both) Recognition of lower or higher possibilities of injury/fatal accidents conditions for single and multi-vehicle separately. (e.g. old driver (higher for MV accidents), light traffic (lower for both SV and MV accidents), low truck percentage (lower for MV accidents), etc.)
Kononen et al. (2011)	Nationwide	Injury severity estimation	Multivariate Logistic Regression Model	NASS-CDS[12] data for 1999–2008 in which 14,673 motor vehicles were investigated.	The most important predictors in serious injuries (i.e. seat belt use and crash direction)
Kashani and Mohaymany (2011)	Iran	Injury severity estimation (Rural Roads)	Classification and Regression Tree (CART) Model	Traffic Secretary of the Iran Traffic Police for 2006-2008 include 7,241 vehicle crash records.	The most important factors affecting the injury severity (i.e. Improper overtaking and not using a seatbelt)
Anastasopoulos and Mannering (2011)	Indiana	Injury severity estimation	Random Parameters Mixed Logit Model	Crash data on rural interstate highways from Indiana DOT, Indiana State Patrol database, and Purdue's Center for Road Safety over 1995-1999 included 5,795 crashes.	Reasonable level of accuracy provided by random parameter models
Jermakian (2012)	Nationwide	Examining crash avoidance technologies (e.g. side view assist systems, forward collision warning systems, lane departure warning systems, vehicle stability control systems)	Coding Crash Method and Descriptive Statistics	NASS-GES[13] and the FARS from 2004-2008, 57,000 truck crashes were sampled each year and after being weighted, the yearly sample was representative of about 6 million crashes nationwide.	Huge prevention potential of truck-based crash avoidance systems and among them side view assist system provide highest potential prevention from large truck crashes.

Table 1 Summary of Relevant Studies in Crash Analysis (Continued)

Study	Location	Purpose	Methodology	Data set	Major Findings
Anastasopoulos et al. (2012)	Indiana	Crash rate estimation (Accidents per 100-million VMT)	Random Parameters Tobit Regression Model (Descriptive statistics of selected variables was also done)	1- Motor vehicle accident data on urban interstate roads in Indiana (1999 to 2007). 2- Indiana DOT pavement databases 3- Indiana State Patrol accident-data files for number of accidents happened in each segment over 9 years.	1- Better performance of random-parameters Tobit model compared to fixed parameters. 2- Significant impacts of factors related to pavement condition and quality, geometric factors, traffic situations on accident rate.
Xie et al. (2012)	Florida	Injury severity estimation	Latent Class Logit (LCL) Model	Florida Traffic Crash Records Database for five years including 4285 vehicle crash records in Florida.	1- Key injury severity impact factors (i.e. driver age, seat belt usage, points of impact, lighting condition etc.) of rural single-vehicle crashes. 2- better prediction performance of latent class logit (LCL) model compare to multinomial logit (MNL) model.
Park and Pierce (2013)	Nationwide	large truck crash trends analysis considering crash distribution, frequency and crash rate index (CRI)	Descriptive Statistics	MCMIS[14] crash data from 2000-2010 (25000-40000 observations each year in Nation's roadways)	Medium Duty (10,001 to 26,000 lbs) and Heavy Duty (26,001+ lbs) trucks showed distinct crash trends. Non-interstate carrier crashes exhibited a steep increase in CRI compared to interstate crashes, particularly among medium duty truck crashes. Adverse weather conditions showed an equalizing effect, reducing the differences between medium and heavy duty CRIs.
Islam et al. (2014)	Nationwide	Injury severity estimation	Fixed- and Random-Parameters Ordered-Probit Model	NASS-GES crash database from 2005 to 2008 include 8,291 crash observations.	Relationship between injury severity outcomes and number of contributing factors such as drinking-driving, seatbelt use, vehicle type, collision type, contributing circumstance and driver/vehicle action, number of vehicles involved in the accident and accident location.
Chang and Chien. (2013)	Taiwan	Injury severity estimation (truck-involved accidents)	Non-Parametric Classification and Regression Tree (CART) Model	National Traffic Accident Database for Taiwan from 2005 to 2006 including 705 reported truck-involved and 1701 vehicle involved accidents.	key determinants of injury severity outcomes for truck accidents (drinking-driving, seatbelt use, vehicle type, collision type, contributing circumstance and driver/vehicle action, number of vehicles involved in the accident and accident location)

Table 1 Summary of Relevant Studies in Crash Analysis (Continued)

Study	Location	Purpose	Methodology	Data Set	Major Findings
Venkataraman et al. (2013)	Washington State	Crash occurrence based on different aggregation methods (vehicle involvement, collision type, severity, geographic location and operation type)	Random Parameter Negative Binomial (RPNB) Model	10,377 observations from 1999 to 2007, from continuous panel of crash histories on interstates in Washington State	1- Better performance of random parameter negative binomial (RPNB). 2- Different impacts of parameters on crash frequencies (i.e. lighting type, road curvature, and traffic volume had different affects). Internal interaction effects b/w different situation of considered variables (e.g. for lighting type, Median lighting or right-side lighting, both-sides lighting interaction on crash frequency). 3- Complexity of effect of traffic volume
Toma et al. (2014)	Nationwide		Descriptive Statistics (e.g. Tabulation Heavy Truck Crash Contributing and Causal Factors, Critical Reason Statistics,)	1- Five year(2004-2008) crash data from GES (to quantify the societal cost and describe the driving environment, driver characteristics, and crash contributing factors) 2- LTCCS database (to describe crash causal factors)	Detailed descriptions for crash scenario framework in order to propose countermeasure profile based on V2V communications (e.g. A set of five rear-end, pre-crash scenarios accounted for the most harm at about 24 percent of the societal costs of all 22 applicable V2V pre-crash scenarios.)
Islam et al. (2014)	Alabama	Injury severity estimation (Single and multi large truck crashes-urban and rural)	Random Parameter Logit Model	Police reported crash database from 2010 to 2012 for Alabama including 8171 observations.	Difference in factors impacts from single and multi-vehicle at-fault accidents on different road types. (e.g. 7 variables including truck model, single unit truck, no traffic control, off peak, Shopping/business, etc., are significant only in the rural SV model but not in any other model)
Dong et al. (2014)	Tennessee	Crash frequency estimation by vehicle type (urban signalized intersections)	Multivariate Regression and Poisson, Univariate and Multivariate Poisson-lognormal	TRIMS[17] from 2005 to 2009 include a total of 6790 crashes.	1- Critical safety parameters (i.e. Traffic volume, truck percentage, lighting condition, and intersection angle etc.) and different risk factors of different vehicle involvements. 2- Better exploring of significant factors and predicting crash frequencies by MVPLN model.
Olson et al. (2009)	Nationwide	Crash frequency/rate estimation (Electronic Hours-of-Service Recorders (EHSR), Non-EHSR)	Count-Based Poisson Regression Model	FMCSA-SMS's[18] data set was applied for the years 2008-2012 including a total of 82,943 crashes, 970 HOS violations, and 224,034 truck-years that drove a total of 15.6 billion miles.	Reliable safety benefits of EHSR equipment in trucks (i.e. Trucks with EHSRs had a significant 45 percent ($p < 0.001$) lower total crash rate, a 38 percent ($p < 0.001$) lower preventable crash rate, and a 55 percent ($p > 0.001$) lower USDOT-recordable crash rate than non-EHSR trucks)

Table 1 Summary of Relevant Studies in Crash Analysis (Continued)

Study	Location	Purpose	Methodology	Data set	Major Findings
Schaudt et al. (2014)	Nationwide	Examining effects of new technology	Performance Evaluation Method	Naturalistic data for a fleet with 20 CMVs over a period of 11 months, resulting in 722,639 of analyzed data.	Safety benefits of BSW system
Dong et al. (2015)	Tennessee	Crash frequency estimation by car-truck crashes and truck-only crashes.	Zero-Inflated Negative Binomial (ZINB) Model	Tennessee crash record information system from 2004 to 2007 including 1787 truck involved crashes.	Better performance of ZINB models together with identification of significant truck-involved crashes variables
Knipling (2015)	Nationwide	LTCC contributing factors study	Descriptive Statistics	NMVCCS[19] data collected between 2005 and 2007 involving 5,471 crashes.	Contributing factors relating to driver impairment or stress noted more frequently for car drivers. Trucks were more likely to be assigned vehicle-related CRs and associated factors.
Anastasopoulos (2016)	Indiana	Injury-severity and frequency estimation with rate analysis	Random Parameters Multivariate Tobit and Zero-Inflated Count Data Models	Indiana State Patrol accident-data files and Purdue's Center for Road Safety, over a five-year period between 2005 and 2009 include 6,555 accidents.	Advantages of applied crash prediction model and model accuracy
Linchao and Fratrović (2016)	Nationwide	Study of contributing factors to Vehicle damage estimation considering different location types	Generalized Ordered Logit Model	TIFA[20] 2010 database including 3699 crashes.	Most effective factors categorized by locations (e.g. curve, dark - not lighted, snow, work zone, two-way with left-turn lane, front-to-rear, turning left, braking and speed limit 26.822 m/s, significantly affect disabling damage in both areas)
Burks et al. (2016)	Nationwide	Study of contributing factors	Retrospective Analysis of Cohorts	HSIS data set for ten years (1991-2000) including 19,741 truck-involved accidents.	Multi-vehicle accidents differ from single-vehicle crashes in terms of general trends and influential variables.

Table 1 Summary of Relevant Studies in Crash Analysis (Continued)

Study	Location	Purpose	Methodology	Data set	Major Findings
Bin Islam and Hernandez, (2016)	Nationwide	Fatality rate (fatalities per million truck-miles traveled or per ton-miles of freight)	Random Parameters Tobit Regression Model	FARS data from 2005 to 2008. Three years of ton-miles of freight data from the BTS special tabulation, and truck-miles traveled data from FHWA travel reports.	Better performance of random parameters Tobit regression model compared to fixed parameter version. Type of collision, time of day and month of year, with some location and weather variables, road geometry drivers and passenger attributes found as statistically significant variables.
Vachal (2016)	Nationwide	Injury severity estimation	Logistic Regression Model	Police reports between 2009 and 2014 including 3,811 crashes, with 82% multiple vehicle.	Alcohol or drug involvement, failure to use proper restraint, collision impact type, and rollover event found as significant predictors. Passenger vehicles more likely for severe injuries compared to trucks
FMCSA (2016)	Nationwide	Alcohol and Drugs consumption rates (by violation and drivers involved in fatal crashes)	Descriptive Statistics	NHTSA includes, 3838, 4027, and 4138 large truck and bus drivers were involved in fatal crashes in 2011, 2012, and 2013 respectively.	Positive trends for drug and alcohol usage rate for both pre-employment screening and post-crash investigation
FMCSA (2015)	Nationwide	Study of contributing factors (asleep and fatigued) based on fatal crashes involving large trucks)	Data Visualization (bar graph and pie chart)	1- FARS in 2013, including 59 fatal crashes. 2- FMCSA's Driver Information Resource (DIR) database (to examine their driving history for a 13-year period).	1- Examination of number of vehicles involved and light condition for crash characteristics for large truck drivers coded as asleep or fatigued. 2- Frequent crash-causing violations (i.e. Log violations, hours-of-service violations, or reporting violations)
Blanco et al. (2011)	North Carolina-Virginia	Study of contributing factors related to: restart period, Sleep pattern, vehicle interactions by type of maneuver, and functional countermeasures	Descriptive Statistics	On-road 4-week period Naturalistic data collected in 2007. 14,500 driving hours during 2,200 driving shifts from nine trucks from four different fleet company were involved.	1- First day after restart being the most critical day in terms of crash probability. 2- 8.9 percent of CMV drivers found drowsy or fatigued during a safety-critical event.

2.6. Data Sources for Large Truck Crash Study

Access to reliable data sources is vital in crash analysis. This section provides a review of major national data sources that have been applied in truck crash analysis. It should be noted that in these data sources, large trucks are defined as those with gross vehicle weight rating (GVWR) of more than 10,000 lb.

2.6.1. Large Truck Crash Causation Study (LTCCS) Database

The LTCCS is a mutual effort by the FMCSA and the National Highway Traffic Safety Administration (NHTSA), to collect data on large-truck crashes (Starnes, 2006). The study was conducted at 24 data collection sites located in 17 States. Data were collected by trained researchers and Commercial Vehicle Safety Alliance (CVSA)-trained truck inspectors through visual site inspections and interviews. A total of 963 large truck crashes including 1,123 trucks and 932 other vehicles occurred between April 2001 and December 2003 were obtained. Each crash in the database involved one large truck and at least one evident injury. All factors describing the driver, the vehicle, and environment conditions were collected, resulting in 43 data sets with more than 1000 data variables. The LTCCS data were assessed based on four different conditions; pre-crash movement, critical event, critical reason, and associated factors.

During the three-year study period, it was estimated by FMCSA that there were around 141,000 injury rashes in which at least one large truck was involved. Applying sampling weight method and based on relative probabilities, LTCCS observations were then expanded for national large truck crash estimation.

2.6.2. Fatality Analysis Reporting System (FARS)

The FARS consists of data on all motor vehicle fatal crashes occurred on public roadways in the United States and it is collected and maintained by The National Center for Statistics and Analysis within NHTSA (NHTSA, 2019a). It is a nationwide census of fatal injuries suffered in motor vehicle traffic crashes which provides public access to fatality data through its web interface. FARS data are collected within each state from different sources including: police accident reports, death certificates, medical examiner reports, hospital reports, emergency medical services reports, state vehicle registration files, state driver licensing files, and state highway department data etc. A total of 100 factors including crash characteristics, environmental conditions, vehicle specifications (e.g., type, make/model, model year, cargo body for trucks), driver characteristics (e.g., age, gender, restraint use, injury severity) and distractions, driver's vision characteristics, etc. were coded in the database.

2.6.3. Trucks Involved in Fatal Accidents (TIFA)

The TIFA database was developed by the University of Michigan Transportation Research Institute (UMTRI) with support from the FMCSA (NHTSA, 2019b). TIFA combines data from different sources, including accident data from the Federal Highway Administration Bureau of Motor Carrier Safety (BMCS), information of vehicle, accident, and occupant records from FARS, information about the physical attributes and operating authority of the truck from the TIFA survey plus results of telephone surveys. These combination of different data sources produced a very detailed account of fatal truck crashes in terms of crash variables, vehicle variables, driver variables, occupant variables and survey variables. TIFA dataset can be downloaded from the NHTSA official website.

2.6.4. National Automotive Sampling System (NASS)

The NASS maintained by the NHTSA is aimed to collect nationally representative data on fatal and nonfatal motor vehicle traffic crashes in order to evaluate and develop safety standards and propose safety countermeasures (NHTSA, 2019c). The NASS has two major operating components. The first is the Crashworthiness Data System (CDS), however, as it mainly focuses on light vehicles, it is not further discussed here. The second is the General Estimates System (GES) which contains the general purpose crash data of motor vehicle crashes in the United States. Crashes involved at least one vehicle with property damage, injury, or death reported by police were classified in GES database. Weekly investigation around 400 police jurisdictions in 60 different sample units across the U.S. results a sample of approximately 50,000 police accident reports each year, by which GES data were coded entirely. That makes the GES database a source of comprehensive national-level estimates of crashes.

2.6.5. Highway Safety Information System (HSIS)

The HSIS is funded by the FHWA as a cooperative endeavor, with data voluntarily provided to FHWA by the participating States (FHWA, 2019a). HSIS provides a multistate database comprising crash, roadway inventory, and traffic volume data for a select group of States. Various crash-related variables are classified as: time characteristics (date, day of week, hour of occurrence, etc.), environment characteristics (surface road condition, light and weather condition), accident-related information (collision type, severity, number of vehicles involved, etc.) vehicle information (type, year, damage area, etc.), driver information (age , sex, sobriety, alcohol percentage, etc.), occupant information (age, sex, position in vehicle, safety equipment, etc.), roadway characteristics (milepost, traffic control devices, etc.), pedestrian and bicycle information. Only police-reported crash data on the State-maintained highway system on a case-by-case basis is available in the HSIS database for different years and different States. Data are available by submitting request through the highway safety information system from the FHWA official website.

2.6.6. Data on Vehicle-Miles Traveled (VMT)

Crash risk factor estimation is correlated with the distance driven. The FHWA provides Table VM-1 which includes VMT statistics by year, vehicle and roadway types (FHWA, 2015), which is recognized as the main source of VMT. The tabulations are aggregated at state level. Different road types including interstate/arterial rural, interstate urban etc., are considered for different vehicle types, however, trucks are classified as a single unit or as a combination of multiple trailers on tractor trucks. Table VM-1 is open to public access through the FHWA official website.

2.7. Crash Contributing Factors

Understanding the nature of crash contributing factors and how they impact crash occurrence (or severity) is critical in crash analysis. This section provides a brief summary of the findings in the literature in terms of the contributing factors. Both large truck studies and general crash studies were included.

The types of explanatory variables being analyzed highly depends on the level of analysis, as discussed in section 2. Segment-level analysis is only capable of exploring aggregate variables such as roadway characteristics, geometric design, weather conditions, traffic flow, and temporal/spatial attributes (seasonal factors, land-use, etc.). Since segment is the unit of analysis, variables of higher resolution such as crash attributes, or driver/vehicle characteristics cannot be directly inserted into the models. Such disaggregate variables, on the other hand, are well explored using crash-level data, where individual crashes (or in more details, individual people/vehicles involved in each crash) are the smallest units of analysis. With this in mind, general findings in terms of variable impacts could be summarized in the following subsections.

A quick review of literature on general crash studies highlights the following five major categories of factors that may influence the occurrence or severity of crashes.

2.7.1. Roadway Characteristics

Roadway characteristics include a variety of factors ranging from geometric design to lighting conditions, road type, terrain, pavement attributes, land use, etc.

- Geometric design: includes median type, median width, shoulder width, number of grade breaks, information on horizontal and vertical curves, number of lanes, number of interchanges, etc.
- Lighting conditions: may include lighting type (e.g. median lighting, right-side, left-side or both-side lighting), or the proportion of any type of lighting within the segment.
- Road type: includes different types of facilities such as arterial, collector, freeway, on/off ramp, etc.
- Terrain: could be mountainous, level, etc.
- Pavement attributes: mainly includes rut depth, friction coefficient, international roughness index (IRI), and pavement condition rating.
- Land use: a simple urban vs. rural classification has been widely considered in the literature.

The FMCSA published a brief report in 2014 focusing on work zone fatal crashes involving large trucks (FMCSA, 2014b). Using FARS data from 2008 to 2012, researchers developed frequency tables for fatal large-truck crashes based on several criteria including crash type, crash location, truck weight, traffic way description, pre-crash event, manner of collision, crash size (number of vehicles involved), and functionality of the trucks involved. They concluded that large truck involvement in fatal crashes significantly increased in work zone areas. In addition, the majority of work zone incidents involving large trucks included at least three vehicles and are mostly rear-ended.

Duncan et al. (1998) showed that wet/snowy road surface will decrease car-truck crash severities, while the combination of steep grades and wet surface tends to increase severity. As expected, darkness leads to higher crash severities. Hakkanen and Summala (2001) reported higher probability of crash responsibility on 4 lane roadways.

Linchao and Fratrovic (2016) highlighted the differences of roadway condition impacts in rural and urban areas. Accordingly, curves were more likely to cause severe disabling vehicle damage in rural areas compared to urban land use, probably because road alignments were more complex in rural areas and drivers are less familiar with sudden changes in road alignment. Two-way roads increased vehicle damage probability in both rural and urban areas, however presence of a physical median increased safety, as expected. Results also showed that compared to level-grade, all other grades including hillcrest, uphill and downhill increased the probability of disabling crashes in rural areas. In addition, four-lane roadways had the highest contribution to disabling and minor crashes in rural areas while two-lane roadways showed higher probabilities of functional and no-damage conditions in urban land use.

In a comparison between highway and interstate truck crashes, Zhu and Srinivasan (2011a) inferred that highway intersections highly increased crash severity compared to other locations. A study by Lemp et al. (2011) showed that rural non-freeway roads are highly likely for incapacitating injury/fatal crashes. In terms of roadway geometry, it was concluded that the probability of incapacitating injuries increases by around 18% on crest curves while sag curves increase non-incapacitating injuries by 35%. In addition, dark-lighted and foggy conditions increased both crash-level and vehicle-level severity.

In a study in California, Khorashadi et al. (2005) confirmed that highways in urban areas and highway intersections in rural areas were more prone toward severe crash outcomes rather than vehicle-damage only conditions. In addition, presence of a physical barrier significantly decreased fatal crashes both in urban and rural areas. Low lighting conditions would favor more severe crashes (compared to PDO) in rural areas, while lighting has no significant contribution to urban crashes.

As part of their truck crash and rollover analysis, Khattak et al. (2002) showed that a slippery surface reduced the probability of roll-over and consequent injury severity, perhaps because drivers tend to be more cautious on wet surfaces. On the contrary, roadway grade and presence of curves tended to increase rollover probability.

Daniel et al. (2002) reported positive impacts of segment length, number of lanes, signal density, horizontal length of curve, and crest curve grade on truck crash frequencies at intersections. On the other hand, pavement width, interchange density, horizontal degree of curve, and length of vertical curve had negative impacts on crash occurrence.

According to Dong et al. (2014), lane width on both major and minor roadways increased car-truck and truck-truck crash frequencies at signalized intersections. Median width and presence of left-turn lanes were other contributing factors that increased the number of car-truck crashes. As expected, number of intersection crashes tended to decrease as the lighting condition improves. In a later research work, (Dong et al., 2014) concluded that segment length, degree of horizontal curvature, mountainous and rolling terrain, as well as industrial and commercial land use increase both car-truck and truck-truck crash frequencies. On the contrary, presence of raised median, lane width, and lighted conditions reduce both frequencies.

(Bin Islam and Hernandez, 2016)showed that the presence of median barrier reduced fatality rates while ambient lighting conditions and wet surfaces reflected positive impacts on fatality rates.

Contributions of roadway factors in general crash analysis have also been well documented in the literature (Anastasopoulos et al. 2008; Ma et al. 2008; Anastasopoulos and Mannering 2009; 2011; Venkataraman et al. 2011; Venkataraman et al., 2013; Xie et al. 2012; Anastasopoulos 2016).

Results from Anastasopoulos et al. (2008) showed that the presence of median barriers, wide medians, wide shoulders, and the presence of rumble strips would decrease the probability of positive crash rates in the analysis segment. Interestingly, the number of bridges and vertical curves also had negative impacts on crash rates. Authors inferred that the presence of bridges and vertical curves probably increased drivers' awareness, leading to lower number of crashes. On the contrary, the presence and number of ramps in the driving direction increased crash rates, probably due to complicated weaving trajectories. In terms of pavement characteristics, high quality indices including high-friction, smooth surface, as well as good/excellent rutting indicators would reduce crash rates. Similar results were reported later on by Anastasopoulos and Mannering (2009).

Ma et al. (2008) inferred that roadway characteristics could have multiple impacts on different severity types. Accordingly, increase in vertical curve lengths was likely to increase the percentage of fatal crashes but reducing other injury severities. In terms of horizontal curves, an increase in the length reduced fatal and non-disabling crashes but increased disabling incidents. Surface width showed a negative impact on all crash severities except for PDOs.

According to Schneider et al. (2009), both length and degree of curvature increased crash frequencies on horizontal curves.

Venkataraman et al. (2011) showed that the number of lanes had a positive effect on crash frequencies, with four-lane roads showing the highest impact (171% higher crash frequencies). They also inferred that wider shoulder (either right or left) decreased crash frequencies by at least 18 to 25%. In terms of lighting conditions, median continuous lighting system was associated with the highest crash frequencies, while point lighting system showed the lowest positive impact on the model. Unlike previous studies, results indicated that number of curves within a segment increased crash frequency. In a later study, researchers inferred that segment length as well as for-lane segment proportion tends to increase the frequency of incapacitating/fatal injury while fatal crash frequency decreases along with no lighting segment proportion, number of horizontal curves and on urban segments (Venkataraman et al. 2011).

Anastasopoulos and Mannering (2011) showed that crash severity would increase in parallel with segment length and presence of vertical curves. Anastasopoulos et al. (2012) found that vertical grade, junction locations, presence of median barrier, and low pavement quality increased crash frequency while the presence of horizontal curves reduced number crashes.

According to Xie et al. (2012), crashes on divided roadways were more likely to result in no injuries (compared to other injury severity types) while crashes on interstate roadways were the most probable for fatality. In terms of lighting, dark conditions were reported as highly prone toward no injury outcomes, probably because drivers tended to be more cautious in low lighting conditions. Presence of median highly decreased probability of incapacitating injuries.

Results of Islam and Hernandez (2013) showed that curved segments were more likely to result in fatal crashes while dark conditions tend to decrease crash severity.

2.7.2. Traffic Attributes

In view of large truck crashes, a positive impact of AADT had been reported on crash frequencies (Dong et al. 2014, 2015). In disaggregate studies, more complexities were observed. According to Duncan et al. (1998), injury severity in rear-end car-truck crashes decreases with traffic volume and increases with posted speed limit. (Daniel et al., 2002) reported positive AADT impacts on truck crash frequency at intersections, followed by a negative impact of truck percentage in the traffic stream. A negative impact of posted speed limited was also inferred. Chen and Chen showed that light traffic (AADT < 2k) was likely to increase incapacitating injury probability both in single-vehicle and multi-vehicle cases. Schneider et al. (2009) inferred that both truck and passenger traffic volumes increase crash frequency. Khorashadi et al. (2005) used travel time as an alternative traffic index in their study and showed that higher travel times would lead to higher probability of injury type 2 (complaint of pain) both in peak and off-peak hours, while they tended to decrease other injury probabilities. Lemp et al. (2011) reported positive impacts of posted speed limit on crash severity. Although posted speed limit was considered as a potential factor by Chang and Chien (2013), the factor did not turn out to be significant in their study.

Average Annual Daily Traffic (AADT) and posted speed limit were the two major factors explored in the general crash literature. Percentages of different vehicle types in the traffic stream have also been incorporated in some studies. In general, early studies with traditional modeling techniques agreed on a negative impact of traffic volume on crash occurrence (Zhou and Sisiopiku 1997; Dickerson et al. 2000; Qi et al. 2007; Anastasopoulos et al., 2008, 2012). However, considering heterogeneity in traffic volume resulted in a positive impact of the AADT on crash frequencies (Anastasopoulos and Mannering 2009; Venkataraman et al. 2011). It is also inferred that percentage of trucks in traffic stream decreased crash occurrence (Anastasopoulos et al. 2008; Anastasopoulos and Mannering 2009), probably because truck drivers were more experienced in hazardous situations or because passenger car drivers perform more carefully in presence of trucks. Mixed impacts of traffic characteristics on different severity types were reported in other studies (Anastasopoulos and Mannering 2011; Xie et al. 2012; Venkataraman et al. 2013).

Application of real-time traffic data is only limited to general crash studies, where traffic patterns right before crash occurrence will be compared to matched-case non-crash conditions. The variables used in the literature include average speed and occupancies on upstream and downstream loop detectors as well as volume and speed standard deviations between lanes (Abdel-Aty et al. 2008; Ahmed et al. 2012; Yu and Abdel-Aty, 2013a, 2013b, 2014).

2.7.3. Driver Characteristics

Analysis of driver characteristics were limited to disaggregate analysis. This analysis may include a variety of attributes such as driving background, socio-economic and demographics, incident liability, asleep/fatigued situation, and seat belt usage (Chen and Chen 2011; Anastasopoulos and Mannering 2011; Xie et al. 2012; Chang and Chien, 2013; Islam et al. 2014).

Hakkanen and Summala (2001) showed that younger drivers (below 50), driving for more than an hour, as well as driver's illness had positive impacts on crash liability. On the other hand, low truck driving experience, number of traffic incidents in the past 5 years, and certain sleeping durations before the road trip (less than 6 hours or 7-8 hours) lowered the probability of crash liability.

Khattak et al. (2002) reported alcohol abuse as a significant contributing factor to both rollover events and crash severity. According to Khorashadi et al. (2005), males were more likely to be involved in PDO crashes while females were more prone toward injury type 2 (complaint of pain). Duncan et al. (1998) inferred that female and drunk drivers are more likely to be involved in severe crashes. On the other hand, presence of child restraint (e.g. seat belt) and younger drivers (age < 16) tends to lower crash severity.

McKnight and Bahouth (2009) summarized major rollover causing factors on the drivers' side as lack of speed adjustments, inattention, and control errors.

Drivers' distraction was detailed studied for Commercial Motor Vehicles (CMV) in Olson et al. (2009). Results revealed that 71 percent of drivers involved in crash, 46 percent in near-crash situation, and 60 percent in safety-critical event, were engaged in non-driving related tasks.

Hickman et al. (2010) studied the probabilities of cellular telephone distractions used by commercial trucks and buses drivers. Crash, near-crash and crash-relevant conditions were taken into account based on definition in Olson et al. (2009). Results surprisingly showed the non-significant impact of talking or listening on a cell phone while driving on involvement in critical safety events, although, other tasks like texting, dialing were found having significant impacts.

Zhu and Srinivasan (2011a) inferred that vision problem and alcohol abuse increases truck crash severity while fatigue and familiarity with the roadway reduce crash severity. Presence of younger drivers (< 45) also tends to decrease crash severity.

Chen and Chen (2011) showed that age categories could have different impacts on crash severity. Accordingly, individuals 50 years or older decreased fatal/incapacitating injury severity in multi-vehicle accidents, while their impact was totally opposite in single-vehicle crashes. This mixed effect could stem from the fact that on one hand individuals tended to become more cautious as they get older and on the other hand, older drivers probably required longer reaction times. When it comes to young drivers (25 or older), they significantly decreased fatal single vehicle crashes by 21.5%. In terms of gender, female showed higher probabilities of incapacitating injury/fatal crashes. Situations such as drivers being trapped, not using a seat-belt, or being fatigued/asleep decreased the probability of PDO crashes leading to significant increases in more serious crash outcomes. Similar inferences were made by Anastasopoulos and Mannering (2011).

According to Islam and Hernandez (2013), male and younger drivers are more likely to be involved in PDO crashes compared to other crash severities.

Chang and Chien (2013) explored three major driver attributes: gender, seat-belt usage, and sobriety condition. Accordingly, combination of a drunk driver and not using seatbelt, the crash was most likely to be fatal.

Islam et al. (2014) incorporated impacts of age, gender, fatigue, ethnicity, and alcohol influence. Various inferences were made. For instance, Male drivers significantly increased probability of major severities in multi-vehicle crashes; Fatigue was a significant factor in severe injuries in rural area, but with no significance in urban areas. Complex patterns were observed for the impact of ethnicity.

A brief report published by the FMCSA in 2016 investigated fatal crashes involving drivers recorded as asleep or fatigued (FMCSA, 2016a). 59 fatal crashes were extracted from the FARS data in 2013, where the drivers were coded as asleep or fatigued. The Driver Information Resource (DIR) database from the FMCSA was then used to inspect the driving history of the drivers involved in the crashes. Using data visualization techniques, the top 10 prior violations in roadside inspections for those truck drivers were identified. The report indicated that log violations, hour-of-service and reporting violations were the most frequent violations for truck drivers recorded as asleep or fatigued during a 13-year study period (2000-2013).

In another report in 2016, the FMCSA explored the role of drug/alcohol abuse in large truck and bus crashes (FMCSA, 2016b). This study was mainly designed to provide guidelines for the required drug/alcohol test rates described in commercial motor vehicle license regulations. Results showed that drug and alcohol abuse were responsible for 19 percent and 4 percent of the fatal crashes, respectively.

Application of driver/passenger attributes was also reported in general crash analysis. According to Xie et al. (2012) Hispanic and white drivers were less likely to get involved in fatal crashes. Gender was a significant contributor in PDO crashes, where males were more likely to get involved in no injury crashes. In addition, drivers under influence were more prone towards PDO and fatal crashes. Also, wearing a seat belt significantly decreased the probability of severe injuries.

Similarly, Vachal (2016) inferred that alcohol/drug involvement as well as not using seat belt significantly increase injury severity.

2.7.4. Vehicle Characteristics

Any specific vehicle attribute could be incorporated into disaggregate crash analysis, including vehicle model, type, occupancy, as well as certain functional defects.

Park and Pierce (2013) investigated large truck crash trends considering crash distribution, frequency and crash rate index (CRI). Data for this research came from the FMCSA Motor Carrier Management Information System (MCMIS) crash dataset. Data were collected for a ten-year period from 2000 to 2010 including 25,000-40,000 observations each year for 3,147 counties over the country. Considering two types of trucks, medium duty (10,001-26000 lb) and heavy duty (26,000 lb and greater) trucks, fatal and injury only records were compared and associated contributing factors were explored. Several interesting distinctions between Medium Duty and Heavy Duty truck crash trends were recognized. As an example of findings, heavy duty truck followed a decreasing trend of -24.6% during the study period, while, medium duty trucks vice versa had increase of 38.3% in the same time period. Non-interstate carrier crashes exhibited a steep increase in CRI compared to interstate crashes, particularly among medium duty truck crashes. Adverse weather conditions showed an equalizing effect, reducing the differences between medium and heavy duty CRIs.

Duncan et al. (1998) showed that crashes in which defective brakes are present lead to lower severity outcomes. According to Khorashadi et al. (2005), tractors with/without trailers, and vehicle models between 1981 and 1988 would significantly increase the probability of fatal/severe crashes, while foreign-made vehicles are less likely to result in severe injury outcomes.

In a detailed analysis of vehicle defects' inspection, Blower et al. (2010) showed that trucks with an out-of-service brake condition were more likely to cause a crash by 1.8 times. Similarly, hours-of-service and log out-of-service violations increased crash odds by 2.0 and 2.2 times, respectively. In particular, it was inferred that the odds of Brake-Relevant (BR) crashes increases by 1.8 times in presence of break service violations.

Chen and Chen (2011) showed that truck type, freight type, and system defects were significant contributors to single/multi vehicle crash severities. Accordingly, single unit trucks (compared to other truck types) had 20.4% higher probability to result in non-incapacitating injuries in single-vehicle situations, as well as 39.8% higher probability to end in a fatal outcome. Among different types of system defects, both brakes and tire defects reflected significant impacts on the model, but in different directions. Tire defects mainly increased incapacitating injury/fatal crashes while brake defects were most likely to encourage non-incapacitating injuries. Among different types of vehicle characteristics, carrying hazardous materials had the highest encouraging effect on fatal outcomes, increasing the probability by almost 48%.

Two types of vehicle characteristics were analyzed by Islam et al. (2014): truck weight and truck type. Results showed that depending on land use (rural/urban) and crash type (single/multi vehicle), truck characteristics could have different impacts on crash severity. Complex impacts of vehicle characteristics had been confirmed by several other studies (Chang and Chien 2013).

Khattak et al. (2002) reported that defective brakes were a significant contributor to overall truck crash injury severity model. Also, single-unit trucks were less likely to be involved with serious injuries in a rollover incident. In their crash-level analysis, Lemp et al. (2011) showed that fatalities and severe injuries increased by number of truck trailers but decreased by truck length and weighting rate (GVWR). Islam and Hernandez (2013) showed that presence of a trailing unit decreases crash severity.

Vehicle type was probably the most popular vehicle-related variable in general crash studies. Kononen et al. (2011) used vehicle type as a contributing factor in his study. Taking cars as the base category, results showed that vans and SUVs were less likely to result in sever crashes while pickups reflected higher risk of a severe injury. In a similar analysis, Xie et al. (2012) inferred that vans were less likely to be involved in incapacitating or fatal injuries, compared to autos. Similar comparison was conducted by Zhu and Srinivasan (2011a; 2011b) in view of truck-car crash analysis. Accordingly, researchers inferred that vehicle type was only significant in car-truck crashes and only on injury severities of car-passengers. In addition, medium-size autos were more likely to be involved in a severe injury compared to vans or utility vehicles.

2.7.5. Crash Attributes

Mainly extracted from Police Accident Reports (PAR), this class contains several informative details of crash conditions, including:

- Crash type: based on number vehicles being involved, point of impact, etc.
- Major cause as reflected in police reports
- Pre-crash vehicle movements
- Exact location (median, shoulder, turn lane, work zone, etc.)
- Time-of-day and weather conditions (e.g. daylight, nighttime, rain, fog, etc.)

McCartt et al. (2004) showed that there was a correlation between crash type and crash location. In particular, ramps were highly associated with run-off-road and rear-end crashes while ramp margins showed higher probabilities of sideswipe/cutoff incidents. Furthermore, high potential for rear-end crashes was observed on access roads.

Duncan et al. (1998) reported lower severities where a rollover event is present. In a study by McKnight and Bahouth (2009), researchers investigated major causes of 239 rollover incidents from the LTCCS data. Rollover refers to the condition where the centrifugal force upon a large truck on tight curves is sufficient enough to roll it outwards. Results showed rollover causes could be classified into four major groups, including speed, attention, control, and non-driving factors, with high speed being the single largest factor in rollover cases (responsible for more than 45 percent of the sample crashes).

Zhu and Srinivasan (2011a) inferred that among different crash types, head-on truck –car crashes were the most severe type. In addition, sever injuries were likely to happen in dark, lighted conditions after 7:30 pm. Anastasopoulos and Mannering (2011) showed that angle and head-on crashes were less likely to cause injury crashes (compared to PDO or fatality). According to Xie et al. (2012), overturns (either as first or second harmful event) as well as running into ditches, water, and trees reflected positive impacts on severe injuries/fatalities. Vachal (2016) showed that head-on and rollover crashes were the most likely to cause severe injuries.

Some studies particularly incorporated truck-specific crash types such as going off road, overturns, and rollovers (Chen and Chen 2011; Islam et al. 2014). Based on Chen and Chen (2011), truck overturn was the most influential factor in multi-vehicle minor injuries, followed by driving on wrong side/wrong way. Similar trend was observed in single-vehicle jackknife situations.

According to Islam et al. (2014), truck crash trends tended to be different in rural and urban areas. Results showed that in terms of single-vehicle crashes, PDOs were highly probable in truck overtaking situations in rural areas while rollover/overturns were more likely to cause major injuries/PDOs (rather than minor injuries) in urban locations. The major cause of severe multi-vehicle crashes was recognized as rollovers and hitting fixed objects in rural areas and speeding in urban areas.

Some studies went further into details and analyzed vehicle movements momentarily before the crash happens. Chen and Chen (2011) showed that passing/overtaking, and skidding were the most likely movements that lead to incapacitating injury/fatality in single-vehicle truck crashes. In view of multi-vehicle incidents, Skidding was the most likely movement to cause severe injury.

According to Chang and Chien (2013), improper lane changing and following too closely were two major factors that led to PDO and injury outcomes. More than 65% of overturn crashes lead to fatality. Islam and Hernandez (2013) inferred that lane changing and going straight right before the crash increases the probability of PDO crashes. According to FMCSA (2014a), front to rear collisions were the most frequent crash types in work zones followed closely by stationary vehicle crashes.

Knipling (2015) analyzed car-truck crashes using the National Motor Vehicle Crash Causation Survey (NMVCCS). The motivation behind using NMVCCS is that it is a more recent database compared to LTCCS and represent a wider range of crash severities. Several frequency tables based on crash configurations, critical reasons, associated factors, and conditions of occurrence were developed. The results showed that 71% of critical reasons were assigned to cars, indicating that cars were more likely to be responsible in car-truck accidents. Among different critical reasons, cars were more prone toward going out of control, violating rights of way, and driver impairment/stress. Trucks, on the other hand, were more likely to be assigned to vehicle-related critical reasons.

Table 2 provides a brief summary of contributing factors that have been studied in the literature.

Table 2 Summary of Contributing Factors and Impacts on Frequency and Severity

Contributing Factors			Measures	Severity	Frequency	Study References
Roadway Characteristics	**Geometric design**	Curves	presence of curves	Positive		Duncan et al. (1998); Khattak et al. (2002); Daniel et al. (2002); Khorashadi et al. (2005); Anastasopoulos et al. (2008); Ma et al. (2008); Schneider et al., (2009); Anastasopoulos and Mannering (2009, 2011); Lemp et al. (2011); Zhu and Srinivasan (2011a, 2011b); Venkataraman et al. (2011); Xie et al. (2012); Venkataraman et al. (2013); Dong et al., (2015); Anastasopoulos (2016); Linchao and Fratrovic (2016); Bin Islam and Hernandez (2016)
			presence of horizontal curves	Negative	Mixed	
			number of horizontal curves		Negative	
			horizontal curve length		Positive	
			horizontal degree of curve		Negative	
			presence of vertical curves	Positive	Positive	
			length of vertical curves		Negative	
			vertical curve length/segment length		Positive	
			number of vertical curves per mile		Negative	
			crest curve grade		Positive	
		Median	presence of median	Negative		
			median width		Mixed	
			median barrier	Negative	Mixed	
			raised median		Negative	
			two-way left turn lane median		Positive	
		Number of lanes	number of through lanes	Mixed	Positive	
			number of left-turn lanes		Positive	
		Shoulder	shoulder width		Mixed	
			right side shoulder width		Negative	
			median shoulder width	Negative	Positive	
		Lane width	total combined width of all lanes		Negative	
			through lane width		Mixed	
		Inter-change	number of interchanges	Positive	Positive	
			interchange density		Positive	
		Inter-section	presence of intersection	Positive	Positive	

Table 2 Summary of Contributing Factors and Impacts on Frequency and Severity (Continued)

Contributing Factors		Measures	Severity	Frequency	Study References
		angle of intersection		Negative	
	Lighting conditions	road lighting	Positive	Negative	
	Lighting conditions	right/left-side lighting	Positive		
	Road type	Two-way	Positive		
	Pavement attributes	Slippery surface	Negative		
	Pavement attributes	Quality		Positive	
	Terrain	steep grade	Positive		
	Terrain	level-grade	Positive		
Traffic Flow Attribute	**AADT**	AADT		Positive	Zhou and Sisiopiku (1997), Dickerson et al. (2000),Khorashadi et al. (2005), Qi et al. (2007), Chen and Chen (2011), Lemp et al. (2011), Chang and Chien (2013), Dong et al. (2014, 2015) Anastasopoulos et al. (2008), Xie et al. (2012), Venkataraman et al. (2011, 2013), Anastasopoulos and Mannering (2009)
Traffic Flow Attribute	**AADT**	percentage of trucks		Mixed	
Traffic Flow Attribute	**Time-of-day**	morning peak	Positive		
Traffic Flow Attribute	**Time-of-day**	off-peak	Positive		
Traffic Flow Attribute	**Time-of-day**	weekend	Positive		
Traffic Flow Attribute	**Speed**	posted speed limit	Positive	Mixed	
Driver Characteristics	**Age**	driver age ≤45	Negative		Duncan et al. (1998); Khattak et al. (2002); Khorashadi et al. (2005); Lemp et al. (2011); Chen and Chen (2011); Anastasopoulos and Mannering (2011); Xie et al. (2012); Chang and Chien (2013); Islam et al. (2014)
Driver Characteristics	**Age**	driver age ≥50	Positive		
Driver Characteristics	**Age**	occupant age (55–65)	Positive		
Driver Characteristics	**Ethnicity**	truck occupant (white/black/Hispanic)	Positive		
Driver Characteristics	**Ethnicity**	car occupant (American/Indian/Asian)	Positive		
Driver Characteristics	**Ethnicity**	truck driver (Hispanic)	Mixed		
Driver Characteristics	**Gender**	driver (female)	Positive		
Driver Characteristics	**Gender**	driver (male)	Mixed		
Driver Characteristics	**Gender**	occupant (female)	Positive		
Driver Characteristics	**Gender**	occupant (male)	Negative		
Driver Characteristics	**Gender**	presence of older occupants	Positive		
Driver Characteristics	**Asleep/fatigued**	driver asleep/fatigued	Positive		
Driver Characteristics	**Seat belt usage**	Seatbelt not used	Positive		
Driver Characteristics	**Alcohol usage**	driver under the influence of alcohol or drugs	Positive		
Vehicle Characteristics	**Model Year**	truck model 1981–1990 (collision year 2010-2012)	Positive		Khattak et al. (2002); Blower et al. (2010); Lemp et al. (2011); Kononen et al. (2011), Zhu and Srinivasan (2011a); Chen and Chen (2011); Xie et al. (2012); Chang and Chien (2013); Islam et al. (2014); Bin Islam and Hernandez (2016)
Vehicle Characteristics	**Model Year**	truck model: 2001–2010 (collision year 2010-2012)	Positive		
Vehicle Characteristics	**Model Year**	vehicle model 1981 and 1988 (collision year 1998)	Positive		
Vehicle Characteristics	**Vehicle Type**	truck	Positive		
Vehicle Characteristics	**Vehicle Type**	pickup	Positive		
Vehicle Characteristics	**Vehicle Type**	auto	Positive		
Vehicle Characteristics	**Vehicle Type**	bus	Positive		
Vehicle Characteristics	**Vehicle Type**	single-unit truck	Positive		

Table 2 Summary of Contributing Factors and Impacts on Frequency and Severity (Continued)

Contributing Factors		Measures	Severity	Frequency	Study References
		semi tractor-trailer	Positive		
		van	Negative		
	Occupancy	vehicle occupancy=2,4,or 5	Positive		
	Functional defects	truck brake defect	Mixed		
		truck tire defect	Positive		
		truck cargo defect	Positive		
Crash Attribute	**Crash type**	rollover/overturn	Mixed		McCartt et al. (2004); Khorashadi et al. (2005); Zhu and Srinivasan (2011a, 2011b); Anastasopoulos and Mannering (2011); Chen and Chen (2011); Kononen et al. (2011); Xie et al. (2012); Chang and Chien (2013); Islam et al. (2014); FMCSA (2014a); Vachal (2016); Bin Islam and Hernandez (2016)
		jackknife	Negative		
		rear end	Positive		
	Pre-crash vehicle movements	lane changing	Negative		
		passing/overtaking	Positive		
		turning left/right	Positive		
		merging	Negative		
		skidding/control loss	Positive		
	Crash location	median	Negative		
		work zone	Negative		
		highway intersection	Positive		
		highway main body	Positive		
		turn lane		Positive	
		interstate ramp	Negative		
	Weather conditions	rainy/foggy	Mixed		
		Snow/ice	Negative		

2.8. Recommended Countermeasures

One outcome of predictive analytics is to provide recommendations on potential countermeasures that can help reduce crash occurrence, crash severity, and improve overall safety. However, it should be noticed that crash/severity modeling does not evaluate the efficiency of a practical countermeasure. Instead, it identifies crash contributing factors and provide basic suggestions that are expected to reduce/minimize the impacts of each potential factor. In this section, some of the suggestions that were pointed out in the literature will be summarized.

Khattak et al. (2002) generally named technology, engineering, enforcement and encouragement as major countermeasure policies that need to be considered in rollover and truck crash severity prevention programs. In particular, specific strategies need to be employed in order to identify hazardous roadways and try to reduce truck exposure in those specific locations.

McKnight and Bahouth (2009) emphasized on the importance of truck driver education programs, which could lead to truck crash (specifically rollover) reductions. In particular, education through showing real-life rollover videos to drivers or allowing them to experience rollover conditions in simulation labs seemed to provide drivers with enough knowledge and required skills to avoid rollover conditions.

Dong et al., (2015) provided basic countermeasures based on their results for signalized intersections. Accordingly, if an intersection experiences high car-truck crashes (with no serious truck crash problem), decreasing the median width might be a solution. Improvements in lighting conditions or intersection angle could effectively reduce crashes of all type, including car crashes, car-truck crashes, and truck crashes.

Toma et al. (2014) provided detailed statistics on pre-crash scenarios and critical crash reasons that could lead to updating countermeasure profiles. In particular, the statistics presented on target pre-crash scenarios will facilitate the development of countermeasure functional requirements and minimum performance specifications in addition to the estimation of potential safety benefits.

A similar study was conducted by Olson et al. (2009), providing statistics on different types of driver distraction involvement in critical crash events for commercial vehicles. Specific countermeasures were recommended including, reduction or elimination of in-vehicle devices, prohibition of texting/looking at maps/reading or other distractive behaviors while driving, etc.

2.8.1. Countermeasures Related to Specific Types of Crashes

2.8.1.1. Truck crashes during darkness

Sullivan and Flannagan (2013) studied the countermeasures to reduce risk of truck crashes under not-lighted conditions. They analyzed fatal crashes using FARS data from 1987 to 2009, selecting all fatal crashes involving no more than two vehicles in which at least one of the involved vehicles was a tractor-semitrailer. Seven years from the beginning of the study time, in 1993, the Federal Motor Vehicle Safety Standard required all heavy trailers to use conspicuity treatments. This study applied a logistic regression model to identify if there is any truck crash reduction related to the conspicuity treatments. The findings revealed a strong decline in the odds of nighttime versus daytime fatal crashes (58%). The study used certain types of crashes pertaining to nighttime truck crashes which are rear end and angle crashes. "The study asserts that this crash reduction was much larger than any changes observed in control crashes for which truck conspicuity treatments are not relevant (including other types of truck crashes and light vehicle crashes)." The study suggested the conspicuity treatments as the major contributor to the crash reduction and affirmed the effectiveness of conspicuity treatments. It also found the treatment most effective in reducing rear-end collisions and moderately effective in reducing angle collisions in darkness.

The results are consistent with prior studies by Minahan and O'Day (1977) and Green et al., (1979) that recommended the high visibility of heavy trucks. The former study on fatal car-truck underride crashes in Michigan and Texas found a linkage between the visibility of heavy trucks and risk of car-truck underride crashes that happened to be the most common type of severe nighttime crash. In a similar way, the latter study emphasized the fatalities resulted from crashes involving angle and rear-end collisions between cars and tractor-semitrailers at nights. Adding lights or retroreflective paint were advocated to reduce the crash risks.

Hildebrand and Fullerton (1997) examined the visibility of different conspicuity treatments under different weather conditions, including clear, rain, snow, and fog. They evaluated 14 conspicuity configurations overall (including NHTSA suggested configuration) for the rear and side of the trailer. The visibility test identified a "complete outline of solid white retro-reflective tape" as the most effective visibility improvement for the rear of the trailer, and a "continuous stripe of white retro-reflective tape" as an effective countermeasure to improve visibility of the sides under adverse weather conditions. The effectiveness of retroreflective tape on enhancing the visibility of heavy trailers and reducing truck crashes was also confirmed by the Morgan (2001). The analysis of historical crash data between 1997 and 1999, revealed that retroreflective tape countermeasure reduced side and rear impacts into trailers, in dark conditions (including "dark-not-lighted," "dark-lighted," "dawn," and "dusk") by 29 percent. This is most effective under "dark-not-lighted" condition for which the side and rear impact crashes declined by 41 percent. Narrowing down the crashes into injury or fatal crashes, the tape reduced the side and rear impact crashes by 44 percent.

2.8.1.2. Truck crashes related to fatigue

Countermeasures to reduce driver fatigue-related collisions have been emphasized in truck safety researches. Driver fatigue is identified as an important contributor to head-on crash when a vehicle's drifting across the center line of a roadway and hitting another vehicle Blower and Campbell (2005). Overall, the recommended or applied fatigue countermeasures are a combination of vehicle devices, driver trainings, and regulations. The technological countermeasure to cope with driver fatigue has received growing attention over the past decades. These technologies aimed to detect and improve driver performance. They detect drowsiness behaviors such as drivers' slow eye closure, steering wheel movements, lateral lane position, longitudinal speed, lateral and longitudinal acceleration, and braking Grace et al. (1998). However, validation of measurements to detect the drowsiness and fatigue with low risk of false alarm is a critical issue. Also, devices should not distract a driver or be any kind of nuisance for him. Several applied methods comprising (Lal and Craig, 2001):

- Eye closer monitor with buzzer feedback to a driver_ had not been tested extensively.
- Head nodding monitors__ doesn't allow enough time that a driver reacts and prevents a collision.
- Eye activity monitor__ applying video images and image processing to extract eye blink rate and blink duration. Disadvantages are high costs, and not working properly with drivers wearing sunglasses.
- Electroencephalogram (EEG) device__ claimed to predict a possible fatigue accident by detect electrical activity of the brain and alert a driver automatically with an electrical

or sound stimulus. This is potentially the best device for detecting vigilance while driving.

- Steering wheel reversals__ detects changes in the driver's alertness through steering behavior.

Some of these technology devices are promising to prevent collisions, yet they are not widely accepted by drivers. A survey found that nearly half of the drivers opposed a view towards developing a possible technological countermeasure to cope with driver fatigue. Surprisingly, most of the opposing drivers were night shift drivers that might have a higher probability of fatigue driving (Häkkänen and Summala, 2001). The uncertainty of the public acceptance of these devices are also argued by several researchers (Summala and Mikkola, 1994; Brown, 1997; Summala et al., 1999) that believed technological devices may not prevent those drivers who are highly motivated to complete a journey, from continuing to drive after a device alarms.

On the contrary, the study by Gander et al., 2005 verified the success of fatigue management approach on ameliorating driver fatigue. The study developed a driver education program as part of a comprehensive fatigue management approach for light and heavy vehicle drivers in New Zealand. The whole process includes a pre-lecture quiz, a 2-hour fatigue management training session, an after-lecture quiz, and finally a month later survey. From all participants, 75% thought that fatigue management training was at least moderately useful, 47% had changed their strategies at home, and 49% had changed their strategies at work. Thus, the study concluded that fatigue management education for drivers may be an effective countermeasure. However, there isn’t a consensus on what fatigue management policies are the main effective ones.

Studies have found different perspectives towards these policies between transport companies and drivers. The 7-day survey on Australia interviewed truck drivers and transport companies, found that 70% of company managers accused long hours of driving of exacerbating fatigue whilst drivers blamed both loading the truck and delays in loading for their fatigue (Arnold et al., 1997). This is consistent with another survey that listed the difficulties with loading and unloading and delays at loading spots as the main concerning feedbacks of drivers to the companies. This study interviewed 84 of management representatives of transport companies operating in Western Australia. Fatigue management policies that has been used by these companies are restriction on driving hours, self-regulation, rostering system, crewing system, and driver education. Interviewed drivers noted the most common applied policies by their companies is restricting driving hours and allowing drivers some degree of self-regulation within their delivery schedules (Arnold and Hartley, 2001).

Inadequate parking spots is identified as a primary contributor to trucks fatigue-related collisions. Multi use of existing spaces as trucks parking during certain time periods time periods that the space is not being used for its original intended purposes, is a cost-effective solution but not sufficient to fulfill truckers need to rest. This issue has attracted more attention after an FHWA report revealed the significant nationwide shortage of truck parking space (FHWA, 1996). More recently, in 2002, FHWA documented the possible interventions to improve truck rest parking as to reduce truck crashes.

2.8.1.3. Rollover truck crashes

Analyzing traffic safety for trucks, some studies focused on frequency of all truck-related crashes, some concerned about the injury severity of truck drivers and occupants and some followed either of the two-focused area for crashes in which a truck driver is at-fault. The report conducted by University of Michigan (Woodrooffe and Blower, 2015) suggested the countermeasures to improve occupant safety in truck involved crashes. It focused on truck-tractors and single-unit vehicles that are listed in the NHTSA Class 7 and 8 weight range. The study revealed the high risk of severe and fatal injuries for vehicle occupants in rollover crashes. The analysis showed that truck rollover crashes accounted for 40 percent of all truck driver injuries while this rate for non-rollover crashes is not more than 4 percent. In a similar way, one in eight truck drivers die or receive incapacitating injuries in the events where the truck rolled over compared to one in 167 drivers who died from the non-rollover truck collisions. Potential countermeasures to reduce truck rollover, are all vehicle-related countermeasures, listed as follows:

- Increasing the Integrity and Robustness of Cab Structures. The LTCCS revealed that SUTs with tanks or substantial body structures helped mitigate cab deformation during rollover events. Truck manufacture companies asserted that more recent models of trucks after the LTCCS study period (1995-2003) have improved structurally as did the trucks' cab strength.
- Seat Belts and Side Curtain Air bags. Quantitate analysis of truck crashes underscores the importance of wearing seat belt. Ejection accounted for 35 percent of all SUT driver fatalities and 22.6 percent of truck-tractor driver fatalities. The strategy of truck manufactures applying advanced system of seat belt warning, is suggested for preventing severe injuries for a given crash. The enhanced warning system can use warning light, and alerting sound when seat belt is not fastened. Side curtain air bags is another potential strategy to prevent ejection through the side window and provide lateral head protection in events that trucks rollover.
- Automatic Pull-Down Seats. In the event of rollover crashes the larger survival space overhead and preventing abrupt and intense movement of the occupants are two factors that can mitigate level of injuries. The automatic seat pull-down (market name RollTek) insures the safety by incorporating seat belt pretensions to pull seat belts tight when crash occurs. The system compounded from the roll sensor, air-suspended seat, and integrated side air bag. The roll sensor is activated when a truck rollovers and triggers the seat pull down system. This system tights driver to the lower-height seat and creates the larger space overhead.
- Frontal Air bags. Significant proportion of fatal and severe truck crash (23%) is resulted from frontal impact collisions. Some previous studies have discussed that frontal air bags are less effectiveness in truck collisions than the light vehicle collisions. The reason

is attributed to automobiles and trucks exposure to different severe crash types. Compared to light vehicles, trucks are more involved in rollover crashes in which air bags should have no effect (Hu, 2013). However, frontal airbags are claimed to be promising for preventing injuries from striking to steering wheels that are happened to be a primary source of high injury severity of truck drivers (FMCSA, 2006).

- Crash Avoidance Technology. The report summarized the list of crash avoidance technologies from prior studies. The list includes: electronic stability control (ESC), roll stability control (RSC), and commercial vehicle forward collision avoidance and mitigation systems (F-CAM). All these are suggested as potential countermeasures to reduce rollover crash injuries, yet are not considered to be relevant to crashworthiness. Adding to this list, the study suggested the implication of automatic brake application coincident with the initial impact event in a crash as a possible future technology.

2.8.2. Comprehensive Truck Crash Reduction Countermeasures

This section provides an overview of three studies that conducted detailed analysis of all types of truck crashes and recommended comprehensive list of countermeasures to reduce safety risks. Two of the studies dated back before 2000, and this opens the possibility of more update researches on truck safety countermeasures.

2.8.2.1. In relation to crash types and measurement types

The first study by Pigman and Agent (1999) used police reported truck-involved fatal crashes between 1994 and 1997. The most common crash type involved a vehicle crossing the centerline into the path of the truck. Analyzing the risk factors and harmful events for common crash types, the study suggested potential countermeasures for each crash type:

a. Crash type: Other Vehicle Crossed Centerline into Path of Truck
    - Warning devices to alert drivers when crossing the centerline into the opposing lane
    - Centerline rumble strips (applied in Maryland and confirmed effective in reducing the risk of head-on crashes)
b. Other Vehicles Pulled or Turned into Travel Path of Truck
    - Increasing public awareness of the longer stopping distance required for a large truck
    - Removing obstacles to increase sight distance
    - Warning signs for intersections with lower speed advisories
c. Single Vehicle (a truck driver losing control on a curve)
    - Driver training (For example drivers of trucks hauling a liquid load must be aware of the possibility of load shifting and its consequences and drive at a speed which will not result in a shifting of the center of gravity which could cause loss of control)
    - Stability measuring device

- Warning signs in advance of sharp curves, specifically on exit ramp curves where accidents involving overturning trucks have occurred

d. Other Vehicle Ran into Rear of Slow-Moving Truck
- Proper underride protection as well as adequate lighting and reflectivity. All Trucks should be equipped with rear impact guards that meet the requirements of Federal Motor Vehicle Safety Standards (FMVSE;) 223 and 224 Trucks should also be equipped with appropriate FMVSS lighting and reflectivity.
- Truck drivers should use the truck's emergency flashers when driving at a speed substantially slower than the prevailing traffic speed.
- Warning signs should be posted at steep grades to alert motorists of the presence of slow moving trucks.
- Truck climbing lanes should be constructed at locations with steep grades and high truck volumes.
- The truck volume should be considered when determining the maximum grade in the roadway design process.

e. Pedestrian/Bicycle crashes
- Adequate mirrors to allow the driver observe around the truck

f. Truck Crossed Centerline into Path of Other Vehicle
- Driver training on how to handle trucks after dropping tires onto the shoulder considering characteristics of different types of trucks. The problems of off-tracking must also be emphasized to truck drivers.

g. Truck Ran into Rear of Vehicle(s) in Road:
- Driver training on adequate distance required to stop, the limited handling characteristics of a truck, and the need to avoid driving for an excessive number of hours.

h. Other Vehicle Ran into Rear of Truck Stopped on Road
- Provide proper underride protection

i. Other Vehicle Ran into Rear of Truck Stopped off Road
- Driver training not to park on the shoulder unless an emergency exists
- Prohibiting stopping signs at problematic locations
- Providing additional proper areas to park

j. Vehicle Hit Side of Truck Trailer while Truck Making Turn
- Increase reflectorization along the sides of trailers, e.g. the use of reflective tape.

In addition to the countermeasures for each common crash type, the study grouped potential safety solutions into three categories of vehicle-, roadway-, and driver-related measures, as shown in Table 3.

Table 3 List of Countermeasures (Pigman and Agent, 1999)

Measurement groups	Countermeasures
Vehicle Countermeasures	Adequate rear underride protection
	Adequately maintained and properly located lights and reflectors
	Continuing maintenance with emphasis on brakes, lighting, and tires.
	Truck rollover warning system
	Side underride protection
	Load security with improved procedures and enforcement
	Interactive technologies such as collision avoidance and obstacle detection systems, on-board safety monitoring systems, and intelligent mirror systems
	Truck brake screening systems (infra-red systems and performance-based brake testing systems should be considered).
	Increase enforcement to detect braking problems especially for heavily loaded trucks
Roadway Countermeasures	Centerline rumble strips (warrants for installation of centerline rumble strips should include curved sections of two-lane roads with a high frequency of opposite-direction Accidents).
	Widen pavement and post appropriate advisory speeds at sharp curves
	Advance warning at traffic signals on high-speed roadways
	Signing at steep grades
	"No parking" signs on shoulders at locations where trucks have been observed stopping for non-emergency reasons
	Physical barrier (delineators) at locations with a high incidence of parking use (near on-ramps at rest areas)
	Additional parking for truck drivers and enforce parking restrictions. Promote use of parking at existing weigh stations.
	Truck climbing lanes at locations with steep grades and high ruck volumes.
	Consider the truck volume when determining the maximum allowed grade
	Lane use restrictions for trucks on multilane roadways with steep grades.
	Truck escape ramps at locations with high truck volumes and where there is roadside development and a lack of a clear zone at the end of a long downgrade
	Active warning devices in advance of problematic curves with high frequency of overturning trucks.
	Roadway lighting where there is a high incidence of nighttime accidents
Driver Countermeasures	Truck drivers training (i.e. use flashers when speed slow for conditions, do not stop on shoulder unless there is an emergency, be aware of the center of gravity of the load and its related handling characteristics, be aware of off tracking characteristics of trucks, and emphasize log book and hours in service requirements).
	All drivers should be educated how to behave relating to trucks' operational characteristics (i.e. longer stopping distances, limited handling characteristics).
	Address driver fatigue through an improved method of logging driving hours in combination with development of an in-vehicle driver monitoring system.
	Reinforce the need for improved/increased enforcement of typical moving violations by non-vehicle enforcement law enforcement agencies.

2.8.2.2. Truck crash countermeasures on urban freeways

The second study was published in 1994 by FHWA (Middleton et al., 1994). The study identified the countermeasures that have been implemented to reduce the frequency and input of truck accidents on high volume urban freeways. It found that despite numerous articles on truck traffic safety, very few studied the countermeasures to reduce truck accidents. This study carried out a survey to collect the implemented countermeasures from agencies and individuals nationwide. The focus was only on roadway design and operation countermeasures. Those countermeasures that directly pointed to drivers and vehicles were excluded. Overall, 12 countermeasures were identified: active signs, differential speed limits, fixed radar, height warning systems, increased enforcement, urban truck inspection stations, Lane restrictions, incident response management (major and minor), passive signs, reduction of shoulder parking, separate truck roadways and truck bans (Middleton et al., 1994).

From this list, a subset of 7 countermeasures were identified that either had higher perceived potential accident reduction capability or were more extensively applied. The subset includes: lane restrictions, restrictive truck facilities, ramp treatment, truck bans/diversions and time restrictions, reduced shoulder parking, urban truck inspection stations, major incident response and clearance.

Table 4 below summarizes findings of the seven countermeasures. It should be noted that each study followed different methods and criteria evaluating the countermeasures. Very few of them applied the long-term, before-and-after study. Most of them focused on crash rates and crash frequencies rather than crash severities. Some of the studies considered the effectiveness on overall crash rate than truck crashes. In addition, there was a lack of statistical approach to identify if the changes were statistically significant. For the purpose of this review, incident management and clearance programs were excluded as they did not directly address traffic safety but the impacts of incidents on traffic flow and operation.

Table 4 Effectiveness of Countermeasures (Middleton et al., 1994)

Study	Conditions	Countermeasures	Safety Effectiveness
Strategy1. Lane Restrictions			
Florida, 1988	To reduce crashes along I-95 in Broward County.	No truck on left turn lane from 7 am to 7 pm	Overall crash went up 6.3%, Truck crash went down 3.3%.
Georgia, 1986	Truck over-involvement in weaving and lane changing accidents, trucks were at fault in 72% of lane-changing violations on I-285	Trucks were restricted to the right lane(s)	Unknown
Chicago, IL	Road blockage to other traffic as trucks occupying all lanes	Trucks restricted to two right lanes	Public felt safer, better traffic operations.
Maryland	Severe truck accident in Capital beltway	Restrict trucks from certain lanes	No statistical evaluation on truck crash reduction, Public felt safer.
Virginia, 1984	Crashes along Capital Beltway	Restrict trucks from certain lanes	First study revealed crash frequency/severity decrease, another before/after study showed an increase in crash rate, no change in fatality, 1988 study revealed an increase for truck crash rate, restriction removal recommended.
Garber and Gadiraju study	Used data from 9 sites	Applied simulation restricting trucks to the right lane, smaller headway for right lane	Slight increase in right lane crashes.

Table 4 Effectiveness of Countermeasures (Middleton et al., 1994) (Continued)

Study	Conditions	Countermeasures	Safety Effectiveness
Strategy2. Separate Truck Facilities			
Lamkin and McCasland	Feasibility analysis for Beaumont Houston corridor, Houston TX	Exclusive truck facilities	Unknown
Stokes and Albert	Feasibility analysis for roadway parallel to I-10 and I-45 Houston TX	Exclusive truck facilities	Truck accident reduction and traffic operation improved.
Los Angeles, CA	Separate truck facilities started from1970s (I-405/route 110 bypass, I-5/route 14, etc.)	Truck bypass	No direct safety effectiveness analysis, eliminated weaving for truck and thus traffic operation improved.
New Jersey	Turnpike dual-dual roadway separated by metal beam guardrail	Truck and buses are restricted to outer roadway	Truck crash rate declined in dualized section compared to the non-dualized.
Portland, OR	Significant grades and undesirable weaving situation at Tigard street interchange	Truck bypass	No safety effectiveness analysis, traffic operation improved along weaving section.
Strategy3. Ramps Treatments			
Firestin et al	Aimed to reduce the likelihood of truck crashes on highway interchanges	Greater safety margin into formulations for side friction factors, modifying posted and advisory speeds, improving curve condition and downgrade signs at interchanges, increasing deceleration lane length, eliminating outside ramp curves or overlaying with wedges of pavement, resurfacing ramps with high friction overlays	Unknown
VDOT,1988	Field study of ramps and interchanges	Recommend reduce speed limits on several ramps, improving poor visibility of advanced signing and landscaping and vegetation	Unknown
FHWA, 1991	Research on active and passive devices to reduce truck crashes	Use loops and sensors to monitor truck speed and add flashing to the static warning sign when approaching the curve at an unsafe speed	Unknown
New Jersey	Ramp shoulder improvement along new jersey turnpike	Leveled super-elevated curvature ramps with shoulders	Unknown
Atlanta, GA	High crash rate on ramps, improving truck crash at interchanges of radial freeways with I-285	Static warning signs, over-speed warning device, improving inside shoulder cross slope to match cross slope of the main line ramp lanes and added a concrete safety barrier, increased a super-elevation on the main lines of the ramp, add chevrons	No safety effectiveness analysis, Effectiveness of active warning device on speed reduction is minimal after a month (derivers get familiar to the system).

Table 4 Effectiveness of Countermeasures (Middleton et al., 1994) (Continued)

Study	Conditions	Countermeasures	Safety Effectiveness
Maryland, Capital Beltway	Some ramps had high posted advisory speeds	“Truck tipping” signs with reduced advisory speed were installed on ramps with high crash rate	
Detroit, MI	2-lane freeway ramp treatment (along I-75) to mitigate accidents involving trucks	Installing signs, increasing super elevation (mainly on the inside lanes), outside barrier curb, constant super elevation over the full width of the ramp to the outside barrier, tall barrier	No safety effectiveness analysis.
Hagerstown, MD	Aimed to reduce the number of truck rollover accidents on some ramps on I-70	Oversized truck tipping signs, diamond grade reflective sheeting, signs too close to ramps were moved upstream or additional signs were installed upstream (allow enough reaction time), increasing shoulder cross slope to match ramp super elevation	Unknown
Los Angeles, CA	Route 91 eastbound to the I-605 northbound ramp with numerous accidents involving both automobiles and trucks	Adding chevrons, large truck tipping signs, turn warning signs, large overhead signs with yellow wig-wags	A before-after study shows a 50% reduction in truck overturning and single vehicle struck guardrail accidents, fewer severe crashes .
Pittsburgh, PA	Aimed to improve safety at Interchange of I-70/I-79 due to the several fatalities occurred at this location	Installation of structure-mounted signs, removal of certain existing signs, tall barrier,	A before-after study shows no truck accident after compared to 2 to 6 truck accident per year during before study period.
Strategy4. Truck Diversions or Bans			
Covington, KY	Tuck accidents on the I-71/75	Truck diversion from northbound I-71/75 to I-275 (freeway bypass)	Diversion was expected to shift accidents from the interior interstate highways to I-275 with no accident for the entire region, for the section of the road with unbalanced truck volume, the diversion was expected to reduce truck involvement in crashes by 9%.
Atlanta, San Francisco, Los Angeles, Minneapolis/St. Paul	Aimed to improve traffic flow	Countermeasures include: ban trucks, truck decals required to use interior freeways, peak period truck bans, truck diversion to circumferential freeways	Unknown
Strategy5. Reduction of Shoulder Parking			
FHWA study	Fatigue as a primary cause of severe crash with parked vehicles on highway shoulders	Pavement texture that produce a rumble effect, signs of proceeding to rest facilities	Unknown

Table 4 Effectiveness of Countermeasures (Middleton et al., 1994) (Continued)

Study	Conditions	Countermeasures	Safety Effectiveness
Columbus, OH	Due to number of fatalities from crashes to parked vehicles on shoulders	Time restriction for all vehicles to park on the right-hand shoulder of freeway (reduced from 12 hours to 3 hours)	Unknown
Michigan	Aimed to reduce illegal truck parking on shoulders of state highways, much of them occurred in vicinity of rest areas	Recommendations of stricter enforcement of shoulder parking restrictions, limit the length of stay in freeway rest areas, provide information on appropriate overnight truck parking facilities at the rest areas	Unknown
Strategy6. Urban Truck Inspection Stations			
Maryland	Aimed to reduce truck crashes which are caused by mechanical problems or operator related problems on the Capital Beltway	Inspection station at I-95/I-495, added inspection forces over years instead of building a new station, focus on intra-city delivery trucks	Percentage of inspected out of service truck decreased over years.
Los Angeles		Urban inspection station on I-405 in the city of Carson. Troopers select trucks for inspection (Separated loaded and unloaded trucks on two lanes). Weigh-in-motion device to verify whether the truck is loaded or not. Mobile Road Enforcement (MRE) officers inspect trucks at various locations not necessarily at stations.	Some CALTRANS sources believed constructing inspection/weigh facilities in urban environment is not a good investment due to the numerous bypass opportunities.
Strategy7. Deferential Speed Limit			
University of Maryland,1974	Vehicular speed and accident data were collected at 84 study sites	Speed deferential	Compliance of trucks with posted limits is dependent on geometric design of the road and the existence of deferential speed limits . No reliable relationship between speed parameters and crash rates.
Gaber and Gadiraju, 1991	Effect of speed deferential on vehicle speed and crash characteristics on collected data from California, Maryland, Virginia, and West Virginia	Speed deferential	Speed differential had no significant effect on trucks average speed or on reducing crash rates. Speed deferential increased vehicle interactions and so did certain crash types such as rear-end and sideswipe on interstate highways with an AADT less than 50,000.
Strategy8. Tall Barriers			
New Jersey, 1984		Constructing tall concrete barriers (42 inch) along turnpike separating opposing directions of traffic	During a 5-year period, out of the 55 trucks which struck median barrier, none penetrated the opposite traffic direction.

Table 4 Effectiveness of Countermeasures (Middleton et al., 1994) (Continued)

Study	Conditions	Countermeasures	Safety Effectiveness
Pittsburgh, PA		Tall reinforced concrete barrier (90 inch) installed at the interchange of I-70/I-79 at 1985	The before/after study by PennDOT showed no truck crash during a 3-year after study whereas 2 to 6 truck crashes occurred during each year of the 3-year before study.
		Strategy9. Mainline Treatments	
Pittsburgh, PA	Truck braking problem due to highway grades coupled with high volume-to-capacity ratio, and high volume of heavy trucks. Significant number of runaway truck accidents at sites with steep grades	Truck escape ramp at Greentree Hill	Significant number of trucks using the escape ramp and the lower severity compared to the scenario of non-existent ramp. Effectiveness evaluation estimated that at least 10 automobiles would have been involved for each runaway truck if the ramp had not been built.
Pennsylvania, turnpike	Trucks exiting a tunnel (with horizontal curve) at high speeds had problem negotiating the curve to the left. Numerous overturn truck accidents running onto the shoulder with negative supper-elevation	Change mainline super-elevation slope to the inside of the curve, and shoulders slope downward to the outside of the curve.	After improvement, more recovery area was available to vehicles by use of shoulder. According to turnpike sources, improvements have significantly reduced the number of truck crashes at this location.
Portland, OR	Super-elevation and cross-slope problems at Terwilliger curve	Super-elevation was increased to the maximum of 5% within the curve, by constructing asphalt wedge with its depth increasing from inside toward outside of the curve	Super-elevation improvement coupled with advisory speed signs (the sign shows the curve direction as well) resulted in 20% truck crash reduction (the study suggested more information is required to evaluate the effectiveness of this countermeasure).

2.8.2.3. Heavy truck crash reduction countermeasures

This study was a part of the "Guidance for Implementation of the AASHTO Strategic Highway Safety Plan" sponsored by the National Cooperative Highway Research Program (NCHRP). One can argue that the suggested crash reduction solutions were represented in format of strategies rather than the executive scale countermeasures. The study searched for widespread application of low-cost, proven countermeasures that reduced the number of crashes on the nation's highways, as it was emphasized in the Strategic Highway Safety Plan. The strategies to reduce heavy-truck crashes were categorized under six major objectives:

- Reducing truck driver fatigue,
- Strengthening commercial driver's license (CDL) requirements and enforcement,
- Increasing public knowledge about sharing the road,

- Improving maintenance of heavy trucks,
- Identifying and correcting unsafe roadway and operational characteristics,
- Improving and enhancing truck safety data, and
- Promoting industry safety initiatives.

These objectives aimed to address the main identified safety issues. The report suggested strategies that meet each safety objective, shown in the following Table 5. It also provided guidance on how to evaluate the effectiveness of strategies by classifying them into three types:

- Proven (P): Those strategies that have been used in one or more locations, and for which properly designed evaluations have been conducted that showed them to be effective.
- Tried (T): Those strategies that have been implemented in several locations, and that may even be accepted as standards or standard approaches, but for which no valid evaluations have been found.
- Experimental (E): Those strategies that are ideas that have been suggested and that at least one agency has considered sufficiently promising to try them on a small scale in at least one location.

Table 5 Heavy Truck Crash Reduction Countermeasures (NCHRP, 2004)

Objectives	Strategies	Effectiveness Group
Truck fatigue-related crashes	- Increasing the efficient use of existing parking spaces for truckers - Creating additional parking spaces for truckers - Incorporating rumble strips into new or existing roadways	E T
CDL Program	- Improve test administration for the CDL - Increase fraud detection of state and third-party testers	T T,E
Sharing the road	- Incorporate Share the Road information into driver handbooks knowledge tests, and license renewal - Promulgate Share the Road information through print and electronic media reporting	T T
Maintenance of heavy trucks	- Increase and strengthen truck maintenance programs and inspection performance - Conduct post-crash inspections to identify major problems and problem conditions	E
unsafe roadway and unsafe operational characteristics	- Identify and treat truck crash roadway segments - Use signs - Install interactive truck rollover signing on hazardous off-ramps - Modify speed limits and increasing enforcement to reduce truck and other vehicle speeds	E P T
Improve and enhance truck safety data	- Increasing the timeliness, accuracy, and completeness of truck safety data	
Promote industry safety initiatives	- Perform safety consultations with carrier safety management - Promote development and deployment of truck safety technologies	P E

2.9. Literature Summary

This section summarizes the literature in truck crash analysis, as well as general crash studies, with a focus on the modeling methodologies, contributing factors and suggested countermeasures. The modeling methodologies applied in truck crash analysis were fairly similar to those for general crash studies, while more recent efforts were found in applying more advanced methods in general crash analysis. Table 1 presents a brief summary of the studies included in the literature review.

Based on findings from the studies, major contributing factors were identified, and their effects on either the occurrence or severity of crashes were summarized as shown in Table 2. It should be noted that different studies used different analytical methods and various definitions of the measures, which has led to mixed results in terms of the impacts on crash occurrence or severity.

In addition, the literature also showed that although various recommendations on countermeasures have been developed and implemented to reduce crash rate or severity, very few studies have explicitly focused on assessment of the effectiveness of those countermeasures. The last comprehensive study of this nature could be dated back before 2000. This points to the need for further research that examine the impacts of countermeasures on crash reduction.

3. DATA ACQUISITION AND PREPARATION

For the purpose of this study, three types of data were assembled and prepared to support the statistical and spatial analysis. Three types of data were collected: crash data, roadway network characteristics data and traffic volumes data.

3.1. Crash Data

Crash data were acquired from the Signal Four Analytics for a period of ten years from 2007 to 2016. Signal Four Analytics includes all police crash reports in the state of Florida and it is obtained daily from the DHSMV. The crash dataset for this study includes all crashes involving large trucks based on the definition for large trucks from the Federal Motor Carrier Safety Administration (FMCSA) as "trucks with a gross vehicle weight rating over 10,000 lbs”. To identify records involving large truck crashes, multiple attributes from Florida police crash reports are considered. Crashes containing any of such attributes are selected as large truck crashes. The Table 6 shows the attributes considered:

Table 6 Large Truck Attributes

Attribute	Value	Description
Vehicle Body Type	20	Medium/Heavy Trucks (more than 10,000 lbs (94,536 kg))
Commercial Motor Vehicle Configuration	2	Single-Unit Truck (2-axle and GVWR more than 10,000 lbs (4,536 kg))
	3	Single-Unit Truck (3 or more axles)
	4	Truck Pulling Trailer(s)
	5	Truck Tractor (bobtail)
	6	Truck Tractor/Semi-Trailer
	7	Truck Tractor/Double Truck
	8	Tractor/Triple
	9	Truck more than 10,000 lbs (4,536 kg)
Comm GVWR/GCWR	2	10,001-26,000 lbs (4,536-11,793 kg)
	3	More than 26,000 lbs (11,793 kg)

Signal Four Analytics database produced 243,017 crashes involving large trucks, 98,790 of which occurred from 2007 to 2010 and 144,227 occurred from 2011 to 2016. The crashes occurred prior to 2011 were produced by considering only the Vehicle Body type attribute because CMV configuration and GVWR attributes were not available until 2011. Figure 2 below shows the crash frequencies for the 10-year study period.

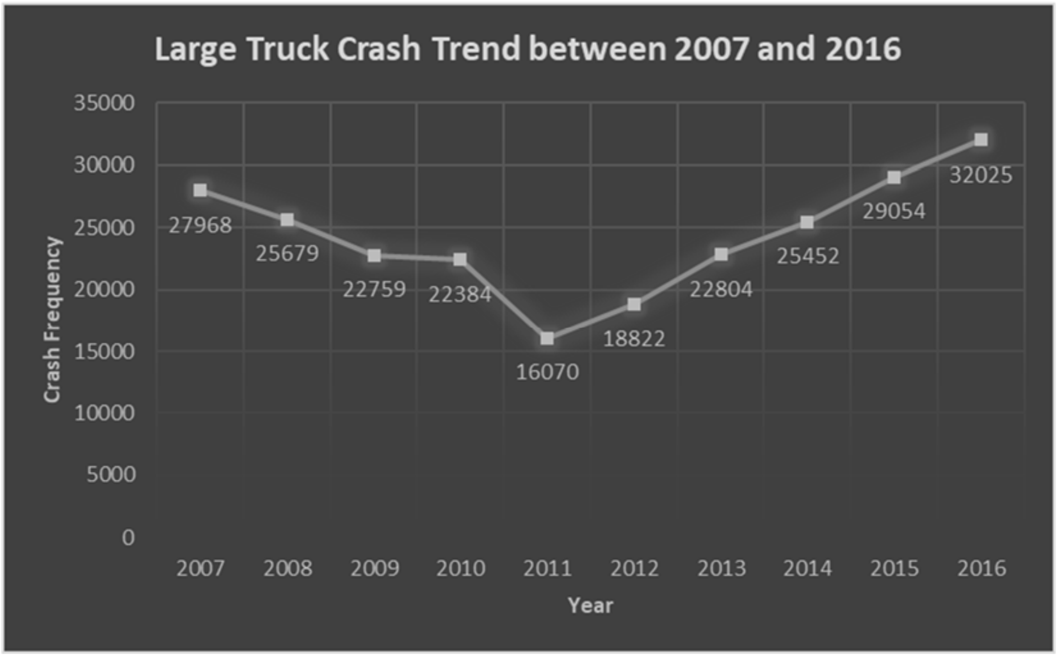


Figure 2 Crash frequencies for the 10-year period.

An additional source for large truck crash data is the federal Fatality Analysis Reporting System (FARS). FARS covers a large set of attributes specifically for fatal crashes. However, most of the attributes available in FARS are already are listed in the Florida police reports. The few exceptions are roadway functional classification, number of occupant, underride/override crashes, previous recorded crashes/suspensions/DWI convictions/Speeding convictions/Other harmful MV conviction, and occupant seating positions. Using FARS data, University of Michigan's Transportation Research Institute has prepared a detailed truck crash database called TIFA (Trucks in Fatal Accidents). The source for TIFA is mainly from FARS but some variables are added from a survey for large truck crashes such as hours and mile of driving, and the vehicle safety devices. Unfortunately, the TIFA data was collected from 1980 until 2010. The 2011 to 2016 data are not available. Based on personal communication, we learned that although more updated data can be obtained from FARS, the FARS data lack the details of the TIFA. Given that FARS data attributes are already available in the Florida police reports available in Signal Four Analytics, the FARS data is not included at this time.

Florida crash reports contains over 110 data attributes organized in several categories. The relevant categories for this study include the crash event, drivers, vehicles, non-motorists, and violations. Each of these data categories are explained below and the detailed listing of their attributes are presented in appendix A.

3.1.1. Crash Events

Crash event contains attribute that apply to the crash itself such as time and place, weather, crash type, harmful events etc. The complete list of attributes and their descriptions are shown in the appendix A. The Table 7 shows crash frequencies for each year from 2007 to 2016. As mentioned above there is a total of 243,017 crash events that involved large trucks in Florida for this study period.

Table 7 Crash Counts

Crash Counts										
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Count	27968	25679	22759	22384	16070	18822	22804	25452	29054	32025

3.1.2. Drivers

The Driver category includes information about the drivers involved in the large truck related crashes such as age and gender, drug or alcohol involved, restraint system applied etc. The complete list of driver attributes and their descriptions are shown in the appendix A.

There was a total of 455,699 drivers, or on average of 1.9 drivers per crash during the study period. The Table 8 shows the number of drivers involved in these crashes during the study period by year. The numbers range from a minimum of 29,096 in 2011 to a maximum of 57,726 in 2016.

Table 8 Driver Counts

Driver Counts										
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Count	56462	51169	45230	44267	29096	33749	40623	45431	51946	57726

3.1.3. Vehicles

The Vehicle category includes information about the vehicles such as make and model, body type, area of initial impact, extent of damage, vehicle maneuver action etc. The complete list of vehicle attributes and their descriptions are shown in the appendix A.

There was a total of 479,472 vehicles, or on average 2 vehicles per crash involved in the large truck related crashes during the study period. The involved vehicles range from a minimum of 31,445 in 2011 to a maximum of 63,085 in 2016. The Table 9 shows the number of vehicles involved in these crashes during the study period by year.

Table 9 Vehicle Counts

Vehicle Counts										
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Count	56462	51169	45230	44378	31445	36686	44402	49704	56911	63085

3.1.4. Non-Motorists

The Non-motorist category contains information about the non-motorists, such as pedestrians and bicyclists, involved in the large truck crashes. Attributes of non-motorists include gender and age, involvement of alcohol and/or drugs, safety equipment in use, relevant violation, action circumstances etc. The complete list of vehicle attributes and their descriptions are shown in the appendix A.

There was a total of 4,315 non-motorists involved in the large truck related crashes during the study period. The numbers range from a minimum of 299 in 2010 to a maximum of 624 in 2016. The Table 10 shows the number of non-motorists involved in these crashes during the study period by year.

Table 10 Non-motorist Counts

Non-motorist Counts										
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Count	365	344	324	299	405	448	440	511	555	624

3.1.5. Violations

The Violations category contains information about traffic violations involved in the large truck crashes during the study period. Attributes of violations include gender and age of violator, the role of violator e.g. driver or non-motorist and the type of violation. The complete list of violation attributes and their descriptions are shown in the appendix A.

There was a total of 152,764 violations in the large truck related crashes during the study period. The numbers range from a minimum of 8,413 in 2011 to a maximum of 20,495 in 2007. The Table 11 shows the number of violations in these crashes during the study period by year.

Table 11 Violation Counts

Violation Counts										
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Count	20495	17892	15279	14821	8413	11775	13687	15113	16957	18332

3.2. Street Network and Traffic Data

This study uses the Florida all roads GIS street basemap (ARBM) or usually referred to as Navteq streets. This data includes a complete and detailed coverage of the street network in Florida. The current version of the ARBM uses Navteq 2015 quarter 1. Some of the main attributes of this database include street names, length, speed category, number of lanes category, roadway system such as Interstate, US Roads, State or County roads, whether the road is divided or not etc. FDOT

Safety Office has applied the FDOT linear referencing system on the ARBM which provides milepost measures that can be used to map additional information from FDOT Roadway Characteristics Inventory (RCI) not available in the Navteq streets.

Relevant FDOT roadway characteristics were obtained from the FDOT Statistics Office to supplement ARBM network data. They include Functional Classification, Maximum Speed Limits, Median Type, Median Width, Number of Lanes, Bridges, Surface Width, Inside Shoulder Type, Inside Shoulder Width, Outside Shoulder Type, Outside Shoulder Width. Traffic data include Annual Average Daily Traffic and Truck Traffic Volume. They were obtained from the FDOT Statistics Office as well.

The FDOT roadway characteristics and the traffic data are mapped on the ARBM using linear referencing of event tables and dynamic segmentation. The detailed event mapping process is described in section 3.2.2 Combining Network and Traffic Data. The selected roadway characteristics and traffic attributes useful for the spatial and statistical analysis is presented below.

Table 12 Selected Roadway Attributes and Traffic Attributes

Milepost		
Fields	***BMP***	Begin mile post of a specific road segment
	EMP	End mile post of a specific road segment
Roadway		
Field	***ROADWAY***	Roadway ID
Roadway Side		
Fields	***ROADSIDE***	Side of a roadway
Values	***C***	Center for bidirectional undivided roads
	L	Left
	R	Right
Annual Average Daily Traffic		
Fields	***YEAR_***	Calendar year for which record applies.
	K100FCTR	K factor for highest 100 Hour
	DFCTR	Total traffic in peak direction as % of two-way traffic.
	TFCTR	Truck and bus factor is the proportion of trucks for 24 hours
	KFCTR	Proportion of AADT occurs in the 30th highest hour.
	AADT_	Total highway traffic volume for one year, divided by the number of days.
Truck Traffic Volume		
Field	***TruckAADT***	Truck annual average daily traffic
Functional Classification		
Field	***FUNCLASS***	Functional Classification Roadways

	1	Principal Arterial-Interstate - RURAL
	2	Principal Arterial-Expressway - RURAL
	4	Principal Arterial-Other - RURAL
	6	Minor Arterial - RURAL
	7	Major Collector - RURAL
	8	Minor Collector - RURAL
Values	***9***	Local - RURAL
	11	Principal Arterial-Interstate - URBAN
	12	Principal Arterial-Freeway and Expressway - URBAN
	14	Principal Arterial-Other - URBAN
	16	Minor Arterial - URBAN
	17	Major Collector - URBAN
	18	Minor Collector (Fed Aid) - URBAN
	19	Local - URBAN
	Median Type	
Field	*MEDIAN_TYPE*	Median type in feet
	1	Painted two-way left turn lane
	2	Traffic Separator (all concrete curb medians)
	3	Cable Barrier - deleted code
	4	Guardrail (all types) - deleted code
	5	Fence - deleted code
	6	Barrier Wall - deleted code
	8	Lawn/Turf
	9	Gravel/Marl
	10	Paved (painted hatching, painted gores)
	11	Depressed Median - deleted code
	12	Paved with Guardrail - deleted code
Values	***13***	Paved with Barrier Other Than Guardrail - deleted code
	14	Curb <= 6" and Guardrail - deleted code
	15	Curb <= 6" and Fence - deleted code
	16	Curb <= 6" and Barrier Other Than Guardrail - deleted code
	17	Curb with Lawn/Turf
	18	Curb > 6" and Guardrail - deleted code
	19	Curb > 6" and Fence - deleted code
	20	Other
	21	Curb > 6" and Barrier Other Than Guardrail - deleted code
	22	Curb > 6" and Lawn - deleted code
	23	Lawn and Guardrail - deleted code
	24	Grassed with Fence - deleted code

	25	Lawn and Barrier - deleted code
	26	Lawn, Barrier and Curb <= 6" - deleted code
	27	Lawn, Barrier and Curb > 6" - deleted code
	28	Canal, river, waterway, etc. - deleted code
	29	Combination of 02 or 03 and 28 - deleted code
	30	Combination of 02 or 03, 05, and 28 - deleted code
	31	Lawn with double Guardrail - deleted code
	32	Unpaved w/ landscaping (vegetation)
	33	Wooded (trees)
	34	Curb w/ landscaping (vegetation)
	41	Counted Roundabout
	42	Non-counted Roundabout
	43	Counted Traffic Circle
	44	Non-counted Traffic Circle
	50	Non-counted Managed Lane
	Maximum Roadway Speed	
Field	*SPEED*	Maximum posted speed in miles
	Median Width	
Field	*MEDIAN_WIDTH*	Median width in feet
	Number of Lanes	
Field	*LANE_CNT*	Number of lanes
	Bridges	
Field	*STRUCTURE_*	Bridge structure ID
	Surface Width	
Field	*SURF_WIDTH*	The width of the roadway segment in feet
	Inside Shoulder Type	
Field	*ISLD_TYPE*	Simple (the road segment has one order) /Compound (the road segment has multiple orders)
	ISLD_ORDER_1_TYPE	Type of the shoulder next to the travel lane
	ISLD_ORDER_2_TYPE	Type of additional shoulder next to Shoulder 1
	ISLD_ORDER_3_TYPE	Type of additional shoulder next to Shoulder 2
Values	10	Raised Curb - no shoulder
	1	Paved
	2	Paved with Warning Device
	3	Paved with warning device (any device that serves to warn the motorist)
	4	Gravel/Marl
	5	Valley Gutter (not a barrier)
	6	Curb and Gutter
	7	Other
	8	Curb with Resurfaced Gutter

	9	None (managed lane)
	Inside Shoulder Width	
Fields	*ISLD_WIDTH*	Total width of order 1, order 2, and order 3
	ISLD_ORDER_1_WIDTH	Width of the shoulder next to the travel lane in feet
	ISLD_ORDER_2_WIDTH	Width of additional shoulder next to Shoulder 1 in feet
	ISLD_ORDER_3_WIDTH	Width of additional shoulder next to Shoulder 2 in feet
	Outside Shoulder Type	
Fields	*OSLD_TYP*	Simple (the road segment has one order) /Compound (the road segment has multiple orders)
	OSLD_ORDER_1_TYP	Type of the shoulder next to the travel lane
	OSLD_ORDER_2_TYP	Type of additional shoulder next to Shoulder 1
	OSLD_ORDER_3_TYP	Type of additional shoulder next to Shoulder 2
	OSLD_CL_TYP	the left of the undivided road segment: Simple (has one order) /Compound (has multiple orders)
	OSLD_ORDER_CL1_TYP	Type of the shoulder next to the travel lane (Left of C)
	OSLD_ORDER_CL2_TYP	Type of additional shoulder next to Shoulder 1 (Left of C)
	OSLD_ORDER_CL3_TYP	Type of additional shoulder next to Shoulder 2 (Left of C)
	OSLD_CR_TYP	the right of the undivided road segment: Simple (has one order) /Compound (has multiple orders)
	OSLD_ORDER_CR1_TYP	Type of the shoulder next to the travel lane (Right of C)
	OSLD_ORDER_CR2_TYP	Type of additional shoulder next to Shoulder 1 (Right of C)
	OSLD_ORDER_CR3_TYP	Type of additional shoulder next to Shoulder 2 (Right of C)
Values	*0*	Raised Curb - no shoulder
	1	Paved
	2	Paved with Warning Device
	3	Paved with warning device (any device that serves to warn the motorist)
	4	Gravel/Marl
	5	Valley Gutter (not a barrier)
	6	Curb and Gutter
	7	Other
	8	Curb with Resurfaced Gutter
	9	None (managed lane)
	Outside Shoulder Width	
Fields	*OSLD_WID*	Total width of order 1, order 2, and order 3
	OSLD_ORDER_1_WID	Width of the shoulder next to the travel lane
	OSLD_ORDER_2_WID	Width of additional shoulder next to Shoulder 1
	OSLD_ORDER_3_WID	Width of additional shoulder next to Shoulder 2
	OSLD_CL_WID	Total width of order 1, order 2, and order 3
	OSLD_ORDER_CL1_WID	Width of the shoulder next to the travel lane (Left of C)
	OSLD_ORDER_CL2_WID	Width of additional shoulder next to Shoulder 1 (Left of C)
	OSLD_ORDER_CL3_WID	Width of additional shoulder next to Shoulder 2 (Left of C)

OSLD_CR_WID	Total width of order 1, order 2, and order 3
OSLD_ORDER_CR1_WID	Width of the shoulder next to the travel lane (Right of C)
OSLD_ORDER_CR2_WID	Width of additional shoulder next to Shoulder 1 (Right of C)
OSLD_ORDER_CR3_WID	Width of additional shoulder next to Shoulder 2 (Right of C)

3.3. Data Preparation

Data preparation involved two major steps: data cleaning required to check the quality of the data and identify missing values or bad data, and establishing the proper relationship among data such as association of crash events with proper vehicles and drivers and mapping of roadway characteristics and traffic information on the GIS basemap.

3.3.1. Data Cleaning

Spatial Data: The ideal spatial data for this project is every crash has its crash location, and every crash is linked to the road segment where it occurred. The raw spatial crash data from Signal Four geolocated the crashes base on Highway Safety Motor Vehicle information, FDOT crash location information, and Federal Highway Patrol proximate crash location. To check the quality of the data, the spatial crash data is screened to identify the crash points that are not mapped correctly. About 0.1% of the crashes has obvious wrong locations, such as crashes in the oceans, crashes mapped outside of the U.S. with wrong latitudes and longitudes. About 10% of the crash records have no geolocation. The totally number of crashes that are not mapped correctly are 24,169, and they were flagged as "Not Mapped" in the attribute table, and they were also relocated to the zero point of the map projection (lower left corner on the map). The purpose is to still include unmapped crash records for the statistical analysis, but exclude them from the spatial analysis.

As mentioned, 24,169 (about 10%) of the crashes that involved large trucks are unmapped for a multitude of reasons, but primarily due to poor crash address information in the crash report. The following maps show crashes involving large trucks symbolized by crash severity. The detailed study of the location of unmapped crashes (shown in appendix B) reveals that the majority of them occurred in 2016. About 91% of those crashes are related to no injury crashes, and only one record is a fatal crash which occurred in a local road that doesn't exist in the map. Almost half of those crashes are the parking lot crashes. They are also more and less evenly distributed within counties proportionate to the mileage of roads.

Figure 3 Large truck crashes by injury severity

Figure 4 PDO large truck crashes

Figure 5 Injury large truck crashes

Figure 6 Fatal large truck crashes

Attribute Data: An analysis of values for each crash attribute of interest was conducted to get a better understanding of each attribute and find any missing values or bad data. A detailed listing of the results is presented in Appendix C. Below is a discussion of issues identified:

1 - Difference between Null and Unknown values: Unknown is a valid data attribute chosen by the police officer in the crash report. Null represents missing data or bad data.

2 - Possible inconsistency between "crash type" (derived variable generated by Signal Four Analytics) and the "manner of collision" attribute (from the crash report): There is no single 'crash type' field in the Florida Traffic Crash Report. Rather, crash type is derived based on the values of several fields such as First Harmful Event, Manner of Collision/Impact, Number of Vehicles, Vehicle Maneuver Action, Vehicle Direction of Travel, and Vehicle Area of Initial Impact. Manner of collision is considered when crash type is determined.

3 - Drivers younger than 15 years old in the driver table (244 observations): Records for drivers less than 15 years old can be either related to driving under the legal age or it can be bad data.

4 - "Total Lanes" equal to 0: 67.8% of cases where the total number of lanes is zero is related to the Road System being parking lots, private roads, or other. The remaining 31.1% can be missing information.

Table 13 Frequency for Road System Identifier

Road System Id	Count
9 - Parking Lot	1,171
5 - Local	312
4 - County	188
8 - Private Roadway	108
77 - Other	89
3 - State	87
2 - U.S.	44
Null	9
1 - Interstate	9

5 - Some crashes have no citations. This is possible because in many cases, police officers do not decide the at-fault driver and do not give tickets, but rather let the insurance company decide.

6 - Unmatched number of drivers and vehicles. There are 23,773 more vehicles than drivers. Most of them may be due to hit-and-run crashes, when no driver is located. Also for collisions with parked vehicles, the parked vehicle is reported in the vehicle table, but not in the driver table.

7 - One driver may have two property damages in the driver table but in the crash table lists only one vehicle damage: This can reflect non-vehicle damages. A vehicle can hit multiple objects that are considered as property damage.

8 - Distracted driver = 0 in the driver table: Zero in this case represent Null or no information is provided.

9 - No airbag deployment information (Null values) for 122,481 driver records, approximately equal to 27% of drivers: 90.7% of all Null values are for old crash data (pre- 2011).

Table 14 Distribution of Crashes Based on the year

Year	Crash Count	Percentage
2007	20,751	27.2%
2008	18,363	24.1%
2009	15,619	20.5%
2010	14,388	18.9%
2011	615	0.8%
2012	1,012	1.3%
2013	1,164	1.5%
2014	1,168	1.5%
2015	1,466	1.9%
2016	1,656	2.2%

10 – How to treat "Non-traffic fatalities": Non-traffic fatality means that fatality is not caused by a crash. For analysis, it should be treated as no injury crash or Property Damage Only (PDO) crash.

11- In the restraint system table, 5995 driver records, equal to approximately 1.3% of drivers, are listed as "Not Applicable (not motorists)": This can be related to drivers of Moped vehicles (such as ATV, or golf cart) that are filled as not applicable in the crash report. It is also possible that the police officers filled the form incorrectly and checked the 'Not Applicable' for a passenger.

12 – Estimated speed with values of "0" and "999": Zero and very low estimated speed can be either related to the parked vehicle, or vehicles stopping at the intersections. The value 999 represents the unknown speed. Null value is for records left blank in the crash report.

3.3.2. Data Relationship

3.3.2.1. Relating Crash Data

Crash data is organized as a set of related tables. Typically, this relationship is one to many e.g. one crash many vehicles. The following diagram illustrates the crash data relationships: One Crash Event is related to one or more Drivers, one or more Vehicles, Zero or more Non-Motorist and Zero or more Violations.

In ArcGIS this relationship is established through a mechanism called "Relate". An ArcGIS project is setup for this study and all the relationships above are established by relating the crash point event layer to the driver, vehicle, non-motorist, and violation tables. This enables selection of drivers for a given crash and vice versa, for any selected drivers the crash points can be easily identified.

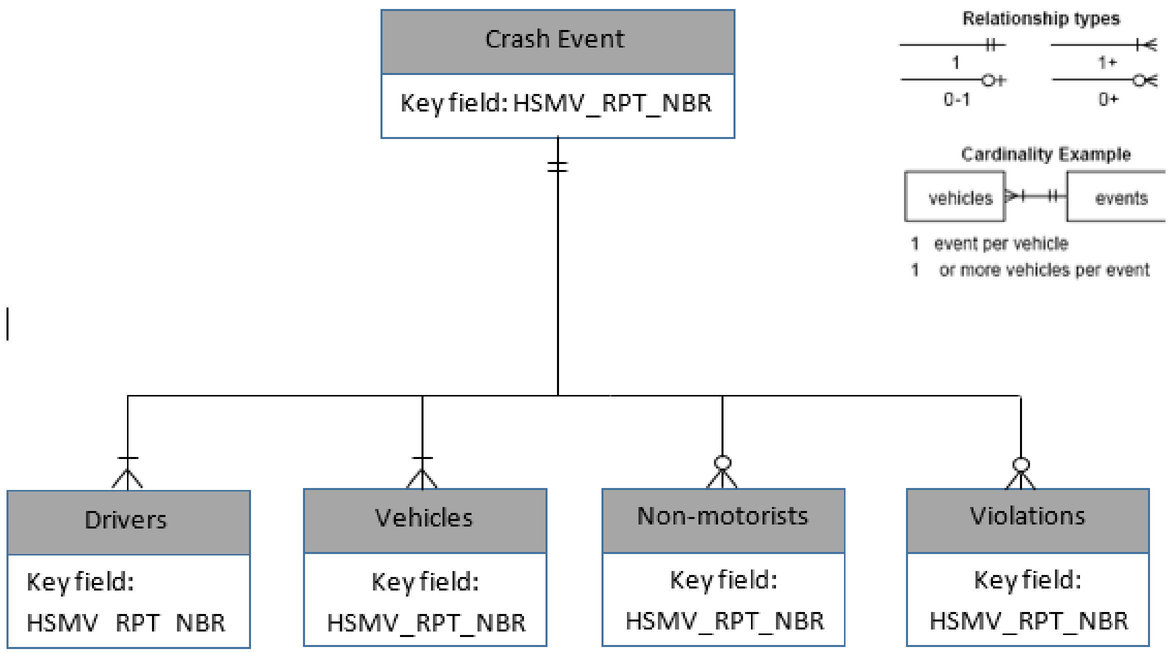


Figure 7 Data relationship diagram

3.3.2.2. Mapping of Roadway Characteristics and Traffic Data

FDOT roadway characteristics and traffic data are mapped onto the street network by using linear referencing and dynamic segmentation. This only applies to FDOT roadways available in the RCI. For local roads, we will have to go with the information that is already available in the Navteq street network because the equivalent information is not available from local sources or impossible to collect for this study.

The product of this mapping process is a comprehensive feature class of FDOT road network with road information and traffic information. During this process, multiple issues emerged. The issues and the solution are described at the end of this section.

Linear referencing locates events on linear features (e.g. roadways) based on measures from the origin. Point or line events along a roadway are measured by mileposts which indicate the beginning and ending of the feature. E.g. a segment with the same constant speed limit of 70 miles/hour can run from milepost 0.23 to milepost 4.10 on the roadway 01000002. Point features are located by a single milepost value. E.g. a traffic light may be located at the milepost 0.2 on the roadway 01000002.

Dynamic segmentation is the process that allows multiple attributes associated with any portion of a linear feature to be mapped on the street network, by segmenting the street network into smaller homogenous segments. The result of dynamic segmentation produces a feature layer in ArcGIS that can be exported as feature class after associating all the necessary attributes on the GIS streets basemap.

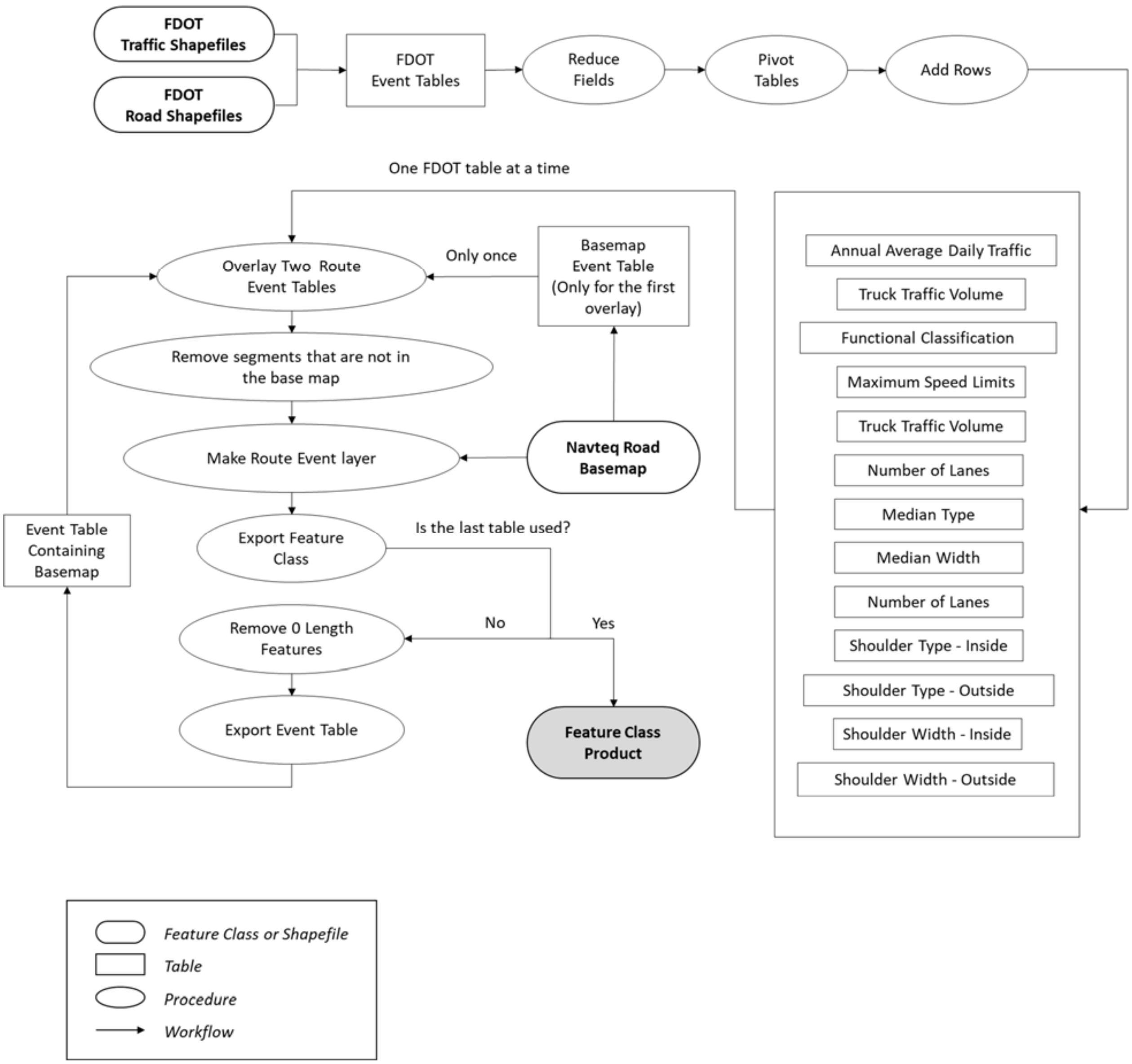


Figure 8 Mapping of roadway characteristics and traffic data

FDOT roadway characteristics described in section '2.2. Street network and Traffic Data' are structured as 'event' tales and are mapped on the GIS streets basemap using the process shown in Figure 8.

During this process, we encountered several issues related to the computing capability, data source problems, and discrepancies between data sources.

Computing capability

Event table size too large for ArcGIS to process: Each individual statewide event table has many fields, and each segmentation increases the number of records in the final feature class multifold to achieve the required homogeneous segments. This takes hours to process and frequently ArcGIS cashes. To prevent this from happening, each attribute table is examined before dynamic segmentation process and the fields unnecessary for analysis are removed.

Event layer too large for ArcGIS to load and export completely: similarly, it takes too long for the final event layer to even draw in ArcGIS and the memory will run out during the export feature class process even on a computer with large amount of RAM. This results in incomplete final map.

The reason of this issue is each event table overlaying will produce two categories of unnecessary records: a) When overlaying event tables, the milepost measure of the base map from Navteq does not include all the milepost measures from the event tables. This leads to empty attributes on these extra milepost measures. However, because the milepost difference between Navteq and event table attributes are minor, these records can be removed safely without compromising the data. b) When exporting the event layer to the final feature class, the outcome contains some zero length features. These are due to the difference between the length in digits of the milepost measures of the streets basemap and those in the event tables. For example, the street basemap uses a measure of 2.0390000000043074 miles while the event table uses a measure of 2.039 miles. This creates a new record of 0.0000000000043074 length. ArcGIS, treats this as a zero-length feature and given the minute data discrepancy these records are also safe to remove. These two categories of records will multiply at every table overlaying step that finally leads to a huge product file.

To prevent this issue, the unnecessary records were checked and removed before overlaying each event table. This could dramatically reduce the file size and chance of ArcGIS software crash.

Data source problems

We highlighted some problems in the data source during the data processing since they created unexpected results.

Conflict records in the FDOT shapefiles: there are conflict records both in Outside_shoulder_type shapefile and Outside_shoulder_width shapefile. When pivoting the out_shoulder_type tables, we notice that the records we change were more than the records we should change. The reason is the outside_shoulder_type table from FDOT has some conflict records (as shown in the following image). The same segment on the same side and in the same order have two different types.

Table 15 Screenshot Illustration 1

Table

outside_shoulder_type

OBJECTID *	ROADWAY	ROAD_SIDE	OSLD_ORDER	OSLDTYPE	BEGIN_POST	END_POST
79546	01000037	L	1	3	1.13	1.282
79547	01000037	R	1	3	1.13	1.215
79548	01000037	R	1	6	1.215	1.282
79549	01000037	C	1	3	1.282	1.415
79550	01000037	C	1	6	1.282	1.343
79551	01000037	C	1	3	1.343	1.415
79552	01000037	C	1	3	0	0.686
79553	01000037	C	1	3	0.686	0.745
79554	01000037	C	1	6	0.686	0.745
79555	01000037	C	1	6	0.745	1.014
79556	01000037	C	1	0	1.014	1.13
79662	01000037	C	1	3	0.745	1.13

After consulting FDOT, we got new shapefiles from them. A new OFFST_DIR field were added to the data to explain these kinds of records (as shown in the following image). The new field OFFST_DIR means an undivided ROAD_SIDE C could also have different left and right shoulder attributes. If both sides of the undivided road have the same attributes such as type, the value of OFFST_DIR will be 'R and L', otherwise the table will use two records to indicate the attribute value on R and L.

Table 16 Screenshot Illustration 2

Table

outside_shoulder_type

FID	Shape	ROADWAY	ROAD_SIDE	BEGIN_POST	END_POST	OFFST_DIR	OSLD_ORDER	OSLDTYPE
1563	Polyline M	01000037	C	0	0.686	R and L	1	3
90	Polyline M	01000037	C	0.686	0.745	L	1	6
2378	Polyline M	01000037	C	0.686	0.745	R	1	3
255	Polyline M	01000037	C	0.745	1.13	L	1	3
1727	Polyline M	01000037	C	0.745	1.014	R	1	6
1400	Polyline M	01000037	C	1.014	1.13	R	1	0
1238	Polyline M	01000037	R	1.13	1.215	R	1	3
2704	Polyline M	01000037	L	1.13	1.282	L	1	3
583	Polyline M	01000037	R	1.215	1.282	R	1	6
1075	Polyline M	01000037	C	1.282	1.415	L	1	3
1728	Polyline M	01000037	C	1.282	1.343	R	1	6
584	Polyline M	01000037	C	1.343	1.415	R	1	3

Outside_shoulder_width shapefile conflict records were fixed in the same way.

Discrepancies between data sources

Since the data used are from different sources (road characteristic, traffic attribute shapefiles are collected from FDOT and road network geometries are from Navteq all road basemap), there are data structure and data quality differences which prevent combing these data into a single file.

The challenge with dual centerline cases: normally, any event table is mapped on the street network using the linear referencing system defined as a combination of a roadway identifier and the 'beginning' and 'end' milepost measures. However, when the network is represented using a dual centerline (or dual carriageway), the same event will automatically be mapped on both centerlines which share the same roadway ID and thus losing the recognition of the left and right side of a divided roadway which may have different values for a given attribute e.g. the shoulder width could be different.

To solve this problem, a composite roadway identifier must be used to uniquely identify each side of the roadway, both on the street map and the event tables. We accomplish this by creating a new field named ROADWAY_SIDE_ID by combining the values in ROADWAY and ROADSIDE on both. This will correctly apply the mapping of the event table on the street network by respecting the left and right side of the roadway in the dual centerline cases.

Maxspeed road side C issue: shapefiles collected from FDOT and Navteq street adopt base map digitizing. There are minor geometry differences. There will be problems when overlaying RCI tables and SSO tables directly.

The letter 'C' in maxspeed is defined as 'Center of the roadway' in its FDOT metadata. But it means more likely 'both the right side and left side' according to the nature of the data. Thus, we can interpret it as both the right and the left side have a same maximum speed.

About 90% of the records in maxspeed have an ROAD_SIDE 'C' but Navteq base map only has about 50% of ROADSIDE 'C'. Therefore, overlaying these tables using ROADWAY ID and ROAD_SIDE information will lead to many records in the product having no maxspeed information even they could be obtained.

Solution: to keep the most information in the maxspeed table, we will duplicate two new rows of the ROADSIDE C records in the maxspeed table, and then change the ROADSIDE of the two new records to L and R respectively. Thus, they could match the Navteq ROADSIDE 'C' when operating the overlaying tool.

It is also possible that Navteq have a C side while the Maxspeed split it as L and R. In case of missing this information in overlaying tables, we created a new C side row in the maxspeed table to catch this possibility. The condition for add a C record is if there are two same value in speed fields with same ROADWAY ID, same BMP – EMP, one record is L side, and the other record is R side. Result: the first picture shows a product without adjusting the table before overlaying. The second one is the product after applying the solution.

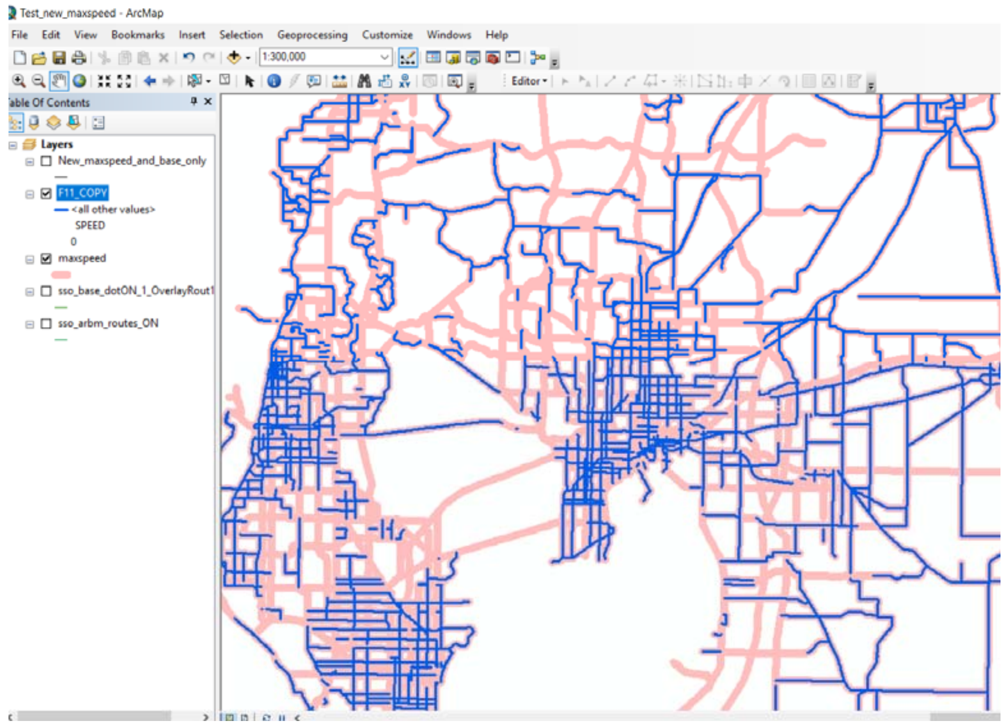


Figure 9 Screenshot illustration 3

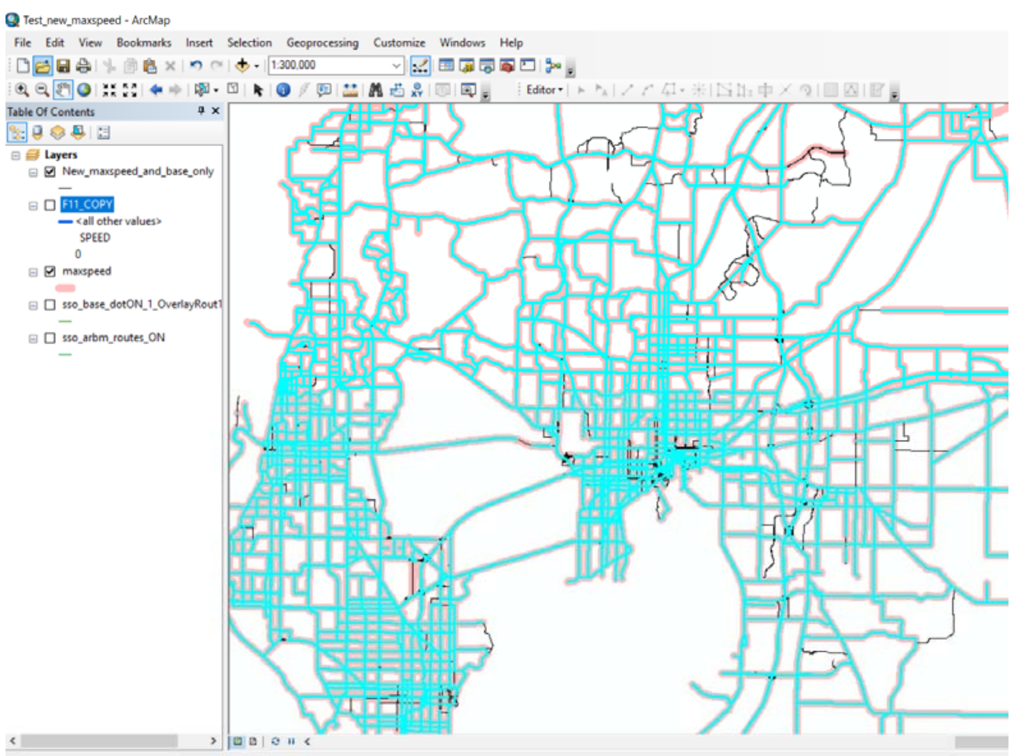


Figure 10 Screenshot illustration 4

Green highlighted features are available speed information in the product. Compared with the previous product, almost all the information from maxspeed tables are kept. It is noticeable that there are a few segments still have a 0-speed limit (red bottom with black lines). This is because FDOT maxspeed shapefile assign these feature segments with only one single L or R side, while in the Navteq base map these feature segment is assigned with a C. Thus, there is no proof to be sure that both sides have same speed value and to duplicate a C for them. The speed limit information for these segments cannot be kept.

This issues also happened when combining surface width, bridges, number of lanes. Similar solutions are adopted to acquire more information from the FDOT tables.

Python scripting is applied to this process considering the large amount of records.

Pivoting tables: the goal of this data is to produce a feature class without repetitive segments. That means each record will have a unique roadway ID + roadside + begin milepost + end milepost. Therefore, each events table should follow this rule when overlaying.

For example, the first and third highlighted two records in the following picture should be combined into one record before overlaying, since the begin post and end post are the same, roadway IDs are the same and side are both L. They are considered duplicates.

Table 17 Screenshot Illustration 5

able

nside_shoulder_width

OBJECTID *	ROADWAY	ROAD_SIDE	ISLD_ORDER	BEGIN_POST	END_POST	WIDTH	ISLD_ORDER_1_WIDTH	ISLD_ORDER_2_WIDTH	ISLD_ORDER_3
10326	01010000	R	1	12.489	12.613	2	<Null>	<Null>	<Null>
10479	01010000	L	1	15.295	21.055	2	<Null>	<Null>	<Null>
10555	01010000	R	1	12.77	12.86	2	<Null>	<Null>	<Null>
10556	01010000	L	1	10.184	10.324	2	<Null>	<Null>	<Null>
10633	01010000	R	1	25.871	25.946	2	<Null>	<Null>	<Null>
9446	01040000	L	1	1.532	2.68	6	<Null>	<Null>	<Null>
9754	01040000	R	1	1.532	2.68	6	<Null>	<Null>	<Null>
10480	01040000	R	1	2.772	2.945	2	<Null>	<Null>	<Null>
9447	01050000	L	1	17.016	17.549	2	2	<Null>	<Null>
9675	01050000	R	1	17.016	17.549	2	2	<Null>	<Null>
9989	01050000	L	1	9.145	16.881	2	2	<Null>	<Null>
10171	01050000	R	1	9.145	16.881	2	2	<Null>	<Null>
10172	01050000	L	1	2.237	4.484	2	2	<Null>	<Null>
10401	01050000	R	1	2.237	4.484	2	2	<Null>	<Null>
9676	01050001	L	2	0.011	0.036	2	<Null>	2	<Null>
9907	01050001	R	2	0.011	0.036	2	<Null>	2	<Null>
9908	01050001	L	1	0	0.011	2	2	<Null>	<Null>
10090	01050001	R	1	0	0.011	2	2	<Null>	<Null>
10402	01050001	L	1	0.011	0.036	1	1	<Null>	<Null>
10634	01050001	R	1	0.011	0.036	2	2	<Null>	<Null>
9598	01060000	R	1	4.936	5.088	2	<Null>	<Null>	<Null>
9832	01060000	L	1	5.088	7.288	2	<Null>	<Null>	<Null>

The solution for this issue is to create new fields in one record to store such information. In this case, ISLD_ORDER_1_WIDTH, ISLD_ORDER_2_WIDTH, and ISLD_ORDER_3_WIDTH fields are created to combine these two records into one row. Python scripting is applied to identify such records and pivoting them.

Overlapped mileposts: although outside shoulder width and type could be pivoted, there are some overlapped mileposts within a segment. To fix the overlapped records, we need complex

Python scripts. The time to run it will take days to finish. Until that time, we can check if the script covered all the cases and decide whether to fix it the script and run it again.

Table 18 Screenshot Illustration 6

256	01000037	R	1.13	1.215	R	1	8	1
3206	01000037	L	1.13	1.215	L	1	12	1
2577	01000037	L	1.215	1.282	L	1	6	1
2789	01000037	R	1.215	1.282	R	1	2	1
255	01000037	C	1.282	1.415	L	1	12	CL1
2369	01000037	C	1.282	1.343	R	1	2	CR1
1099	01000037	C	1.343	1.415	R	1	12	CR1
Click to add new row.								

To save time and maintain the accuracy, our solution is to decompose the two tables of outside shoulder. 9 tables were extracted from each table. These event tables then overlaid with the intermediate table one by one as independent tables.

AADT and the sides: FDOT organize AADT use roadway ID but in the Navteq basemap some road segments with same ID are divided using C, R, and L. In the AADT shapefile shown in the following picture, one roadway has only one record. It is obvious that one side of the road cannot represent the total volume of both sides.

Table 19 Screenshot Illustration 7

Table

aadt

FID	Shape	YEAR_	DISTRICT	COSITE	ROADWAY	DESC_FRM	DESC_TO	AADT	AADTFLG	KFLG
45	Polyline	2016	1	014422	01000002	CR 768/JONES LOOP RD	FAIRWAY DR S	1000	C	F
270	Polyline	2016	1	014400	01000003	TAYLOR RD	GOLF COURSE RD	3800	S	F
201	Polyline	2016	1	014423	01000004	FLORIDA ST	PIPER RD	1450	F	F
108	Polyline	2016	1	014424	01000005	CHARLOTTE CO LN	CR 775/PLACIA RD	7800	F	F
46	Polyline	2016	1	014425	01000006	CR 775/PLACIDA RD	PARADE CIR	6000	R	F
338	Polyline	2016	1	014426	01000007	US-41/SR-45	I-75 OFRMP	9500	F	F
271	Polyline	2016	1	014178	01000009	SR-35/US-17/MARION	DARST AVE	2450	S	F
176	Polyline	2016	1	014401	01000010	FAIRWAY DR S	SR 35/US 17 NB	4100	S	F
19	Polyline	2016	1	014428	01000011	SUNSET RD	N/A	5700	C	F
109	Polyline	2016	1	014427	01000011	SUNSET RD	CONCORD RD	2100	C	F
339	Polyline	2016	1	014310	01000011	N/A	SARASOTA CO LINE	5000	S	F

The product has multiple records with various sides. For roadway 01000002, the AADT value should be 1000 in the C side, but should not be 1000 in the L and R sides.

Table 20 Screenshot Illustration 8

Table

F11

OBJECTID *	Shape *	ROADWAY_SIDE_ID	BMP	EMP	ROADWAY	ROADSIDE	RD_STATUS	COUNTY	YEAR_	AADT
3434	Polyline M	01000002C	2.1829	2.184	01000002	C	09	01	2016	1000
3801	Polyline M	01000002C	2.25	2.274	01000002	C	09	01	2016	1000
3957	Polyline M	01000002C	2.465	3.503	01000002	C	09	01	2016	1000
4803	Polyline M	01000002C	2.274	2.465	01000002	C	09	01	2016	1000
4870	Polyline M	01000002C	2.184	2.25	01000002	C	09	01	2016	1000
329	Polyline M	01000002L	0	0.082	01000002	L	09	01	2016	1000
2917	Polyline M	01000002L	0.801	2.113	01000002	L	09	01	2016	1000
3899	Polyline M	01000002L	2.113	2.1829	01000002	L	09	01	2016	1000
4331	Polyline M	01000002L	0.082	0.801	01000002	L	09	01	2016	1000
540	Polyline M	01000002R	2.184	2.1906	01000002	R	09	01	2016	1000
1019	Polyline M	01000002R	0.801	2.113	01000002	R	09	01	2016	1000
1091	Polyline M	01000002R	2.113	2.184	01000002	R	09	01	2016	1000
1563	Polyline M	01000002R	0.082	0.801	01000002	R	09	01	2016	1000
2959	Polyline M	01000002R	0	0.082	01000002	R	09	01	2016	1000
108	Polyline M	01000003C	1.159	1.263	01000003	C	09	01	2016	3800

Solution: we assume both road sides have same traffic volume. If the ROADSIDE is L or R in the combined product, we divided it by 2 (as shown in the following image AADT vs. AADT_SIDE_SPLIT).

Table 21 Screenshot Illustration 9

Table

F11_copy

OBJECTID *	Shape *	ROADWAY_SIDE_ID	BMP	EMP	ROADWAY	ROADSIDE	RD_STATUS	COUNTY	YEAR_	AADT	AADT_SIDE_SPLIT	KFCTR	K100FCTR	DFCTR
2864	Polyline M	01000002C	2.1829	2.184	01000002	C	09	01	2016	1000	1000	9	0	52
3177	Polyline M	01000002C	2.25	2.274	01000002	C	09	01	2016	1000	1000	9	0	52
3305	Polyline M	01000002C	2.465	3.503	01000002	C	09	01	2016	1000	1000	9	0	52
3986	Polyline M	01000002C	2.274	2.465	01000002	C	09	01	2016	1000	1000	9	0	52
4039	Polyline M	01000002C	2.184	2.25	01000002	C	09	01	2016	1000	1000	9	0	52
272	Polyline M	01000002L	0	0.082	01000002	L	09	01	2016	1000	500	9	0	52
2444	Polyline M	01000002L	0.801	2.113	01000002	L	09	01	2016	1000	500	9	0	52
3259	Polyline M	01000002L	2.113	2.1829	01000002	L	09	01	2016	1000	500	9	0	52
3612	Polyline M	01000002L	0.082	0.801	01000002	L	09	01	2016	1000	500	9	0	52
449	Polyline M	01000002R	2.184	2.1906	01000002	R	09	01	2016	1000	500	9	0	52
856	Polyline M	01000002R	0.801	2.113	01000002	R	09	01	2016	1000	500	9	0	52
918	Polyline M	01000002R	2.113	2.184	01000002	R	09	01	2016	1000	500	9	0	52
1314	Polyline M	01000002R	0.082	0.801	01000002	R	09	01	2016	1000	500	9	0	52
2480	Polyline M	01000002R	0	0.082	01000002	R	09	01	2016	1000	500	9	0	52
92	Polyline M	01000003C	1.159	1.263	01000003	C	09	01	2016	3800	3800	9	0	52
263	Polyline M	01000003C	0.983	1.159	01000003	C	09	01	2016	3800	3800	9	0	52

Basemap O, B, F, P, N sides: in the All Roads Basemap (ARBM) 2015, there are multiple side values: 1. R = Right side 2. L = Left side 3. C = Center (Bidirectional undivided road) 4. O = One-Way 5. B = Busway 6. F = Ferry 7. P = Pedestrian walkway 8. N = No Roadside. In the base map we use in this project (system ON), only ROADSIDE B and O exist – 2 rows for B and 4780 rows for O.

Rows with ROADSIDE O, B have limited information because the FDOT road shapefiles and traffic shapefiles do not contain these sides so when overlaying the tables with sides, no information will be added to these rows by overlaying route events.

For example, in the base map, the record shown in the following screen shot has a side of O. But in the number of lanes shapefile, this record side is assigned as C.

Solution: considering the importance of the O side records (most show as ramps), and limited number of B side records we will treat the O side and B side as C side when overlaying events tables, and keep the original side information unchanged.

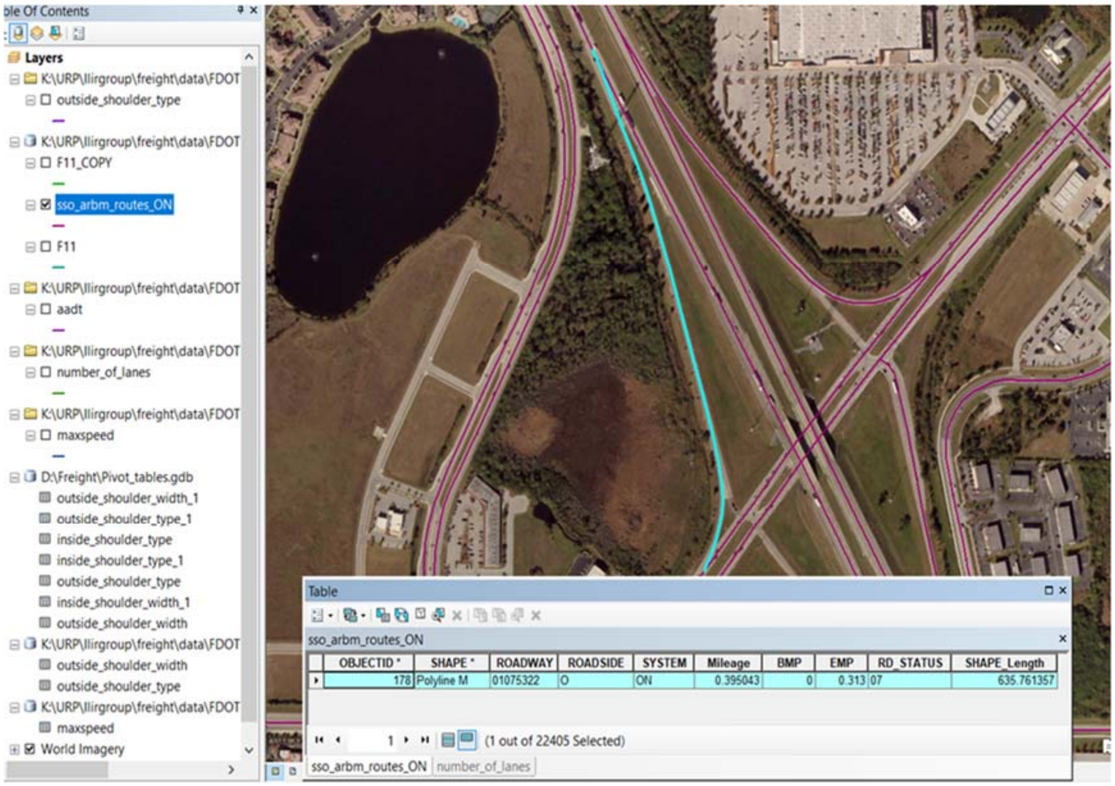


Figure 11 Screenshot illustration 10

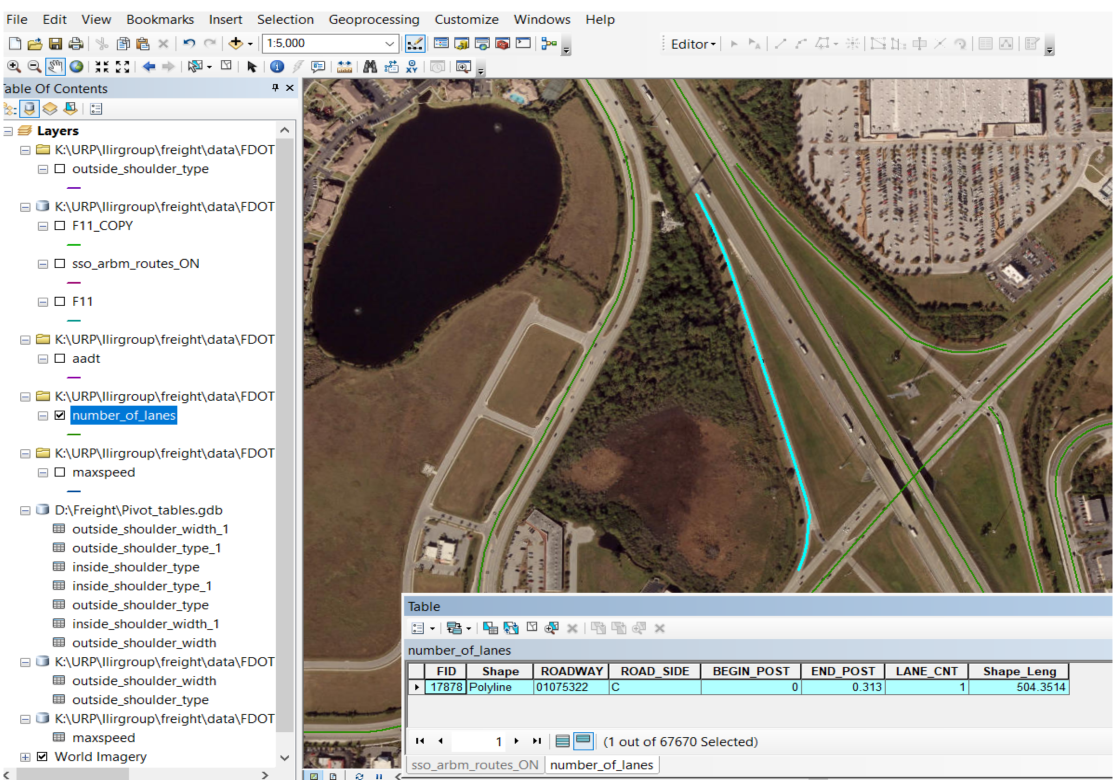


Figure 12 Screenshot illustration 11

4. DESCRIPTIVE ANALYSIS

This section presents descriptive statistics to help understand the distribution of the data values for most of the crash attributes of interest.

4.1. Crash Event General Statistics

4.1.1. Crash Attributes

The share of fatal crashes of large trucks is 1.8 times higher than the share of all vehicle fatal crashes, shown in Table 22 and 23.

Table 22 Large Truck Crash Severity Frequencies

Large Truck Crashes (2007-2016)	Frequency	Percent
No Injury Crashes	187,971	77.3%
Non-Serious Injury Crashes (possible injury + non-incapacitating injury)	44,986	18.5%
Serious Crashes (fatal+ incapacitating injury)	10,060	4.1%
Total	243,017	100.0%
Fatal Crashes	2,148	0.9%

Table 23 All Vehicle Crash Severity Frequencies

All Crashes (2007-2016)	Percent
No Injury Crashes	70.9%
Non-Serious Injury Crashes	25.1%
Serious Crashes	4.1%
Total	100.0%
Fatal Crashes	0.5%

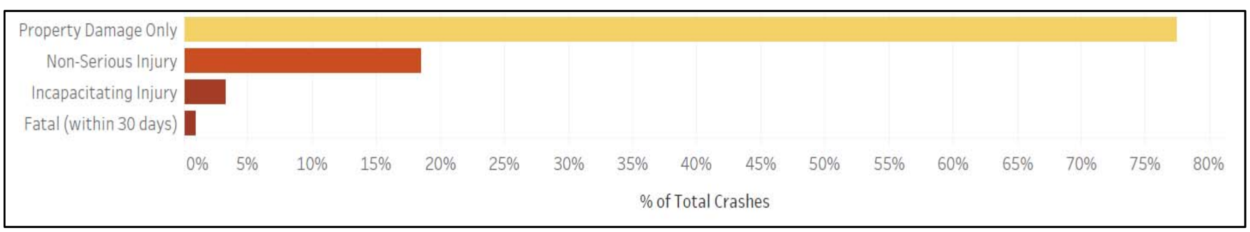


Figure 13 Crash severity of crashes involving large trucks

The most frequent crash type involving large trucks is rear end, followed by same direction sideswipe. Interestingly, collisions with parked vehicles is the third most frequent crash type (Table 24 and Figure 14).

Table 24 Crash Type Frequencies

Crash Type	Frequency	Percent	Cumulative Percent
10 - Rear End	59,425	24.5%	24.5%
16 - Same Direction Sideswipe	40,769	16.8%	41.2%
19 - Parked Vehicle	29,478	12.1%	53.4%
8 - Other	24,869	10.2%	63.6%
6 - Off Road	22,528	9.3%	72.9%
20 - Backed Into	12,617	5.2%	78.1%
18 - Single Vehicle	8,918	3.7%	81.7%
11 - Right Angle	8,817	3.6%	85.4%
3 - Left Entering	5,836	2.4%	87.8%
17 - Unknown	5,542	2.3%	90.0%
13 - Right/Through	4,802	2.0%	92.0%
2 - Head On	3,878	1.6%	93.6%
15 - Rollover	3,379	1.4%	95.0%
7 - Opposing Sideswipe	3,258	1.3%	96.3%
5 - Left Rear	3,118	1.3%	97.6%
4 - Left Leaving	2,589	1.1%	98.7%
9 - Pedestrian	1,213	0.5%	99.2%
21 - Animal	760	0.3%	99.5%
1 - Bicycle	709	0.3%	99.8%
12 - Right/Left	475	0.2%	100.0%
14 - Right/U-Turn	37	0.0%	100.0%
Total	243,017		

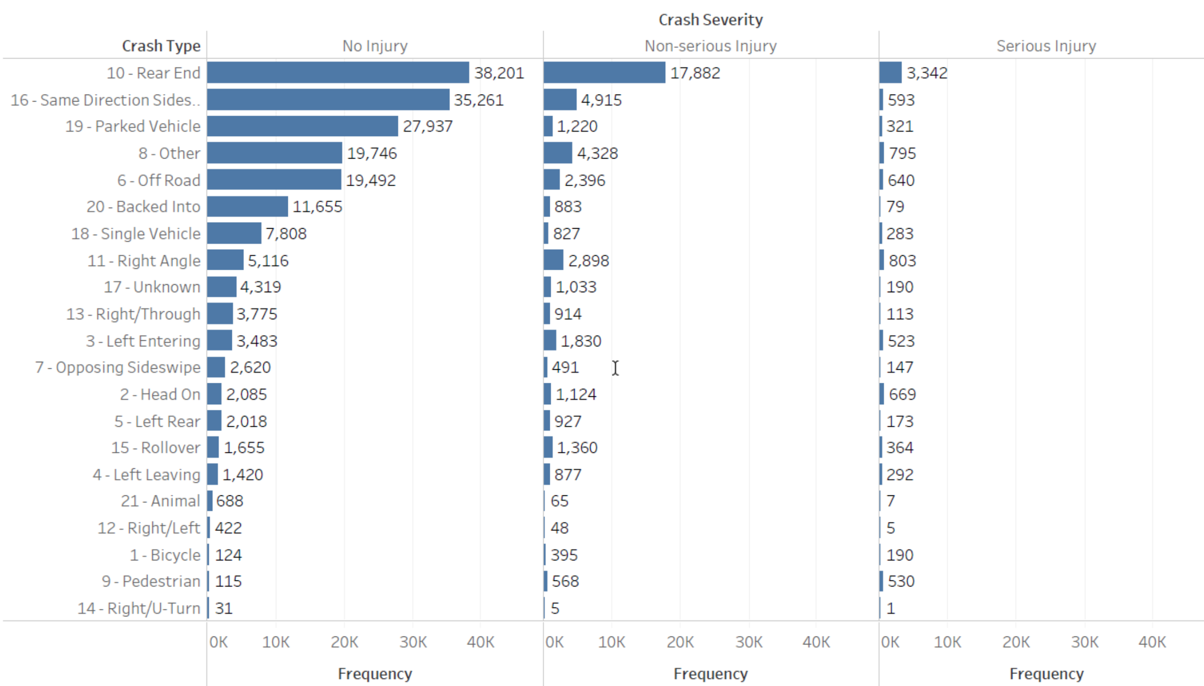


Figure 14 Crash types relative to injury severity

Rear end, head on, and pedestrian crashes are respectively the most common fatal crash types (Figure 15). While rear end is also the most common crash type for incapacitating injury severity, the right angle stands second (Figure 16).

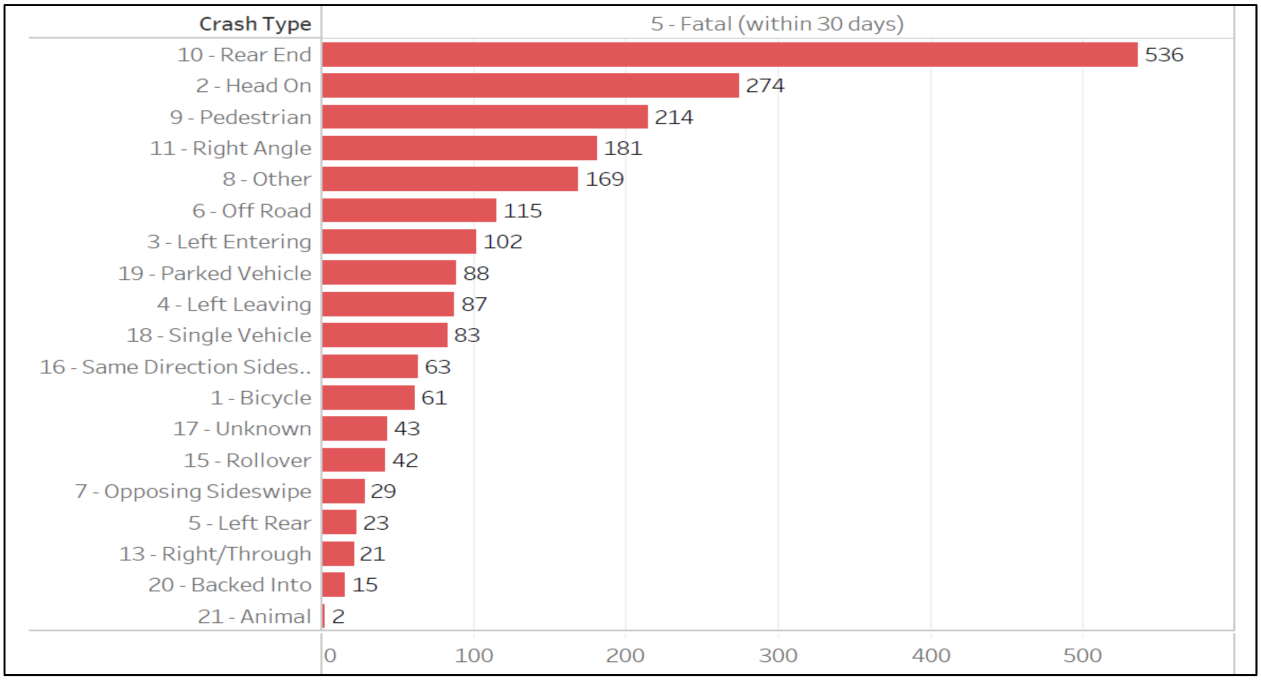


Figure 15 Fatal crash types

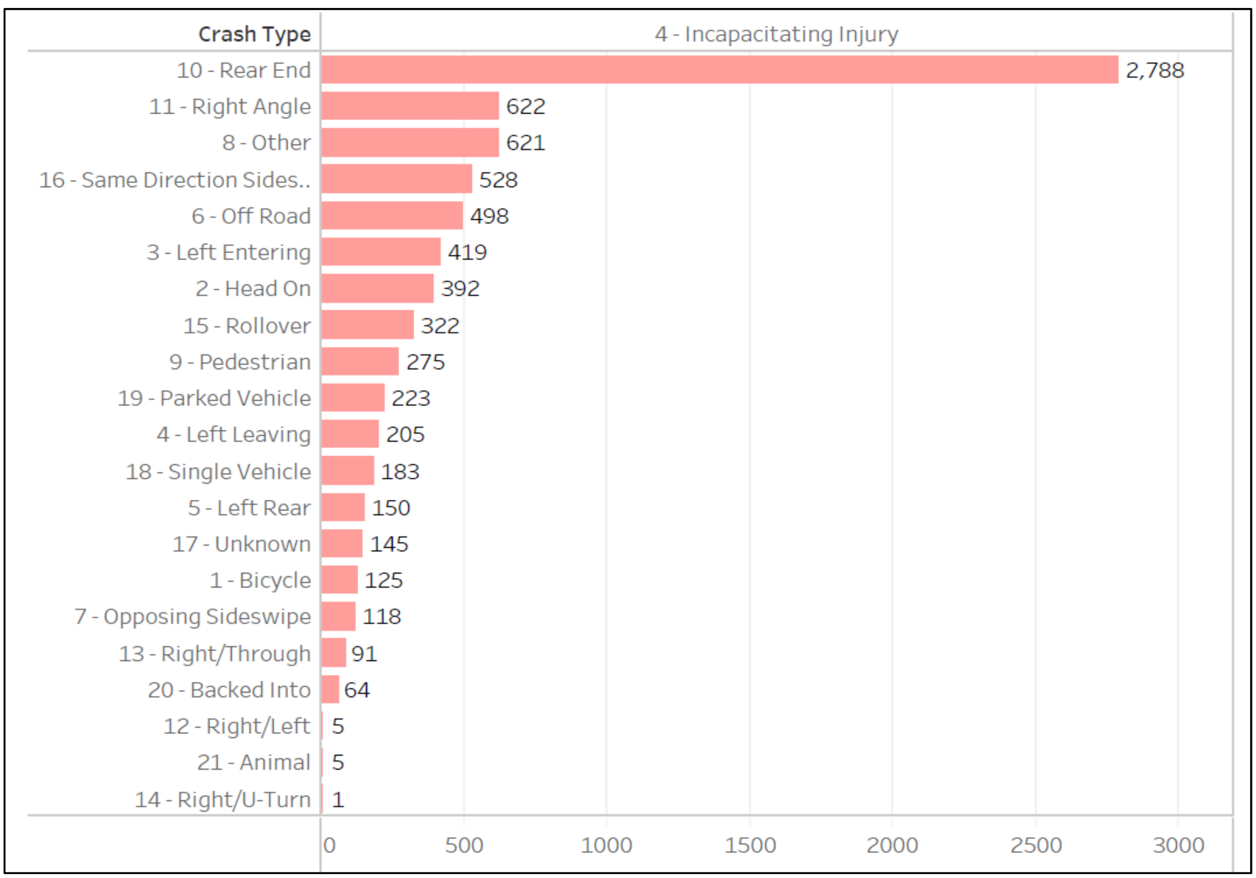


Figure 16 Incapacitating crash types

As the injury severity level increase, so does the share of out of city crashes (Figures 17 and 18). Among fatal crash types, opposing sideswipe, rollover, and head-on have the highest share of crashes that occur out of cities, whereas bicycle, pedestrian, and single vehicle crashes have the lowest share.

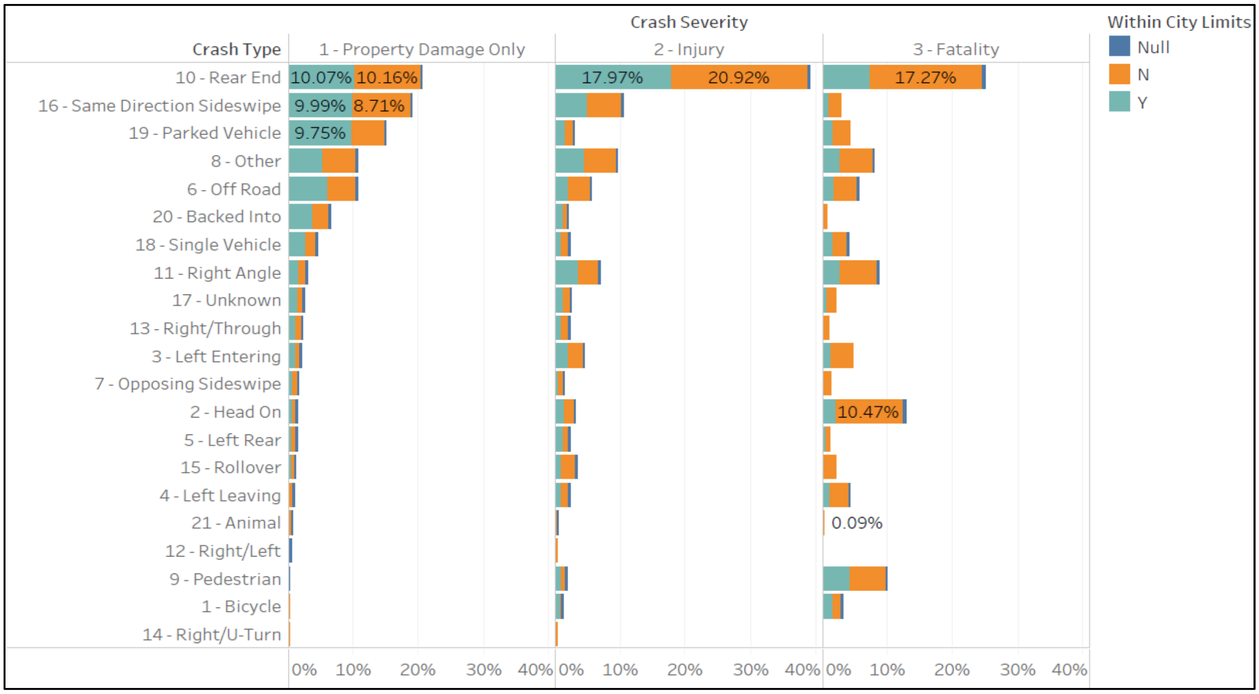


Figure 17 Crash type relative to injury severity and location within city

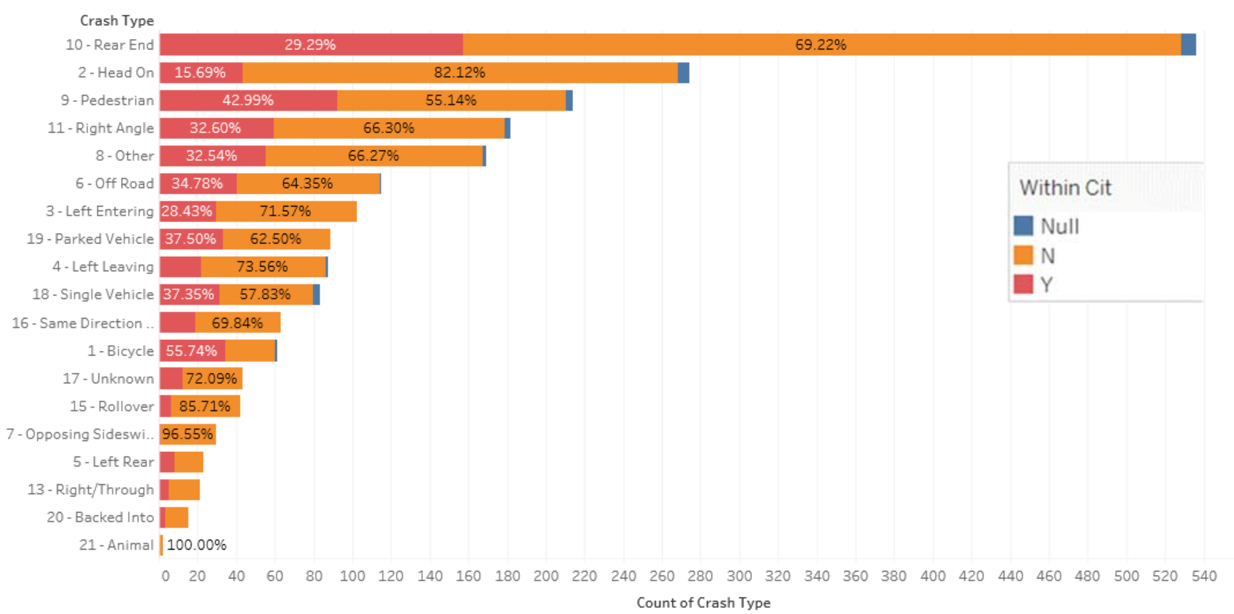


Figure 18 Crash type relative to fatal injury and location within city

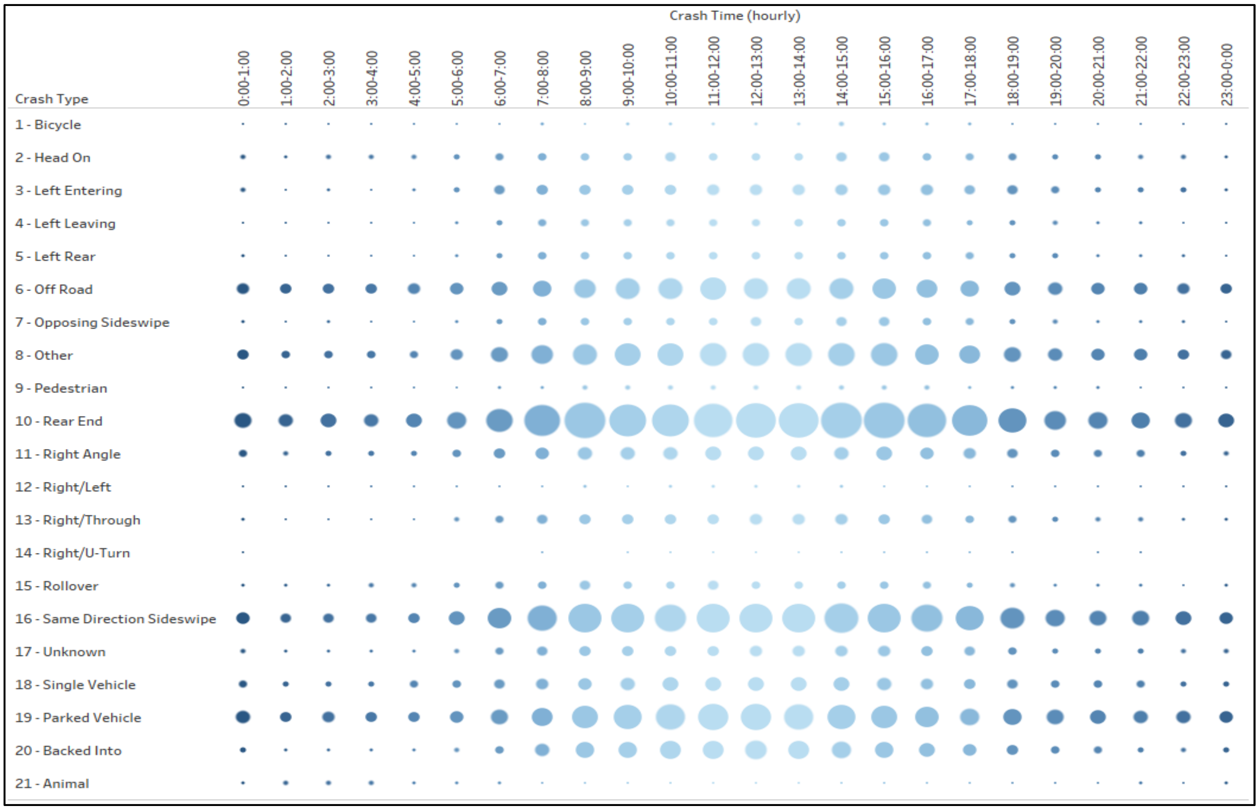


Figure 19 Crash type pattern over 24 hours

Crash Time ..	1 - Property Damage Only	Crash Time ..	2 - Injury	Crash Time ..	3 - Fatality
0:00-1:00	2,723	0:00-1:00	971	0:00-1:00	71
1:00-2:00	1,709	1:00-2:00	686	1:00-2:00	75
2:00-3:00	1,716	2:00-3:00	820	2:00-3:00	84
3:00-4:00	1,667	3:00-4:00	726	3:00-4:00	79
4:00-5:00	1,881	4:00-5:00	810	4:00-5:00	78
5:00-6:00	3,029	5:00-6:00	1,329	5:00-6:00	126
6:00-7:00	5,742	6:00-7:00	2,266	6:00-7:00	149
7:00-8:00	9,928	7:00-8:00	3,059	7:00-8:00	96
8:00-9:00	13,375	8:00-9:00	3,713	8:00-9:00	99
9:00-10:00	13,613	9:00-10:00	3,285	9:00-10:00	83
10:00-11:00	14,057	10:00-11:00	3,421	10:00-11:00	108
11:00-12:00	14,763	11:00-12:00	3,616	11:00-12:00	112
12:00-13:00	15,267	12:00-13:00	3,617	12:00-13:00	96
13:00-14:00	15,088	13:00-14:00	3,723	13:00-14:00	102
14:00-15:00	14,975	14:00-15:00	3,811	14:00-15:00	94
15:00-16:00	13,988	15:00-16:00	3,776	15:00-16:00	110
16:00-17:00	11,783	16:00-17:00	3,182	16:00-17:00	92
17:00-18:00	9,329	17:00-18:00	2,572	17:00-18:00	65
18:00-19:00	6,719	18:00-19:00	1,880	18:00-19:00	73
19:00-20:00	4,624	19:00-20:00	1,438	19:00-20:00	55
20:00-21:00	3,671	20:00-21:00	1,143	20:00-21:00	77
21:00-22:00	3,343	21:00-22:00	1,119	21:00-22:00	79
22:00-23:00	2,729	22:00-23:00	961	22:00-23:00	71
23:00-0:00	2,311	23:00-0:00	817	23:00-0:00	74

Figure 20 Crash distribution over 24 hours per crash severity

As shown in Figure 19 and 20, in general, most of crashes occur between 7:00 am to 6:00 pm, with the peak between 12:00 pm to 15:00 pm. However, this shifts up for fatal crashes in a way that majority of fatal crashes happen between 5:00 am and 5:00 pm. The peak of fatal crashes is observed between 5:00 am to 7:00 am.

Figure 21 shows that crashes involving large trucks show a declining trend between 2007 and 2009, remain constant between 2009 and 2010, before it decreases rapidly to 16,070 in 2011. After 2011 large truck crashes increase constantly. Overall, crashes follow a decreasing trend before 2011, and an increasing trend afterward.

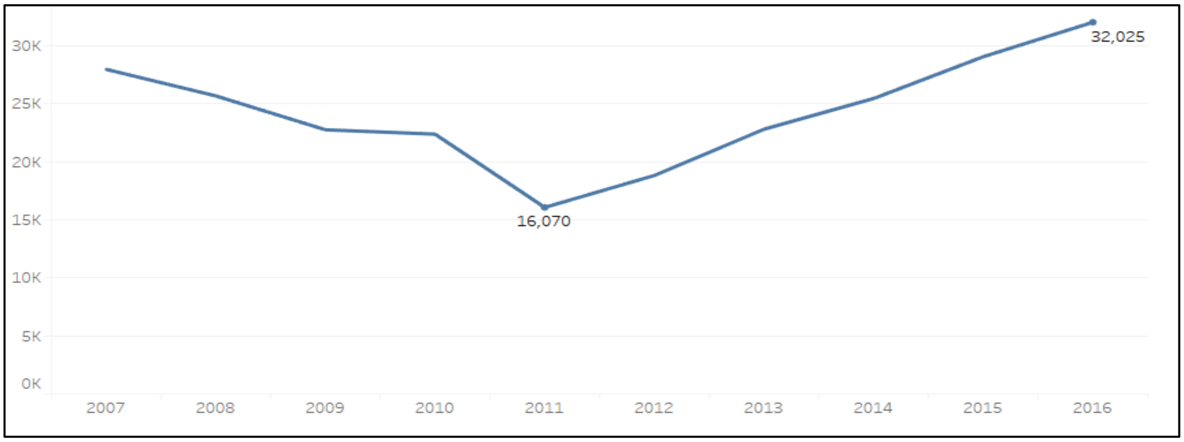


Figure 21 Large truck crash trend over 10 years

Fatalities follow a U-shape trend. The annual fatalities decrease from 333 in 2007 to 217 in 2009. From 2009 to 2013 the annual crash numbers don't fluctuate that much. Afterwards it shows a steady increase to 294 in 2016. Comparing all severity crashes and fatal crashes involving large trucks, fatalities decrease by 12% over a decade, even though crashes increases by 14.5% within the same time. Incapacitating injuries overall trend is similar to the fatalities trend (Figure 23).

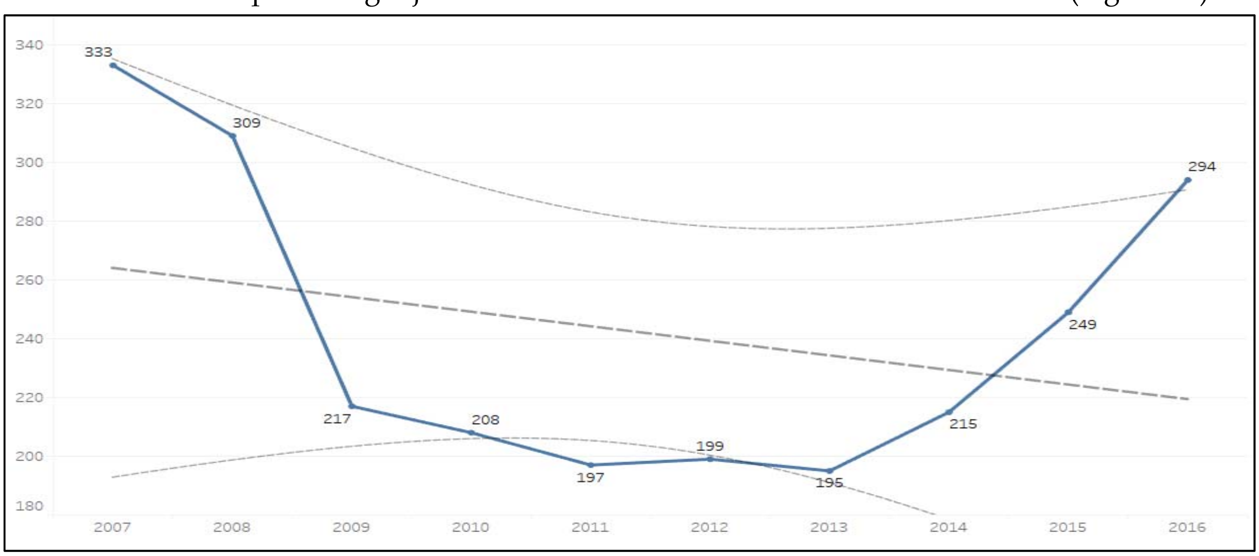


Figure 22 Large truck fatal crash trend over 10 years

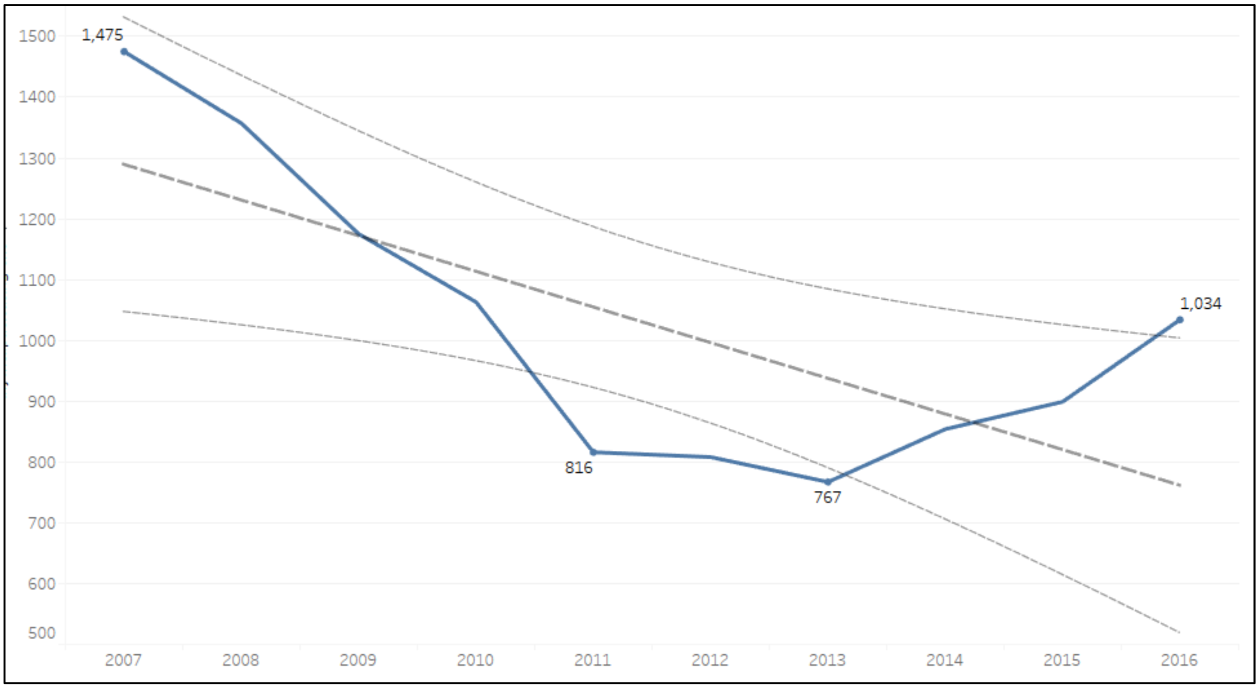


Figure 23 Large truck incapacitating crash trend over 10 years

Serious crashes follow a relatively different trend compared to other severity types (Table 25). Fatality counts have the highest percentage increase over the past four years.

Table 25 Large truck crash percentage changes

	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2013-2016
All crashes	-8.2%	-11.4%	-1.6%	-28.2%	17.1%	21.2%	11.6%	14.2%	10.2%	25.8%
Non-injury crash counts	-10.0%	-12.3%	-0.5%	-23.1%	17.3%	17.9%	13.9%	14.2%	9.8%	25.3%
Non-serious injury crash counts	-17.0%	-9.8%	-4.7%	-36.4%	4.2%	10.8%	7.7%	11.3%	14.8%	27.8%
Incapacitating injury crash counts	-8.0%	-13.4%	-9.5%	-23.2%	-1.0%	-5.1%	11.3%	5.3%	15.0%	21.1%
Fatal crash counts	-7.2%	-29.8%	-4.1%	-5.3%	1.0%	-2.0%	10.3%	15.8%	18.1%	36.7%

Table 26 Large truck crashes compared to all vehicle crash percentage change

	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2013-2016
Crash counts (LT)	-8.2%	-11.4%	-1.6%	-28.2%	17.1%	21.2%	11.6%	14.2%	10.2%	25.8%
All crashes	15.2%	-10.9%	-3.4%	7.2%	31.3%	24.0%	7.9%	8.0%	5.2%	22.6%
Fatal crash counts (LT)	-7.2%	-29.8%	-4.1%	-5.3%	1.0%	-2.0%	10.3%	15.8%	18.1%	36.7%
All fatal crashes	-8.0%	-12.6%	-6.0%	0.3%	0.8%	-0.9%	5.3%	15.8%	8.4%	32.2%

Compared to all crashes, large truck crashes increase at a higher rate over the past four years (Table 26). This is true for all severity and fatal severity crashes (Figure 24 and 25).

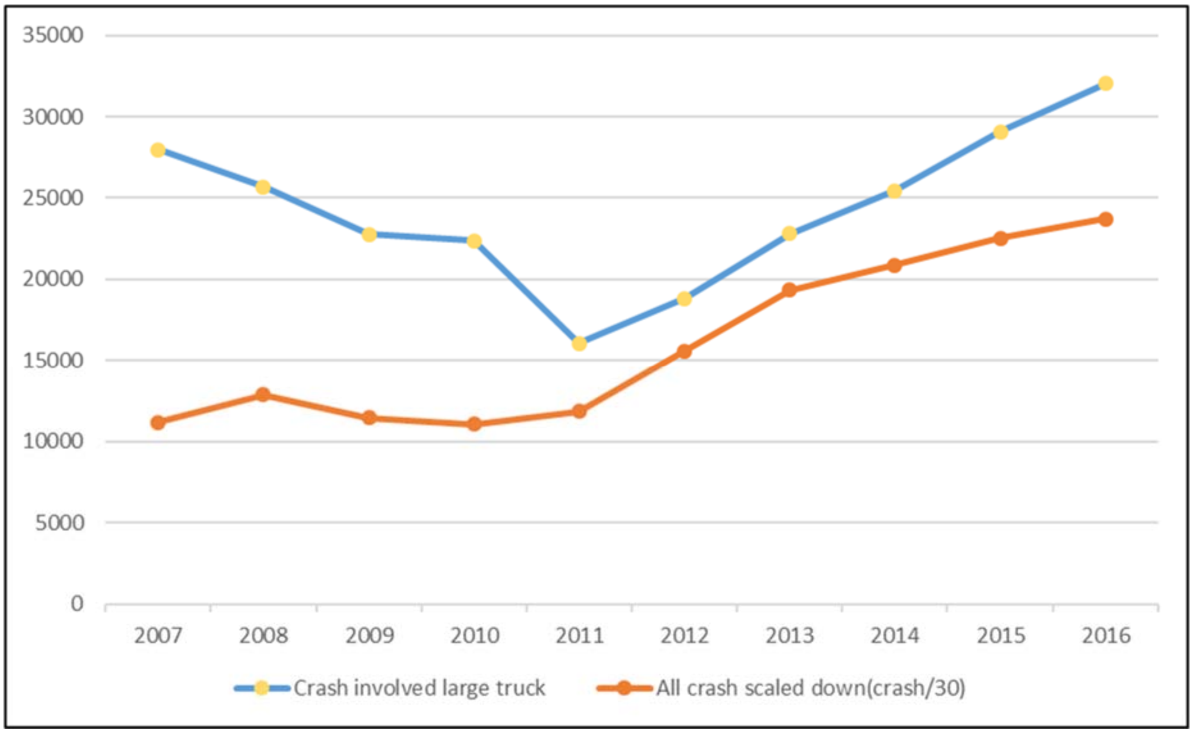


Figure 24 All crashes trend versus large truck crashes trend

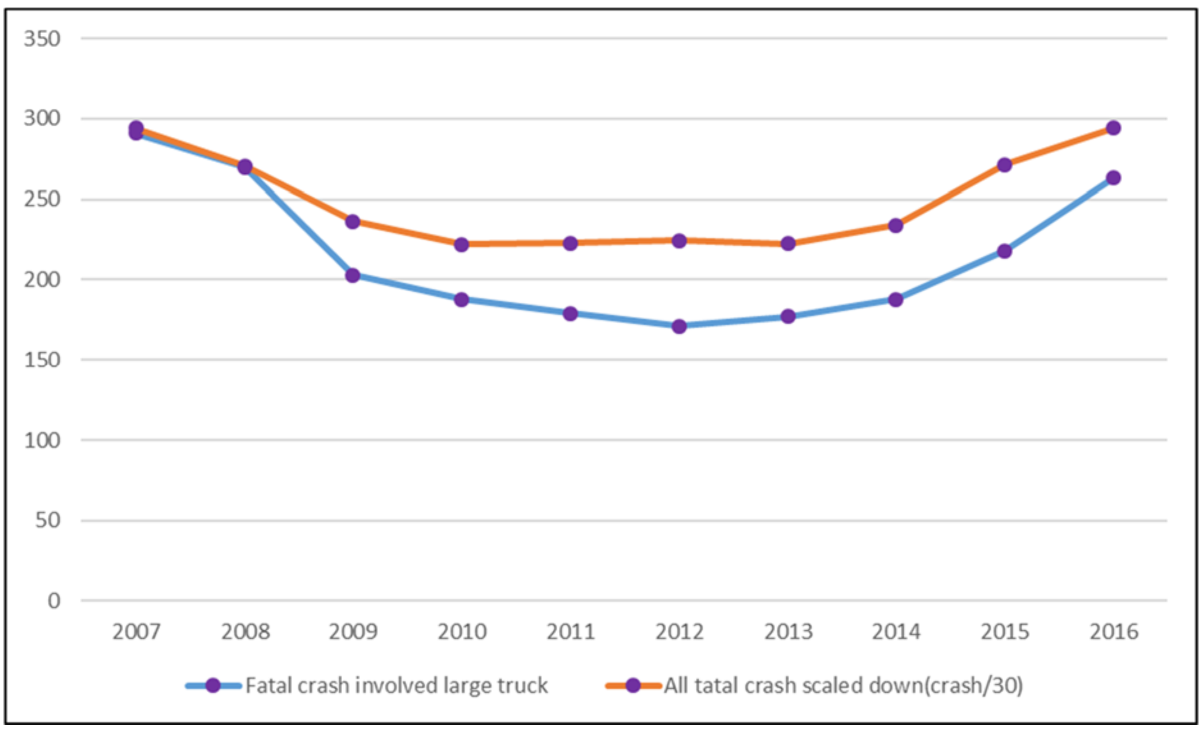


Figure 25 All fatal crashes trend versus large truck fatal crashes trend

4.1.2. Environmental Attributes

Table 27 Light Condition Relative to Crash Severity

Light Condition	All Crashes	1 - Property Damage Only	2 - Injury	3 - Fatality
1 - Daylight	79.1%	80.6%	74.9%	51.1%
4 - Dark - Lighted	11.1%	10.7%	12.2%	16.9%
5 - Dark - Not Lighted	5.7%	4.6%	8.6%	26.8%
2 - Dusk	1.8%	1.8%	1.8%	1.2%
3 - Dawn	1.8%	1.7%	2.1%	3.5%
88 - Unknown	0.5%	0.5%	0.3%	0.1%
6 - Dark - Unknown Lighting	0.1%	0.1%	0.0%	0.2%
Null	0.0%	0.0%	0.0%	0.0%
77 - Other	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%

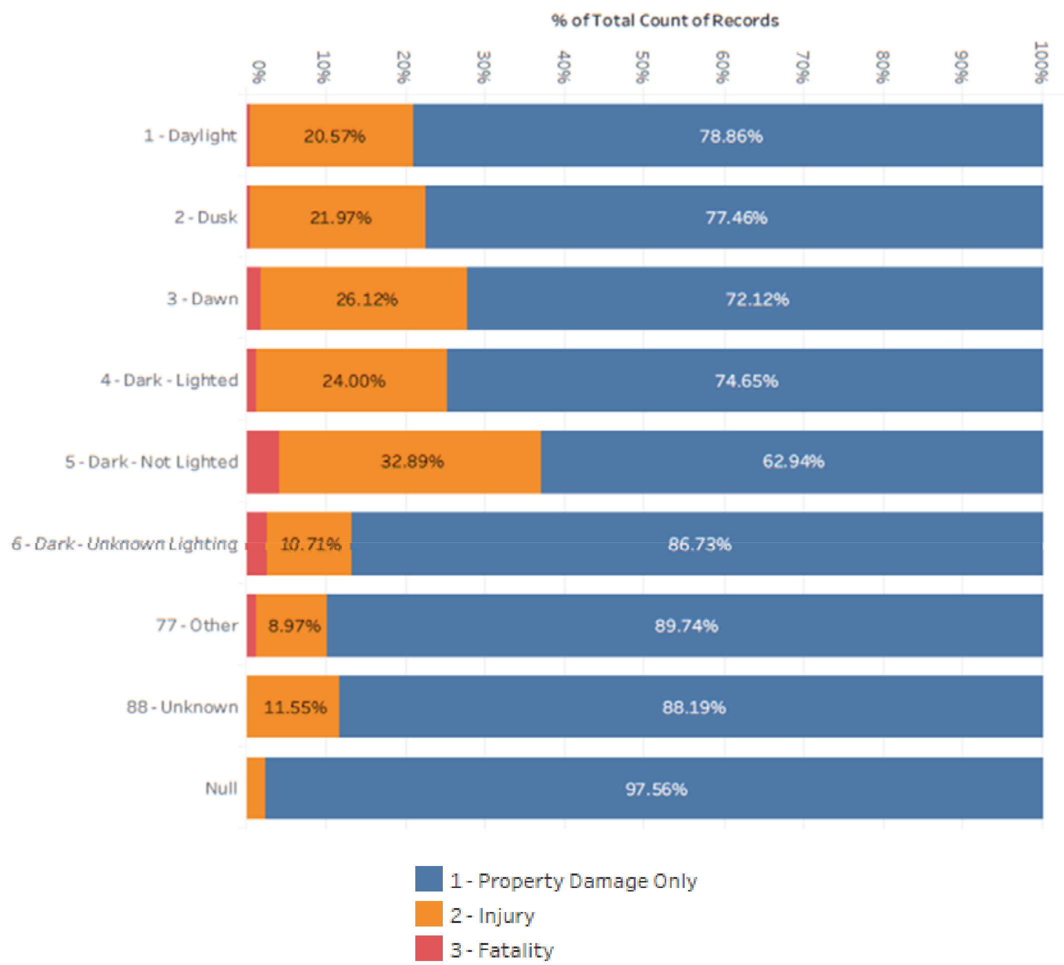


Figure 26 Light condition relative to crash severity

Highest share of fatal crashes has occurred during dark-not lighted situation. Fatal crashes have the lowest share of occurring during daylight. The share of 'dark-not lighted' of fatal crashes is approximately 27%, while the share of 'dark-not lighted' in all crashes is not more than 6%.

Table 28 Impaired Driving (Alcohol or Drug)

Impaired Driving	Frequency	Percent
Not Impaired	237,957	97.9%
Impaired	5,060	2.1%
Total	243,017	100.0%

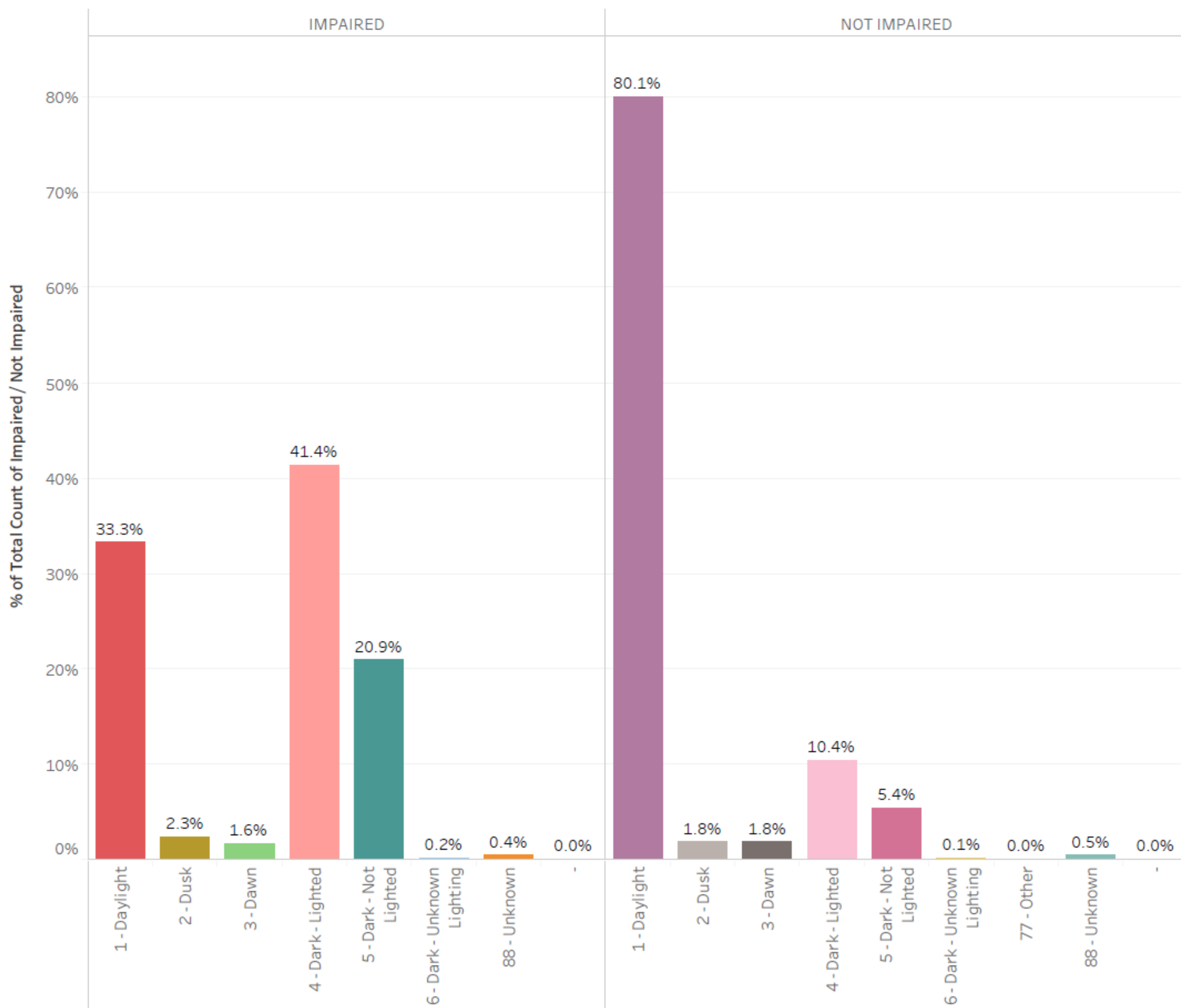


Figure 27 Share of impaired driving under each light condition

While dark lighted condition accounts for 11.1% of all crashes, it accounts for 41.4% of impaired crashes. In the same way, the share of dark not lighted from all impaired crashes is 20.9% while the its share from all crashes is just 5.7%. Thus, impaired crashes are more likely to occur in dark condition (dark lighted/dark not lighted). This is most pronounced for fatal crashes.

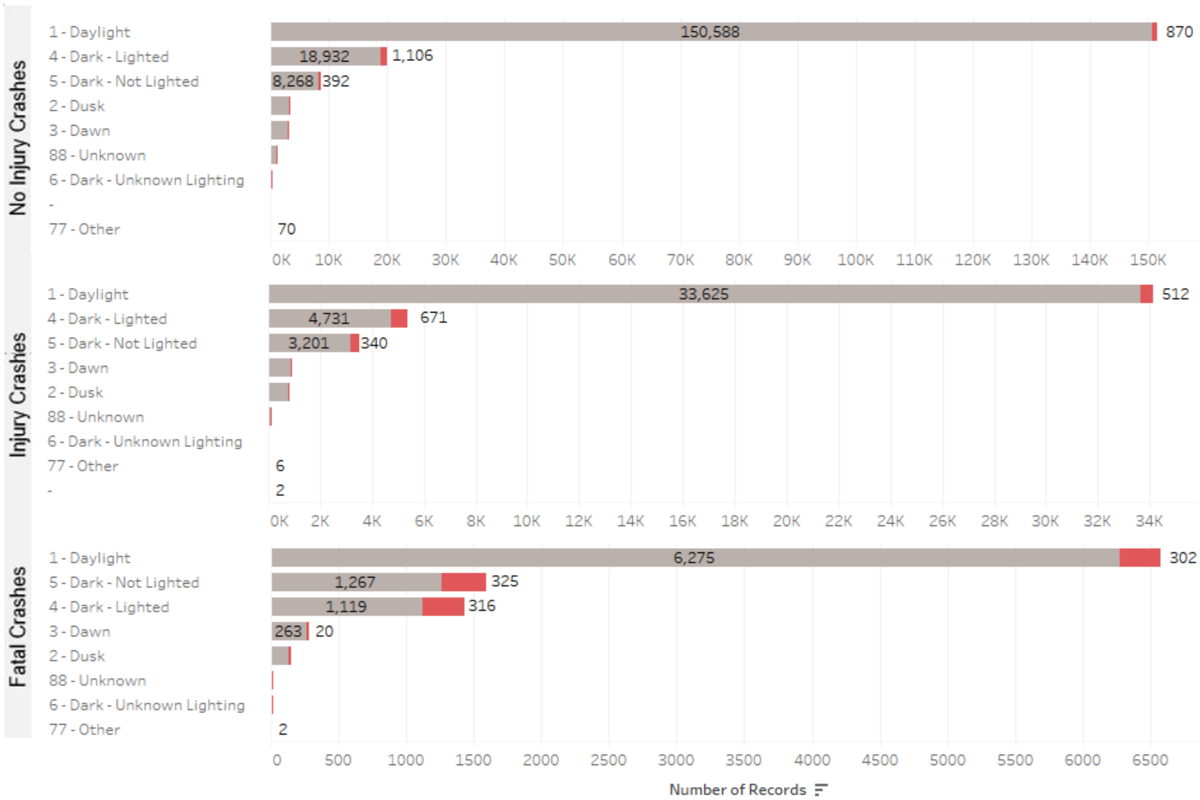


Figure 28 Light condition relative to crash severity and impaired driving

Table 29 Weather Condition Relative to Crash Severity

Weather Condition	All severity		PDO		Injury		Fatal	
	Count	pct	Count	pct	Count	pct	Count	pct
1 - Clear	175499	72.2%	137050	72.9%	36954	70.0%	1495	69.6%
2 - Cloudy	43229	17.8%	32510	17.3%	10250	19.4%	469	21.8%
3 - Rain	17330	7.1%	12540	6.7%	4662	8.8%	128	6.0%
77 - Other	4404	1.8%	4123	2.2%	280	0.5%	1	0.0%
4 - Fog, Smog, Smoke	1335	0.5%	837	0.4%	449	0.9%	49	2.3%
Null	1173	0.5%	1009	0.5%	159	0.3%	5	0.2%
7 - Severe Crosswinds	30	0.0%	22	0.0%	8	0.0%	0	0.0%
5 - Sleet/Hail/Freezing Rain	12	0.0%	9	0.0%	2	0.0%	1	0.0%
6 - Blowing Sand, Soil, Dirt	5	0.0%	3	0.0%	2	0.0%	0	0.0%

Injury crashes have significantly higher percentage of occurrence in cloudy and rainy weather, and lower percentage of occurrence in clear weather. The most significant difference between fatal crashes and other crash severities, is the higher percentage of crash occurrence in cloudy, fog, smog, and smoke weather conditions.

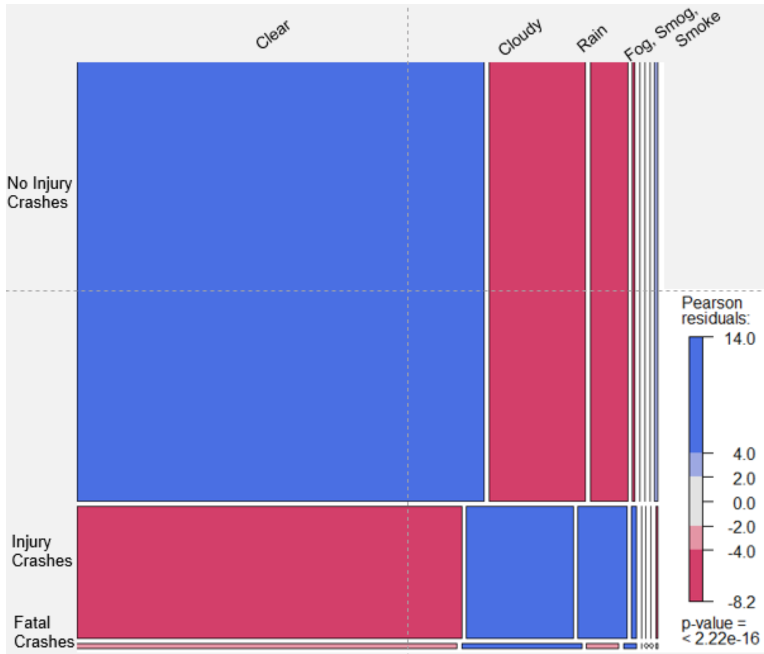


Figure 29 Weather condition relative to crash severity (standardize residuals)

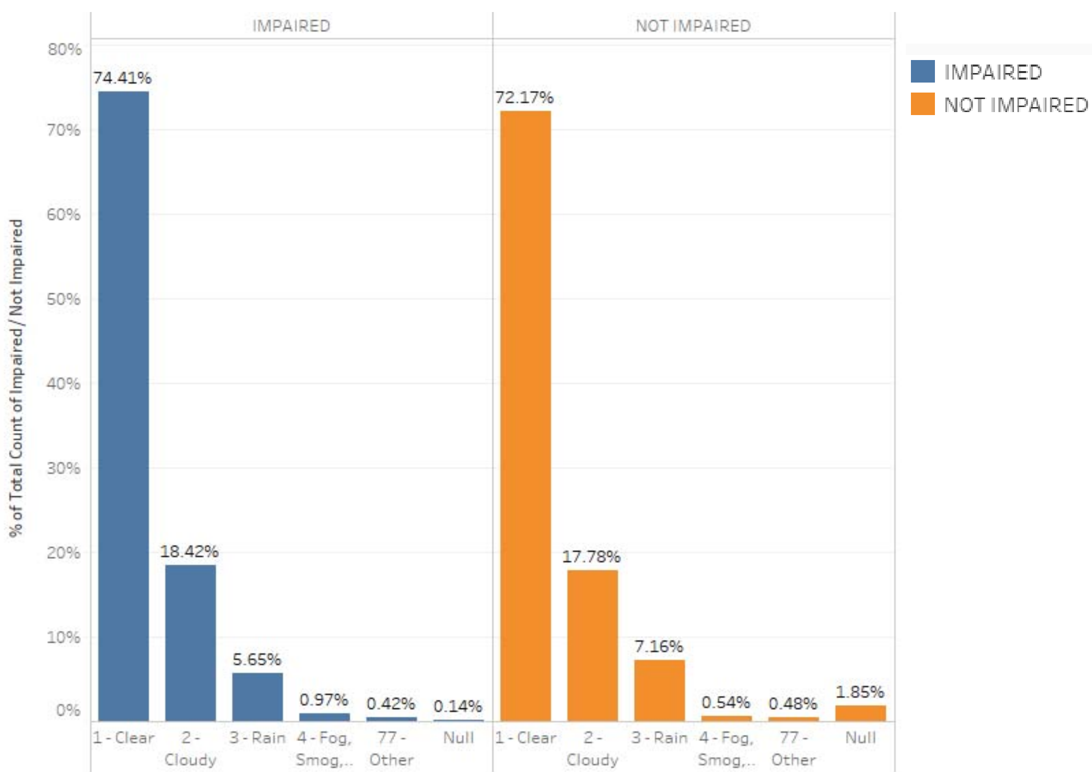


Figure 30 Share of impaired driving under each weather condition

4.1.3. Network Attributes

Table 30 Road System Identifier per Crash Severity

Road System Identifier	All Crashes	PDO	Injury	Fatality
1 - Interstate	16.3%	14.8%	21.3%	23.5%
2 - U.S.	8.4%	7.3%	11.9%	20.0%
3 - State	22.0%	20.1%	28.6%	29.5%
4 - County	12.7%	12.4%	13.7%	13.4%
5 - Local	23.2%	24.7%	18.2%	8.6%
6 - Turnpike/Toll	2.9%	2.8%	3.5%	3.8%
7 - Forest Road	0.0%	0.0%	0.0%	0.0%
8 - Private Roadway	1.8%	2.2%	0.6%	0.4%
9 - Parking Lot	11.1%	13.9%	1.7%	0.5%
77 - Other	1.4%	1.7%	0.5%	0.3%
Null	0.0%	0.1%	0.0%	0.0%

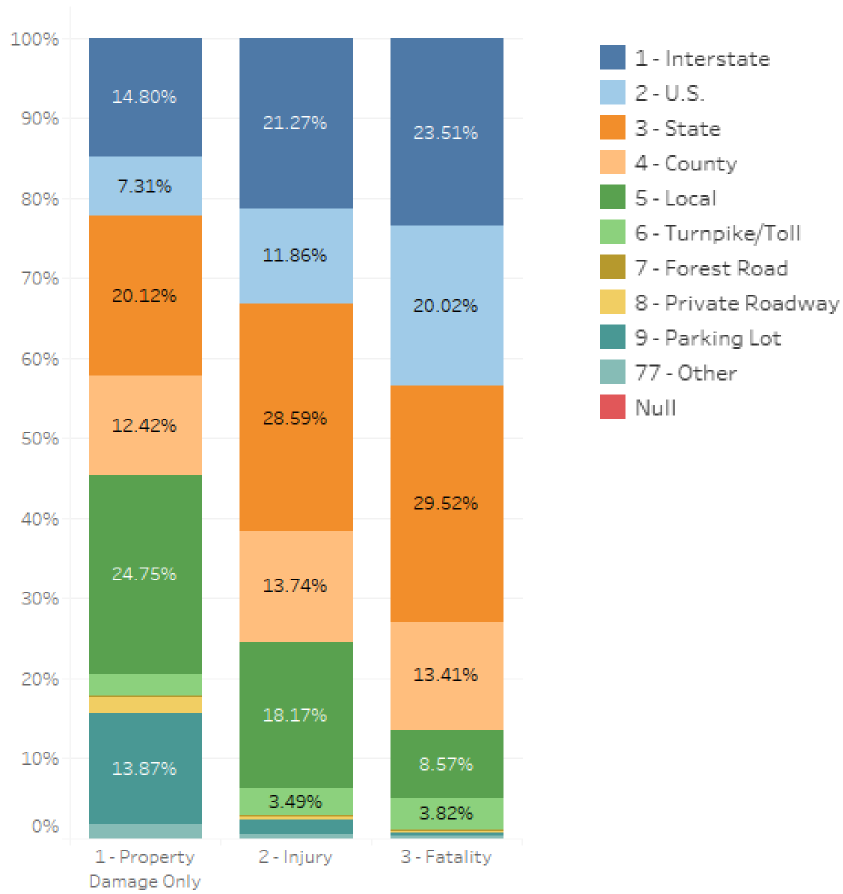


Figure 31 Road system identifier per crash severity

Crashes in local, state, and interstate roads have the highest share of all severity types. Fatal crashes have the highest share of state, interstate, and US roads. The share of US roads from all fatal crashes is more than two times the share of US roads from all crashes.

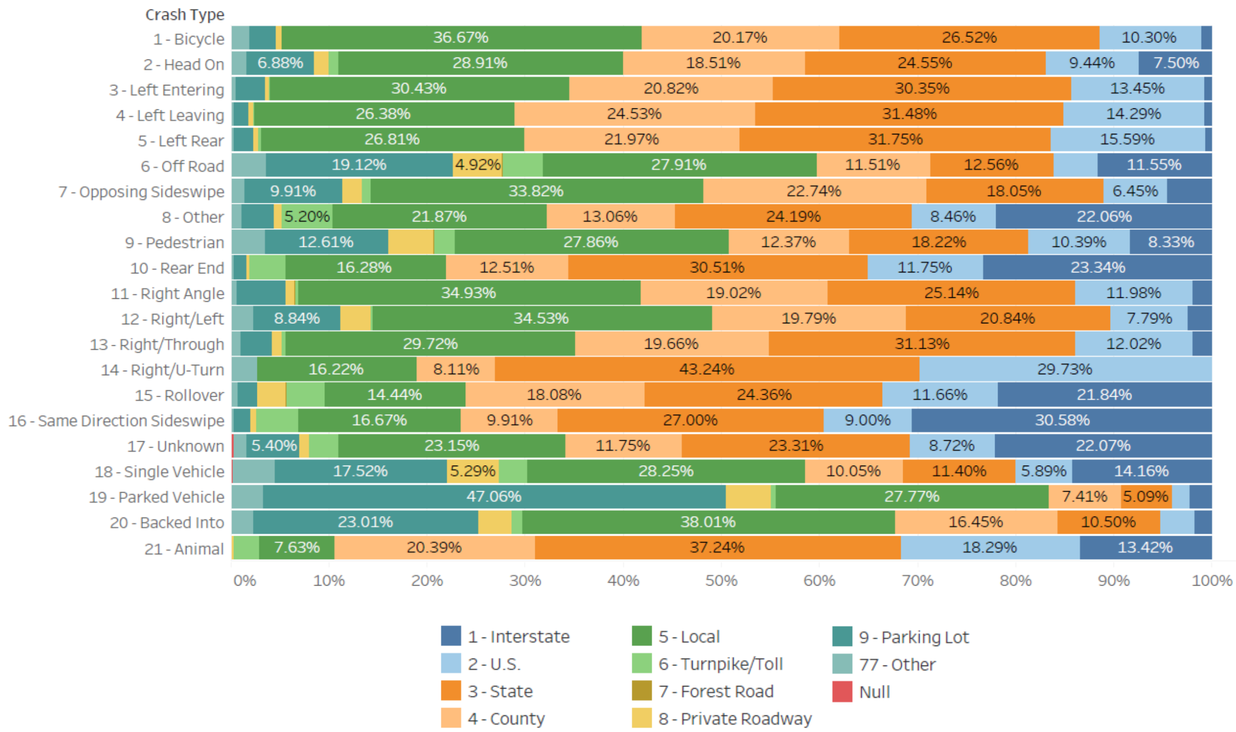


Figure 32 Road system identifier per crash type

Among all crash types, rear end, and same direction sideswipe have significantly higher share of interstate roads. Parked vehicle, off road, backed into, single vehicle, and pedestrian have significantly higher share of parking lot crashes. Crashes involving bicycles have a high share of county and local roads.

Table 31 Type of Intersection per Crash Severity

Type of Intersection	All Crashes	PDO	Injury Crashes	Fatal Crashes
1 - Not at Intersection	69.1%	71.1%	61.9%	68.0%
2 - Four-Way Intersection	20.5%	18.5%	27.7%	21.9%
3 - T-Intersection	6.3%	6.1%	6.9%	7.8%
4 - Y-Intersection	1.3%	1.2%	1.7%	1.0%
5 - Traffic Circle	0.0%	0.1%	0.0%	0.0%
6 - Roundabout	0.1%	0.1%	0.0%	0.0%
7 - Five-Point, or More	0.1%	0.1%	0.0%	0.0%
77 - Other	2.5%	2.8%	1.7%	1.3%
Null	0.1%	0.1%	0.0%	0.0%

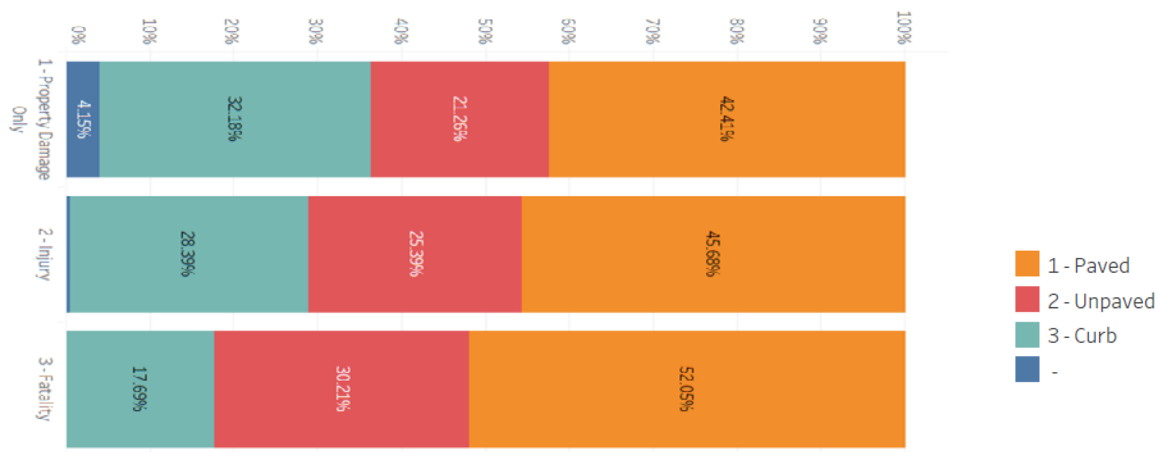


Figure 33 Type of intersection by crash severity

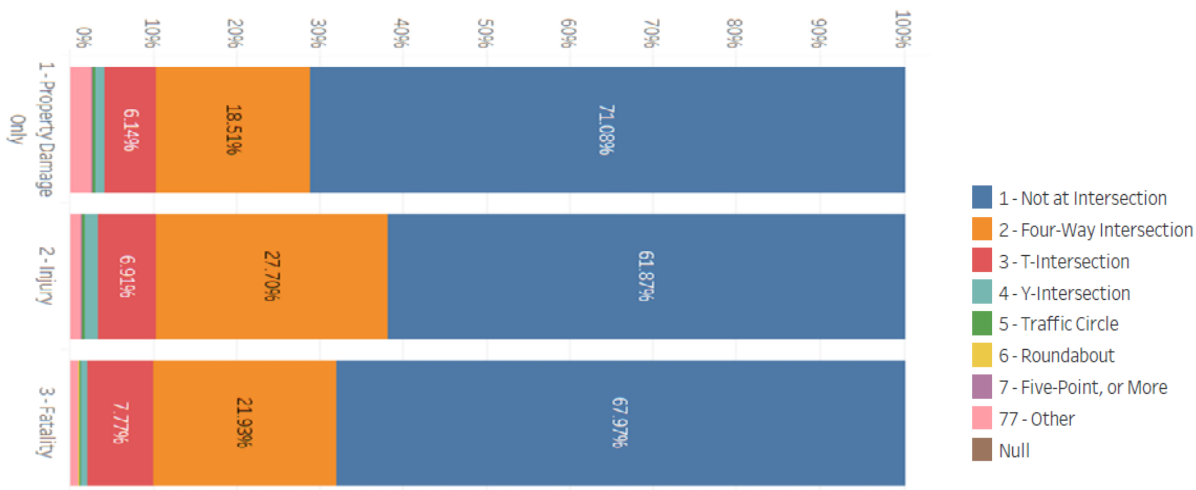


Figure 34 Type of shoulder by crash severity

Injury and fatal crashes have smaller share of 'not at intersection' crashes, and higher share of four-way and T-intersection crashes. Fatal crashes have the highest share of T-intersection crashes among all severity types.

Table 32 Crashes by Type of Shoulder

Type of Shoulder	Frequency	Percent
1 - Paved	104,993	43.2
2 - Unpaved	554,028	22.2
3 - Curb	75,896	31.2
Null	48,100	3.3

As the crash severity increases, the share of shoulder curb goes down, and the share of paved and unpaved curves increases.

4.2. Driver Event General Statistics

Table 33 Vehicle Types Involved in Large Truck Crash and Associated Fatal Risks

VEH_BODY_TYPE	Drivers Percent	Drivers fatality within drivers involved	Drivers injury within drivers involved
20 - Medium/Heavy Trucks (more than 10,000 lbs (4,536 kg))	52.7%	0.10%	5.47%
1 - Passenger Car	28.5%	0.56%	21.58%
3 - Pickup	6.9%	0.76%	20.82%
16 - (Sport) Utility Vehicle	3.6%	0.56%	20.29%
2 - Passenger Van	3.0%	0.61%	19.66%
8 - Bus	1.3%	0.14%	6.50%
19 - Other Light Trucks (10,000 lbs (4,536 kg) or less)	0.9%	0.14%	7.43%
77 - Other	0.9%	0.03%	5.99%
Null	0.7%	0.03%	0.82%
17 - Cargo Van (10,000 lbs (4,536 kg) or less)	0.5%	0.37%	9.22%
88 - Unknown	0.3%	0.00%	2.61%
11 - Motorcycle	0.3%	12.87%	63.64%
7 - Motor Home	0.1%	0.00%	5.74%
18 - Motor Coach	0.1%	0.00%	2.68%
15 - Low Speed Vehicle	0.0%	1.00%	14.50%
21 - Farm Labor Vehicle	0.0%	0.66%	8.61%
12 - Moped	0.0%	6.62%	58.09%
13 - All Terrain Vehicle (ATV)	0.0%	3.85%	25.00%

Most of large truck crashes involve passenger cars, followed by pickups and utility vehicles. The highest fatal risk of large truck crashes is imposed to motorcycles, mopeds, and ATVs respectively. The fatal risk to drivers of large trucks is limited to 10 fatalities out of 10,000 crashes. The highest injury risk of large truck crashes is for drivers of motorcycles and mopeds.

Table 34 Unrestrained Drivers by Gender

	Gender				
Restraint System	1 - Male	2 - Female	88 - Unknown	Null	Grand Total
-	1.58%	2.00%	2.65%	96.60%	7.39%
1 - Not Applicable (non-motorist)	1.52%	0.80%	5.77%	0.09%	1.32%
2 - None Used - Motor Vehicle Occupant	4.48%	3.26%	0.81%	1.03%	4.01%
3 - Shoulder and Lap Belt Used	90.45%	92.60%	24.46%	2.11%	85.15%
4 - Shoulder Belt Only Used	0.59%	0.50%	0.32%	0.01%	0.53%
5 - Lap Belt Only Used	0.39%	0.11%	0.32%		0.31%
6 - Restraint Used - Type Unknown	0.19%	0.13%	3.72%	0.04%	0.19%
7 - Child Restraint System - Forward Facing	0.00%	0.01%	0.18%		0.01%
8 - Child Restraint System - Rear Facing	0.00%		0.04%		0.00%
9 - Booster Seat	0.00%				0.00%
10 - Child Restraint System - Type Unknown	0.03%	0.06%	0.04%	0.00%	0.03%
77 - Other	0.78%	0.53%	61.70%	0.12%	1.07%

Table 35 Unrestrained Drivers per Injury Severity

Injury Severity	Count of drivers	Injury Unrestrained Pct	Fatality Unrestrained Pct
Null	32,768	0.0%	0.0%
1 - None	365,104	0.0%	0.0%
2 - Possible	30,655	3.9%	0.0%
3 - Non-Incapacitating	18,284	7.2%	0.0%
4 - Incapacitating	7,158	13.2%	0.0%
5 - Fatal (within 30 days)	1,628	0.0%	33.6%
6 - Non-Traffic Fatality	102	0.0%	28.4%

33.6% of fatalities and 28.4% of non-traffic fatalities are related to unrestrained driving. 13.2% of incapacitating injuries are unrestrained.

Table 36 Fatal Risk Associated with Large Truck Crashes and the Share of Unrestrained Drivers in Fatalities

Crash Type	Driver Count	Driver fatality within drivers involved	Unrestrained within drivers fatalities	Pct of large truck drivers from Unrestrained fatalities	Drivers injury within drivers involved	Unrestrained within drivers injuries	Pct of Large truck drivers from Unrestrained injuries
10 - Rear End	130,411	0.36%	35.76%	13.17%	18.06%	4.59%	17.67%
16 - Same Direction Sideswipe	82,221	0.06%	30.43%	14.29%	6.79%	3.49%	15.90%
8 - Other	52,835	0.29%	22.52%	5.88%	10.09%	7.20%	25.26%
19 - Parked Vehicle	45,047	0.14%	39.06%	16.00%	2.94%	14.89%	28.93%
6 - Off Road	25,235	0.40%	56.44%	68.42%	11.47%	10.50%	75.00%
20 - Backed Into	24,937	0.05%	38.46%	0.00%	3.45%	6.50%	23.21%
11 - Right Angle	18,316	0.87%	36.25%	6.90%	21.91%	6.48%	18.46%
3 - Left Entering	12,075	0.72%	25.29%	4.55%	21.01%	6.39%	16.67%
17 - Unknown	11,479	0.34%	38.46%	13.33%	11.30%	4.86%	15.87%
13 - Right/Through	9,778	0.18%	44.44%	12.50%	10.40%	6.69%	13.24%
18 - Single Vehicle	8,688	0.46%	65.00%	100.00%	7.23%	10.99%	98.55%
2 - Head On	8,315	3.28%	35.53%	4.12%	24.49%	11.20%	21.49%
7 - Opposing Sideswipe	6,597	0.42%	17.86%	20.00%	10.91%	6.67%	14.58%
5 - Left Rear	6,431	0.23%	13.33%	0.00%	18.04%	4.83%	23.21%
4 - Left Leaving	5,350	1.63%	20.69%	0.00%	23.35%	5.92%	17.57%
15 - Rollover	3,962	0.91%	55.56%	65.00%	42.15%	10.60%	92.66%
9 - Pedestrian	1,360	0.07%	100.00%	0.00%	4.85%	22.73%	60.00%
12 - Right/Left	955	0.00%			5.45%	5.77%	33.33%
21 - Animal	864	0.23%	50.00%	0.00%	7.52%	1.54%	0.00%
1 - Bicycle	766	0.00%			4.44%	29.41%	30.00%
14 - Right/U-Turn	77	0.00%			9.09%	14.29%	0.00%

Driver's most dangerous crash types are "Head on", "Left leaving", "Rollover" and "Right angle". More than half of the driver's fatalities on Single vehicle and Rollover crashes are related to unrestrained drivers. In 65% of those rollover crashes and 68% of those off-road crashes, an unrestrained driver is a large truck driver. Also, in case of unrestrained injuries from rollover and off-road crashes, 93% and 75% of the time, respectively, an unrestrained driver is a large truck driver. Off-road and rollover crashes have the highest share of unrestrained large truck drivers from all unrestrained fatalities/injuries.

Table 37 Ejection per Crash Severity

Ejection	1 - None	2 - Possible	3 - Non-Incapacitating	4 - Incapacitating	5 - Fatal (within 30 days)	6 - Non-Traffic Fatality	Null
1 - Not Ejected	98.43%	98.47%	96.84%	93.13%	75.25%	91.18%	8.69%
2 - Ejected, Totally	0.18%	0.62%	1.87%	4.61%	15.79%	4.90%	0.07%
3 - Ejected, Partially	0.04%	0.14%	0.36%	0.71%	2.95%	1.96%	
4 - Not Applicable	0.46%	0.19%	0.44%	0.45%	2.27%	0.98%	0.04%
88 - Unknown	0.65%	0.32%	0.15%	0.18%	0.37%	0.98%	1.71%
-	0.23%	0.25%	0.35%	0.92%	3.38%		89.50%

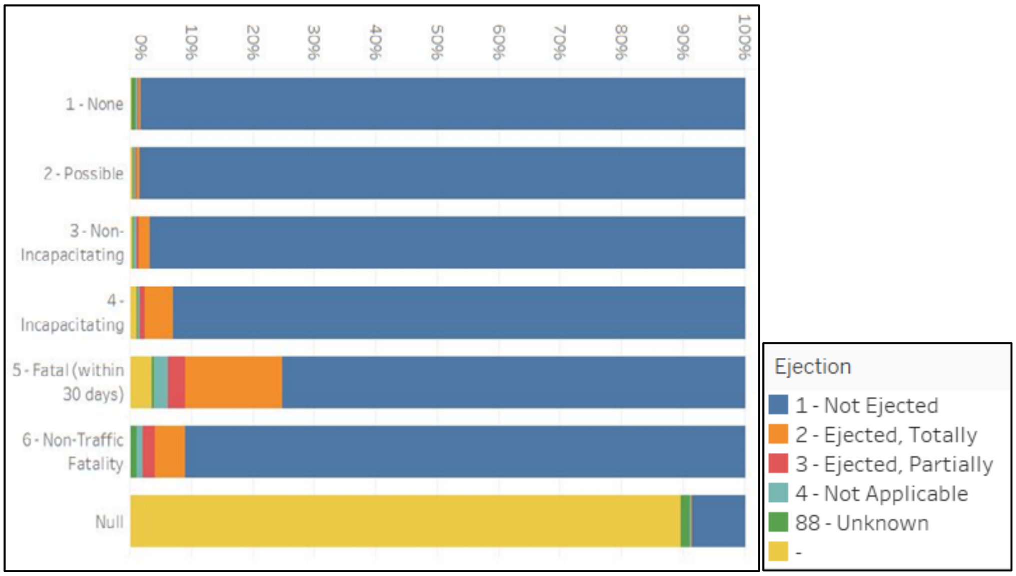


Figure 35 Ejection per crash severity

The share of totally or partially ejected is higher for more severe injuries.

Table 38 Airbag Deployment

Airbag Deployed	Count of drivers	Percent
1 - Not Applicable	55,817	12.25%
2 - Not Deployed	251,779	55.25%
3 - Deployed - Front	18,662	4.10%
4 - Deployed - Side	947	0.21%
5 - Deployed - Other	27	0.01%
6 - Deployed - Combi..	2,085	0.46%
7 - Deployed - Curtain	111	0.02%
88 - Deployment Un..	3,790	0.83%
Null	122,481	26.88%

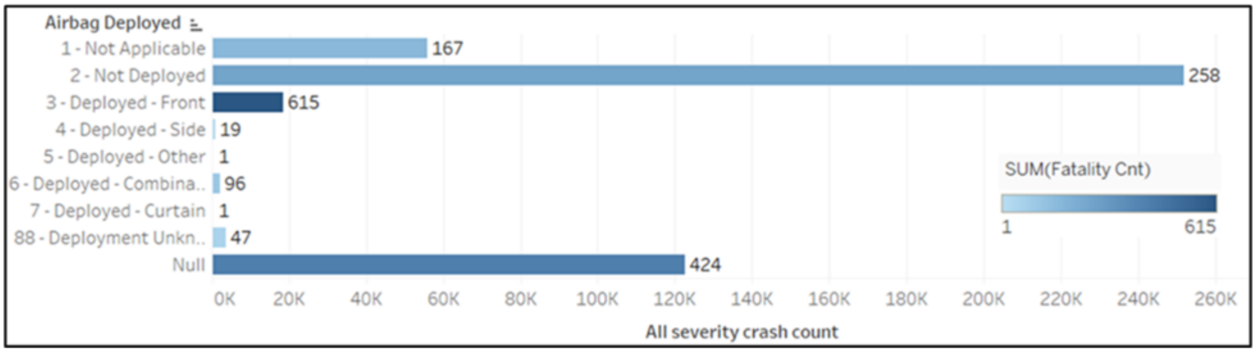


Figure 36 Fatalities relative to airbag deployment

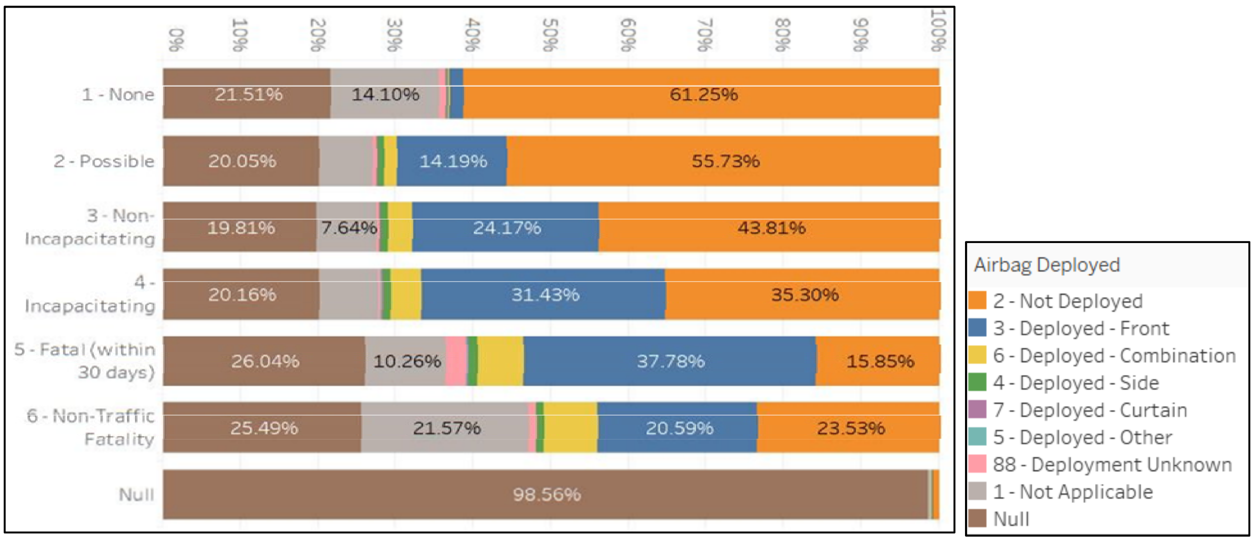


Figure 37 Airbag deployment per crash severity

Table 39 Airbag Deployment by Gender

	Gender			
Airbag Deployed	1 - Male	2 - Female	88 - Unknown	Null
1 - Not Applicable	14.69%	6.65%	14.87%	0.57%
2 - Not Deployed	57.40%	64.70%	21.98%	1.41%
3 - Deployed - Front	3.46%	7.79%	0.92%	0.10%
4 - Deployed - Side	0.13%	0.55%		0.00%
5 - Deployed - Other	0.00%	0.01%		
6 - Deployed - Combination	0.37%	0.93%	0.21%	
7 - Deployed - Curtain	0.02%	0.05%	0.04%	
88 - Deployment Unknown	0.50%	0.43%	58.80%	0.21%
Null	23.43%	18.89%	3.19%	97.71%

Most of drivers' fatalities (29.6%) occur in a condition that front airbag is deployed. Within injury severities, fatal crashes have the highest share of airbags deployed from front. Within female drivers, the share of crashes in which the front/side/curtain/other/combination air bag has deployed is more than that of male drivers.

4.3. Vehicle Event General Statistics

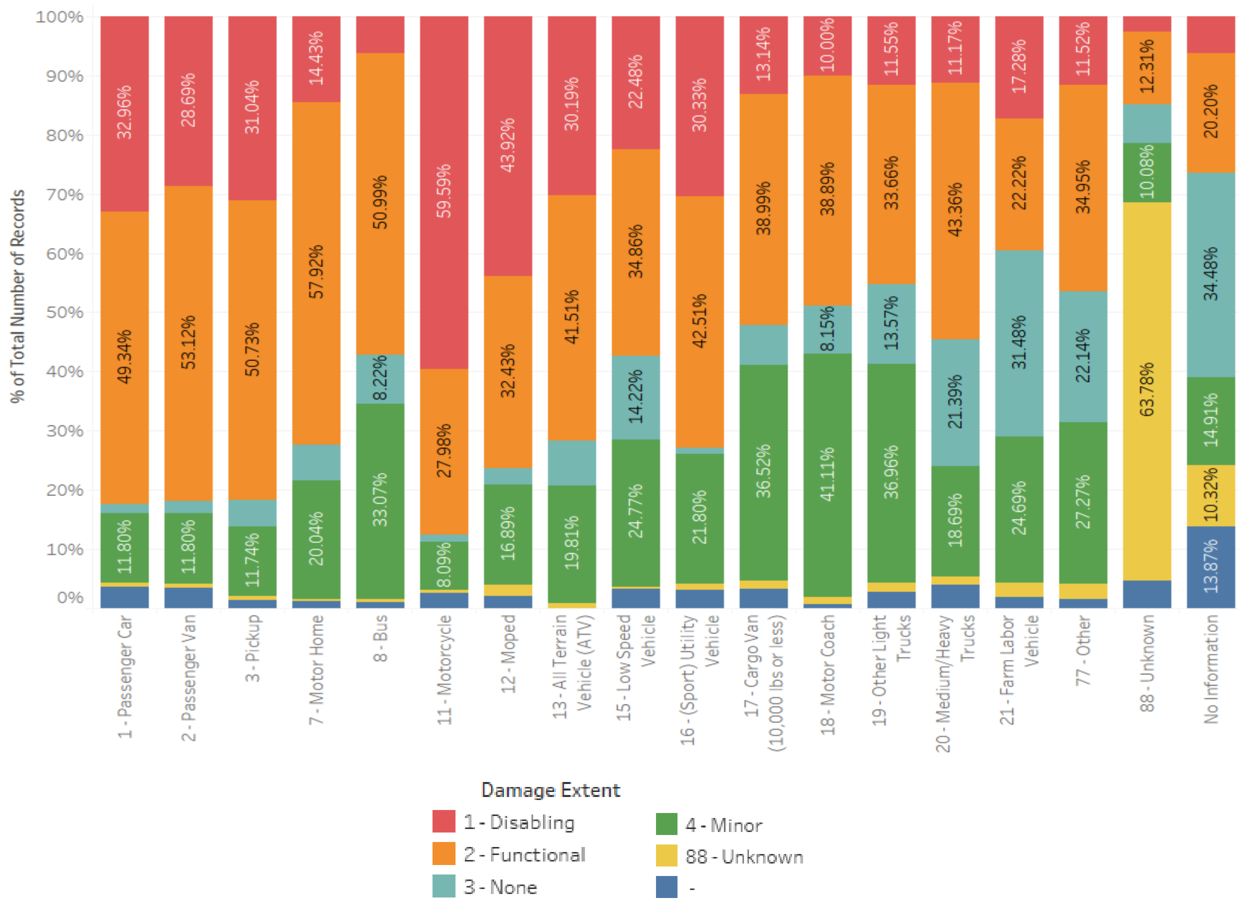


Figure 38 Damage extent per vehicle type

Collisions between large trucks and motorcycles have the highest chance of experiencing disabling damages. Large truck crashes involving passenger cars and passenger vans have higher share of disabling and functional damage (82%), after those involving motorcycles (88%). Most of large trucks are functionally damaged. They also have the highest share of no damage after the farm labor vehicles.

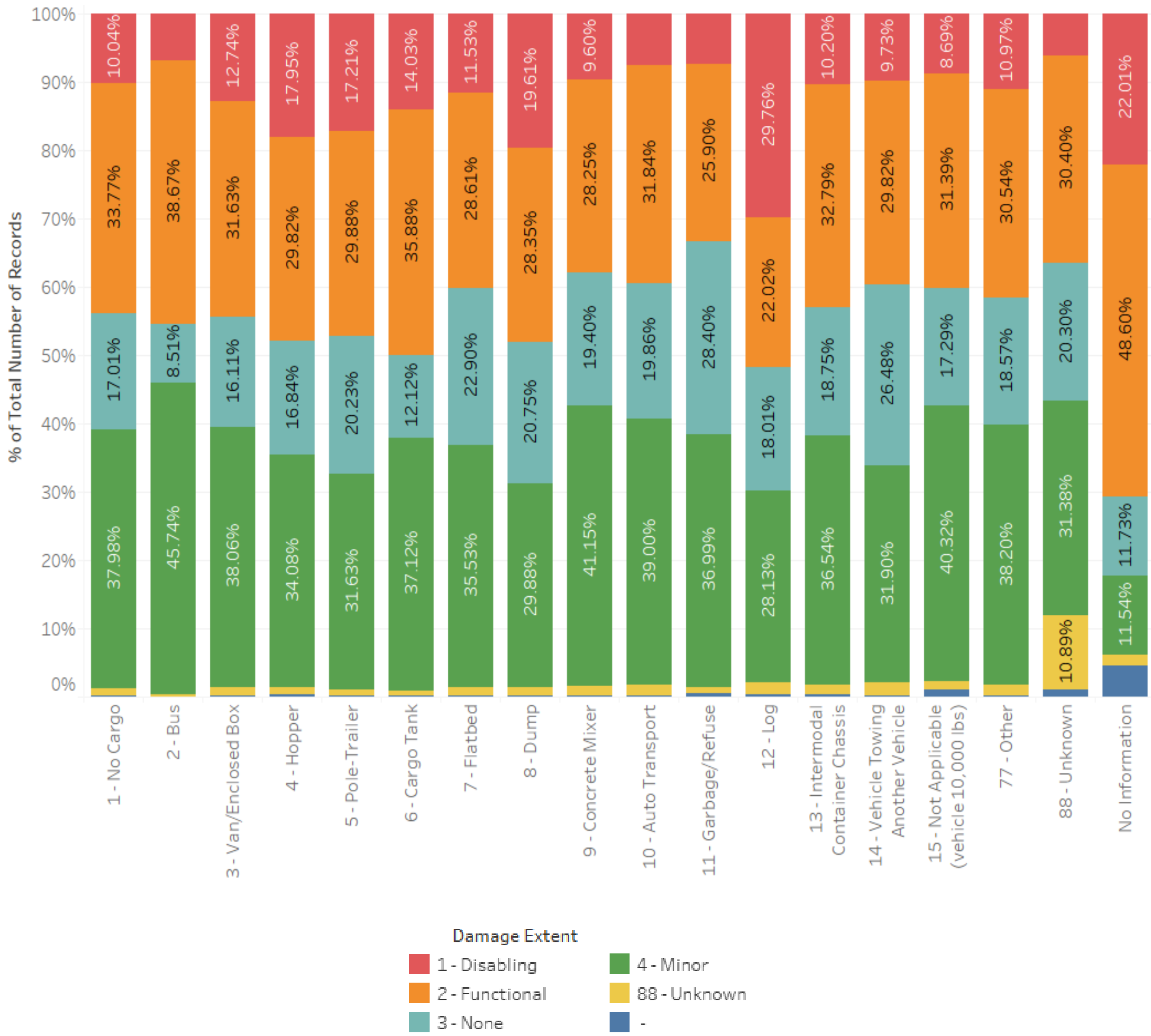


Figure 39 Damage extent by cargo type

Log cargo, followed by Dump, Hopper, and Pole-trailer, account for highest share of disabling damage among each cargo type.

Table 40 Hazmat Released Crashes

Haz Mat Released	% of Number of Crashes	% of Total Fatality Counts	% of Total Incapacitating Injury Counts	% of Total Non Incapacitating Injury Counts	% of Total Possible Injury Counts	% of Total Injury Counts
Null	95.67%	94.16%	93.09%	93.42%	93.95%	93.67%
N	22.93%	5.21%	6.70%	6.43%	5.93%	6.19%
Y	0.41%	0.63%	0.21%	0.14%	0.12%	0.14%

Hazmat released crashes account for 0.41% of all vehicles, while it accounts for 0.63% of all vehicles involved in a fatal crash. That shows a higher tendency of hazmat released crash to be fatal.

Table 41 Damage Extent among Commercial Motor Vehicles

	Damage Extent					
Cmv Configuration	1 - Disabling	2 - Functional	3 - None	4 - Minor	88 - Unknown	-
1 - Vehicle 10,000 lbs or less Placarded for Hazardous Materials	9.7%	39.7%	14.3%	34.9%	1.2%	0.2%
2 - Single-Unit Truck (2-axle and GVWR more than 10,000 lbs (4,536 kg))	11.2%	32.4%	17.2%	38.1%	0.9%	0.2%
3 - Single-Unit Truck (3 or more axles)	13.4%	31.1%	19.0%	35.6%	0.9%	0.1%
4 - Truck Pulling Trailer(s)	13.8%	32.5%	16.6%	35.8%	1.1%	0.2%
5 - Truck Tractor (bobtail)	14.0%	33.6%	12.9%	38.5%	0.9%	0.2%
6 - Truck Tractor/Semi-Trailer	12.2%	28.7%	19.5%	37.3%	2.1%	0.3%
7 - Truck Tractor/Double Truck	23.4%	29.1%	14.6%	30.7%	2.2%	
8 - Tractor/Triple	12.8%	37.6%	14.5%	32.5%	2.6%	
9 - Truck more than 10,000 lbs (4,536 kg), Cannot Classify	8.7%	31.7%	22.4%	35.2%	1.9%	0.2%
10 - Bus/Large Van (seats for 9-15 occupants, including driver)	8.6%	38.9%	9.1%	41.9%	1.5%	
11 - Bus (seats for more than 15 occupants, including driver)	7.6%	39.9%	7.3%	44.9%	0.3%	
77 - Other	12.1%	27.7%	20.5%	37.1%	2.4%	0.1%
88 - Unknown	5.7%	35.4%	20.0%	26.4%	12.1%	0.5%
-	13.9%	56.7%	27.5%	1.1%	0.6%	0.2%

Among CMVs, buses and trucks more than 10,000 lbs have the lowest share of disabling damage. The share of disabling damages among truck tractor/double truck is approximately 23%, while the equivalent share among all other CMVs is no more than 14%.

Table 42 Crashes along Curves

Roadway Alignment	% of Total Vehicle along Roadway Alignment	% of Total Fatality along Roadway Alignment	% of Total Incapacitating along Roadway Alignment	% of Total Injury along Roadway Alignment
1 - Straight	53.81%	50.58%	47.09%	47.32%
2 - Curve Right	1.54%	2.99%	2.05%	1.82%
3 - Curve Left	1.43%	2.03%	1.60%	1.44%
-	43.22%	44.40%	49.26%	49.41%

Table 43 Curve-Related Crashes Relative to Crash Types

Crash Type	All Vehicles	Vehicles in Curve-related crash	Difference
1 - Bicycle	0.2%	0.1%	-0.1%
2 - Head On	1.8%	1.8%	0.1%
3 - Left Entering	2.5%	2.1%	-0.4%
4 - Left Leaving	1.1%	0.7%	-0.4%
5 - Left Rear	1.4%	1.0%	-0.4%
6 - Off Road	5.5%	9.2%	3.7%
7 - Opposing Sideswipe	1.4%	4.1%	2.7%
8 - Other	11.2%	7.6%	-3.6%
9 - Pedestrian	0.3%	0.3%	0.0%
10 - Rear End	27.5%	18.6%	-9.0%
11 - Right Angle	3.9%	2.9%	-0.9%
12 - Right/Left	0.2%	0.5%	0.3%
13 - Right/Through	2.0%	0.8%	-1.3%
14 - Right/U-Turn	0.0%	0.0%	0.0%
15 - Rollover	0.9%	4.2%	3.4%
16 - Same Direction Sideswipe	17.7%	26.2%	8.5%
17 - Unknown	2.5%	3.8%	1.3%
18 - Single Vehicle	1.9%	3.6%	1.7%
19 - Parked Vehicle	12.7%	9.7%	-3.0%
20 - Backed Into	5.3%	2.7%	-2.6%
21 - Animal	0.2%	0.3%	0.1%

The shares of curve-related crashes from fatal crash (5.0%) and incapacitating injury crash (3.7%) are higher than the equivalent share from all types of injuries (3.3%). Thus, curves could be considered as risk factors for serious injury crashes. Same direction sideswipe and rear end crash types account for 44.8% of all vehicles involved in a crash along curves, together. However, given the count of each crash type, crash types of same direction sideswipe, off road, rollover, and opposing sideswipes, respectively, are more likely to occur along curves.

Table 44 Crashes on Hills

Roadway Grade	% of Total Vehicle along Roadway Grade	% of Total Fatality along Roadway Grade	% of Total Incapacitating along Roadway Grade	% of Total Injury along Roadway Grade
1 - Level	54.47%	49.13%	45.56%	45.84%
2 - Hillcrest	0.38%	0.87%	0.79%	0.54%
3 - Uphill	1.55%	2.70%	1.83%	1.91%
4 - Downhill	1.75%	2.85%	2.35%	2.15%
5 - Sag (bottom)	0.09%	0.05%	0.21%	0.15%
-	41.76%	44.40%	49.25%	49.40%

Table 45 Crashes on Hilly Roads Relative to Crash Types

Crash Type	All Vehicles	Vehicles crash in Hilly roads	Difference
1 - Bicycle	0.1%	0.1%	0.0%
2 - Head On	1.2%	1.0%	-0.2%
3 - Left Entering	2.7%	1.7%	-1.0%
4 - Left Leaving	0.8%	0.7%	-0.1%
5 - Left Rear	1.3%	0.6%	-0.7%
6 - Off Road	5.3%	7.6%	2.3%
7 - Opposing Sideswipe	1.5%	1.3%	-0.2%
8 - Other	8.3%	8.2%	-0.1%
9 - Pedestrian	0.3%	0.3%	0.0%
10 - Rear End	25.7%	34.3%	8.6%
11 - Right Angle	3.8%	2.3%	-1.5%
12 - Right/Left	0.1%	0.1%	0.0%
13 - Right/Through	1.1%	0.5%	-0.6%
14 - Right/U-Turn	0.0%	0.0%	0.0%
15 - Rollover	1.0%	2.1%	1.1%
16 - Same Direction Sideswipe	21.2%	23.4%	2.2%
17 - Unknown	3.4%	3.9%	0.5%
18 - Single Vehicle	2.1%	2.7%	0.7%
19 - Parked Vehicle	14.1%	5.9%	-8.2%
20 - Backed Into	5.7%	3.0%	-2.7%
21 - Animal	0.2%	0.2%	0.0%

Compared to the share of hill-related crashes (hillcrest, uphill, and downhill) for all types of injuries (4.6%), more vehicles crash on hills when it is a fatal crash (6.4%), or it is an incapacitating injury crash (5.0%). Thus, hilly road segments need to be assessed as risk factors for serious injury crashes. Crash types of rear end, and same direction sideswipes, respectively, are more likely to occur on hills.

Table 46 Crashes by Traffic Control System

Traffic Control Device	% of Total Vehicle along Roadway Alignment	% of Total Fatality Counts	% of Total Incapacitating Injury Counts	% of Total Non Incapacitating Injury Counts	% of Total Possible Injury Counts	% of Total None Cnt along Traffic Control
1 - No Controls	59.06%	48.46%	47.87%	49.89%	48.37%	58.20%
4 - School Zone Sign/Device	0.14%	0.24%	0.23%	0.17%	0.23%	0.17%
5 - Traffic Control Signal	18.91%	10.67%	17.77%	20.88%	23.61%	20.11%
6 - Stop Sign	5.17%	9.17%	6.43%	5.81%	5.42%	5.53%
7 - Yield Sign	0.50%	0.24%	0.46%	0.42%	0.60%	0.51%
8 - Flashing Signal	0.30%	1.54%	0.91%	0.66%	0.54%	0.28%
9 - Railway Crossing Device	0.19%	0.39%	0.48%	0.19%	0.18%	0.21%
10 - Person	0.29%	0.53%	0.37%	0.32%	0.25%	0.28%
13 - Warning Sign	12.79%	26.45%	23.19%	19.64%	18.63%	12.09%
77 - Other	2.15%	2.32%	2.22%	1.94%	2.00%	2.30%
88 - Unknown	0.24%	0.00%	0.07%	0.05%	0.11%	0.21%
-	0.25%	0.00%	0.00%	0.03%	0.06%	0.09%

The majority of vehicles involved in large truck crashes occur at no control condition, most possibly along segments (59.0%). The share of yield sign, no control, and traffic control signals is the lowest for fatal crashes, while the share of flashing signal, and warning sign is the highest for fatal crashes. Among vehicles involved in serious crashes (fatal and incapacitating), warning sign control has the second highest share after no control system, while for all other severity types it stands as the third highest.

Table 47 Crashes by Traffic Way

Trafficway	% of Total Vehicle along Trafficway	% of Total Fatality along Trafficway	% of Total Incapacitating along Trafficway	% of Total Non Incapacitating along Trafficway	% of Total Possible Injuries along Trafficway	% of Total None Cnt along Trafficway
1 - Two-Way, Not Divided	20.03%	19.64%	14.67%	13.68%	12.92%	20.11%
2 - Two-Way, Not Divided, with a Continuous Left Turn Lane	1.83%	0.77%	1.37%	1.49%	1.86%	2.07%
3 - Two-Way, Divided, Unprotected (painted >4 feet) Median	3.71%	4.54%	4.38%	4.16%	4.17%	4.09%
4 - Two-Way, Divided, Positive Median Barrier	25.82%	29.54%	28.63%	29.19%	28.71%	28.51%
5 - One-Way Trafficway	3.96%	1.01%	1.56%	2.03%	2.47%	4.35%
88 - Unknown	1.41%	0.10%	0.14%	0.17%	0.28%	1.22%
-	43.24%	44.40%	49.25%	49.28%	49.58%	39.65%

Table 48 Crash Injury Risks by Traffic Way

Traffic way	Fatalities per 1000 crash	Incapacitating per 1000 crash	None incapacitating per 1000 crash	Possible injuries per 1000 crash
1 - Two-Way, Not Divided	4.2	14.8	35.2	58.8
2 - Two-Way, Not Divided, with a Continuous Left Turn Lane	1.8	15.1	41.9	92.7
3 - Two-Way, Divided, Unprotected (painted >4 feet) Median	5.3	23.9	57.8	102.5
4 - Two-Way, Divided, Positive Median Barrier	4.9	22.4	58.3	101.3
5 - One-Way Trafficway	1.1	7.9	26.4	56.7
88 - Unknown	0.3	2.1	6.4	18.2
-	4.4	23.1	58.7	104.5

The majority of vehicles involved in large truck crashes occur at two-way divided traffic (positive median barrier), followed by two-way not divided traffic. However, per given number of crashes, the chances of fatalities, incapacitating, and possible injuries on two-way divided with unprotected median is the highest.

Table 49 Crashes by Vehicle Defects

Veh Defect1	Vehicles	Fatalities	Incapacitating Injuries	Non Incapacitating Injuries	Possible Injuries
1 - None	443,800	1,869	9,206	23,437	41,797
2 - Brakes	1,555	6	42	115	142
3 - Tires	4,170	55	211	499	499
4 - Lights (head, signal, tail)	280	6	12	32	32
6 - Steering	239	0	7	26	27
7 - Wipers	26	0	1	1	5
9 - Exhaust System	7	0	0	0	1
10 - Body, Doors	366	0	0	15	32
11 - Power Train	369	5	1	10	8
12 - Suspension	58	0	2	4	5
13 - Wheels	205	1	4	7	10
14 - Windows/Windshield	18	0	0	1	1
15 - Mirrors	60	0	0	1	0
16 - Truck Coupling/Trailer Hitch/Safety Chains	171	0	0	3	3
77 - Other	8,293	43	81	211	344
88 - Unknown	7,958	81	93	179	519
-	11,897	6	43	169	262

5. CRITICAL REASON ANALYSIS

In crash studies, the term “cause” refers to a condition that augmented either the risk of being involved in a crash or the severity of a crash (Blower et al. 2010, Spainhour et al. 2005). Hence, crash causation study seeks to represent and gain a perception of the accident generation process (Perchonok 1972). The Motor Carrier Safety Improvement Act of 1999 (MCSIA), P.L. 106-159, directed the Secretary of Transportation to plan and manage a comprehensive study to find the causes of, and contributing factors to, crashes (FMCSA, 2006).

Crash causation has been investigated using two main approaches. The first one is the clinical method, which relies on experts’ judgment in identifying the major cause of each crash. In this approach, a team including experts in crash reconstruction, vehicle dynamics, psychology, and other relevant disciplines studies individual crashes (Blower et al. 2010, Treat et al. 1979). In this method, primary and contributing causes were identified for each crash using some hierarchy of causation based on the clinical judgment of the experts. The Indiana Tri-Level Study (Treat et al. 1979) utilized the clinical approach to identify the causation of 420 crashes in Monroe County. In this study, the cause was defined as "a factor necessary or sufficient for the occurrence of the crash; had the factor not been present in the crash sequence, the crash would not have occurred".

In the second approach, which is the statistical method, a data set describing crash, environment, driver, and the vehicle is used for identifying associations between various factors and changes in the risk of crash involvement. The most significant factor that increases the risk of a crash is assigned as the cause of the crash (Blower et al. 2010). The Large Truck Crash Causation Study (LTCCS) (FMCSA, 2006; Singh, 2015; Starnes, 2006; Toth et al., 2003) utilized the statistical approach, in which a statistical analysis of aggregated crash records was conducted to demonstrate associations between potential factors and particular types of crashes.

The clinical approach would not be feasible for a large-scale study such as statewide analysis because it involves intensive investigation that essentially reconstructs the crash scene. On the other hand, the statistical approach uses aggregated analysis focusing on the probabilistic nature of crash occurrence, which may not represent individual crash cases well.

For this study, a comprehensive framework was developed to identify the critical reason for each crash. It retrieves available information from the crash data and covers all possible elements, including driver attributes, vehicle conditions, roadway characteristics, and environmental situation. Police-reported crash data is one of the most comprehensive and detailed assets which can be used in crash analysis. The report is written by trained officers soon after a crash has occurred and consists of reasonably detailed information about all aspects of a crash (Farmer, 2003). In this regard, the proposed framework takes advantage of all relevant information available in the report.

For the purpose of this analysis, the crash data were segmented into sub-datasets by general crash type categories, including: non-collision, collision with fixed objects, collision with pedestrian, bicycles and animals, collision with parked vehicles, collision with vehicle in motion, and collision with other non-fixed objects.

It is reasonable to assume that different causality factors and mechanisms are associated with different types of crashes. To further explore how truck drivers and passenger car drivers may be involved with different types of causes, the analysis datasets were further segmented by whether the truck was identified as the primary/first vehicle involved in the crash.

5.1. Framework for Identifying Critical Reason

Figure 40 presents the framework for identifying critical reason for each crash.

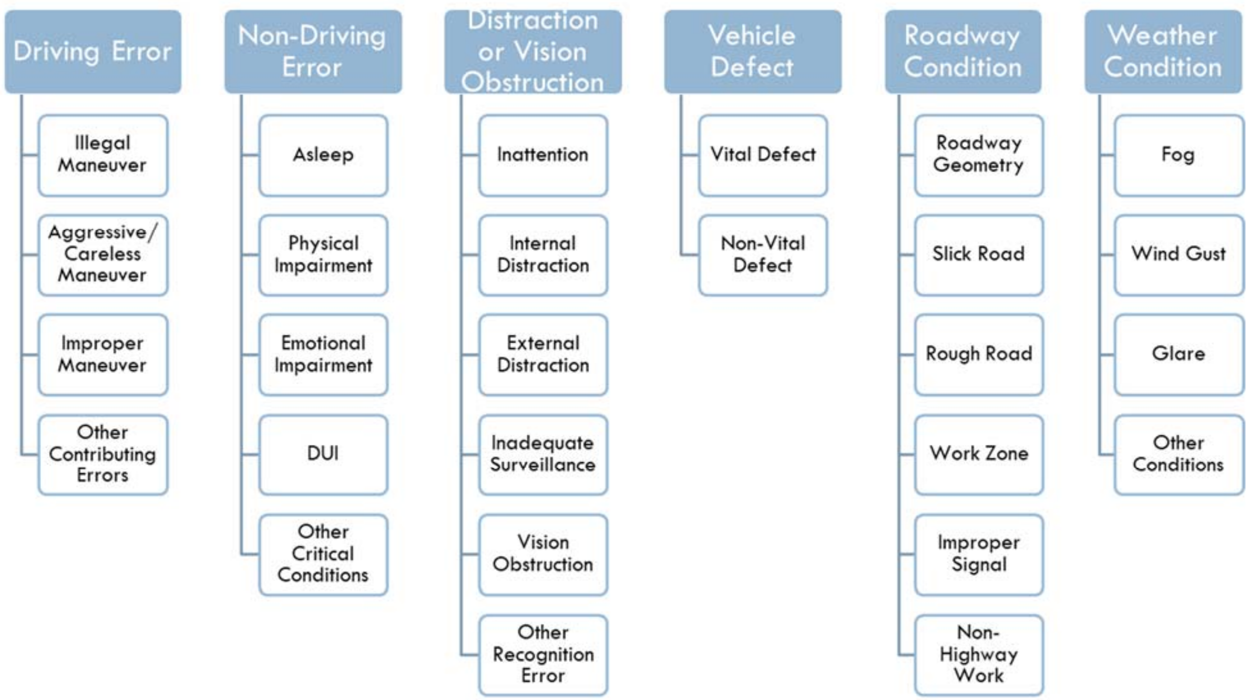


Figure 40 Critical reason framework.

The framework identifies six general categories of potential causes to a crash, including:

- Driving Error
- Non-Driving Error
- Driver Distraction or Vision Obstruction
- Vehicle Defect
- Roadway Conditions
- Weather Conditions

Each category is further broken down into several sub-categories that identifies unique contributing factors. All information available from the crash reports were used to identify potential contributing factors. Table 50 presents the detailed variables and categories that were used to identify whether particular condition(s) were present for each crash. When multiple factors were identified for a single crash, the factors were ranked based on the hierarchy shown in Figure 40. From left to right represents highest rank to lowest rank. For example, a crash that was associated with "improper maneuver", "inattention" and "slick road" will be assigned a critical reason of driving error with two contributing factors – driver distraction and roadway condition. When there were multiple drivers and vehicles involved, the factors were identified for all involved parties. The highest ranked factor will be the final critical reason identified for each crash regardless of which driver or vehicle it was associated with.

Table 50 Variables Used to Identify Critical Reason

Critical Reason		Variable	Category
Driving Error	**Illegal Maneuver**	Driver Action at Time of Crash	3. Failed to yield Right of Way
			11. Ran red light
			13. Ran stop sign
			17. Exceeded posted speed
			21. Wrong side of wrong way
			27. Disregarded other traffic sign
			28. Disregarded Other road markings.
	Aggressive and Careless Maneuver		2. Operated MV in careless or negligent manner
			10. Followed too closely
			12. Drove too fast for conditions
			31. Operated MV in erratic, reckless or aggressive manner
	Improper Maneuver		4. Improper backing
			6. Improper turn
			15. Improper passing
			25. Failed to keep in proper lane
			26. Ran off roadway
			29. Over-correcting/ Over steering
			30. Swerved or avoided: due to wind, slippery surface, MV, object, non-motorist in roadway, etc.
	Other		77. Other contributing actions
Non-Driving Error	**Asleep**	Driver Condition at Time of Crash	3. Asleep or Fatigued
	Physical Impairment		5. Ill (sick) or Fainted
			6. Seizure, Epilepsy, Blackout
			7. Physically Impaired
	Emotional Impairment		8. Emotional (depression, angry, disturbed, etc.)
	Other Critical Condition		77. other
	DUI		9. Under the influence of medications/ drugs/ alcohol
			BAC higher than 0.08
			Drug test result positive
Driver Distraction/ Vision Obstruction	**Inattention**	Driver Distracted By	7. Inattentive
	Internal Distraction		4. Other Inside the Vehicle
			2. Electronic Communication Devices
			3. Other Electronic Device
			6. Texting
	External Distraction		5. External Distraction
	Inadequate Surveillance	Driver Vision Obstruction	2. Inclement Weather
			3. Parked/Stopped Vehicle

Table 50 Variables Used to Identify Critical Reason (continued)

Critical Reason		Variable	Category
			4. Trees/Crops/Bushes
			5. Load on Vehicle
			6. Buildings/Fixed objects
			7. Signs/Billboards
			8. Fog
			9. Smoke
			10. Glare
	Other Recognition Error		77. All other
	Obstruction	Contributing Circumstances: Road	11. Obstruction in roadway
		Contributing Circumstances: Environment	3. Physical Obstruction(s)
Vehicle Defect	**Vital**	Vehicle Defect	2. Brakes
			3. Tires
			6. Steering
			9. Exhaust system
			11. Power Train
			12. Suspension
			13. wheels
			16. Truck Coupling/ Trailer Hitch/ Safety Chains
		First Harmful Event	5. Cargo equipment loss or shift
	Non-Vital	Vehicle Defect	4. Lights
			7. Wiper
			10. body, doors
			14. Windows/ Windshield
			15. Mirror
			77. Other
Highway	**Roadway Geometry**	Roadway Alignment	2. Curve Right
			3. Curve Left
		Roadway Grade	2. Hill crest
			3. Uphill
			4. Downhill
			5. Sag
	Slick Roads	Roadway Surface Condition	2.Wet
			4.Ice/Frost
			5. Oil
			8. Water (standing/moving)
		Contributing Circumstances: Road	10. Road surface condition (Wet, icy, snow, slush, etc.)
			12. Debris
	Rough Roads		7. Rut, holes, bumps,
			9. Worn, travel- polished surface
		Roadway Surface Condition	6. Mud, dirt, gravel
			7. sand
	Work Zone	Contributing Circumstances: Road	4. Work Zone
	Improper Signal Control		13. Traffic control device inoperative, missing or obscured
	Non-Highway Work		14. Non-highway work
Weather	**Fog**	Weather Condition	4. Fog, Smog, Smoke
	Wind Gust		7. Severe Crosswinds
	Glare	Contributing Circumstances: Environment	4. Glare

5.2. Critical Reason Analysis for Trucks

In an effort to examine whether trucks may be involved with different types of causes and contributing conditions than other vehicles, this analysis distinguishes crashes where the identified critical reason came from a truck and those with critical reason contributed by non-truck vehicles. It should be noted that identifying at-fault party is a complex task and cannot be determined without intensive investigation of the individual crashes. It is not the purpose of this study to identify the at-fault party, but rather to focus on how trucks and non-trucking vehicles might present different patterns in terms of causes and contributing conditions.

This section focuses on critical reason analysis for trucks, and the next section focuses on non-trucks. Of the 231,890 total crashes, 144,909 crashes (62.5%) had truck as the primary contributor. These crashes were divided into 6 sub datasets as shown in Table 51.

Table 51 Sample Size for Trucks by Crash Type

Crash Type	Sample	Percent
Non-Collision	7,498	5.20%
Collision with Fixed Object	19,878	13.70%
Collision with Pedestrian, Pedal cycle, Animal	2,217	1.50%
Collision with Vehicle in Motion	93,631	64.60%
Collision with Parked Motor Vehicle	11,103	7.70%
Collision with other Non-Fixed Object	10,315	7.10%
Full data	144,909	100.00%

The characteristics of each sub dataset can be found in Figure 41. Non-collision crashes mainly included overturn/rollover (41%), cargo or equipment shift (21%), jackknife (10%), and thrown or falling object (4%). Collision with fixed object mainly included colliding with utility pole/light support (13%), bridge overhead structure (11%), tree (standing) (9%), guardrail face (7%), fence (7%), traffic sign support (6%), and concrete traffic barrier (5%). Collision with pedestrian, bicycle, and animals included 48% pedestrian crashes, 31% animal crashes, 21% bicycle crashes. Collision with other non-fixed objects included struck by falling or shifting cargo (10%), work zone/maintenance equipment (1%), and railway vehicle (1%). Collision with vehicle in motion and parked vehicle were not shown in the figure as they represent specific collision types already.

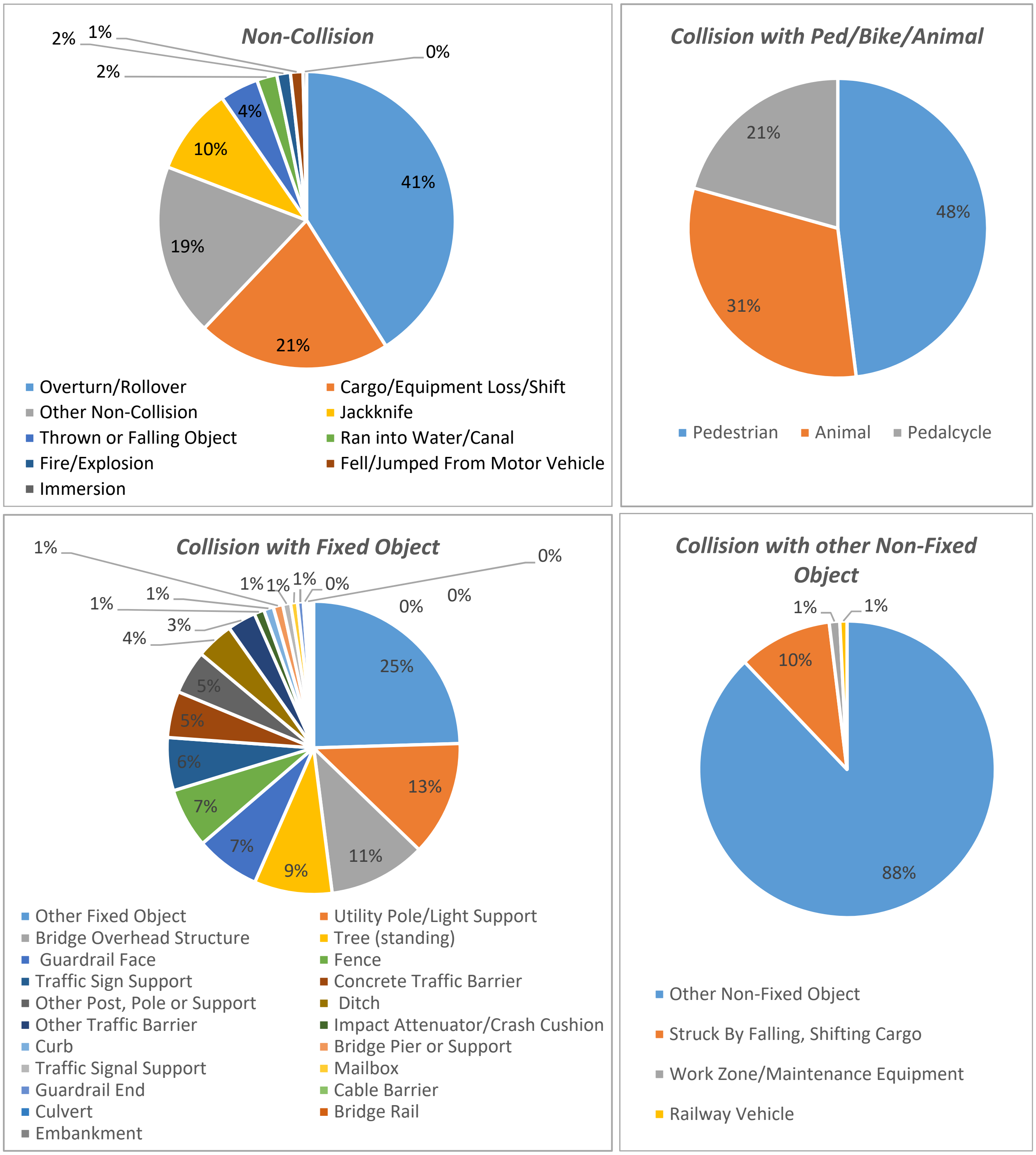


Figure 41 First harmful event for crashes with truck as primary vehicle

5.2.1. Critical Reason for Trucks

Figure 42 presents the general critical reason categories for truck by crash type.

- The most common cause among all crash types was driving error, especially for collision with parked vehicle (96%), vehicle in motion (95%), and with fixed object (92%);
- Relatively speaking, non-collision, collision with other non-fixed object, and collision with pedestrian, pedal cycle and animal were less likely to be caused by driving error;
- In this regard, non-collision and collision with other non-fixed object were more likely to be associated with vehicle defects and roadway conditions than other types of crashes;
- While crashes with pedestrian, pedal cycle and animal were more likely to be associated with driver distraction or vision obstruction, as well as roadway conditions.
- Roadway condition was least likely to be associate with parked vehicle collision (1%);
- Weather condition was only relevant in collision with pedestrian, and bicycle, animal (1.35%);
- Non-driving error (e.g. asleep, DUI, physical or emotional impairment) showed very little contribution across all crash types, indicating that driver conditions that increase crash risks were unlikely to be associated with truck drivers.

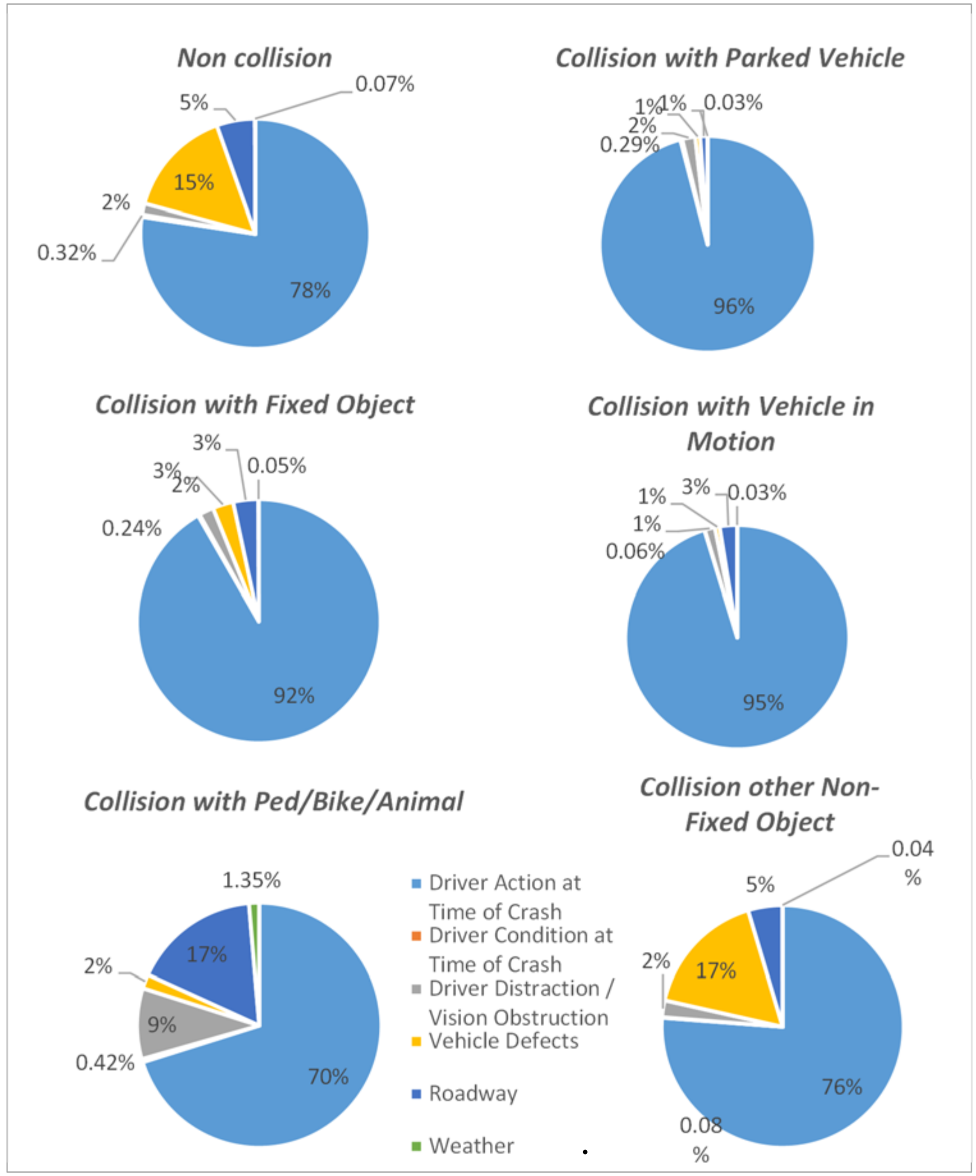


Figure 42 Critical reason for trucks by crash type

5.2.2. Critical Reason for Trucks – Driving Error

Looking into driving errors, defined by driver actions at time of crash, Figure 43 presents the distribution of subcategories across the six crash types.

- Aggressive or careless maneuver was the dominant driving error for non-collision. It was also the most frequent driving error for collision with fixed object, and collision with vehicle in motion;
- Collision with parked vehicle was more likely to be associated with improper maneuver, which is the second most frequent cause for collision with vehicle in motion and fixed object;
- Illegal maneuver was most prevalent in collision with pedestrian, bicycle, and animals (22%) and least common in non-collision and collision with fixed object (2%);
- There were non-trivia proportions of crashes across all crash types that were attributed to other contributing actions, especially for collision with other non-fixed object and collision with pedestrian, pedal cycle and animal. This indicates that analysis for these types of crashes may need to look into the narratives of the crash report to get more information.

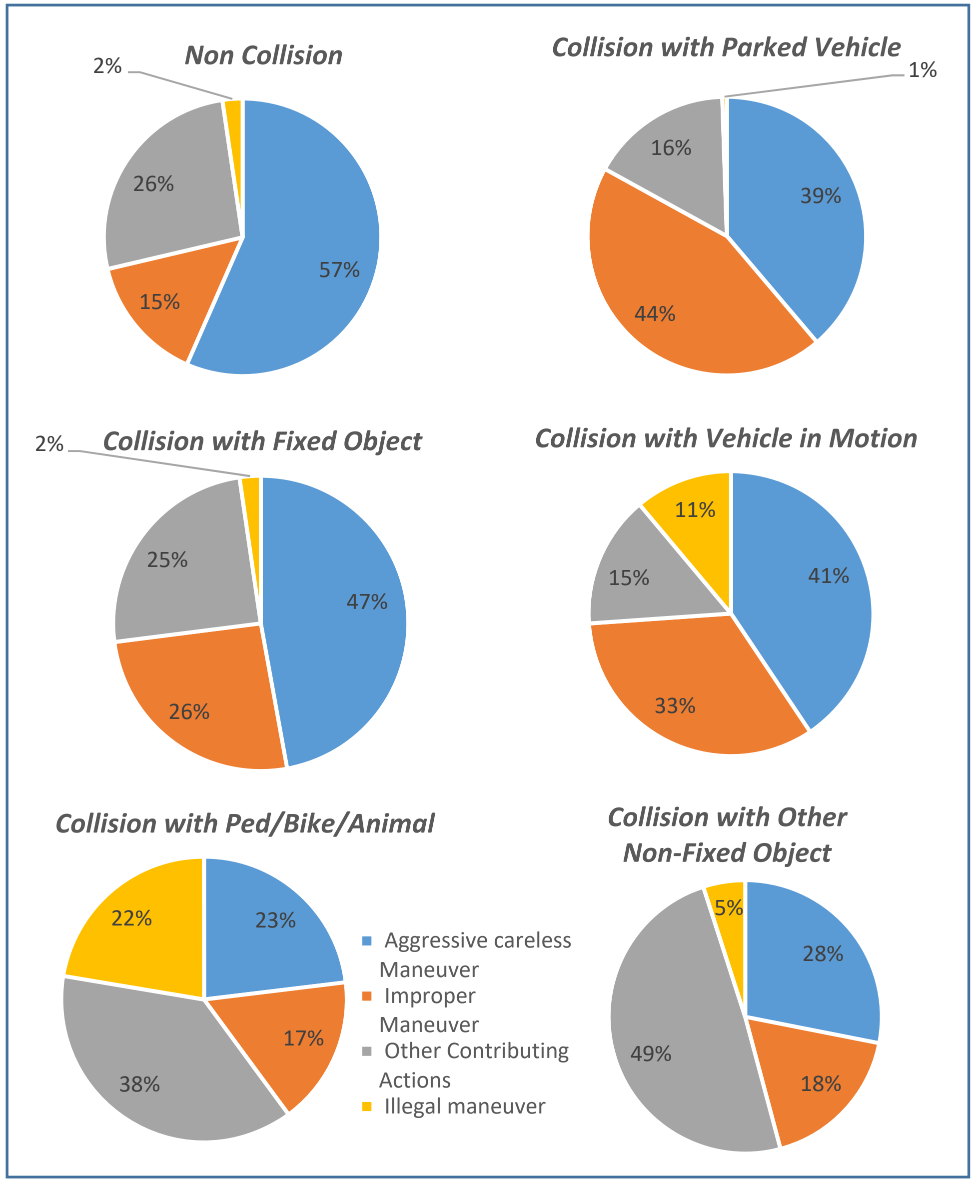


Figure 43 Critical reason for trucks -- driving error

5.2.3. Critical Reason for Trucks – Non-Driving Error

As indicated in Figure 42, overall non-driving error showed very little presence across all crash types. However, the sub-categories within non-driving error showed interesting patterns among the crash types, as shown in Figure 44.

- Asleep and fatigue posed significant risk across almost all crash types, except for collision with pedestrian, bicycle, and animal;
- Physical impairment was dominant in collision with fixed object, and was more likely to be associated with collision with other non-fixed object and non-collision;
- On the other hand, emotional impairment was most prevalent in collision with pedestrian, bicycle, and animals (20%).
- Driving under the influence of medicine, drug or alcohol generally had very little contributions for trucks.

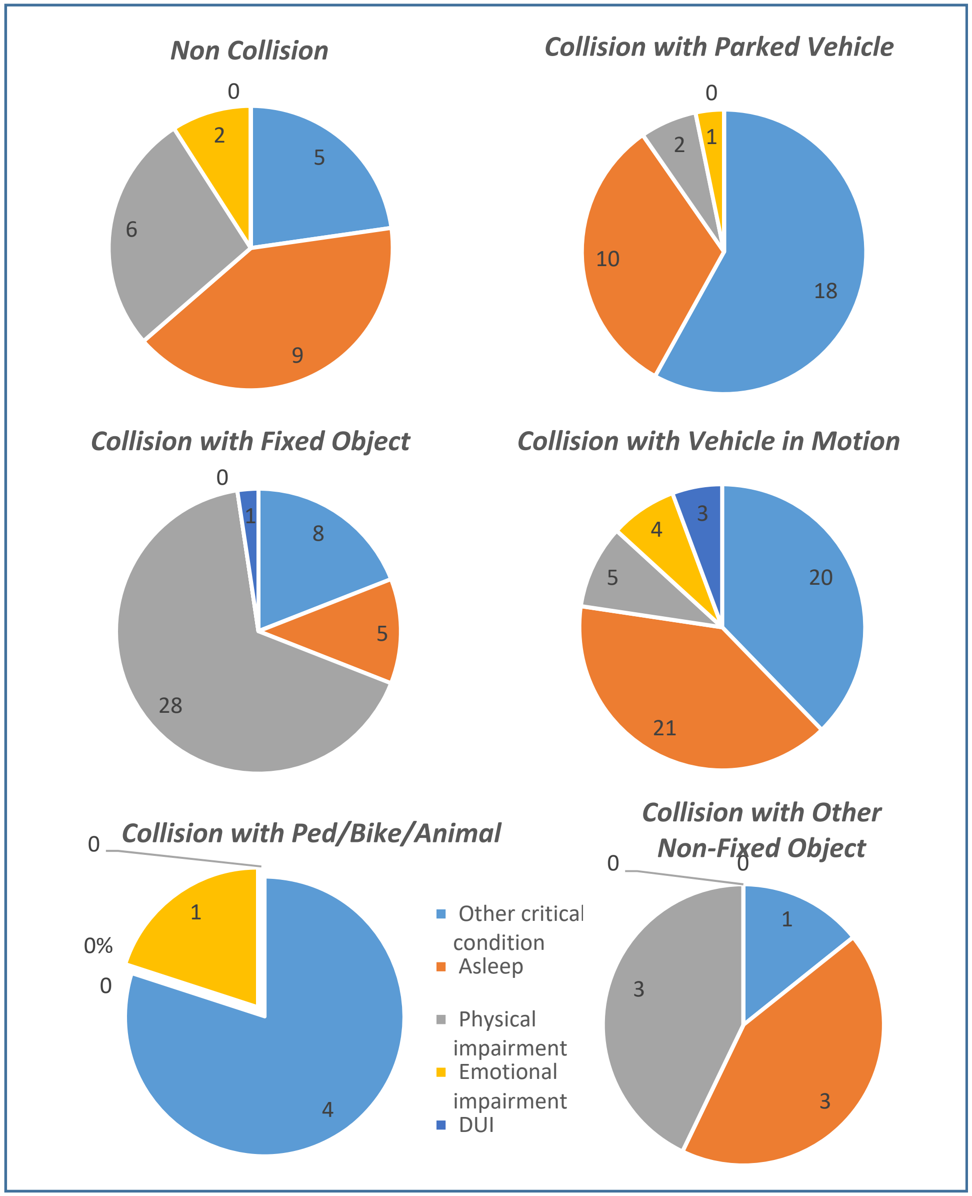


Figure 44 Critical reason for trucks -- non-driving error

5.2.4. Critical Reason for Trucks – Driver Distraction or Vision Obstruction

Figure 45 presents the sub-categories in driver distraction or vision obstruction by crash type.

- Inadequate surveillance, due to weather or obstruction, was the dominant factor across all crash types;
- Other recognition error was identified as the next most frequent factor;
- In attention represented 6% of crashes with parked vehicle, fixed object and vehicle in motion;
- Distractions, both external and internal distraction, were another significant factor for non-collision, collision with parked vehicle, fixed object and vehicle in motion. In most cases, external distraction was more likely to be associated with crashes than internal distraction;
- Obstruction explained about 5% to 6% of crashes in collision with parked vehicle, fixed object and other non-fixed object.

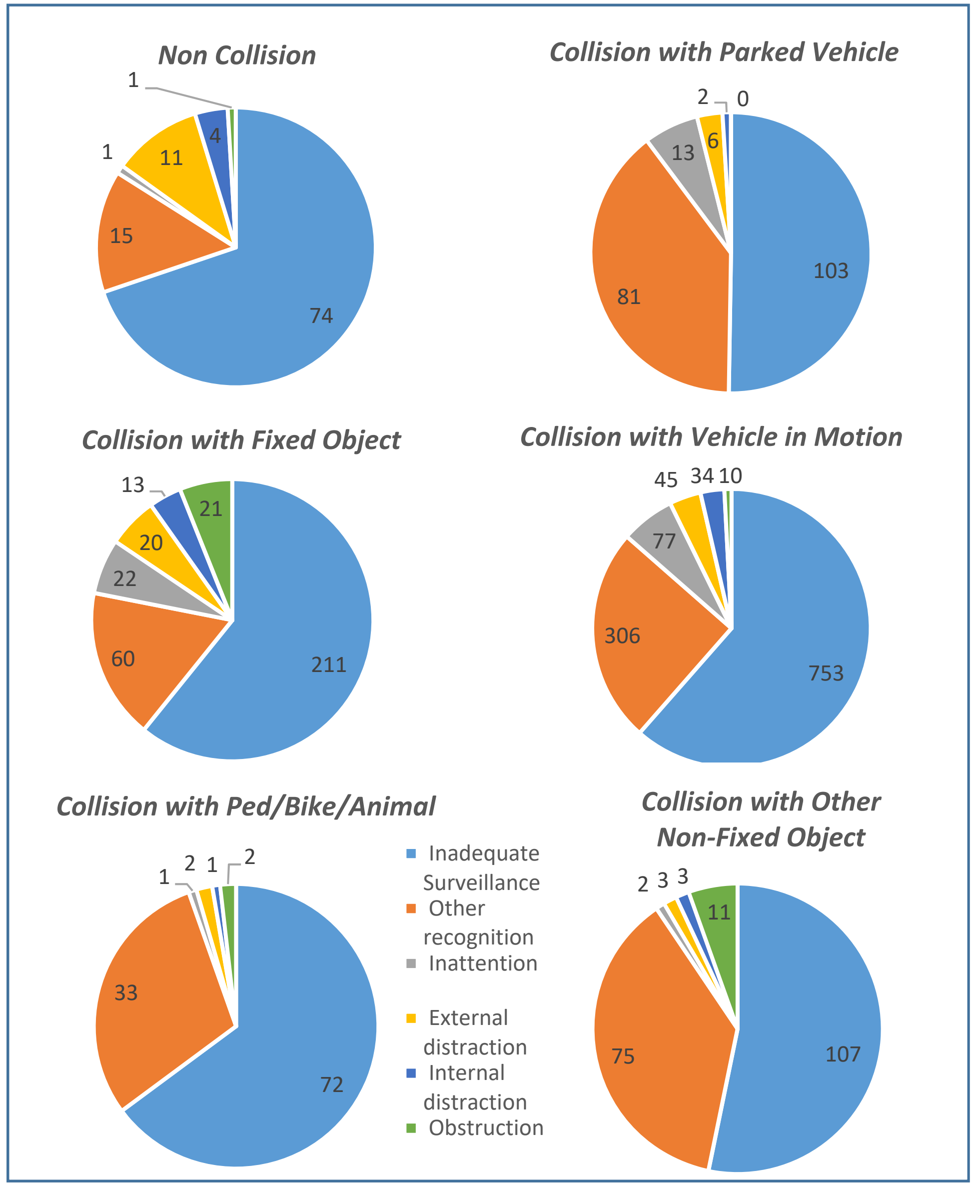


Figure 45 Critical reason for trucks -- distraction/vision obstruction

5.2.5. Critical Reason for Trucks – Vehicle Defect

As indicated earlier in Figure 42, vehicle defects showed significant presence for non-collision (15%) and collision with other non-fixed object (17%). Figure 46 presents a further breakdown by functional and non-functional defect.

- Functional vehicle defects, such as those related to brakes, tires, wheels, power train, suspension, truck coupling, etc., were the dominant factor associated with most of the crash types;
- Except for collision with pedestrian, pedal cycle and animal, and collision with parked vehicle, which were likely to be associated with non-functional defects, such as lights, wipers, windshield, etc.

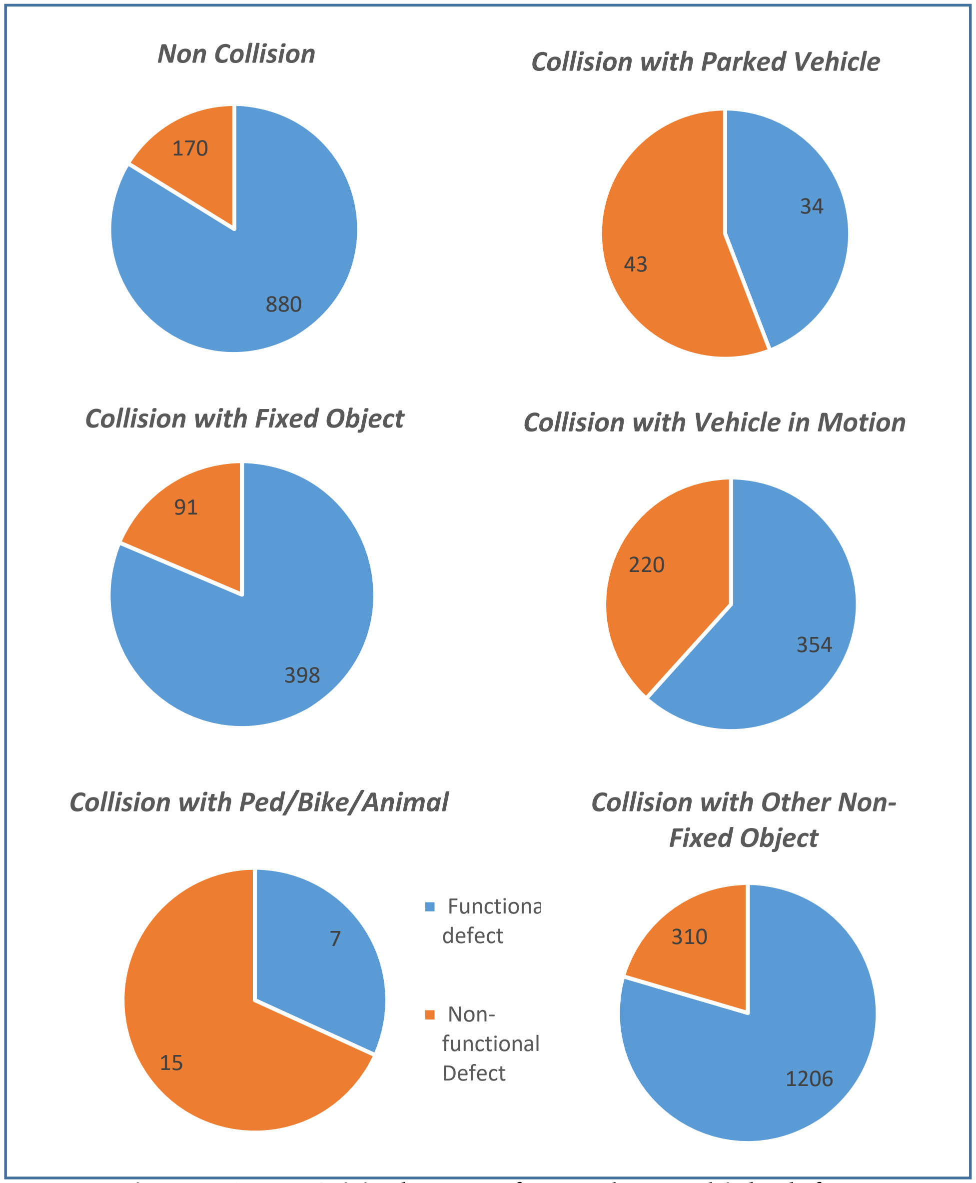


Figure 46 Critical reason for trucks -- vehicle defect

5.2.6. Critical Reason for Trucks – Roadway

In terms of roadway condition, Figure 47 presents similar patterns across the crash types.

- Slick road was found to be the dominant roadway condition for those crashes that were associated with roadway condition factor;
- Roadway geometry, including roadway alignment and roadway grade, was the second most critical roadway conditions;
- Work zone also showed non-trivial presence, especially for collision with other non-fixed object;
- Rough road was found as a contributor to all crash types, representing about 4-7% of crashes that were associated with roadway conditions;
- Improper signal and non-highway work showed little to no presence.

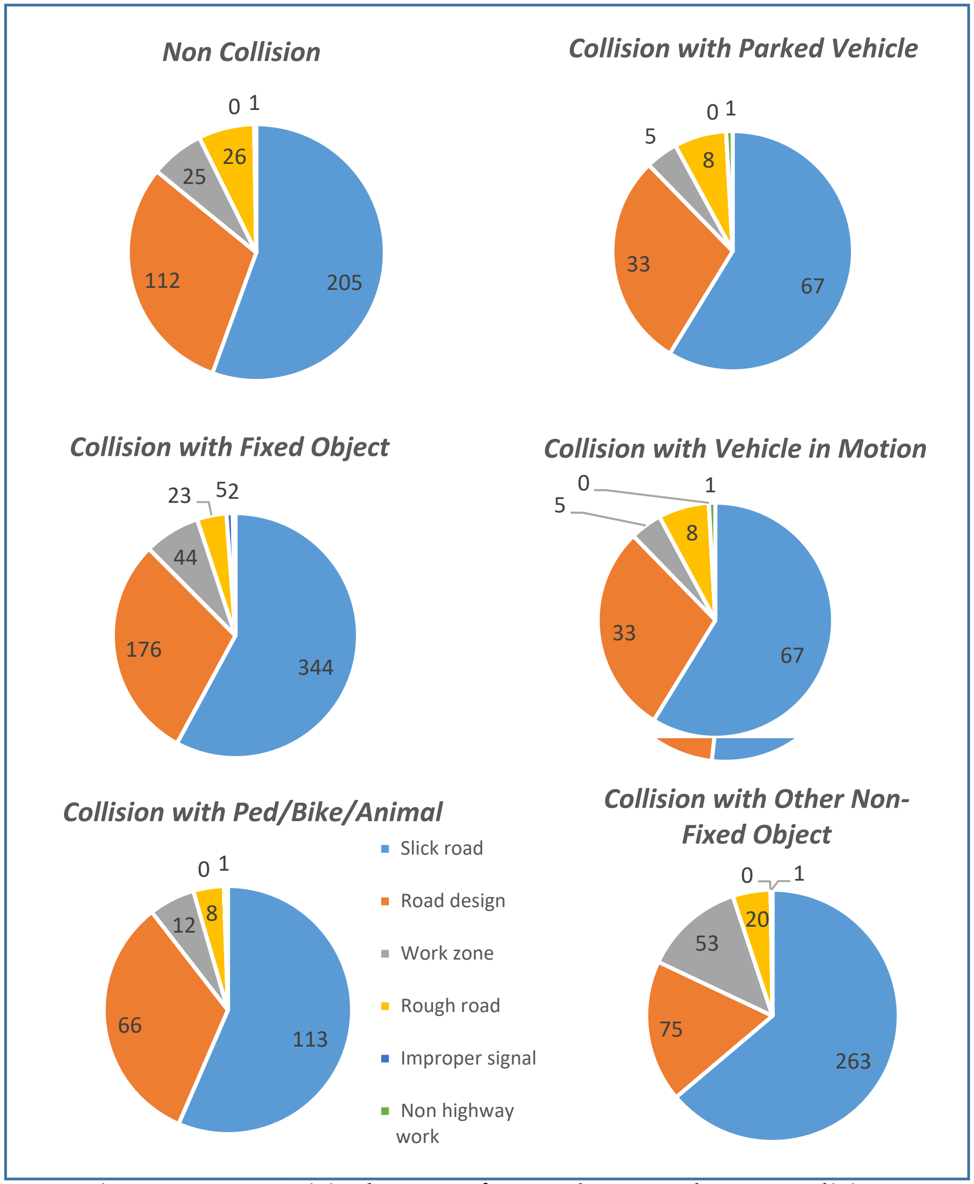


Figure 47 Critical reason for trucks -- roadway condition

5.2.7. Critical Reason for Trucks – Weather

Figure 48 shows the distribution among weather conditions for all crashes that were associated with weather. These crashes did not have any other conditions present, meaning we were not able to identify any driver actions, driver conditions, driver distraction or vision obstruction, or vehicle or roadway conditions that may have contributed to the crash.

- Among the weather conditions, fog was found to be the most critical weather condition;
- Wind gust showed significant presence in collision with fixed object (44%), and non-collision;
- Glare presented 4% of the collision with vehicle in motion that was associated with weather conditions.

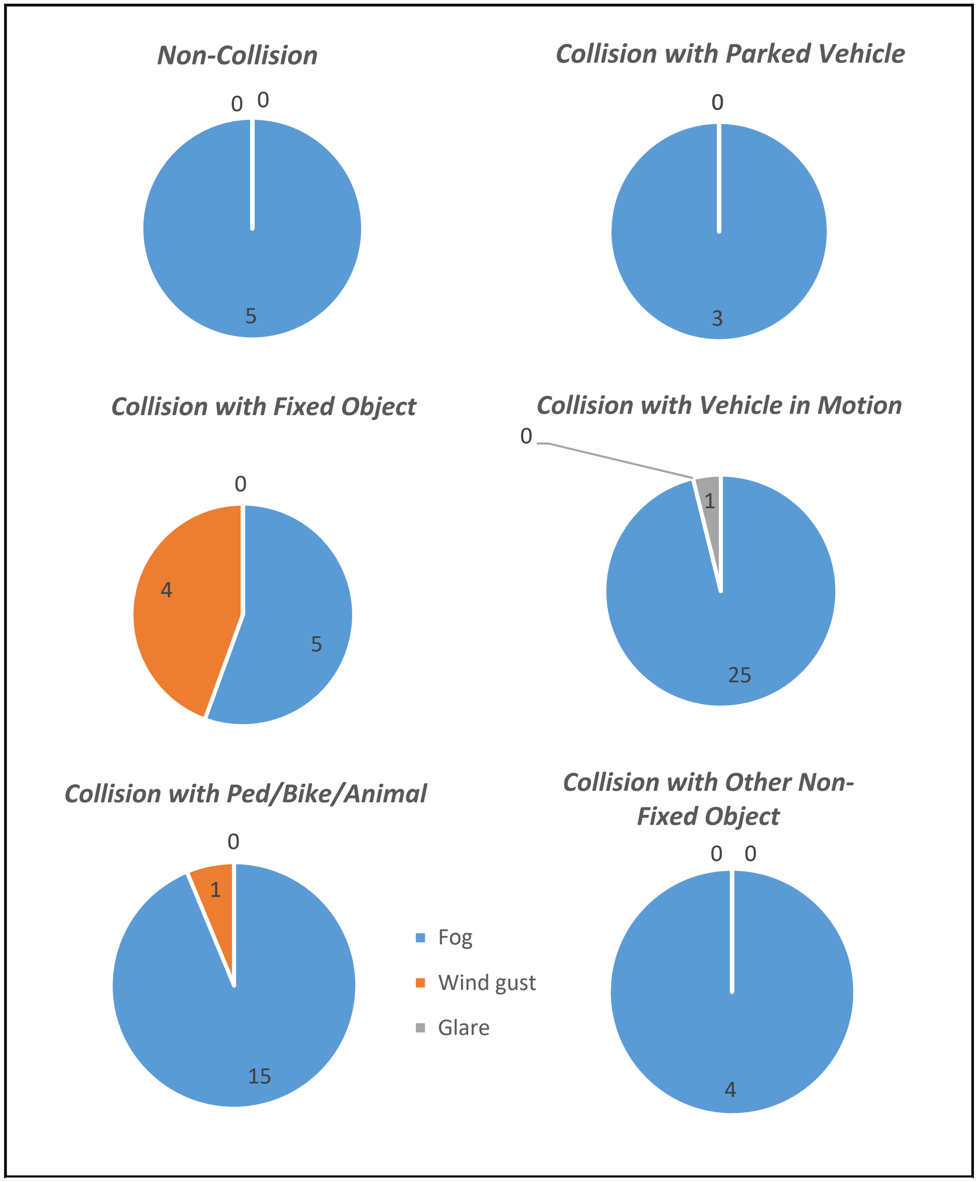


Figure 48 Critical reason for trucks -- weather

5.3. Critical Reason Analysis for Non-trucks

Table 52 shows the sample size by crash type for crashes where the critical reason came from non-trucks. Figure 49 presents the crash characteristics by crash type.

Table 52 Sample Size for Non-Trucks by Crash Type

Crash Type	Sample	Percent
Non collision	1,135	1.4%
Collision with Fixed Object	1,325	1.6%
Collision Non-Fixed Object (Pedestrian, Pedal cycle, Animal)	164	0.2%
Collision Non-Fixed Object (Vehicle in Motion)	70,026	86.1%
Collision Non-Fixed Object (Parked Motor Vehicle)	4,613	5.7%
Collision Non-Fixed Object (Other)	4,011	4.9%
Full data	81,318	100.0%

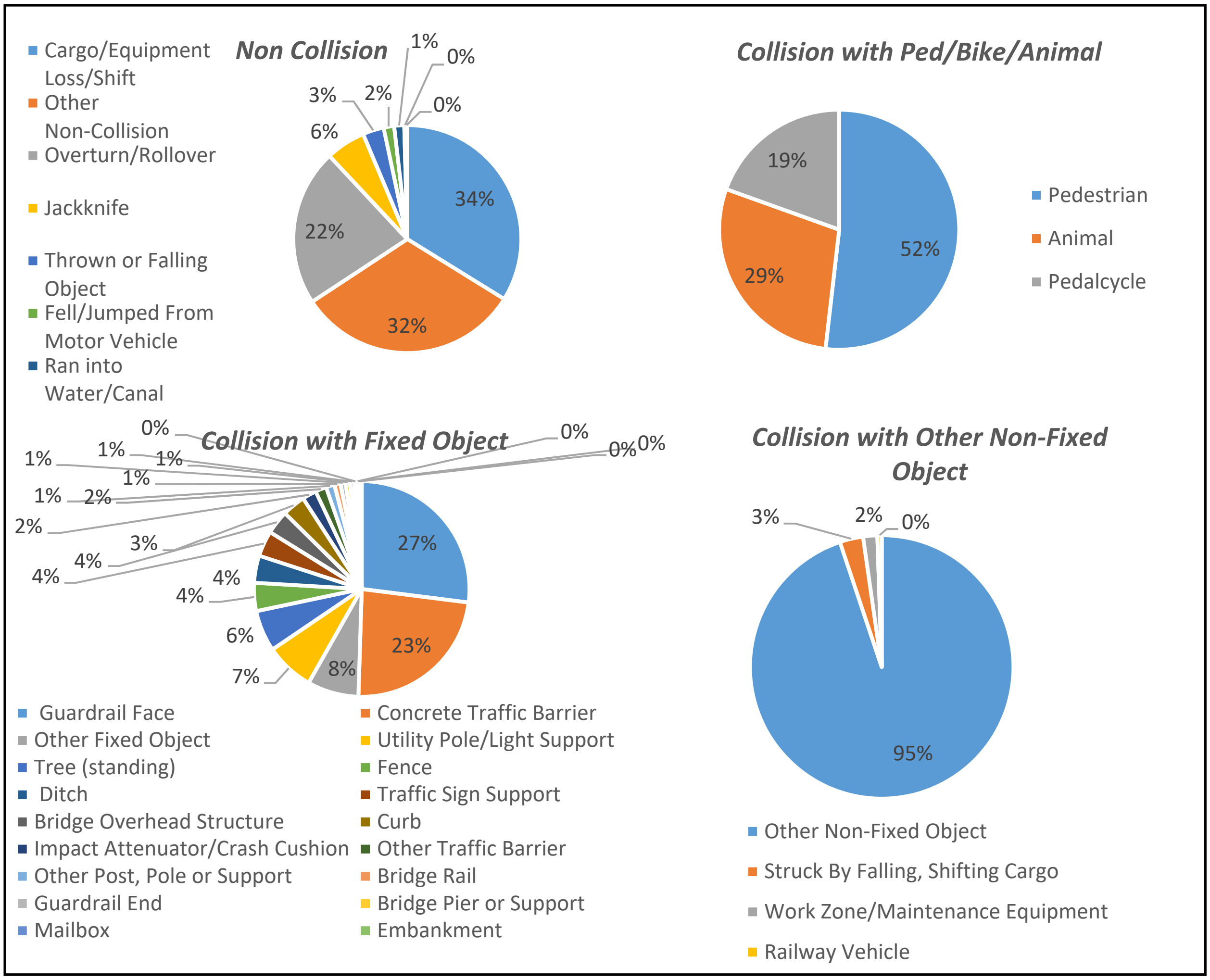


Figure 49 First harmful event for crashes with non-Truck as primary vehicle

5.3.1. Critical Reason for Non – Trucks

This section focuses on critical reason for non-trucks. Figure 50 presents the critical reason by crash type.

- Driving error, also known as driver action at time of crash, was the dominant factor across all types of crashes;
- Similar to trucks, driver condition and weather showed very little contribution to any type of crashes;
- Driver distraction and vision obstruction were particularly relevant for collision with pedestrian, ped cycle and animal, as well as for collision with other non-fixed object;
- Vehicle defects did not show much influence except for non-collision, which explained 13% of the crashes;
- Roadway condition seemed to be relevant for collision with pedestrian, ped cycle and animal;
- Overall, the general patterns for non-trucks are similar to those for trucks. Non-trucks were more likely to show driving errors than trucks, especially for non-collision, collision with pedestrian, pedal cycle and animal, and collision with other non-fixed object.

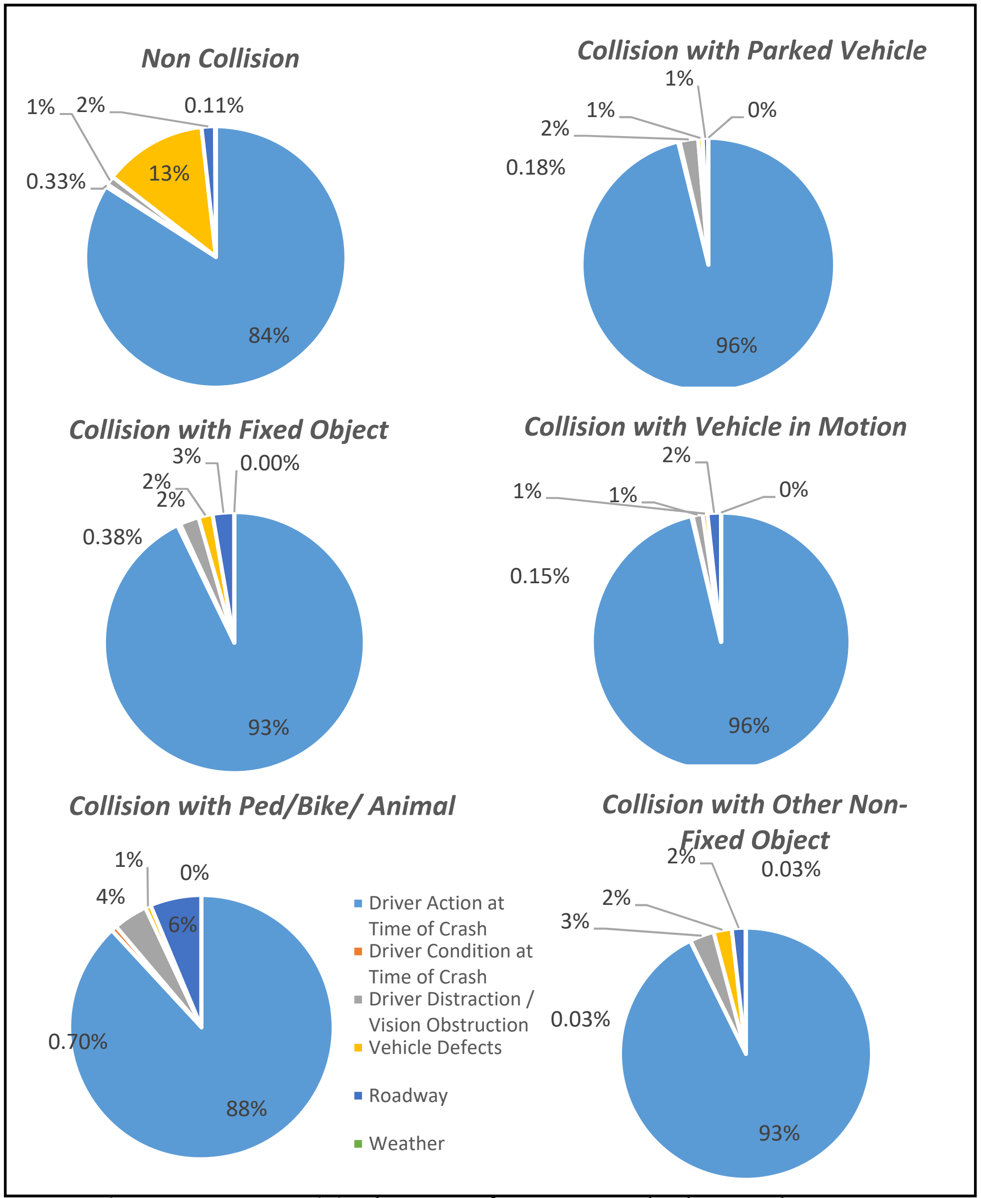


Figure 50 Critical reason for non-trucks by crash type

5.3.2. Critical Reason for Non-Trucks – Driving Error

In terms of driving error, Figure 51 presents the detailed categories by crash type. It reveals some different pattern than trucks (shown in Figure 43).

- Aggressive or careless maneuver was still the dominant cause except for collision with other non-fixed object, but generally showed less contribution than trucks except for collision with pedestrian, bike and animal, where 49% of the crashes were associated with aggressive or careless maneuver, versus 23% for trucks;
- Improper maneuver was the second most frequent factor across all crash types, it's contribution varied from 17% for collision with pedestrian, bike and animal to 29% for collision with parked vehicle;
- Interestingly, illegal maneuver represented 20% of collision with vehicle in motion, almost doubled than trucks (11%);
- Other contributing actions represented a significant portion of the crashes across all crash types. A better understanding of these other actions needs further investigation of the narratives of the crash report.

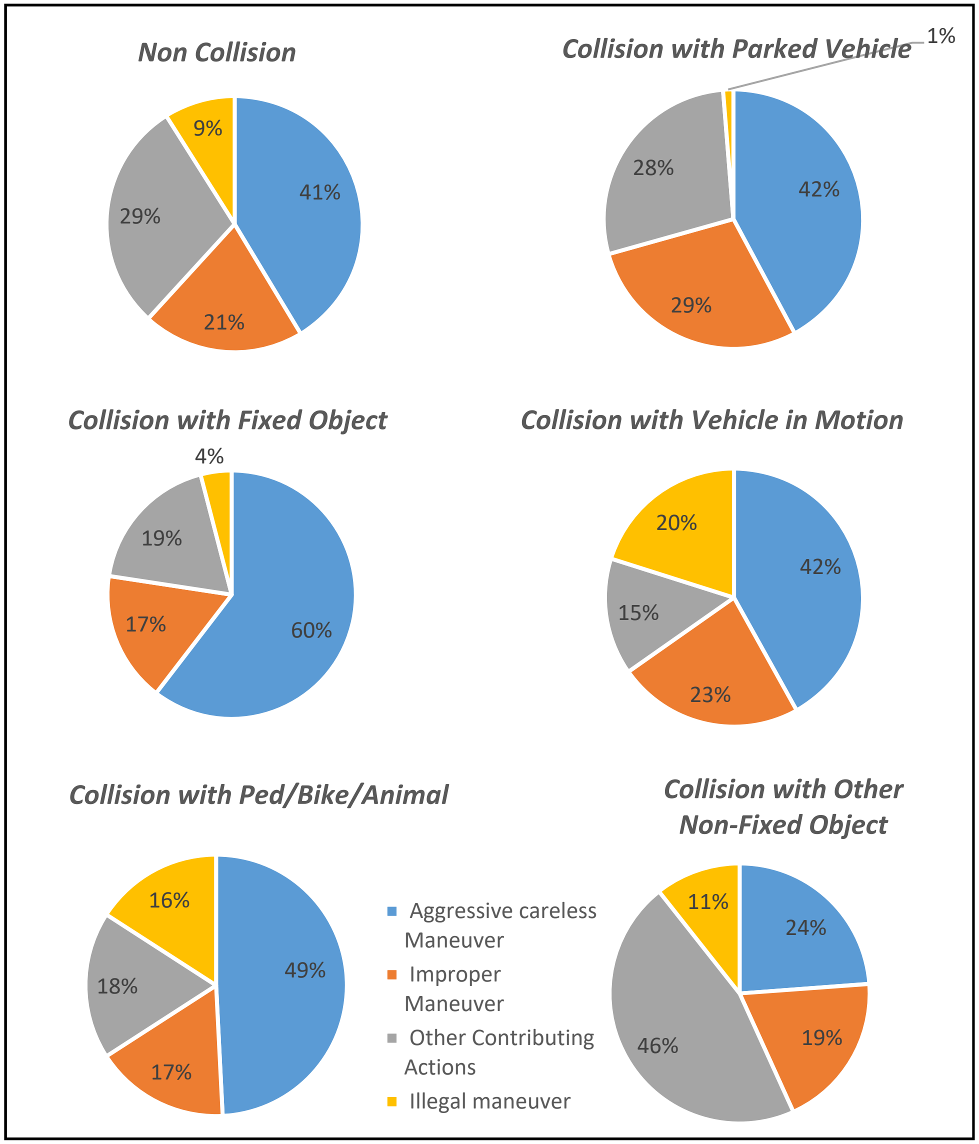


Figure 51 Critical reason for non-trucks

5.3.3. Critical Reason for Non-Trucks – Non-Driving Error

Similar to trucks, non-driving error showed very little contribution across all crash types (Figure 44). As a result, the sample size was generally very small as shown in Figure 52, which shows the subcategories for non-driving errors by crash type. As the sample size was too small to make reliable inferences, we focus on collision with vehicle in motion.

- One can observe that DUI from non-trucks showed much higher contribution (15%) to collision with vehicle in motion than trucks (6%);
- On the other hand, fatigue contributed much less (18%) for non-trucks compared to trucks (40%).

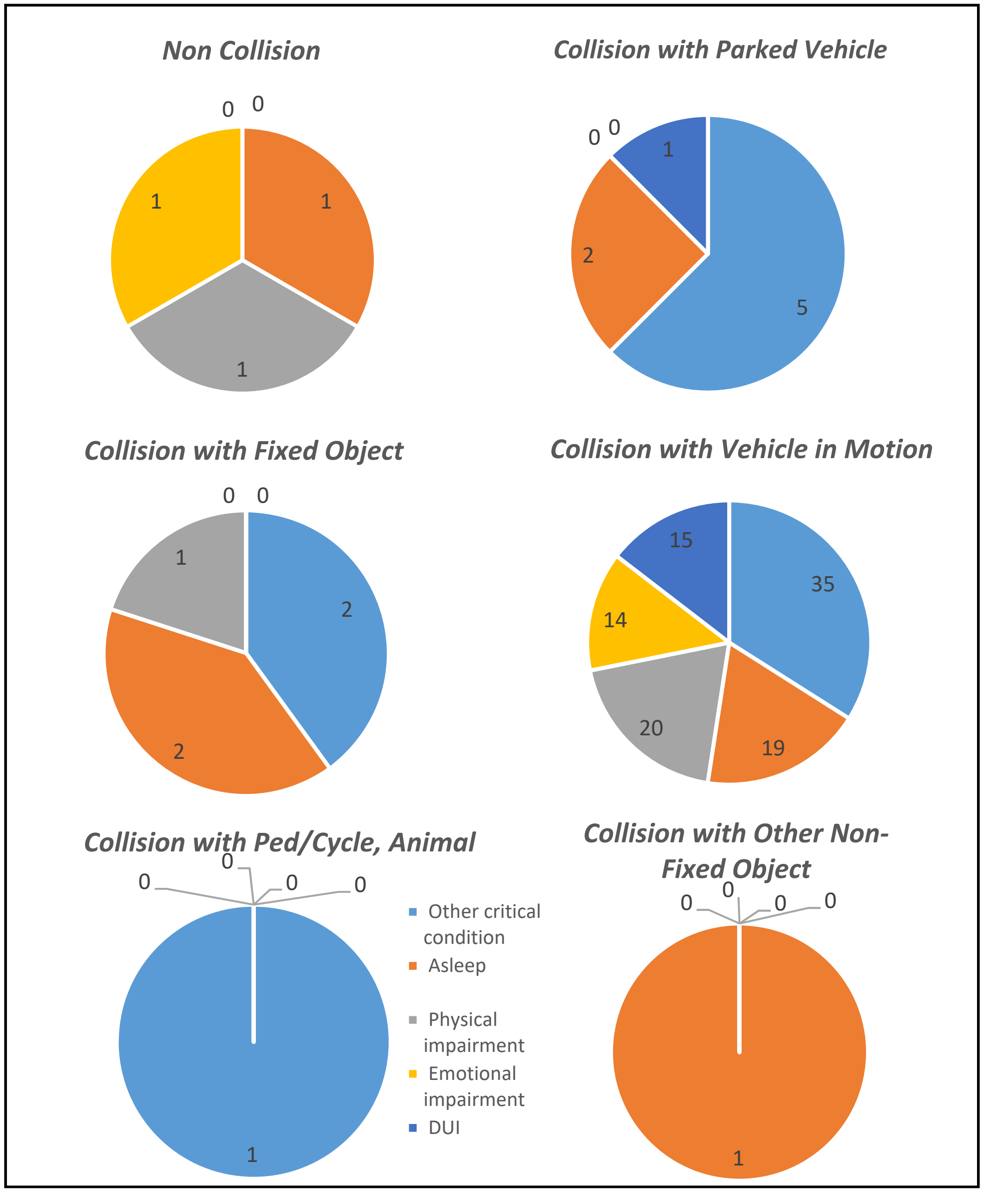


Figure 52 Critical reason for non-trucks – non-driving error

5.3.4. Critical Reason for Non-Trucks – Driver Distraction/Vision Obstruction

Figure 53 presents the sub-categories in driver distraction or vision obstruction by crash type.

- Same as trucks, inadequate surveillance was the dominant factor across all crash types, and other recognition error was the next most critical contributor;
- It is worth noting that, for non-trucks internal distraction was more prevalent than external distraction, which is the opposite for trucks.

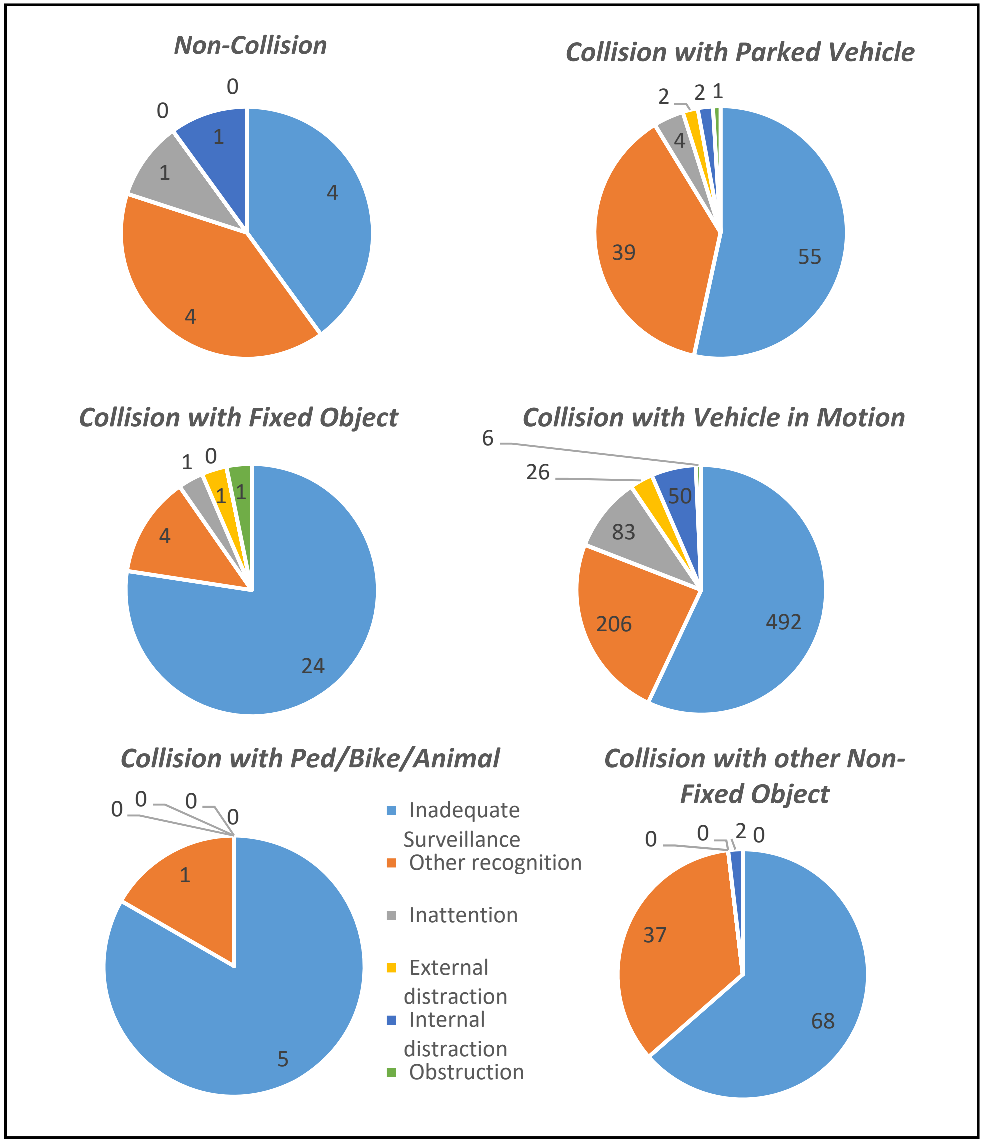


Figure 53 Critical reason for non-trucks - distraction/vision obstruction

5.3.5. Critical Reason for Non-Trucks – Vehicle Defect

The general pattern for non-trucks in terms of vehicle defect was very similar to that for trucks. Overall, vehicle defect was a significant contributor to non-collision, represented about 13% of non-collision crashes (Figure 50). Functional defects were more prevalent for most crash types except for collision with parked vehicle.

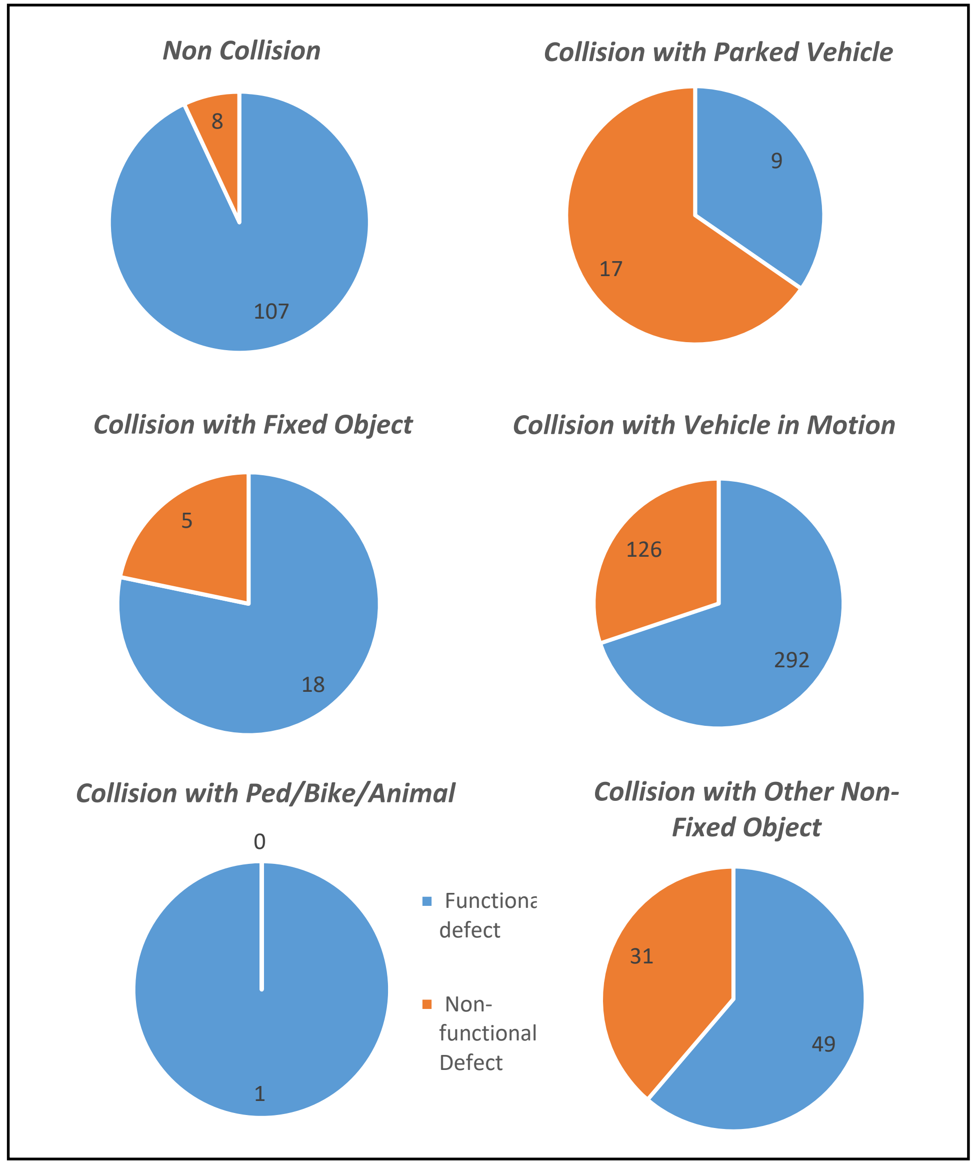


Figure 54 Critical reason for non-trucks - vehicle defect

5.3.6. Critical Reason for Non-Trucks – Roadway

Figure 53 presents the subcategories of roadway conditions for those crashes that were assigned a critical reason of roadway condition, which means no other potential contributors discussed previously were present. The general pattern was very similar to that for trucks (Figure 55).

- Slick road was the dominant condition across all crash types;
- Followed by roadway geometry and work zone;
- No other factors showed significant contribution.

5.3.7. Critical Reason for Non-Trucks – Weather

There were only 15 crashes in total that were assigned a critical reason of weather conditions, all of them were due to fog. 12 of them were in collision with vehicle in motion.

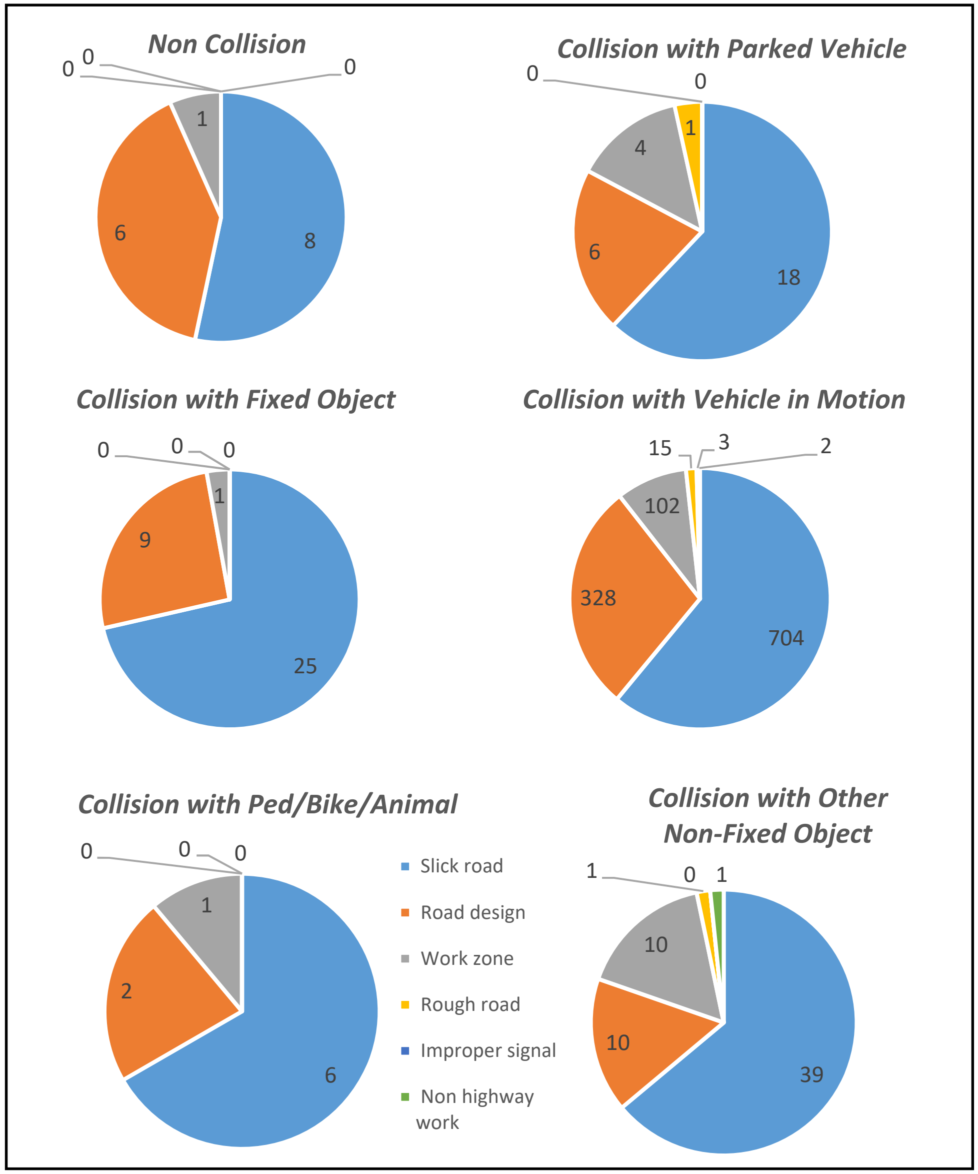


Figure 55 **Critical reason for non-trucks – roadway condition**

Table 53 Summary of Critical Reason by Crash Type

Critical Reason		Non-Collision				Collision with Fixed Object				Collisin with Ped/Bike/Animal				Collision with Parked Vehicle				Collisin with Vehicle in Motion				Collision with other Non-Fixed Object				All Crashes			
		Trucks		non-Trucks		Trucks		non-Trucks		Trucks		non-Trucks		Trucks		non-Trucks		Trucks		non-Trucks		Trucks		non-Trucks		Trucks		non-Trucks	
Category	Sub-Category	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Driving Error	Aggressive careless Maneuver	3,005	43.8%	314	34.8%	7,698	43.2%	733	56.1%	192	16.2%	62	43.4%	3,925	37.2%	1,771	40.5%	32,185	38.7%	27,769	40.4%	1,924	21.4%	757	22.1%	48,929	41.2%	31,406	41.5%
	Improper Maneuver	783	11.4%	155	17.2%	4,220	23.7%	206	15.8%	140	11.8%	21	14.7	4,474	42.4%	1,197	27.4%	26,390	31.7%	15,448	22.5%	1,216	13.5%	616	18.0%	37,223	31.4%	17,643	23.3%
	Other Contributing Actions	1,399	20.4%	222	24.6%	4,035	22.7%	225	17.2%	314	26.5%	23	16.1	1,664	15.8%	1,179	27.0%	11,882	14.3%	9,686	14.1%	3,370	37.5%	1,466	42.8%	22,664	19.1%	12,801	16.9%
	Illegal maneuver	124	1.8%	68	7.5%	377	2.1%	49	3.7%	186	15.7%	20	14.0	54	0.5%	54	1.2%	8,805	10.6%	13,326	19.4%	340	3.8%	338	9.9%	9,886	8.3%	13,855	18.3%
	sub-Total	**5,311**	**77.4%**	**759**	**84.1%**	**16,330**	**91.7%**	**1,213**	**92.8%**	**832**	**70.2%**	**126**	**88.1%**	**10,117**	**95.9%**	**4,201**	**96.2%**	**79,262**	**95.3%**	**66,229**	**96.3%**	**6,850**	**76.2%**	**3,177**	**92.7%**	**118,702**	**92.3%**	**75,705**	**95.9%**
Non-Driving Error	Other critical condition	5	0.1%	0	0.0%	8	0.0%	2	0.2%	4	0.3%	1	.7	18	0.2%	5	0.1%	20	0.0%	35	0.1%	1	0.0%	0	0.0%	56	35.0%	43	35.5%
	Asleep	9	0.1%	1	0.1%	5	0.0%	2	0.2%	0	0.0%	0	.0	10	0.1%	2	0.0%	21	0.0%	19	0.0%	3	0.0%	1	0.0%	48	30.0%	25	20.7%
	Physical impairment	6	0.1%	1	0.1%	28	0.2%	1	0.1%	0	0.0%	0	.0	2	0.0%	0	0.0%	5	0.0%	20	0.0%	3	0.0%	0	0.0%	44	27.5%	22	18.2%
	Emotional impairment	2	0.0%	1	0.1%	0	0.0%	0	0.0%	1	0.1%	0	.0	1	0.0%	0	0.0%	4	0.0%	14	0.0%	0	0.0%	0	0.0%	8	5.0%	15	12.4%
	DUI	0	0.0%	0	0.0%	1	0.0%	0	0.0%	0	0.0%	0	.0	0	0.0%	1	0.0%	3	0.0%	15	0.0%	0	0.0%	0	0.0%	4	2.5%	16	13.2%
	sub-Total	**22**	**0.3%**	**3**	**0.3%**	**42**	**0.2%**	**5**	**0.4%**	**5**	**0.4%**	**1**	**0.7%**	**31**	**0.3%**	**8**	**0.2%**	**53**	**0.1%**	**103**	**0.1%**	**7**	**0.1%**	**1**	**0.0%**	**160**	**0.1%**	**121**	**0.2%**
Driver Distraction / Vision Obstruction	Inadequate Surveillance	74	1.1%	4	0.4%	211	1.2%	24	1.8%	72	6.1%	5	3.5	103	1.0%	55	1.3%	753	0.9%	492	0.7%	107	1.2%	68	2.0%	1,320	60.1%	648	57.9%
	Other recognition	15	0.2%	4	0.4%	60	0.3%	4	0.3%	33	2.8%	1	.7	81	0.8%	39	0.9%	306	0.4%	206	0.3%	75	0.8%	37	1.1%	570	26.0%	291	26.0%
	Inattention	1	0.0%	1	0.1%	22	0.1%	1	0.1%	1	0.1%	0	.0	13	0.1%	4	0.1%	77	0.1%	83	0.1%	2	0.0%	0	0.0%	116	5.3%	89	7.9%
	External distraction	11	0.2%	0	0.0%	20	0.1%	1	0.1%	2	0.2%	0	.0	6	0.1%	2	0.0%	45	0.1%	26	0.0%	3	0.0%	0	0.0%	87	4.0%	29	2.6%
	Internal distraction	4	0.1%	1	0.1%	13	0.1%	0	0.0%	1	0.1%	0	.0	2	0.0%	2	0.0%	34	0.0%	50	0.1%	3	0.0%	2	0.1%	57	2.6%	55	4.9%
	Obstruction	1	0.0%	0	0.0%	21	0.1%	1	0.1%	2	0.2%	0	.0	0	0.0%	1	0.0%	10	0.0%	6	0.0%	11	0.1%	0	0.0%	45	2.1%	8	0.7%
	sub-Total	**106**	**1.5%**	**10**	**1.1%**	**347**	**1.9%**	**31**	**2.4%**	**111**	**9.4%**	**6**	**4.2%**	**205**	**1.9%**	**103**	**2.4%**	**1,225**	**1.5%**	**863**	**1.3%**	**201**	**2.2%**	**107**	**3.1%**	**2,195**	**1.7%**	**1,120**	**1.4%**
Vehicle Defects	Functional defect	880	12.8%	107	11.8%	398	2.2%	18	1.4%	7	0.6%	1	0.7	34	0.3%	9	0.2%	354	0.4%	292	0.4%	1,206	13.4%	49	1.4%	2,879	77.2%	476	71.8%
	Non-functional Defect	170	2.5%	8	0.9%	91	0.5%	5	0.4%	15	1.3%	0	.0	43	0.4%	17	0.4%	220	0.3%	126	0.2%	310	3.4%	31	0.9%	849	22.8%	187	28.2%
	sub-Total	**1,050**	**15.3%**	**115**	**12.7%**	**489**	**2.7%**	**23**	**1.8%**	**22**	**1.9%**	**1**	**0.7%**	**77**	**0.7%**	**26**	**0.6%**	**574**	**0.7%**	**418**	**0.6%**	**1,516**	**16.9%**	**80**	**2.3%**	**3,728**	**2.9%**	**663**	**0.8%**
Roadway Condition	Slick road	205	3.0%	8	0.9%	344	1.9%	25	1.9%	113	9.5%	6	4.2	67	0.6%	18	0.4%	1,074	1.3%	704	1.0%	263	2.9%	39	1.1%	2,066	54.9%	800	61.4%
	Road design	112	1.6%	6	0.7%	176	1.0%	9	0.7%	66	5.6%	2	1.4	33	0.3%	6	0.1%	764	0.9%	328	0.5%	75	0.8%	10	0.3%	1,226	32.6%	361	27.7%
	Work zone	25	0.4%	1	0.1%	44	0.2%	1	0.1%	12	1.0%	1	.7	5	0.0%	4	0.1%	189	0.2%	102	0.1%	53	0.6%	10	0.3%	328	8.7%	119	9.1%
	Rough road	26	0.4%	0	0.0%	23	0.1%	0	0.0%	8	0.7%	0	.0	8	0.1%	1	0.0%	38	0.0%	15	0.0%	20	0.2%	1	0.0%	123	3.3%	17	1.3%
	Improper signal	0	0.0%	0	0.0%	5	0.0%	0	0.0%	0	0.0%	0	.0	0	0.0%	0	0.0%	5	0.0%	3	0.0%	0	0.0%	0	0.0%	10	0.3%	3	0.2%
	Non highway work	1	0.0%	0	0.0%	2	0.0%	0	0.0%	1	0.1%	0	.0	1	0.0%	0	0.0%	3	0.0%	2	0.0%	1	0.0%	1	0.0%	9	0.2%	3	0.2%
	sub-Total	**369**	**5.4%**	**15**	**1.7%**	**594**	**3.3%**	**35**	**2.7%**	**200**	**16.9%**	**9**	**6.3%**	**114**	**1.1%**	**29**	**0.7%**	**2,073**	**2.5%**	**1,154**	**1.7%**	**412**	**4.6%**	**61**	**1.8%**	**3,762**	**2.9%**	**1,303**	**1.7%**
Weather Condition	Fog	5	0.1%	1	0.1%	5	0.0%	0	0.0%	15	1.3%	0	.0	3	0.0%	1	0.0%	25	0.0%	12	0.0%	4	0.0%	1	0.0%	57	90.5%	15	83.3%
	Wind gust	0	0.0%	0	0.0%	4	0.0%	0	0.0%	1	0.1%	0	.0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	5	7.9%	0	0.0%
	Glare	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	.0	0	0.0%	1	0.0%	1	0.0%	2	0.0%	0	0.0%	0	0.0%	1	1.6%	3	16.7%
	sub-Total	**5**	**0.1%**	**1**	**0.1%**	**9**	**0.1%**	**0**	**0.0%**	**16**	**1.3%**	**0**	**0.0%**	**3**	**0.0%**	**2**	**0.0%**	**26**	**0.0%**	**14**	**0.0%**	**4**	**0.0%**	**1**	**0.0%**	**63**	**0.0%**	**18**	**0.0%**
Total		6,863	100.0%	903	100.0%	17,811	100.0%	1,307	100.0%	1,186	100.0%	143	100.0	10,547	100.0%	4,369	100.0%	83,213	100.0%	68,781	100.0%	8,990	100.0%	3,427	100.0%	128,610	100.0%	78,930	100.0%

5.4. Summary for Critical Reason Analysis

A framework was developed to identify critical reasons for individual crashes. The framework considers a hierarchy of factors in this order: driving error, non-driving error, driver distraction, vision obstruction, vehicle defect-vital, vehicle defect-non-vital, roadway condition, and weather conditions. The highest ranked factor was assigned to the crash. It means that there may be multiple conditions present for a single case, but only the highest ordered factor was designated as the critical reason. For example, a driver might have over-steered in a roadway condition on a rainy day; We always assume the driver will do his/her best in all scenarios, so driver-related factors always take higher order here. It should be noted that this analysis is not meant to be used to determine the at-fault party or the actual cause, which requires intensive investigation of each case individually. Rather this analysis intends to draw a general picture of what happened with these crashes.

Out of the 231,890 crashes, 24,194 (10.4%) crashes were not associated with any identifiable factors discussed above, which indicates that there might be other factors at play that were not available from the crash report.

For those crashes to which a critical reason was assigned, Table 53 shows a summary of critical reason by crash type for trucks and non-trucks, respectively. Major findings regarding critical reason are highlighted as follows.

- Overall, driving-error was the dominant critical reason, representing 92.3% of the crashes for trucks and 95.6% for non-trucks. Non-trucks were more likely to be associated with driving errors than trucks across all crash types.
- Collisions with pedestrian, bicycle, animals were the least likely to be associated with driving errors, compared with other crash types, especially for trucks.
- The next critical reason was vehicle defects and roadway conditions for trucks, representing 2.9% of the crashes, respectively. Relatively, non-trucks were less likely to be assigned to vehicle defects (0.8%) and roadway conditions (1.7%) than trucks.
- Vehicle defects for trucks were particularly significant for non-collision (15.3%) and collision with other non-fixed object (16.9%), while roadway condition was particularly critical for collisions with pedestrian, bicycle and animals (16.9%).
- Driver distraction/vision obstruction was another significant factor for collision with pedestrian, bicycle and animals, for both trucks (9.4%) and non-trucks (4.2%).
- Non-driving error shows minimal influence, especially for trucks. It should be noted that while trucks were more likely to be associated with asleep/fatigue, they were much less likely to be involved in DUI conditions than non-trucks.

6. CRASH SEVERITY ANALYSIS

This chapter presents the modeling methodology and the results of crash severity analysis. The analysis focused on crashes where truck was identified as the primary vehicle, and separate models were developed for each crash type, namely non-collision, collision with fixed object, collision with pedestrian, bicycle, animal, collision with parked vehicle, collision with vehicle in motion, and collision with other non-fixed object.

6.1. Model Methodology

Among a variety of discrete choice model structures, mixed logit models (also referred to as random-parameter logit models) have been widely used to analyze crash injury severity due to their capability to address heterogeneity (Hensher et al. 2005, Greene 2009, Fu et al. 2011, Anastasopoulos and Mannering 2011, Eluru 2013). In view of model structure, heterogeneity is incorporated through random parameters, where the coefficient associated with the parameter is allowed to vary across the observations and assumed to follow certain distribution. The concept of random parameters has been successfully accommodated with a variety of basic model structures including count models, as well multinomial and ordered structures (Greene and Hensher, 2009).

A random parameter ordered logit (RPOL) structure was employed for this study, which is capable of accommodating both the ordered nature of the dependent variable and the heterogeneity through incorporating normally distributed random coefficients. The RPOL structure builds an association between a latent continuous function (U_i^*) and j discrete severity categories (j=0, 1, 2 respectively for PDO, injury, and fatal crashes) using certain threshold values denoted as μ_j.

The latent utility function could be formulated as a linear vector of crash contributing factors, including driver, vehicle, roadway, environment, and crash-related characteristics:

$$U_i^* = z_i'\delta + x_i'\beta_i + \epsilon_i$$

Where

U_i^* = Latent severity function associated with severity outcome for observation i

z_i' = Vector of variables with fixed parameters

δ = Vector of fixed coefficients

x_i' = Vector of variables with random coefficients

β_i = Vector of random coefficients

ϵ_i = IID distributed error term

In a random parameter structure where coefficients are individual-specific and differ from one observation to another, β_i is decomposed as follows:

$$\beta_i = \beta + D\omega_i$$

D = diagonal covariance matrix, with diagonal elements δ_m^2 =variance of each random coefficient, 0 for fixed coefficients.

ω_i= vector of standard normal random variables associated with observation i

Considering the ordered nature of the dependent variable, probability of observation i being associated with severity level j would be as follows:

$$Prob\ (y_i = j|x_i, \omega_i) = F\left(\mu_j - \beta_i' x_i\right) - F\left(\mu_{j-1} - \beta_i' x_i\right) =$$

$$F\left(\mu_j - \beta' x_i - (D\omega_i)' x_i\right) - F\left(\mu_{j-1} - \beta' x_i - (D\omega_i)' x_i\right)$$

And the likelihood function will consequently be written as:

$$Logl_i = \int_{\omega_i} \left(F\left(\mu_j - \beta' x_i - (D\omega_i)' x_i\right) - F\left(\mu_{j-1} - \beta' x_i - (D\omega_i)' x_i\right)\right) \phi(\omega_i) d\,\omega_i$$

Where

F = Cumulative Distribution function (normal or logistic)

ϕ = Normal density function

μ_j = Threshold values for j=1, 2, …, k-1 for k different classes of the dependent variable

Interpretation of the coefficients in the ordered choice model is more complicated than in the ordinary regression setting (Daykin and Moffatt, 2002). This mainly stems from the fact that coefficients reflect the impact of parameters on the latent function rather than a direct impact on discrete categorical outcome of the model. The true outcome depends both on the latent function and the estimated thresholds. Hence, in order to attach meaning to the parameters, one typically refers to the probabilities themselves and calculates the magnitude of change in the probability of the model outcome due to a unit shift in any parameter. The result of such calculation is usually referred to as marginal (partial) effects. For continuous parameters, marginal effects can be computed using a simple derivative formula:

$$\delta_j(x_{ik}) = \frac{\partial prob(y = j|x_{ik})}{\partial x_{ik}} = (f\left(\mu_j - \beta_i' x_i\right) - f\left(\mu_{j-1} - \beta_i' x_i\right))\beta_{ik}$$

Where

δ_j = marginal effect on level j of the dependent variable

$x_{ik} =$ an independent variable in the set x_i

f = density function (normal or logistic)

β_{ik} = Coefficient associated with variable x_{ik}

A counterpart result for a dummy variable in the model would be obtained by using a difference of probabilities, rather than a derivative. Accordingly:

$$\delta_j(D_{ik}) = [prob(y = j|D_{ik} = 1) - prob(y = j|D_{ik} = 0)] = \left[F\left(\mu_j - \beta_i' x_i \middle| D_{ik} = 1\right) - F\left(\mu_{j-1} - \beta_i' x_i \middle| D_{ik} = 1\right)\right] - \left[F\left(\mu_j - \beta_i' x_i \middle| D_{ik} = 0\right) - F\left(\mu_{j-1} - \beta_i' x_i \middle| D_{ik} = 0\right)\right]$$

Where

D_{ik} = dummy variable in the set of variables x_i

6.2. Non-Collision Crashes

This dataset contains crashes that their first harmful event is a non-collision phenomenon, such as a rollover or cargo shift event and also the truck driver was at fault for the crash occurrence. In total 7,498 crashes were recorded in this category and 31.7% of these crashes resulted in injury and fatality. Taking the nature of such crashes into account, in most of cases, drivers had no contributing action (32.69%), followed by a careless or negligent driving manner (32.57%). Majority of drivers fell in the range of 36 to 50 years-old, contributing to a total of 43.61% of total crashes. Within a 24-hour daily span, the highest crash percentage occurred in the midday period (45.39%), and with daylight condition (77.51%).

Speed analysis shows that 44.77% of crashes occurred when speed is between 50 and 75 miles per hour. This sounds reasonable because controlling truck movement is difficult and calls for extra care and skills. While the majority of such crashes happened to trucks with no specific defects detected (76.02%), tire (9.52%) and brake defects (1.6%) were the most frequently recorded issues. Interestingly, for vehicle maneuver action, running straight ahead was the predominant category with 67.99% percentage of total crashes which can be another reason for relatively high speed of vehicles. It is observed that the largest percentage of crashes occurred when roadway alignment is straight (53.41%), and when the roadway grade is level (53.41%). In most cases the driver was in apparently normal condition (61.55%), with no vision obstruction (94.69%), or no distraction (57.26%).

Models results are presented in Tables 54 and 55, respectively. Table 54 presents the parameter coefficients in the latent severity function. Each cell includes the coefficient value as well as the corresponding t-value in parentheses which reflects the significance level of the parameter. The models are optimized, i.e. only variables with 90% confidence level or higher (t-value=1.64 or larger) are included. All parameters in Table 54 are accompanied by positive coefficients, indicating that all the significant parameters which were detected during the modeling process, are likely to increase the severity. In view of magnitudes, crash-types as well as certain vehicle maneuvers are ranked among the top high impacts on crash severity. This means that although the first harmful event was not a collision phenomenon, the type of collision that followed the first harmful event has significant impacts on the severity outcome. To be more precise, involvement of a bicycle, left rear, head on, left entering, roll-over and off-road crashes are likely to increase crash severity compared to other crash types.

Table 54 Non- Collision Crashes -- Model Coefficient Estimates

Category	Variable Name	Variable Characteristics	Coeff. (T Value)
	Level 2-3 Threshold		2.25(45.14)
	Level 1-2 Threshold		0.0 (Fixed)
	Constant		-1.688 (-34.32)
Crash	Within City Limits	No	0.1 (2.68)
	Crash Type	Bicycle	3.002 (2.31)
		Head On	1.063 (5.32)
		Left Entering	1.041 (2.97)
		Left Rear	1.209 (2.31)
		Off Road	0.741 (7.37)
		Rollover	1.015 (28.07)
	Vehicle Count	4	0.590 (3.67)
		5+	0.395 (2.29)
	Passenger Count	1	0.404 (8.71)
		2	0.357 (3.95)
		3	0.475 (4.3)
		4+	0.498 (4.35)
Temporal	Year	2010	0.159 (2.55)
Driver	Driver Action at Time of Crash	Operated in Careless or Negligent Manner	0.135 (3.78)
		Failed to Yield Right of Way	0.760 (4.17)
		Ran Red Light	1.050 (2.38)
	Driver Condition at Time of Crash	Asleep or Fatigued	0.464 (2.7)
		Under the Influence of Medications/Drugs/Alcohol	0.861 (3.71)
	Distracted By	Electronic Communication Devices	0.659 (1.65)
	Speed	25 To 50	0.352 (7.6)
		50 To 75	0.294 (6.59)
		More Than 75	0.399 (3.89)
	Age	More Than 65	0.158 (1.96)
Vehicle	Vehicle Maneuver Action	Changing Lanes	0.253 (2.85)
		Other	0.180 (1.95)
	Vehicle Defect	Tires	0.143 (2.52)
		Steering	0.702 (2.26)
	Haz_Mat_Released	Yes	0.443 (3.19)
Roadway	Contributing Circumstances: Road	Rut, Holes, Bumps	0.339 (1.77)
	Road System Id	U.S.	0.125 (2.34)
		County	0.195 (3.88)
	Shoulder Type	Unpaved	0.065 (1.74)
	Roadway Alignment	Curve Right	0.204 (3.04)
	Total Lanes	4	0.095 (2.14)
Environment	Weather Condition	Cloudy	0.126 (3.21)
Random Parameter	Vehicle Maneuver Action	Leaving Traffic Lane (mean)	0.659 (2.64)
		Leaving Traffic Lane (scale)	0.962 (3.73)
	First Harmful Event Location	Off Roadway (mean)	0.150 (2.94)
		Off Roadway (scale)	0.418 (9.06)
		Shoulder (mean)	0.195 (4.03)
		Shoulder (scale)	0.196 (4.65)
		Median (mean)	0.325 (4.07)
		Median (scale)	0.446 (5.78)
Goodness of Fit	N=7498, LL=-4230.81		

Among different vehicle maneuvers, running red light, and failing to yield right of way are among the significant contributors to the model. As expected, driving under influence or under asleep/fatigue conditions will increase the severity. Steering and tire defects showed significant impacts on the model. All speed categories above 25 mph showed fairly positive impacts on the severity, which might imply that non-collision truck crashes are unlikely to result in severe outcomes at speeds below 25 mph. A quick review of environment related parameters reveals that severity levels are probably higher on US or County roads, in presence of low-quality road surface such as ruts and holes, and on curves to the right. Unpaved shoulders and 4-lane roadways are also likely to increase severity, though the impact is very small.

One important factor in crash occurrence and the resulting severity is the location of first harmful event. Interestingly, all the first harmful event location parameters showed a mixed (random) effect on the model. The only other random parameter was "leaving traffic lane" vehicle maneuver. The randomness of the coefficient implies that the magnitude of the parameter impact varies across different observations. More importantly, the large magnitude of scale parameters (standard deviation) associated with these random variables indicates that even the direction of the impact could be reversed. Further investigation requires an analysis of interaction effects to come up with sources of heterogeneity.

While the analysis of model coefficients provides a good picture of how different parameters contribute to crash severity, it should be noted that the final severity outcome is a combination of the latent severity function and the model thresholds. In this regard, a marginal effect analysis is required to provide detailed estimates on how each parameter increases/decreases the probability associated with each severity level. Results of the marginal effect analysis are illustrated in Table 55.

Each marginal effect is accompanied by a correspondent t-value, which denotes its significance level. It should be noticed, however, that a significant coefficient might not necessarily result in a significant marginal effect. For the reader's convenience, top positive or negative marginal effects are highlighted. For instance, one can infer that the probability of an injury outcome will increase by 0.367 when the crash type is revealed to be a head-on (compared to when no information about crash type is in hand).

Stemming from the positive sign of all coefficients in Table 54, it is reasonable to expect negative marginal effects on the base severity level, that is, all the parameters in the model tend to decrease the probability of a PDO crash. Among all variables, bicycle involvement has the highest negative marginal effect on PDO crashes. In other words, when a bicycle is involved in a crash, it is unlikely to expect a PDO outcome. However, the model is unable to define whether the final outcome will be an injury or a fatal crash (since none of the marginal effects associated with these two levels are significant). This probably implies that bicycle-involved crashes are somewhat equally spread between fatal and injury severity categories.

Table 55 Non- Collision Crashes -- Marginal Effects

	Variable		Y=0 (PDO)	Y=1 (Injury)	Y=2 (Fatality)
Crash	Within City Limits	No	-0.034(-2.71)	0.033(2.71)	0.001(2.78)
	Crash Type	Bicycle	-0.707(-25.92)	0.136(0.28)	0.571(1.12)
		Head On	-0.405(-5.73)	0.367(6.85)	0.037(2.18)
		Left Entering	-0.397(-3.17)	0.362(3.76)	0.035(1.23)
		Left Rear	-0.454(-2.68)	0.403(3.58)	0.051(0.9)
		Off Road	-0.283(-7.18)	0.267(7.63)	0.016(3.59)
		Rollover	-0.351(-28.95)	0.338(29.83)	0.013(14.49)
	Vehicle_Count	4	-0.226(-3.49)	0.215(3.63)	0.011(1.96)
		5 and More	-0.146(-2.16)	0.141(2.2)	0.005(1.45)
	Passenger_Count	1	-0.147(-8.31)	0.142(8.42)	0.005(5.82)
		2	-0.131(-3.74)	0.127(3.79)	0.004(2.62)
		3	-0.178(-4.07)	0.171(4.17)	0.007(2.55)
		4 and More	-0.187(-4.12)	0.179(4.23)	0.008(2.52)
Temporal	Year	2010	-0.056(-2.47)	0.055(2.49)	0.002(2.12)
Driver	Driver Action at Time of Crash	Operated MV in Careless or Negligent Manner	-0.047(-3.74)	0.046(3.75)	0.001(3.47)
		Failed to Yield Right of Way	-0.291(-4.08)	0.274(4.36)	0.017(1.99)
		Ran Red Light	-0.400(-2.55)	0.364(3.03)	0.036(0.98)
	Driver Condition at Time of Crash	Asleep or Fatigued	-0.174(-2.54)	0.167(2.61)	0.007(1.6)
		Under the Influence of Medications/Drugs/Alcohol	-0.330(-3.72)	0.308(4.1)	0.022(1.67)
	Distracted By	Electronic Communication Devices (Cell Phone, Etc.)	-0.251(-1.58)	0.238(1.66)	0.013(0.84)
	Speed	25 To 50	-0.125(-7.35)	0.121(7.41)	0.004(5.68)
		50 To 75	-0.100(-6.58)	0.097(6.59)	0.002(5.9)
		More Than 75	-0.147(-3.67)	0.142(3.74)	0.005(2.47)
	Age	More Than 65	-0.056(-1.89)	0.054(1.9)	0.001(1.61)
Vehicle	Vehicle Maneuver Action	Changing Lanes	-0.091(-2.72)	0.089(2.74)	0.003(2.1)
		Other	-0.064(-1.88)	0.062(1.89)	0.002(1.56)
	Vehicle Defect	Tires	-0.050(-2.45)	0.049(2.46)	0.001(2.15)
		Steering	-0.268(-2.18)	0.254(2.31)	0.015(1.12)
	Haz_Mat_Released	Yes	-0.165(-3.01)	0.159(3.08)	0.006(1.93)
Roadway	Contributing Circumstances: Road	Rut, Holes, Bumps	-0.124(-1.67)	0.120(1.7)	0.004(1.18)
	Road System ID	U.S.	-0.044(-2.29)	0.043(2.29)	0.001(2.04)
		County	-0.069(-3.76)	0.067(3.78)	0.002(3.15)
	Shoulder Type	Unpaved	-0.022(-1.73)	0.022(1.73)	0.001(1.67)
	Roadway Alignment	Curve Right	-0.073(-2.92)	0.071(2.94)	0.002(2.38)
	Total Lanes	4	-0.033(-2.11)	0.032(2.11)	0.001(1.96)
Environment	Weather Condition	Cloudy	-0.044(-3.15)	0.043(3.16)	0.001(2.87)
Random Parameters	First Harmful Event Location	Off Roadway	-0.053(-2.86)	0.051(2.87)	0.001(2.51)
		Shoulder	-0.069(-3.91)	0.067(3.92)	0.002(3.3)
		Median	-0.119(-3.87)	0.115(3.91)	0.004(2.8)
	Vehicle Maneuver Action	Leaving Traffic Lane	-0.251(-2.53)	0.238(2.66)	0.013(1.34)

Looking into injury level crashes, results show that certain crash types as well as running red light show the highest increase in an injury outcome. That is, for instance, with all other parameters being constant, a red-light violation, a head-on or a left-rear crash are most likely to result in an injury severity outcome.

In view of fatality, marginal effects are quite small, probably because the probability of a fatal crash in the whole sample was fairly small compared to other levels. Also, it might indicate that there are certain unobserved parameters that result in a fatal crash, which have not been detected by our model. Accordingly, the highest marginal effect on crash fatality belongs to head-on crashes.

6.3. Collision with Fixed Object

This dataset considers crashes that their first harmful event is collision with a fixed object and the truck was recorded as the primary vehicle. There are a total of 21,203 crashes in this dataset from which 14.14% resulted in injury or fatality. Regarding the crash characteristics, 98.4% of the crashes were off-road crashes. By accommodating 60.2% of total crashes, speed of vehicles at the time of crash was mainly below 25 miles per hour.

Considering driver's characteristics, for driver action at the time of the crash, operating motor vehicle in a careless or negligent manner (36.6%), and no contributing action (19.4%) have the highest percentage in comparison to other categories. In most of crashes (87.2%) drivers were male, and for the driver age variable, the age between 36 to 50 years-old has the highest percentage by accommodating 26.9% of total crashes.

In terms of roadway and environment characteristics, 27.4% of crashes occurred on local roads, respectively. Crashes that happened in the midday period formed the prevalent category accounted for 44.5% of total crashes, and consequently, daylight was the most frequent light condition with containing 74.5% of total crashes.

Model results were shown in Table 56. Results show that crashes involving two non-motorists, one pedestrian, or a physically impaired driver have the highest severity impact on the latent severity function. Same is true when collision happens on a shared path or trail. Among different driver actions, exceeding speed limit is the most influential factor, followed by other actions such as running off roadway or following too closely.

In view of roadway systems, higher severity levels could be expected on Forest roads. Speaking of temporal fluctuations, years 2008 and 2009 are accompanied by positive coefficients, indicating that the model predicts higher latent severity values for these two time periods. Likewise, within a 24-hour period, Early morning and AM peak are most likely to indicate higher severity levels. In view of speed, speeds higher than 75 mph pertain to higher severity outcomes while mixed effects are observed for lower speeds, though the mean is positive.

Table 56 Collision with Fixed Object -- Model Coefficient Estimates

Category	Variable Name	Variable Characteristics	Coeff. (T Value)
	Level 2-3 Threshold		2.41(48.07)
	Level 1-2 Threshold		0.0 (Fixed)
	Constant		-2.615(-59.6)
Crash	Drug Related	YES	0.639(4.62)
	Vehicle Count	5 and more	0.654(2.92)
	Non-motorist Count	2	2.722(6.26)
	Passenger Count	1	0.487(12.63)
		3	0.905(7.82)
	Pedestrian Count	1	1.852(13.75)
	First Harmful Event Location	off Roadway	0.231(6.91)
	First Harmful Event relation to Junction	Non Junction	0.21(5.82)
		Intersection Related	0.175(2.11)
		Entrance/ Exit	0.359(4.82)
		Shared use Path or Trail	1.625(2.65)
		Through Roadway	0.439(2.9)
Temporal	Year	2008	0.172(4.35)
		2009	0.225(5.34)
	Time	Early Morning	0.124(3.31)
		AM Peak	0.068(1.99)
Driver	Driver Action at Time of Crash	Followed too Closely	0.425(2.15)
		Drove too Fast for Conditions	0.234(3.32)
		Exceeded Posted Speed	0.938(3.97)
		Ran off Roadway	0.419(5.61)
	Driver Condition at Time of Crash	Physically Impaired	1.88(2.73)
		Other	0.555(3.87)
	Vision obstruction	Fog	0.504(2.55)
	Speed	More than 75	0.742(13.18)
	Age	More than 65	0.176(2.87)
	Restraint System	Other	0.344(3.48)
	Vehicle Maneuver Action	Parked	0.541(4.84)
		Overtaking Passing	0.502(2.69)
		Stopped in Traffic	0.358(3.18)
	Hazardous Material Released	YES	0.657(4.5)
	Vehicle Defect	Brakes	0.266(2.23)
		Tires	0.266(4.61)
Roadway	Contributing Circumstances: Road	Shoulders (none, low, soft, high)	0.357(1.77)
	Road System Identifier	U.S.	0.381(6.27)
		State	0.423(9.97)
		County	0.326(7.04)
		Turnpike/Toll	0.134(2.11)
		Forest Road	0.867(2.33)
	Roadway Alignment	Curve Left	0.126(1.74)
Random Parameters	Alcohol Related	Yes (mean)	0.463(5.68)
		Yes (scale)	0.953(11.62)
	Vehicle Count	4 (mean)	0.851(5.94)
		4 (scale)	0.559(4.04)
	Passenger Count	2 (mean)	0.537(7.83)
		2 (scale)	0.372(5.58)
		4 (mean)	0.8(6.41)
		4 (scale)	0.87(6.49)

Table 56 Collision with Fixed Object -- Model Coefficient Estimates (Continued)

Category	Variable Name	Variable Characteristics	Coeff. (T Value)
Random Parameters	Driver Condition at Time of Crash	Ill or fainted (mean)	0.945(5.67)
		ill or fainted (scale)	0.47(2.73)
	Driver Action at Time of Crash	Failed to yield right of way (mean)	0.786(4.61)
		Failed to yield right of way (scale)	1.293(6.79)
	Road System Identifier	Interstate (mean)	0.292(5.91)
		Interstate (scale)	0.619(21.44)
	Vehicle Maneuver	Changing lanes (mean)	0.225(3.46)
		Changing lanes (scale)	0.55(8.54)
	Speed	25 to 50 (mean)	0.907(22.36)
		25 to 50 (scale)	0.47(16.72)
		50 to 75 (mean)	1.345(30.05)
		50 to 75 (mean)	0.415(18.98)
	First Harmful Event Location	Shoulder (mean)	0.277(7.72)
		Shoulder (scale)	0.174(6.59)
		Median (mean)	0.387(7.13)
		Median (scale)	0.357(7.63)
Goodness of fit	N=21203, LL=-6486.48		

Another interesting outcome of the model is the random effect of alcohol usage with a relatively high standard deviation that calls for further analysis. Among different types of defects, brakes and tire issues significantly contribute to crash severity in fixed object collisions. As expected, hazardous materials spill is another situation that aggravates crash severity.

In addition to the foresaid impacts, many factors turn out to have random (mixed) impacts on the model. In other words, the direction and magnitude of their effects on the model can vary under different conditions. For instance, fixed object collisions that happen on shoulder or median tend to show such randomness in their severity levels. Similar effects are observed when crash happens due to changing lanes, failing to yield right of way, or the condition where the driver is ill or fainted.

Marginal effects of parameters were shown in Table 57. In terms of marginal effects, all variables show a negative effect on PDO level, which is well anticipated due to their positive coefficients. Our analysis shows that in view of injury level, presence of 2 non-motorists, involvement of 1 pedestrian, and forest roads have the highest marginal effects. Other variables that increase injury level probability (but with lower magnitudes) include year 2008, passenger count =3, and speed more than 75 mph.

Table 57 Collision with Fixed Object – Marginal Effects

Category	Variable Name	Variable Characteristics	Y=0 (PDO)	Y=1 (Injury)	Y=2 (Fatality)
Crash	Drug_Related	Yes	-0.12714(-3.35)	0.12667(3.36)	0.00047(1.86)
	Vehicle Count	5 and more	-0.131(-2.11)	0.13073(2.12)	0.0005(1.16)
	Non_Motorist_Cnt	2	-0.822(-9.95)	0.70633(224.93)	0.1157(1.37)
	Passenger Count	1	-0.083(-10.04)	0.08255(10.05)	0.00021(6.28)
		3	-0.207(-5.42)	0.20575(5.46)	0.00122(2.54)
	Pedestrian_Count	1	-0.568(-11.32)	0.54932(12.49)	0.01909(3.07)

Category	Variable Name	Variable Characteristics	Y=0 (PDO)	Y=1 (Injury)	Y=2 (Fatality)
	First Harmful Event Location	off Roadway	-0.024(-3.97)	0.02437(3.98)	0.000042(3.35)
	First Harmful Event relation to Junction	Non Junction	-0.033(-4.73)	0.03305(4.73)	0.000061(3.76)
		Intersection Related	-0.017(-3.09)	0.01721(3.09)	0.000028(2.73)
		Entrance/ Exit	-0.009(-1.93)	0.00903(1.93)	0.000014(1.83)
		Shared use Path or Trail	-0.074(-1.68)	0.07387(1.69)	0.00019(1.1)
		through Roadway	-0.036(-2.86)	0.03554(2.86)	0.00069(2.22)
Temporal	Year	2008	-0.219(-2.73)	0.21799(2.75)	0.0014(1.26)
		2009	-0.072(-4.42)	0.07206(4.42)	0.00019(2.89)
	Time	Early Morning	-0.581(-2.27)	0.55979(2.53)	0.02077(0.6)
		AM Peak	-0.105(-2.88)	0.10451(2.89)	0.00034(1.7)
Driver	Driver Action at Time of Crash	Followed too Closely	-0.092(-1.93)	0.09205(1.94)	0.00028(1.19)
		Drove too Fast for Conditions	-0.149(-9.77)	0.14835(9.8)	0.0006(5.19)
		Exceeded Posted Speed	-0.026(-2.57)	0.02558(2.57)	0.000046(2.12)
		Ran off Roadway	-0.056(-2.85)	0.05619(2.85)	0.00013(2.01)
	Driver Condition at Time of Crash	Physically Impaired	-0.101(-3.65)	0.1009(3.66)	0.00032(2.18)
		Other	-0.092(-2.04)	0.09163(2.04)	0.00027(1.25)
	Vision obstruction	Fog	-0.059(-2.57)	0.05926(2.57)	0.00014(1.78)
	Speed	More than 75	-0.132(-3.25)	0.13159(3.26)	0.00051(1.78)
	Age	More than 65	-0.042(-1.89)	0.04147(1.89)	0.000085(1.42)
	Restraint System	Other	-0.041(-3.9)	0.04118(3.91)	0.000084(2.93)
Vehicle	Vehicle Maneuver Action	Parked	-0.05945(-1.43)	0.05931(1.43)	0.00014(0.99)
		Overtaking Passing	-0.063(-5.1)	0.06295(5.1)	0.00015(3.49)
		Stopped_in_Traffic	-0.069(-8.31)	0.0686(8.32)	0.00016(5.64)
	Hazardous Material Released	YES	-0.051(-6.01)	0.05053(6.02)	0.0001(4.4)
	Vehicle Defect	Brakes	-0.019(-1.95)	0.01896(1.95)	0.0011(1.69)
		Tires	-0.19579(-1.61)	0.19469(1.62)	0.0011(0.78)
Roadway	Contributing Circumstances: Road	Shoulders (none, low, soft, high)	-0.01783(-1.6)	0.0178(1.6)	0.00029(1.39)
	Road System Identifier	U.S.	-0.032(-6.51)	0.03158(6.52)	0.000051(5.48)
		State	-0.026(-5.96)	0.02618(5.96)	0.000037(5.65)
		County	-0.025(-1.88)	0.02538(1.88)	0.000045(1.55)
		Turnpike/Toll	-0.059(-3.9)	0.05899(3.91)	0.00014(2.7)
		Forest Road	-0.482(-1.99)	0.47132(2.1)	0.01091(0.62)
	Roadway Alignment	Curve Left	-0.077(-2.26)	0.07692(2.26)	0.00021(1.46)
Random Effects	Alcohol Related	Yes	-0.082(-4.39)	0.0817(4.39)	0.00022(2.77)
	Vehicle Count	4	-0.19(-4.12)	0.18916(4.15)	0.00103(1.99)
	Passenger Count	2	-0.099(-5.93)	0.09866(5.94)	0.0003(3.55)
		4	-0.174(-4.5)	0.17285(4.53)	0.00085(2.25)
	Driver Condition at Time of Crash	Ill or fainted	-0.221(-3.91)	0.22006(3.94)	0.00142(1.79)
	Driver Action at Time of Crash	Failed to yield right of way	-0.17(-3.25)	0.16883(3.26)	0.00082(1.64)
	Road System Identifier	Interstate	-0.044(-5.14)	0.04425(5.15)	0.000087(3.91)
	Vehicle Maneuver Action	changing lanes	-0.034(-3)	0.03383(3)	0.000065(2.35)
	Speed	25 to 50	-0.181(-17.32)	0.18054(17.4)	0.0008(8.59)
		50 to 75	-0.302(-22.45)	0.29995(22.71)	0.00238(8.99)
	First Harmful Event Location	Shoulder	-0.041(-6.73)	0.04092(6.74)	0.000077(5.1)
		Median	-0.064(-5.71)	0.06416(5.72)	0.00015(3.84)

6.4. Collision with Pedestrian, Bicycle, and Animals

The data consist of 2,217 records from which 37.6% are property damage crashes, 51.7% are injury crashes, and the remaining 10.7% are categorized as fatal crashes. The sample consists of 89.9% male drivers. Main category of driver age is for ages between 36 to 50 years old (42.12%). Majority of crashes (30.4%) happened on midday period, and daylight condition (52.7%). Predominant speed is below 25 miles per hour. Looking into roadway type, the main category is local roads accounting for 23.27% of total crashes. About 51.5% of the crashes were above speed limit. It is observed that the largest percentage of crashes occurred when vehicle had no defects (94.5%). In most cases the driver was either in a normal condition (51.9%), or his condition was not reported (47.5%). In most cases (53.7%) no pedestrian was involved, followed closely by one pedestrian being involved in the crash (44.9%).

Results for the collision with non-fixed objects is presented in Tables 58 and 59. Among different parameters, presence of non-motorists has the highest impact on the latent severity function, followed by exceeding posted-speed limit and violating traffic signs. Interestingly, crashes happening on turnpike, toll roads, and T- intersections are likely to result in higher severities. Same is true about presence of fog/smoke, which tend to increase crash severity. In view of temporal variables, the model reflects more severe pedestrian/bicycle crashes in 2016.

Table 58 Collision with Ped/Bike/Animal -- Model Coefficient Estimates

Category	Variable Name	Variable Characteristics	Coeff. (T Value)
	Level 2-3 Threshold		2.69(37.69)
	Level 1-2 Threshold		0.0 (Fixed)
	constant		-2.107(-21.06)
Crash	ALCOHOL_RELATED	YES	0.349(2.77)
	Vehicle Count	3	1.621(3.93)
	Non- Motorist Count	1	3.108(33.41)
		2	3.298(13.32)
Temporal	Year	2016	0.199(1.59)
Driver	Drivers Actions at Time of Crash	Exceeded Posted Speed	2.177(2.59)
		Disregarded other Traffic Sign	1.928(2.47)
	Speed	25 to 50	0.323(3.79)
Vehicle	Commercial Motor Vehicle Configuration	truck_more_than_10,000	0.624(2.63)
		Other	1.987(3.01)
	Vehicle Maneuver Action	Entering Traffic Lane	0.777(1.77)
Roadway	Road System Identifier	Turnpike/Toll	0.927(3.46)
	Type of Intersection	T_Intersection	0.25(2.16)
Environment	Weather Condition	Fog_Smog_Smoke	0.442(2.05)
Random Parameter	DRUG_RELATED	Yes (mean)	2.191(5.92)
		Yes (scale)	2.266(5.81)
	Speed	50 to 75 (mean)	0.184(2.06)
		50 to 75 (scale)	0.782(10.64)
	Total Lanes	6 (mean)	0.631(5.01)
		6 (scale)	0.92(7.03)
	First Harmful Event	On Roadway (mean)	0.245(3.18)
		On Roadway (scale)	0.435(11.97)
Goodness of fit	N=2217, LL=-1256.74		

Analysis of marginal effects reveals interesting outcomes, presented in Table 59. For instance, when there is only one non-motorist involved, the probability of an injury crash significantly increases. However, when number of non-motorists increase to two, a fatal outcome is more likely to happen. Injury crashes are also more likely to happen on 6 lane roads, under fog-smoke conditions, and when the vehicle maneuver is recorded as "entering traffic lane". As the number of vehicles or number of non-motorists increases, a fatal result is more likely to happen. Another factor which remarkably increases the probability of a fatal crash is drug-related conditions. It should be noticed, however, that drug turned out to be a random parameter whose impact is subject to change from one crash to another.

Table 59 Collision with Ped/Bike/Animal -- Marginal Effects

Category	Variable Name	Variable Characteristics	Y=0 (PDO)	Y=1 (Injury)	Y=2 (Fatality)
Crash	ALCOHOL_RELATED	YES	-0.11536(-3.07)	0.09932(3.31)	0.01604(2.01)
	Vehicle Count	3	-0.30915(-12.83)	0.05687(0.49)	0.25228(1.87)
	Non- Motorist Count	1	-0.87979(-79.05)	0.75097(79.27)	0.12883(11.09)
		2	-0.34266(-22.48)	-0.48974(-7.78)	0.83241(13.96)
Temporal	Year	2016	-0.06857(-1.67)	0.06075(1.72)	0.00782(1.31)
Driver	Drivers Actions at Time of Crash	Exceeded Posted Speed	-0.32168(-17.51)	-0.13947(-0.43)	0.46115(1.38)
		Disregarded other Traffic Sign	-0.31717(-13.81)	-0.04657(-0.17)	0.36375(1.23)
	Speed	25 to 50	-0.11009(-4.07)	0.09685(4.27)	0.01323(2.84)
Vehicle	Commercial Motor Vehicle Configuration	truck_more_than_10,000	-0.18534(-3.43)	0.14551(4.84)	0.03983(1.58)
		Other	-0.3191(-15.9)	-0.06649(-0.28)	0.38559(1.51)
	Vehicle Maneuver Action	Entering Traffic Lane	-0.21663(-2.63)	0.15793(6.24)	0.0587(0.98)
Roadway	Road System Identifier	Turnpike/Toll	-0.24442(-5.6)	0.1646(11.68)	0.07982(1.81)
	Type of Intersection	T_Intersection	-0.08492(-2.3)	0.07462(2.41)	0.01031(1.71)
Environment	Weather Condition	Fog_Smog_Smoke	-0.14073(-2.4)	0.11763(2.78)	0.02311(1.39)
Random Parameter	DRUG_RELATED	YES	-0.33607(-21.86)	-0.11572(-0.8)	0.45179(3.06)
	Total Lanes	6	-0.19152(-6.23)	0.15328(7.72)	0.03824(3.01)
	Speed	50 to 75	-0.06508(-2.12)	0.05861(2.16)	0.00648(1.8)
	First Harmful Event	On Roadway	-0.09095(-3.12)	0.08423(3.08)	0.00673(3.44)

6.5. Collision with Parked Vehicle

11,103 crashes were recorded as collision with parked motor vehicle, and 3.8% of this crashes resulted in injury and fatality. The largest percent of driver action at the time of crash belongs to operated motor vehicle in careless or negligent manner (29.9%) and improper backing (27. 4%).For the driver age variable, the age between 36 to 50 years-old has the highest percentage by accommodating 36.7% of total crashes. Regarding crash time, within a daily span, the highest crash percentage occurred in the midday period (44.8%), and with daylight condition (74.2%).

The descriptive statistics for speed shows that 79.6% of crashes occurred when speed is less than 25 miles per hour. Several reasons might account for the low speed of the vehicle at time of crash. First, 51.1% of crashes occurred in parking lots. Second, 30.2% and 30.4% of the first harmful event location were in parking lane or zone and off roadway, respectively. In parking lots and off roadway locations drivers usually are forced to drive slowly, so it can be one reason of the low speed. Furthermore, for vehicle maneuver action, backing maneuver was the predominant category with 32.3% percentage of total crashes which can be another reason for the low speed of vehicles. It is observed that the largest percentage of crashes occurred when roadway alignment is straight (61.7%), and when the roadway grade is level (62.4%).

Table 60 shows the model coefficients for collision with parked vehicle. Results indicate that crash type, speed, drug influence, and involvement of non-motorists have significant impacts on parked vehicle collisions. Accordingly, severity is expected to increase in cases of left entering, right angle, and rear end crashes. When the truck is in motion (and the other party is parked), speed plays an important role. Accordingly, higher severities are likely to occur at speeds between 25-75 mph. Presence of non-motorists also exacerbates the severity which complies with common sense.

Table 60 Collision with Parked Vehicle -- Model Coefficient Estimates

Category	Variable Name	Variable Characteristics	Coeff. (t value)
	Level 2-3 Threshold		1.54(16.42)
	Level 1-2 Threshold		0.0 (Fixed)
Crash	Crash type	Crash type- Left entering	1.326(3.05)
		Crash type-Rear end	0.451(3.7)
		Crash type-Right angle	0.817(2.66)
	Drug Related	Yes	0.621(4.83)
	Number of vehicles	2	-1.542(-39.59)
	Number of non-motorists involved	1 non-motorist involved	0.566(5.84)
		2 non-motorists involved	0.965(2.88)
	First Harmful Event Location	Entrance/Exit Ramp	0.595(2.58)
		Other	-0.464(-6.56)
Driver	Speed	25 to 50 (m/h)	0.344(3.55)
		50 to 75 (m/h)	0.814(7.21)
Vehicle	Vehicle Maneuver Action	Parked	0.398(6.85)
		Stopped in Traffic	0.371(2.56)
Roadway	Road system identifier	Parking lot	-0.429(-7.44)
	Trafficway	Two-Way, Not Divided	-0.642(-11.55)
Goodness of fit measures	N=11103, LL=-1639.68		

The model also reveals that the most dangerous locations for such crashes are probably the entrance/exit ramps, which is reasonable since drivers are less likely to expect a parked/stopped vehicle in such locations and that they probably do not have sufficient stopping sight distance. On the contrary, lower severities are expected in parking lots or two-way undivided roads. Again, one reason could be lower speeds and higher caution employed by drivers in these locations. One interesting outcome is the negative coefficient associated with crashes involving only two vehicles, which bodes a lower expected severity when minimum number of vehicles are involved. No random effects were detected in this model.

In view of marginal effects (Table 61), results show that crashes involving two vehicles has the highest impact on PDO crashes. In other words, a parked vehicle collision including only two vehicles is most likely to result in a property damage outcome, let all other parameters remain unchanged. Location of the crash ranks second, with parking lots and two-way undivided roads increasing the probability of PDO outcome. However, the impacts are much smaller compared to two-vehicle collisions.

In terms of injury, left-entering crashes as well as presence of two or more non-motorists are likely to result in an injury level severity. Last but not least, drug-related crashes, crashes with one non-motorist involved, and truck speed between 50 to 75 mph are most likely to encourage a fatal outcome, compared to other variables in the model. However, even in presence of these parameters, the probability of an injury outcome is higher and therefore the model is less likely to predict a fatal crash based on existing parameters.

Table 61 Collision with Parked Vehicle -- Marginal Effects

Category	Variable Name	Variable Characteristics	Y=0 (PDO)	Y=1 (Injury)	Y=2 (Fatality)
Crash	Crash type	Crash type- Left entering	-0.22890(-1.66)	0.21558(1.75)	0.01333(0.89)
		Crash type-Rear end	-0.03791(-2.61)	0.03711(2.62)	0.00080(1.96)
		Crash type-Right angle	-0.09646(-1.58)	0.0934(1.61)	0.00306(1.02)
	Drug Related	Yes	-0.06109(-3.1)	0.05955(3.14)	0.00154(2.15)
	Number of vehicles	2	0.28581(22.33)	-0.26576(-24.23)	-0.02005(-10.89)
	Number of non-motorists involved	1	-0.05208(-3.93)	0.05086(3.96)	0.00122(2.8)
		2	-0.12868(-1.64)	0.12381(1.68)	0.00486(0.99)
	First Harmful Event Location	Entrance/Exit Ramp	-0.05773(-1.67)	0.05630(1.69)	0.00143(1.17)
		Other	0.02088(7.43)	-0.02061(-7.44)	-0.00027(-6.48)
Driver	Speed	25 to 50 (m/h)	-0.02602(-2.7)	0.02553(2.71)	0.00049(2.15)
		50 to 75 (m/h)	-0.09459(-4.27)	0.09163(4.35)	0.00295(2.73)
Vehicle	Vehicle Maneuver Action	Parked	-0.02899(-5.35)	0.02846(5.38)	0.00053(4.19)
		Stopped in Traffic	-0.02900(-1.89)	0.02843(1.9)	0.00056(1.49)
Roadway	Road system identifier	Parking lot	0.02428(7.21)	-0.02391(-7.23)	-0.00037(-6.01)
	Trafficway	Two-Way, Not Divided	0.03483(11.1)	-0.03429(-11.16)	-0.00054(-8.1)

6.6. Collision with Vehicle in Motion

There is a total of 93,631 crashes in this dataset from which 23.7% resulted in injury or fatality. Regarding the crash characteristics, rear-end and same direction sideswipe crashes with 31% and 22.7% of total crashes have the highest percentage of crash types. Furthermore, crashes involving bicycle (9.4%), head on crashes (5.2%), and left leaving crashes (2.6%) have the highest percentage of fatal crashes. By accommodating 58.2% of total crashes, Speed of vehicles at the time of crash was mainly below 25 miles per hour.

Considering driver's characteristics, for driver action at the time of the crash, operated motor vehicle in a careless or negligent manner (26.2%), no contributing action (25.4%), and other contributing action (11.7%) have the highest percentage in comparison to other categories. In most of crashes (91.8%) drivers were male, and for the driver age variable, the age between 36 to 50 years-old has the highest percentage by accommodating 41.2% of total crashes.

With respect to roadway characteristics, 24.3%, 23.6%, and 15.9% of crashes occurred at State, local, and interstate roadway types, respectively. Crashes happened in the midday period was the prevalent category that accounted for 46.6% of total crashes, and consequently, daylight was the most frequent light condition with containing 81.6%of total crashes.

Table 62 shows the model results. It shows that crashes that happen in the gore area or involve non-motorists are associated with very severe outcomes. Same as when driver condition is not normal (including fatigued or asleep, sick or fainted, etc.), or the truck suffers light defects. In view of crash type, head-on, left-entering, and left leaving crashes tend to have the highest encouraging impact on crash severity while sideswipe and single-vehicle crashes reflect less severe outcomes. A potential decrease in crash severity is observed from 2011-2016, while crashes that happen in June, early morning, or on weekends saw more severe outcomes. Regarding truck maneuver, higher severity is expected when the truck is making a U-turn or leaving its lane, and on the other hand, a backing movement by the truck lead to lowest severity levels.

Table 62 Collision with Vehicle in Motion -- Model Coefficient Estimates

Category	Variable Name	Variable Characteristics	Coeff. (t value)
	Level 2-3 Threshold		4.718(81.77)
	Level 1-2 Threshold		0.0 (Fixed)
		constant	-0.684(-9.93)
Crash Characteristics	Crash type	Head On	1.278(19.32)
		Left Entering	1.119(19.38)
		Left Leaving	1.03(14.01)
		Left Rear	0.804(10.94)
		Rear end	0.863(24.97)
		Right angle	1(19.97)
		Right Through	0.121(1.85)
		Same Direction Sideswipe	-0.473(-12.06)
		Single Vehicle	-1.066(-13.11)
		Backed into	0.537(6.73)
	Crash location	Not within city limits	0.116(5.55)

Table 62 Collision with Vehicle in Motion -- Model Coefficient Estimates (Continued)

Category	Variable Name	Variable Characteristics	Coeff. (t value)
	Work-zone-related	yes	0.681(3.18)
	Work zone type	Lane Shift/Crossover	-0.468(-2.1)
	Alcohol related	Yes	-0.554(-1.9)
	Number of vehicles	2	-0.972(-29.77)
		4	0.633(8.02)
		5	1.4(10.44)
	Number of non-motorists	1	2.382(26.22)
		2	2.181(4.54)
		3	3.658(2.6)
Temporal Characteristics	Year	Year-2011	-0.35(-7.41)
		Year-2012	-0.411(-8.91)
		Year-2013	-0.474(-10.89)
		Year-2014	-0.555(-13.15)
		Year-2015	-0.559(-13.72)
		Year-2016	-0.538(-13.36)
	Month	June	0.072(2.2)
	Crash time	Early morning	0.181(4.15)
		Weekend	0.183(5.97)
Driver Characteristics	Driver action	Operated MV in Careless or Negligent Manner	0.252(10.24)
		Improper Backing	-0.151(-1.79)
		Improper Turn	0.235(4.35)
		Followed too Closely	0.351(7.62)
		Ran Red Light	0.943(11.96)
		Drove too Fast for Conditions	0.641(5.25)
		Ran Stop Sign	1.005(7.82)
		Exceeded Posted Speed	1.385(2.57)
		Wrong Side of Wrong Way	0.927(4.15)
		Failed to Keep in Proper Lane	0.152(3.28)
		Ran off Roadway	0.929(3.4)
		Over-Correcting/Over-Steering	0.649(3.26)
	Driver condition	Asleep or Fatigued	1.924(3.93)
		Ill (sick) or Fainted	3.106(6.59)
		Seizure, Epilepsy, Blackout	1.363(5.57)
		Other, Explain in Narrative	0.436(2.21)
	Distraction	Electronic Communication	0.664(2.67)
		Other Electronic Device	0.393(3.41)
		Other Inside the Vehicle	0.265(2.35)
		External Distraction	0.112(2.41)
		Inattentive	0.376(1.9)
	Impaired driver	Yes	-0.506(-1.74)
	Gender	Female	-0.195(-4.87)
	Speed	Speed between 25 to 50 (m/h)	0.523(21.72)
		Speed above 75 (m/h)	0.149(3.6)
	Age	20-35	0.05(2.2)
	Hit and Run	Yes	-1.05(-21.07)
	Restraint System	Shoulder and Lap Belt	-0.102(-2.83)
Vehicle Characteristics	Cargo body type	log	0.435(2.43)
		Intermodal Container Chassis	0.231(2.23)
		Bus	0.253(1.89)
		Enclosed Box	0.087(2.43)
		Dump	0.137(2.75)
	Vehicle body configuration	Single-Unit Truck	-0.181(-4.86)
		Truck Pulling Trailer(s)	-0.14(-3.8)

Table 62 Collision with Vehicle in Motion -- Model Coefficient Estimates (Continued)

Category	Variable Name	Variable Characteristics	Coeff. (t value)
Vehicle Characteristics	Vehicle body configuration	Vehicle 10,000 lbs or less Placarded	-0.148(-1.9)
	Vehicle defect	Brakes	0.289(2.77)
		Tires	0.267(2.01)
		Lights	1.519(5.48)
	Vehicle maneuver action	Turning Left	-0.266(-6)
		Backing	-0.675(-7.01)
		Turning Right	-0.11(-2.34)
		Parked	-0.31(-3.05)
		Making U Turn	0.659(8.01)
		Leaving Traffic Lane	0.491(2.49)
		Entering Traffic Lane	-0.242(-1.88)
		Other	-0.204(-3.02)
Roadway Characteristics	Road System Identifier	Interstate	-0.159(-4.9)
		U.S.	0.07(2.22)
		County	-0.145(-4.79)
		Local	-0.272(-9.84)
		Private Roadway	-0.754(-5.91)
		Parking Lot	-0.943(-11.52)
	Road Surface Conditions	Wet	0.07(2.44)
	Type of intersection	Four-Way Intersection	0.072(2)
		T-Intersection	0.207(4.77)
	Traffic way	Two-Way, Divided, Unprotected Median	0.13(2.58)
		Two-Way, Divided, Positive Median Barrier	0.106(3.54)
	Number of lanes	1	-0.357(-3.9)
		4	0.103(3.49)
	Roadway Grade	Uphill	0.166(2.15)
		Downhill	0.184(2.67)
	Contributing Circumstances-Road	Obstruction	-0.61(-2)
Environmental Characteristics	Weather Condition	Weather Condition-Cloudy	0.071(2.99)
	Light Condition	Dawn	0.139(2.02)
		Dark lighted	0.188(5.45)
		Dark-not-lighted	0.534(11.3)
Location parameters	First Harmful Event location	Off roadway	-0.62(-8.29)
		Gore	3.264(2.89)
		In Parking Lane or Zone	-0.816(-7.33)
		Intersection	0.237(6.18)
		Intersection-related	0.073(1.9)
		Driveway/Alley Access	0.313(5.25)
		Through Roadway	0.277(2.32)
		Other	-0.249(-3.77)
Random parameters	Drug-related	Yes (mean)	1.192(4.38)
		Yes (Sd)	2.098(13.67)
	Driver Action	Failed to Yield Right-of-Way(mean)	0.831(17.66)
		Failed to Yield Right-of-Way(Sd)	0.809(5.65)
	Speed	50-75 (mean)	0.73(18.5)
		50-75 (Sd)	1.166(14.7)
	Vehicle body configuration	Truck Tractor/Semi-Trailer (mean)	-0.222(-3.54)
		Truck Tractor/Semi-Trailer (Sd)	0.562(2.7)
	Vehicle Maneuver Action	Changing Lanes (mean)	-0.4(-5.69)
		Changing Lanes (Sd)	1.068(8.03)
	Type of Shoulder	Unpaved (mean)	0.124(4.39)
		Unpaved (Sd.)	0.451(3.93)
Goodness of fit measures		N=93631, LL=-44160	

Table 63 presents the marginal effects of the coefficients. Results from marginal effect analysis shows presence of non-motorists, seizure/epilepsy and sick/fainted conditions significantly increase the probability of an injury outcome. Similarly, presence of 1 or 2 non-motorists in the crash, epilepsy conditions and light defects impose the highest increase on a fatal probability.

Table 63 Collision with Vehicle in Motion -- Marginal Effects

Category	Variable Name	Variable Characteristics	Y=0 (PDO)	Y=1 (Injury)	Y=2 (Fatality)
Crash	Crash type	Head On	-0.24613(-17.97)	0.23781(18.54)	0.00832(9.51)
		Left Entering	-0.20594(-17.57)	0.20001(17.96)	0.00593(10.12)
		Left Leaving	-0.19482(-12.93)	0.18933(13.20)	0.00549(7.57)
		Left Rear	-0.14048(-9.81)	0.13723(9.93)	0.00325(6.47)
		Rear end	-0.12995(-24.22)	0.12767(24.36)	0.00228(18.20)
		Right angle	-0.17636(-17.93)	0.17182(18.23)	0.00453(11.00)
		Right Through	-0.01897(-1.89)	0.01869(1.89)	0.00028(1.76)
		Same Direction Sideswipe	0.05711(12.44)	-0.05641(-12.43)	-0.00069(-13.56)
		Single Vehicle	0.12128(20.45)	-0.12024(-20.37)	-0.00104(-31.79)
		Backed into	-0.08345(-6.49)	0.08194(6.52)	0.0015(5.09)
	Crash location	Not within city limits	-0.01835(-6.13)	0.01809(6.13)	0.00025(6.03)
	Work-zone-related	Yes	-0.11303(-2.96)	0.11064(2.99)	0.00239(2.08)
	Work zone type	Lane Shift/Crossover	0.06418(2.83)	-0.0635(-2.82)	-0.00067(-3.89)
	Alcohol-related	Yes	0.06862(3.21)	-0.06791(-3.20)	-0.00071(-4.47)
	Drug-related	Yes	-0.2543(-6.58)	0.24542(6.80)	0.00888(3.44)
	Number of vehicles involved	2	0.16792(26.90)	-0.164(-27.26)	-0.00392(-16.97)
		4	-0.09404(-6.79)	0.0922(6.84)	0.00184(5.01)
		5	-0.21568(-8.74)	0.20906(8.96)	0.00663(4.89)
	Number of Motorists involved	1	-0.45622(-25.77)	0.42248(29.96)	0.03374(9.33)
		2	-0.439(-4.71)	0.40814(5.40)	0.03086(1.75)
Temporal		3	-0.62557(-3.53)	0.52738(8.51)	.09819(.85)
	Year	2011	0.04654(8.13)	-0.04601(-8.11)	-0.00054(-9.63)
		2012	0.05472(10.10)	-0.0541(-10.08)	-0.00062(-12.20)
		2013	0.0623(12.45)	-0.0616(-12.42)	-0.00069(-15.09)
	Year	2014	0.0707(14.94)	-0.06992(-14.90)	-0.00078(-18.12)
		2015	0.07196(15.64)	-0.07117(-15.61)	-0.0008(-18.66)
		2016	0.07014(15.21)	-0.06935(-15.18)	-0.00079(-17.93)
	Month	June	-0.01154(-2.39)	0.01138(2.40)	0.00016(2.30)
	Crash time	Early morning	-0.02667(-4.14)	0.02627(4.15)	0.0004(3.78)
Driver	Crash in weekend	Yes	-0.02641(-5.74)	0.02601(5.74)	0.00039(5.27)
	Driver Action	Operated MV in Careless or Negligent Manner	-0.03516(-9.41)	0.03465(9.42)	0.00051(8.69)
		Improper Backing	-0.14868(-19.79)	0.14529(20.03)	0.00339(12.95)
		Improper Turn	0.02192(2.04)	-0.02164(-2.04)	-0.00028(-2.19)
		Followed too Closely	-0.03047(-3.61)	0.03(3.61)	0.00046(3.25)
		Ran Red Light	-0.05567(-6.88)	0.05473(6.90)	0.00093(5.70)
		Drove too Fast for Conditions	-0.16486(-10.15)	0.16067(10.31)	0.00419(6.32)
		Ran Stop Sign	-0.10286(-4.59)	0.10077(4.63)	0.00209(3.31)
		Exceeded Posted Speed	-0.18476(-6.69)	0.17968(6.82)	0.00508(3.99)
		Wrong Side of Wrong Way	-0.23656(-2.31)	0.22869(2.38)	.00787(1.24)
		Failed to Keep in Proper Lane	-0.15966(-3.52)	0.15565(3.57)	0.00401(2.21)
		Ran off Roadway	-0.02107(-3.30)	0.02076(3.30)	0.00031(3.08)

Table 63 Collision with Vehicle in Motion -- Marginal Effects (Continued)

Category	Variable Name	Variable Characteristics	Y=0 (PDO)	Y=1 (Injury)	Y=2 (Fatality)
Driver	Driver Action	Over-Correcting/Over-Steering	-0.17052(-3.29)	0.16607(3.35)	0.00446(2.02)
	Driver Condition	Asleep or Fatigued	-0.09863(-2.78)	0.09665(2.80)	0.00197(2.02)
		Ill (sick) or Fainted	-0.36925(-3.62)	0.34931(3.93)	.01995(1.53)
		Seizure, Epilepsy, Blackout	-0.54681(-7.16)	0.48728(10.06)	0.05954(2.13)
		Other, Explain in Narrative	-0.26122(-5.19)	0.25173(5.38)	0.0095(2.67)
	Driver Distraction	Electronic Communication	-0.06572(-1.92)	0.06456(1.93)	.00116(1.54)
		Other Electronic Device	-0.11246(-2.33)	0.11009(2.35)	.00237(1.64)
		Other Inside the Vehicle	-0.06502(-3.16)	0.06388(3.17)	0.00114(2.53)
		External Distraction	-0.03715(-2.07)	0.03656(2.07)	0.00059(1.81)
		Inattentive	-0.01585(-2.29)	0.01562(2.29)	0.00023(2.16)
	Vision Obstruction	Fog	-0.06075(-1.86)	0.0597(1.87)	.00105(1.51)
	Impaired driver	Yes	0.04262(1.72)	-0.04213(-1.72)	-0.00049(-2.10)
	Driver gender	Female	0.0263(4.36)	-0.02591(-4.37)	-0.00039(-4.00)
	Speed	25 to 50 (m/h)	-0.08185(-20.09)	0.08048(20.17)	0.00138(16.05)
		50 to 75 (m/h)	-0.14466(-24.43)	0.14162(24.68)	0.00304(16.52)
		above 75 (m/h)	-0.02017(-3.14)	0.01987(3.14)	0.0003(2.93)
	Drive age	20-35(years old)	-0.00758(-2.31)	0.00748(2.31)	0.00011(2.26)
	Hit and run	Yes	0.1139(28.27)	-0.11282(-28.19)	-0.00108(-35.32)
Vehicle	Restraint System	Shoulder and Lap Belt	0.01622(3.11)	-0.01599(-3.11)	-0.00023(-2.95)
	Cargo body type	log	-0.05939(-1.99)	0.05837(1.99)	.00102(1.62)
		Cargo Body type Intermodal Container Chassis	-0.03777(-2.37)	0.03717(2.38)	0.0006(2.07)
		Bus	.03485*(1.65)	0.03485(1.65)	.00056(1.44)
		Enclosed Box	-0.01321(-2.57)	0.01302(2.57)	0.00019(2.46)
		Dump	-0.02161(-2.87)	0.02129(2.87)	0.00032(2.65)
	CMV	Single-Unit Truck	0.02399(4.88)	-0.02369(-4.88)	-0.0003(-5.27)
		Truck Tractor/Semi-Trailer	0.01991(3.57)	-0.01965(-3.57)	-0.00025(-3.83)
		Truck Pulling Trailer(s)	0.0184(3.75)	-0.01816(-3.75)	-0.00024(-3.97)
		Vehicle 10,000 lbs or less Placarded	0.02144(2.07)	-0.02117(-2.07)	-0.00027(-2.26)
	Vehicle defect	Vehicle Defect-Brakes	-0.04609(-2.61)	0.04533(2.61)	0.00075(2.21)
		Vehicle Defect-Tires	-0.0465(-2.23)	0.04574(2.24)	0.00076(1.89)
		Vehicle Defect-Lights	-0.28649(-4.90)	0.27507(5.12)	0.01142(2.40)
	Vehicle Maneuver Action	Turning Left	0.03693(6.50)	-0.03649(-6.49)	-0.00045(-7.30)
		Backing	0.08111(8.06)	-0.08024(-8.04)	-0.00088(-10.23)
		Turning Right	0.01632(2.56)	-0.01611(-2.56)	-0.00021(-2.71)
		Changing Lanes	0.01854(3.60)	-0.01831(-3.60)	-0.00024(-3.82)
		Parked	0.04277(3.60)	-0.04228(-3.59)	-0.00049(-4.34)
		Making U Turn	-0.11845(-7.55)	0.11591(7.62)	0.00253(5.24)
		Leaving Traffic Lane	-0.07663(-2.33)	0.07522(2.34)	0.00141(1.80)
		Entering Traffic Lane	0.03142(2.01)	-0.03104(-2.00)	-0.00038(-2.30)
		Other	0.0277(3.23)	-0.02736(-3.23)	-0.00034(-3.62)
Roadway	Road System Identifier	Interstate	0.01946(4.55)	-0.01921(-4.55)	-0.00025(-4.79)
		U.S.	-0.01137(-2.41)	0.0112(2.41)	0.00016(2.32)
		County	0.0218(5.23)	-0.02152(-5.22)	-0.00028(-5.56)
		Local	0.03867(10.34)	-0.03818(-10.33)	-0.00049(-10.99)

Table 63 Collision with Vehicle in Motion -- Marginal Effects (Continued)

Category	Variable Name	Variable Characteristics	Y=0 (PDO)	Y=1 (Injury)	Y=2 (Fatality)
		Private Roadway	0.08612(7.79)	-0.08529(-7.76)	-0.00083(-11.98)
		Parking Lot	0.10028(14.30)	-0.09929(-14.26)	-0.00099(-19.89)
	Road Surface Conditions-	Wet	-0.00956(-2.28)	0.00943(2.28)	0.00013(2.21)
	Type of intersection	Four-Way Intersection	-0.01001(-1.89)	0.00987(1.89)	0.00014(1.85)
		T-Intersection	-0.03088(-4.58)	0.03041(4.59)	0.00047(4.13)
	Type of Shoulder-	Unpaved	-0.02251(-6.57)	0.02219(6.57)	0.00032(6.20)
	Trafficway	, Divided, Unprotected (painted >4 feet) Median	-0.01967(-2.59)	0.01938(2.59)	0.00029(2.42)
		Two-Way, Divided, Positive Median Barrier	-0.01568(-3.61)	0.01546(3.61)	0.00022(3.50)
	Total lanes-	1-lane	0.04641(4.44)	-0.04589(-4.43)	-0.00053(-5.43)
		4-lanes	-0.0148(-3.42)	0.01459(3.42)	0.00021(3.27)
	Roadway Grade-	Uphill	-0.02921(-2.52)	0.02877(2.52)	0.00045(2.26)
		Downhill	-0.02974(-2.80)	0.02929(2.81)	0.00045(2.52)
Environmental	Contributing Circumstances	Physical-Obstruction	0.07629(2.70)	-0.07553(-2.69)	-0.00076(-4.02)
	Weather Condition	Cloudy	-0.00971(-2.82)	0.00957(2.82)	0.00014(2.75)
	Light Condition	Dawn	-0.02256(-2.19)	0.02222(2.19)	0.00034(2.02)
		Dark lighted	-0.02807(-5.41)	0.02765(5.42)	0.00042(4.95)
		Dark-not-lighted	-0.08337(-10.97)	0.08184(11.03)	0.00154(8.40)
Location	First Harmful Event location	Off roadway	0.07038(9.43)	-0.06963(-9.40)	-0.00075(-12.43)
		Gore	-0.54787(-3.20)	0.48791(4.51)	.05996(.95)
		In Parking Lane or Zone	0.08241(8.64)	-0.08158(-8.61)	-0.00083(-12.37)
	First Harmful Event Relation to Junction-	Intersection	-0.03664(-6.09)	0.03609(6.10)	0.00055(5.50)
		Intersection-related	-0.01183(-2.04)	0.01166(2.04)	0.00017(1.96)
		Driveway/Alley Access	-0.05172(-5.32)	0.05086(5.34)	0.00086(4.46)
		Through Roadway	-0.04966(-2.68)	0.04884(2.69)	0.00082(2.25)
		Other	0.03993(5.07)	-0.03946(-5.06)	-0.00047(-5.89)

6.7. Collision with other Non-Fixed Objects

This dataset is specific to crashes that happened between trucks and non-fixed objects including railway vehicle, work zone/maintenance equipment, and other non-fixed objects (other than non-fixed objects mentioned in previous sections). The data consist of 10,315 records from which 85.9% are property damage crashes, 13.7% are injury crashes, and the remaining 0.4% are categorized as fatal crashes. The sample consists of 86% male drivers. Main category of driver age is for ages between 36 to 50 years old.

Majority of crashes (47.5%) happened on midday period, and daylight condition (77.7%). Predominant speed is for speed between 51 to 75 mile per hour. Looking into roadway system type, the main category for road system type is intestate roads accommodating 30.7% of total crashes, and also 81.1% of crashes occurred on roadways. These factors can be related to high speed of vehicles at the time of crashes since usually at interstate roads, driving speed is higher than other road types. The interesting point is that for 57.4% of crashes speed was below posted speed. It is observed that the largest percentage of crashes occurred when vehicle had no defects (74.8%), and when then when defect is related to tires (10%).

Table 64 presents the model results. A quick review of model coefficients reveals that the outcome of such crashes is highly aggravated by involvement of non-motorists, number of vehicles involved, and defects regarding truck suspension system. In addition, higher severity is expected when the truck driver experienced a seizure/blackout condition, his vision was obstructed due to glare, or when the collision took place on roadside. It is also inferred that local, interstate, and toll roads showed a negative impact on the latent severity function, which basically indicates a higher chance of less severe crashes compared to US roads. The highest negative impact belonged to parking lots, which sounds reasonable taking into account low speeds and higher levels of care taken by drivers in such areas.

Interestingly, the model showed lower severity levels when trailers or semi-trailers were involved in the crash. The effect was mixed though, where the high standard deviation associated with these two truck types might easily reverse the impact. A detailed heterogeneity analysis is therefore required to provide more insights on these parameters. In view of temporal variables, severity is decrease in 2012, 2014, and 2015.

Table 64 Collision with Other Non-Fixed Object -- Model Coefficient Estimates

Category	Variable Name	Variable Characteristics	Coeff. (t value)
	Level 2-3 Threshold		2.1(32.33)
	Level 1-2 Threshold		0.0 (Fixed)
	Constant		-1.355(-17.51)
Crash	Crash type	Head On	0.338(1.71)
		Rear end	0.218(2.55)
		Right angle	0.719(2.53)
	Crash location	Not within city limits	0.097(2.45)
	Drug-related	yes	0.571(4.39)
	Number of Vehicles	2	0.222(4.42)
		3	0.535(7.86)
		4	0.718(5.54)
		5	1.133(7.45)
	Number of non-motorists involved	1	2.108(20.33)
		2	2.446(5.17)
		3	2.439(3.75)
	First harmful event location	Roadside	1.26(1.91)
		Intersection	0.327(6.03)
Temporal	Year	2012	-0.153(-1.52)
		2014	-0.161(-1.57)
		2015	-0.297(-2.66)
	Month	August	-0.13(-1.98)
Driver	Driver Action	Failed to Yield Right-of-Way	0.881(8.53)
		Followed too Closely	0.556(2.42)
		Ran Red Light	0.99(3.23)
		Drove too Fast for Conditions	1.321(3.51)
		Ran Stop Sign	0.868(3.32)
		Failed to Keep in Proper Lane	0.545(7.38)
	Driver Condition	Seizure, Epilepsy, Blackout	1.853(2.21)
	Vision Obstruction	Obstruction-Fog	0.653(1.93)

Table 64 Collision with Other Non-Fixed Object -- Model Coefficient Estimates (Continued)

Category	Variable Name	Variable Characteristics	Coeff. (t value)
		Obstruction-Glare	1.191(2.97)
	Speed	50 to 75 (m/h)	0.265(4.54)
		Above 75 (m/h)	0.16(2.76)
		Driver License issued in FL-Yes	-0.248(-3.36)
		Hit and Run-Yes	-0.405(-5.56)
	Restraint System	Shoulder and Lap Belt	-0.121(-2.65)
Vehicle		Cargo body type- Flatbed	0.282(2.56)
		CMV-Single-Unit Truck	-0.229(-2.24)
		CMV_Single-Unit Truck (3 or more axles)	-0.375(-3.25)
	Vehicle Defect	Suspension	1.308(1.52)
		Wheels	0.5(2.17)
		Truck Coupling/ Trailer Hitch/	0.719(1.79)
	Vehicle Maneuver Action	Backing	-0.26(-2.13)
		Making U Turn	0.326(1.85)
		Stopped in Traffic	0.253(3.25)
		Hazmat Released-No	0.544(1.82)
Roadway	Road System Identifier	Interstate	-0.254(-4.7)
		Local	-0.334(-6.25)
		Turnpike/Toll	-0.315(-3.79)
		Parking Lot	-0.765(-7.34)
		Other	-0.476(-3.81)
	Contributing Circumstance	Roadway-Other	0.24(2.14)
	Road Surface Conditions	Wet	0.135(2.27)
		Mud, Dirt, Gravel	0.83(1.66)
	Type of intersection	Y-Intersection	0.405(3.1)
	Type of Shoulder	Unpaved	0.147(3.31)
	Roadway Grade	Hillcrest	0.595(2.2)
Weather and Lighting Conditions	Contributing Circumstances	Weather Condition	0.707(2.64)
	Light Conditions	Dark-Not Lighted	0.176(2.89)
Random Parameters	Speed	25 to 50 (Mean)	0.293(5.03)
		25 to 50 (Scale)	0.38(8.88)
	CMV-Body Type	Truck Pulling Trailer (Mean)	-1.304(-7.25)
		Truck Pulling Trailer (Scale)	1.101(8.43)
		Truck Tractor/Semi-Trailer (Mean)	-1.244(-7.07)
		Truck Tractor/Semi-Trailer (Scale)	1.235(9.56)
Goodness of fit	N=10315, LL=-3568.72		

We also looked into the marginal effects to assess how different severity levels are affected by any of the model parameters (shown in Table 65). Accordingly, presence of non-motorists in the crash will significantly reduce PDO probability on one hand and increases the probability of an injury outcome on the other hand. A similar trend is observed for epilepsy/blackout conditions, vision obstruction due to glare, and driving too fast. When positive effects on PDO were considered, the highest magnitudes belonged to parking lot locations, trailers and semi-trailers. It should be noticed however that for the latter two, the marginal effect is associated with the mean value of the parameters and is subject to change due to presence of heterogeneity across the observations. Moreover, these positive marginal effects are relatively small and are rarely comparable with the negative values. Similar to other crash subsamples, the major trade-off is between PDO and injury crashes. The marginal effects associated with fatality outcomes is very minute and does not exceed 0.1, the only exceptions are presence of 2 or 3 non-motorists, which increase the probability of a fatal outcome by approximately 0.14.

Table 65 Collision with Other Non-Fixed Object -- Marginal Effects

Category	Variable Name	Variable Characteristics	Y= 0 (PDO)	Y=1 (Injury)	Y=2 (Fatality)
Crash	Crash type	Head On	-0.06335(-1.42)	0.06282(1.42)	0.00054(1.04)
		Rear end	-0.0374(-2.25)	0.03714(2.26)	0.00027(1.83)
		Right angle	-0.16739(-1.86)	0.16497(1.88)	0.00242(1.04)
	Crash location	Not within city limits	-0.01453(-2.44)	0.01444(2.44)	.0.000083(2.39)
		Drug-related-yes	-0.12219(-3.35)	0.12078(3.37)	0.00141(2.06)
	Number of Vehicles	2	-0.03202(-4.63)	0.03185(4.63)	0.00017(4.54)
		3	-0.10806(-6.26)	0.10695(6.29)	0.00111(4.01)
		4	-0.1654(-4.12)	0.16305(4.17)	0.00235(2.32)
		5	-0.3116(-5.39)	0.30328(5.58)	0.00832(2.38)
	Number of non-motorists involved	1	-0.67273(-20.75)	0.59817(32.71)	0.07456(5.22)
		2	-0.7714(-7.08)	0.62767(142.64)	0.14373(1.35)
		3	-0.76995(-5.1)	0.62732(110.99)	0.14263(0.97)
	First harmful event location	Roadside	-0.36403(-1.39)	0.35191(1.47)	0.01212(0.57)
		Intersection	-0.05871(-5.12)	0.05825(5.13)	0.00046(3.79)
Temporal	Year	2012	0.02093(1.68)	-0.02083(-1.68)	-0.0001(-1.93)
		2014	0.02182(1.75)	-0.02172(-1.74)	-0.00011(-2.01)
		2015	0.03702(3.28)	-0.03685(-3.27)	-0.00017(-4.1)
	Month	August	0.01807(2.14)	-0.01798(-2.14)	-0.56263(0.0183)
Driver	Driver Action	Failed to Yield Right-of-Way	-0.21871(-6.15)	0.21477(6.26)	0.00394(3.11)
		Followed too Closely	-0.11866(-1.85)	0.1173(1.87)	0.00136(1.15)
		Ran Red Light	-0.26031(-2.32)	0.25462(2.37)	0.00568(1.11)
		Drove too Fast for Conditions	-0.388(-2.6)	0.37383(2.76)	0.01417(1.03)
		Ran Stop Sign	-0.21696(-2.4)	0.21302(2.45)	0.00394(1.23)
		Failed to Keep in Proper Lane	-0.11302(-5.69)	0.1118(5.73)	0.00122(3.55)
	Driver Condition	Seizure, Epilepsy, Blackout	-0.5946(-1.98)	0.5456(2.53)	0.04899(0.57)
	Vision Obstruction	Obstruction-Fog	-0.14684(-1.44)	0.14491(1.46)	0.00193(0.84)
		Obstruction-Glare	-0.33686(-2.15)	0.3268(2.25)	0.01006(0.92)
	Speed	50 to 75 (m/h)	-0.04118(-4.36)	0.04092(4.36)	0.00025(3.81)
		Above 75 (m/h)	-0.026(-2.55)	0.02583(2.55)	0.00017(2.22)
		Driver License issued in FL-Yes	0.03458(3.63)	-0.0344(-3.63)	-0.00018(-3.75)
		Hit and Run-Yes	0.04801(7.11)	-0.0478(-7.11)	-0.00021(-7.57)
	Restraint System	Shoulder and Lap Belt	0.01908(2.53)	-0.01897(-2.53)	-0.00012(-2.31)
Vehicle	CMV Body Type	Flatbed	-0.05044(-2.2)	0.05005(2.21)	0.00039(1.7)
		Single-Unit Truck	0.02982(2.61)	-0.02968(-2.61)	-0.00014(-3.13)
Vehicle	CMV Body Type	Single-Unit Truck (3 or more axles)	0.04417(4.29)	-0.04399(-4.28)	-0.00019(-5.51)
	Vehicle Defect	Suspension	-0.38294(-1.12)	0.36921(1.19)	0.01373(0.45)
		Wheels	-0.10339(-1.69)	0.1023(1.7)	0.00109(1.1)
		Truck Coupling/ Trailer Hitch/	-0.16748(-1.32)	0.16505(1.33)	0.00243(0.74)

Table 65 Collision with Other Non-Fixed Object -- Marginal Effects (continued)

Category	Variable Name	Variable Characteristics	Y= 0 (PDO)	Y=1 (Injury)	Y=2 (Fatality)
	Vehicle Maneuver Action	Backing	0.03301(2.57)	-0.03286(-2.56)	-0.00015(-3.22)
		Making U Turn	-0.06058(-1.54)	0.06008(1.54)	0.00129(1.14)
		Stopped in Traffic	-0.04452(-2.82)	0.04419(2.83)	0.00033(2.23)
		Hazmat Released-No	-0.11527(-1.4)	0.11397(1.41)	0.00129(0.88)
Roadway	Road System Identifier	Interstate	0.03565(5.01)	-0.03546(-5.01)	-0.00019(-4.93)
		Local	0.04345(7.17)	-0.04325(-7.17)	-0.00021(-7.01)
		Turnpike/Toll	0.03905(4.65)	-0.03888(-4.64)	-0.00018(-5.46)
		Parking Lot	0.07328(12.09)	-0.073(-12.09)	-0.00028(-9.98)
		Other	0.05213(5.54)	-0.05193(-5.53)	-0.00021(-7.18)
	Contributing Circumstance	Roadway-Other	-0.04195(-1.87)	0.04164(1.87)	0.00031(1.5)
	Road Surface Conditions	Wet	-0.022(-2.1)	0.02186(2.11)	0.00014(1.85)
		Mud, Dirt, Gravel	-0.20374(-1.2)	0.20025(1.22)	0.00349(0.63)
	Type of intersection	Y-Intersection	-0.07886(-2.5)	0.07814(2.51)	0.00073(1.73)
	Type of Shoulder	Unpaved	-0.0234(-3.13)	0.02325(3.13)	0.00015(2.79)
	Roadway Grade	Hillcrest	-0.12972(-1.67)	0.12816(1.68)	0.00156(1.02)
Weather and Lighting Conditions	Contributing Circumstances	Weather Condition	-0.16326(-1.95)	0.16094(1.97)	0.00232(1.1)
	Light Conditions	Dark-Not Lighted	-0.02934(-2.62)	0.02914(2.63)	0.0002(2.22)
Random Parameter	Speed	25 to 50 (m/h)	-0.05098(-4.39)	0.0506(4.4)	0.00038(3.4)
	Vehicle Configuration	Truck Pulling Trailer(s)	0.09025(20.07)	-0.08994(-20.1)	-0.00031(-11.66)
		Truck Tractor/Semi-Trailer	0.09143(19.18)	-0.0911(-19.21)	-0.00033(-11.95)

6.8. Crash Severity Analysis Summary

This chapter focused on predictive analysis of truck crash severity. In this regard, and to provide more homogenous crash groups, the dataset was broken down based on the first harmful event. Consequently, six different subsets were developed: non-collision crashes, collision with fixed objects, collision with pedestrian, bicycle, and animals, collision with other non-fixed objects, collision with parked vehicles, and collision with vehicle in transport.

Based on the ordered nature of the dependent variable, ordered response model was chosen as the most appropriate modeling structure. In addition, and in order to account for the potential heterogeneity in the data, an enhanced version of the model using random parameter effects was employed. Incorporation of random parameter will allow the coefficients to vary across different observations and is expected to provide more accurate estimates as well as paving the path towards a more transparent market segmentation.

Interesting inferences could be made based on model outcomes. For instance, in view of non-collision crashes, probability of injury highly increases when the crash involves a truck roll-over or is followed by a head-on collision. Situation is further aggravated when a bicycle is involved in the crash. In cases of pedestrian-bicycle- animal collision, injury crashes are also more likely to happen on 6 lane roads, under fog-smoke conditions, and when the vehicle maneuver is recorded as "entering traffic lane". As the number of vehicles or number of non-motorists increases, a fatal result is more likely to happen. Drug usage, though being a random parameter, is another factor that increases the probability of a fatality crash, taking its mean impact into account. Presence of non-motorists in the crash will also increases the probability of an injury outcome in collision with other non-fixed objects. Epilepsy/blackout conditions, vision obstruction due to glare, and driving too fast are other contributing factors to injury level severities in other non-fixed collisions.

In view of collision with parked vehicle, crashes that involve two vehicles, occur on parking lots and two-way undivided roads are more likely to result in a PDO outcome. In terms of injury, left-entering crashes as well as presence of two or more non-motorists are likely to result in an injury level severity. Drug-related crashes, crashes with one non-motorist involved, and truck speed between 50 to 75 mph tend to encourage a fatal outcome. Involvement of 2 non-motorists, 1 pedestrian, and occurrence on forest roads have the highest marginal effects on collision with fixed object injury levels. Other variables that increase injury level probability (but with lower magnitudes) include year 2008, passenger count =3, and speed more than 75 mph. When it comes to fatality crashes, presence of 2 non-motorists has the highest marginal effect. Last but not least, marginal effect analysis for vehicle in transport collisions shows that presence of non-motorists, seizure/epilepsy and sick/fainted conditions significantly increase the probability of an injury outcome. Similarly, presence of 1 or 2 non-motorists in the crash, epilepsy conditions and light defects impose the highest increase on a fatal probability.

In a broad picture, the marginal effect analysis emphasizes on a trade-off between PDO and Injury crashes. The marginal effects reported on fatality outcomes are usually minute and hardly exceed 10% in most cases. This might indicate that our models are unlikely to accurately predict a fata outcome. This might stem from two major underlying factors: First, considering that we tried all the parameters reflected in the police report, it could be inferred that no single parameter from any of the police report information could be responsible for a fatality outcome. A cumulative impact of several parameters is needed to result in extremely severe conditions. Second, the relative frequency of fatal crashes is very small in all cases, which limits a correct prediction of a fatal outcome to certain rare conditions.

When random parameters are to be considered, model results show that a variety of parameters including driver conditions, driver actions, vehicle maneuver, lighting and roadway environment can have random impacts on the crash severity outcome. While the mean impact complies with common sense in most cases, it should be noticed that high magnitudes of standard deviation can significantly affect either the magnitude or the direction of impact. Therefore, any inference made based on the mean magnitude of these parameters should be made with extra care. A more detailed analysis using interaction effects is required when dealing with such random effects.

The crash severity analysis incorporated random parameters that allow the contributing factors to vary among the crashes. While it better captures the actual influence of the contributing factors, it does not reveal potential sources of heterogeneity. Random parameters indicate the presence of heterogeneity, but do not reveal the sources of heterogeneity, in other words, what factors or segments might have contributed to the variations in the impacts of the random parameters. To capture the potential sources of heterogeneity, interaction variables can be incorporated into the model. The approach assumes that the mean of the random parameter varies among different classes defined by interaction variables. For instance, by interacting different classes of one specific driver attribute with a certain roadway condition, researchers can analyze how the impact of one specific roadway design can vary across different segments of truck drivers. Further analysis could focus on driver, vehicle, roadway or temporal attributes as potential sources of heterogeneity, to examine how the impacts of the same parameter may vary by driver characteristics or roadway conditions, etc.

While the analyses conducted in this project focused on individual crashes, which could take advantage of individual driver and vehicle characteristics in the severity analysis, aggregated analysis at segment level could provide additional insights focusing on roadway, temporal and other influencing factors. Further predictive efforts on crash severity may take the analysis to aggregate levels using a combination of crash frequency and severity on a segment basis.

7. SPATIAL ANALYSIS

This chapter presents the findings for spatial analysis, which intends to identify crash concentration or problematic areas. ArcGIS Spatial Analyst extension - Kernel Density tool was used to analyze the spatial clustering of large truck crashes. The Kernel Density tool creates a raster output showing the density of crashes within a neighborhood around each raster cell. The tool in ArcGIS Spatial Analyst extension is very easy to execute. However, the methods for computing the density are purely based on the crash locations without any considerations of roadways

The kernel density map from ArcGIS Spatial Analyst gives a general understanding of the areas with high crash density. More detailed methods need to be done in the roadway level to provide more accurate high crash density locations.

The density maps are presented for each district, including district-wide density maps and detailed analysis for the top 10 locations in the district.

7.1. Density Map for District 1

Figure 56 shows the kernel density map of the large truck crashes density locations in District 1.

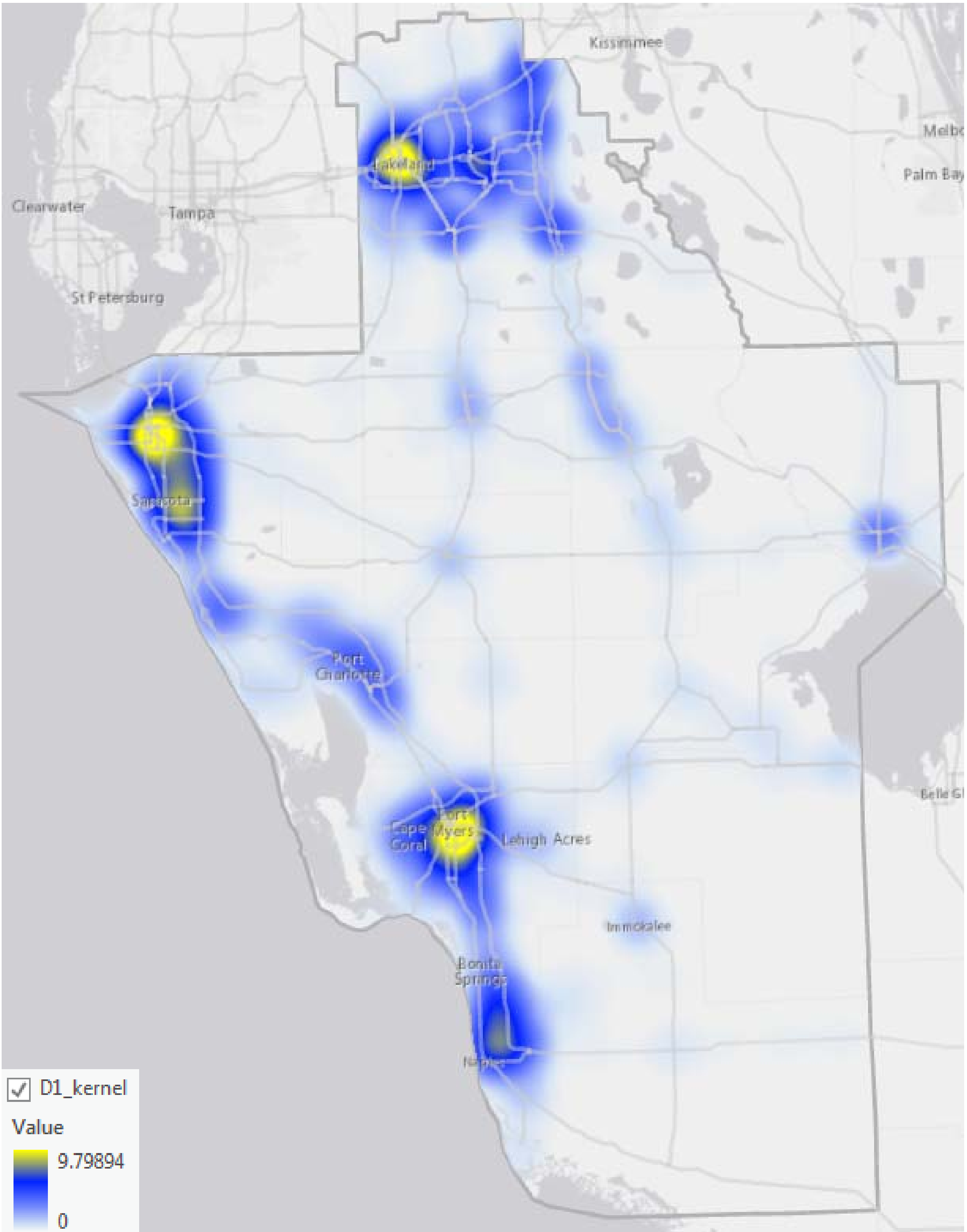


Figure 56 Kernel density mapping of all large truck crashes in District 1

Figure 57 identifies the locations with the top 10 highest kernel density value. We could see that the highest crash density areas are located in the major cities in the district such as Fort Myers, Bradenton, Sarasota and Lakeland. The following maps shows the top 10 locations. Each location is accompanied with a zoomed-in street map to show the details, and a brief description about the location and the surrounding land uses.

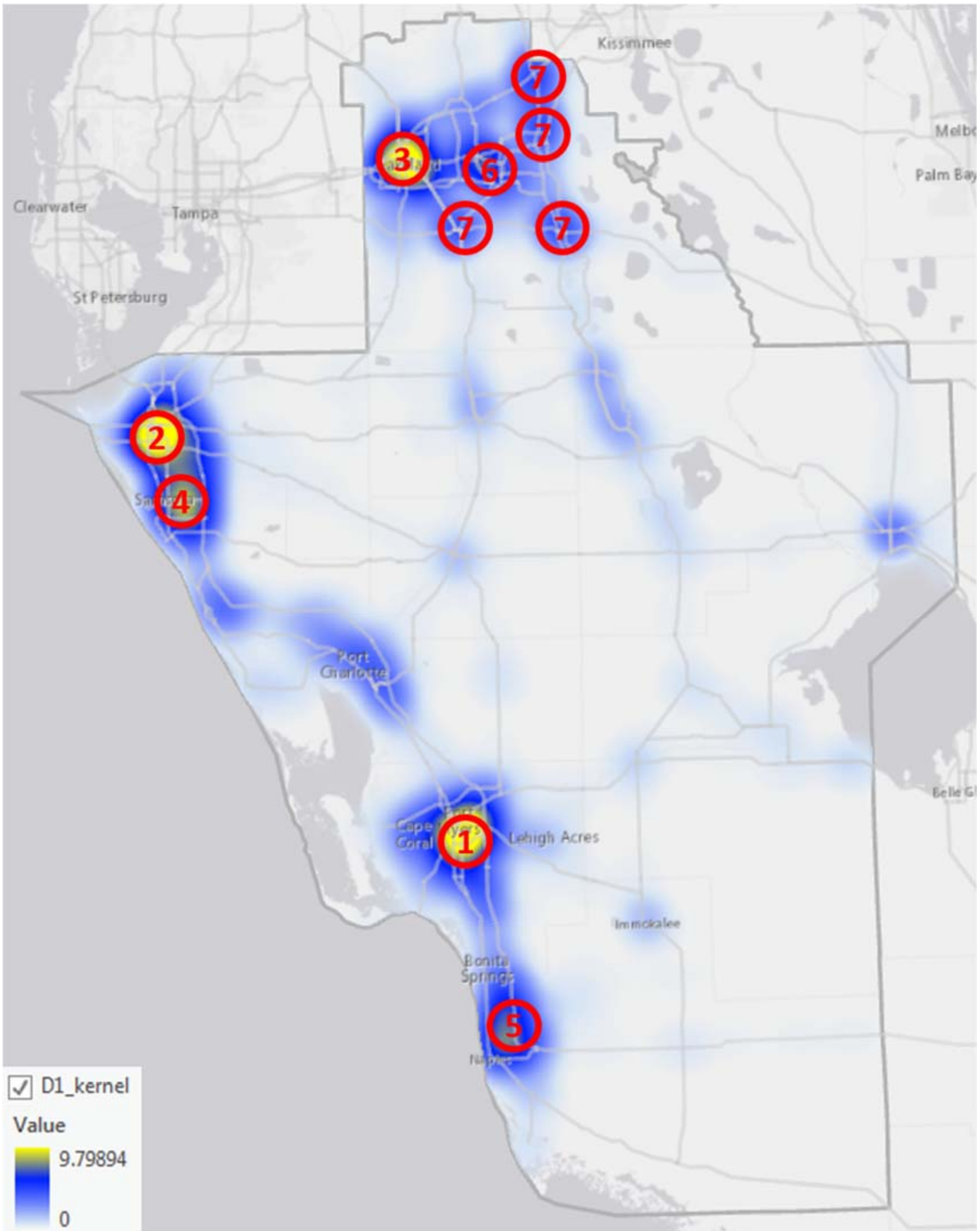


Figure 57 Top 10 locations selected from kernel density of all large truck crashes in District 1

The 1st High crash density Location

Downtown Fort Myers, specifically the area within 3 miles south from the southern shore of Caloosahatchee River, rank the 1st place in the 10 highest crash density locations based on the kernel density map. Several major roads intersect in this area, such as SR-45, SR-739, SR-80, SR-82, and SR-884. Large quantities of retails, entertains, and services with a mixture of residential areas are located in this location.

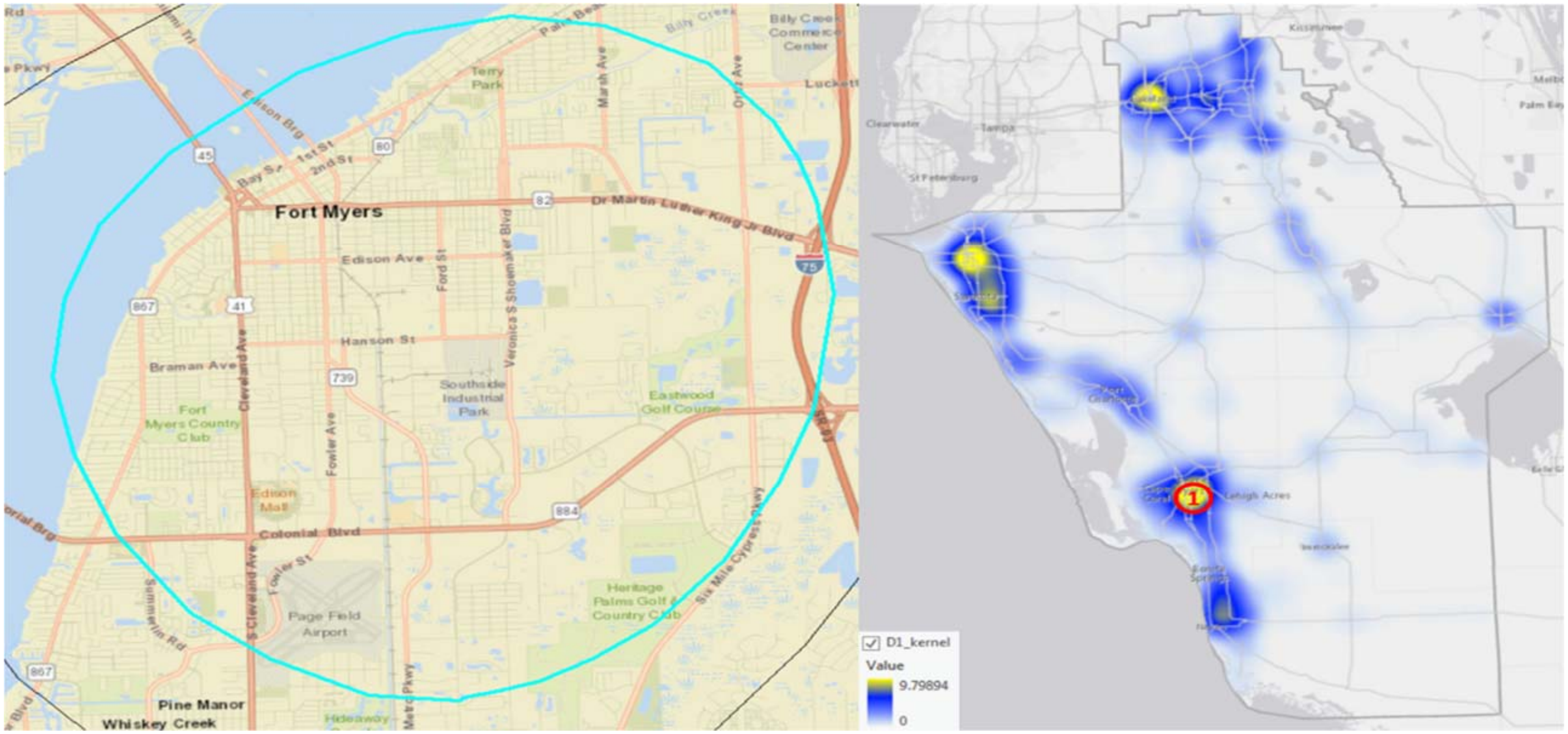


Figure 58 The 1st high crash density location for large truck crashes from the kernel density map - District 1

The 2nd High crash density Location

Downtown Bradenton, specifically the intersection of SR-55 and SR-64, and the area within 4 miles south, rank the 2nd place in the 10 most high crash density locations based on the kernel density map. Several major roads intersect in this area, such as SR-45, SR-70, SR-683, and SR-684. Large quantities of retails, entertains, and services with a mixture of residential areas are located in this location.

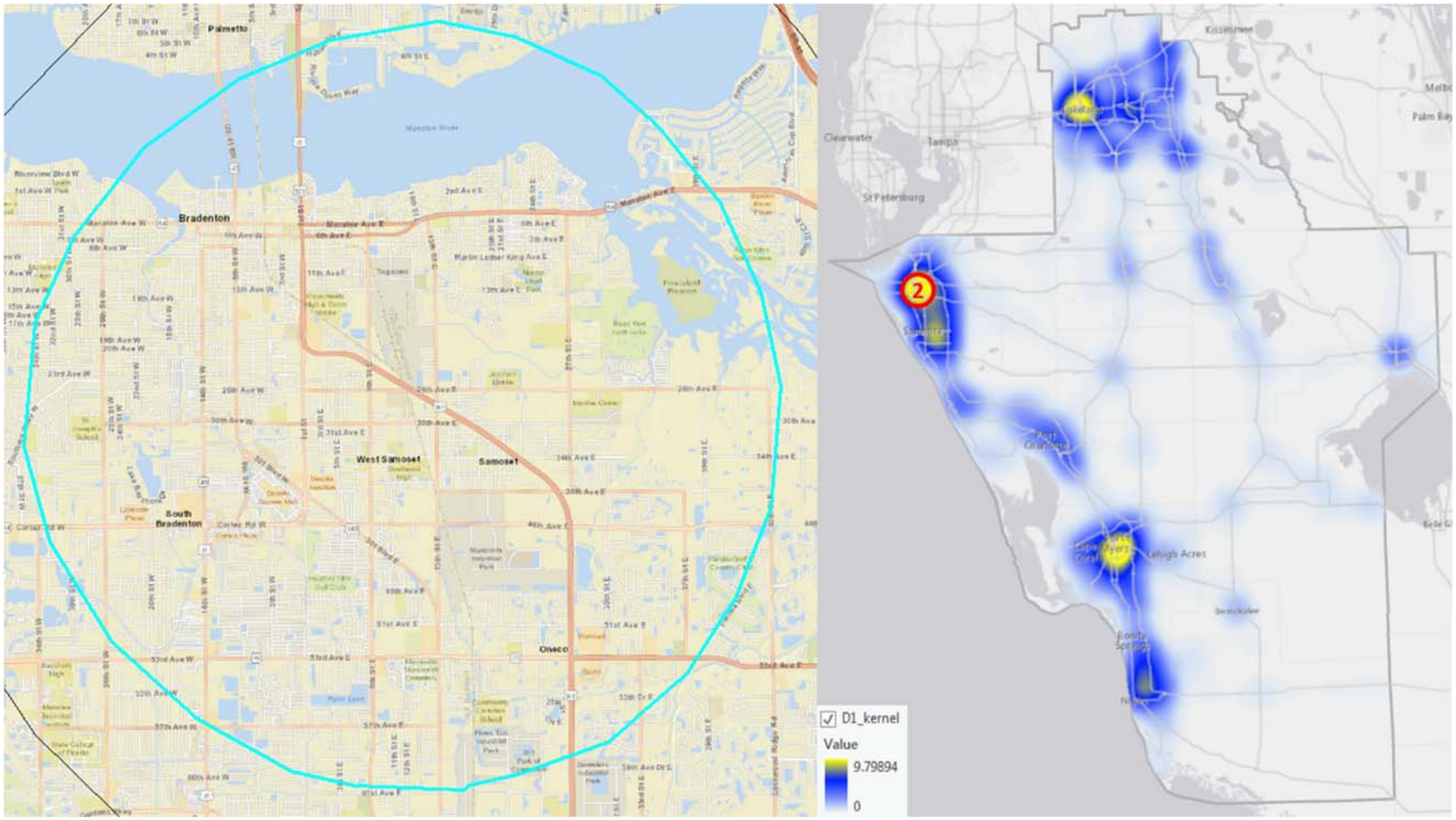


Figure 59 The 2nd high crash density location for large truck crashes from the kernel density map - District 1

The 3rd High crash density Location

The intersection of SR-35 and SR-546, and the surrounding areas within about 1 mile ranks the 3rd place in the 10 most high crash density locations in the district. SR548 also intersects SR-35 in this area. The place locates in the downtown Lakeland. Highly mixed-used lands exist at this location, such as the sports center, the retails and the residential buildings.

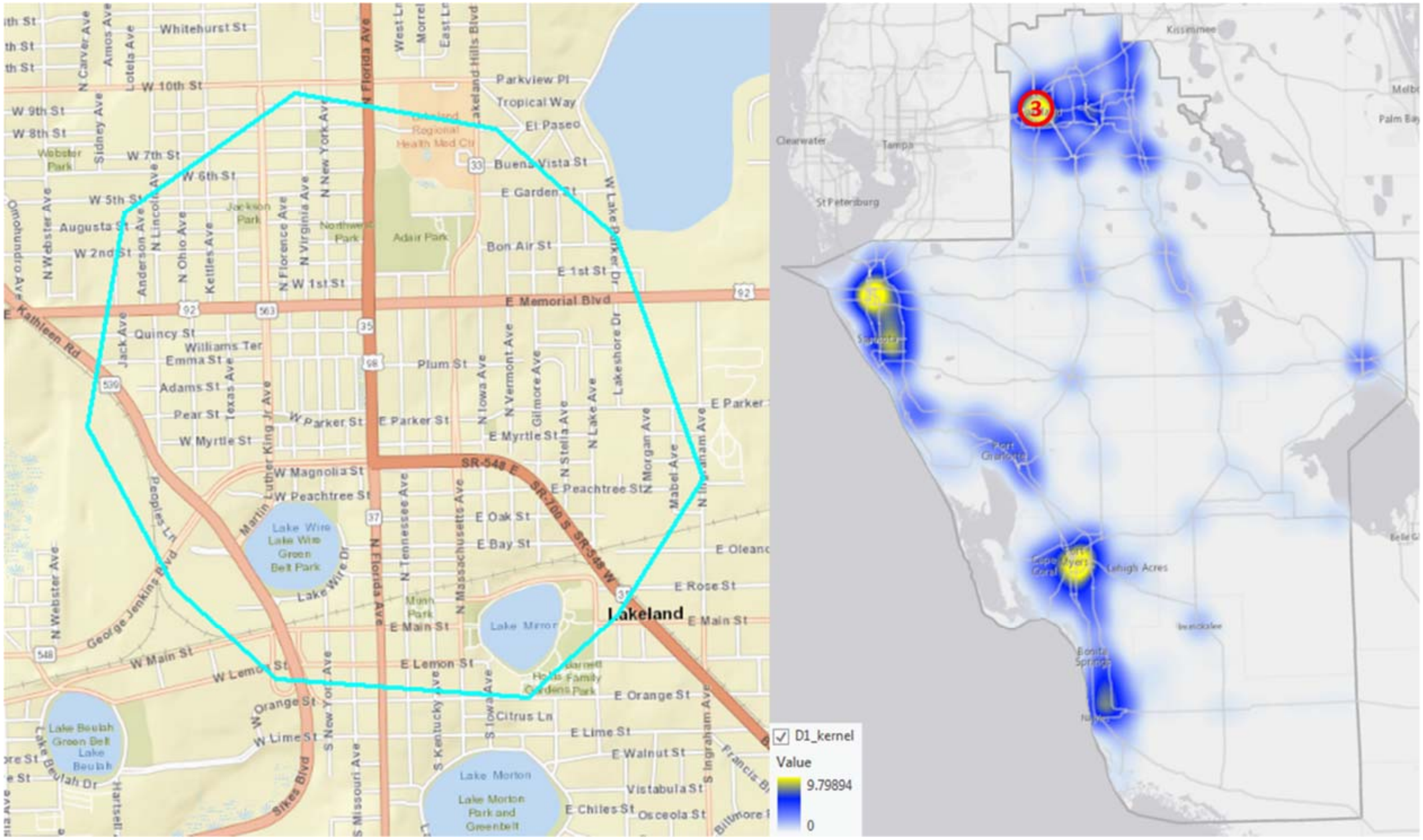


Figure 60 The 3rd high crash density location for large truck crashes from the kernel density map - District 1

The 4th High crash density Location

The southeast area of Sarasota ranks the 4th place. The place locates at the south of SR-780, the north of SR-758, the east of SR-45, and the west of I75. These major roads intersect with each other. The majority of the location are covered with residential areas, with a mix of office buildings and retails.

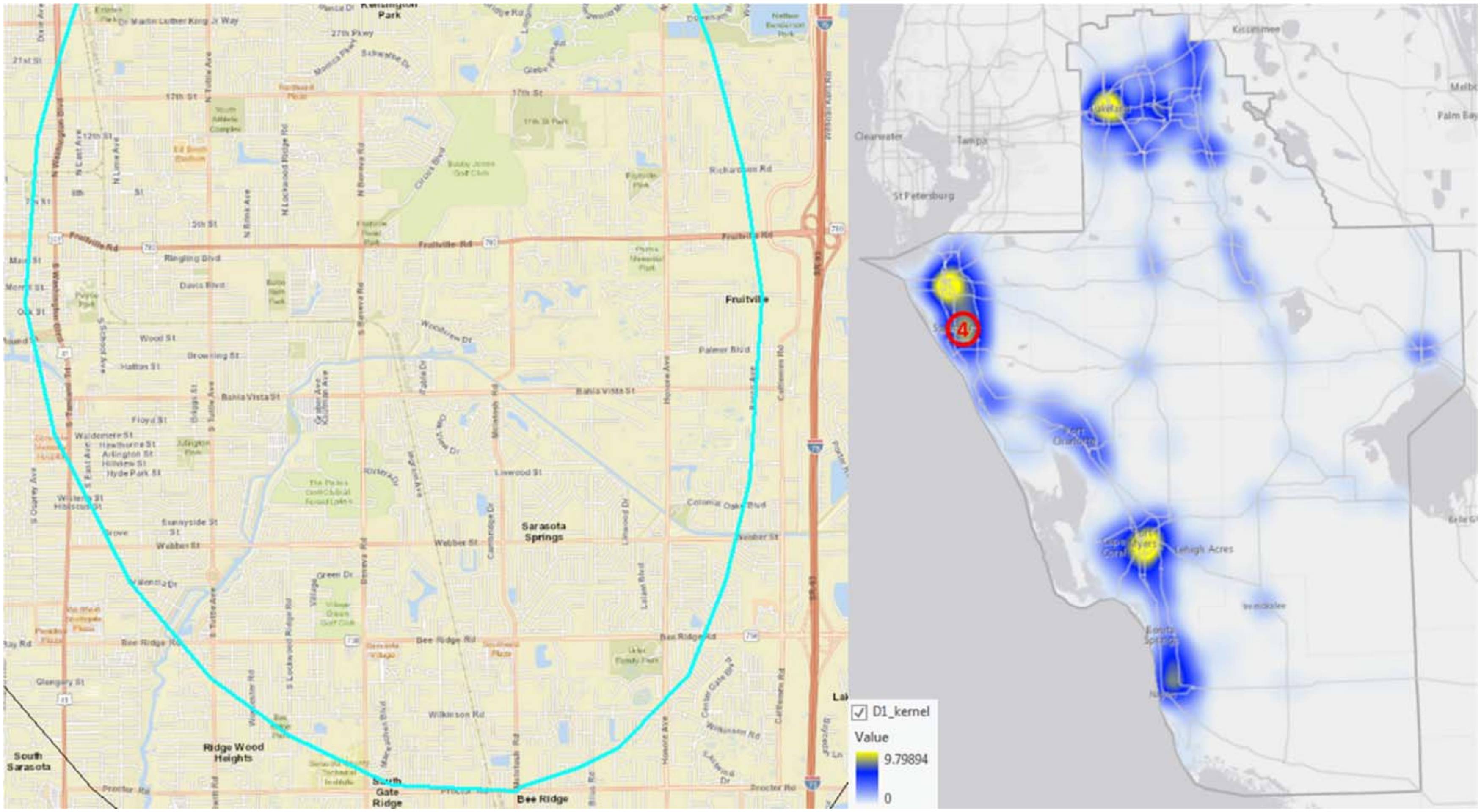


Figure 61 The 4th high crash density location for large truck crashes from the kernel density map - District 1

The 5th High crash density Location

The northeast area of Naples ranks the 5th place. The place locates between I75 and SR-45. The majority of the location are covered with residential areas, with a mix of office buildings and retails.

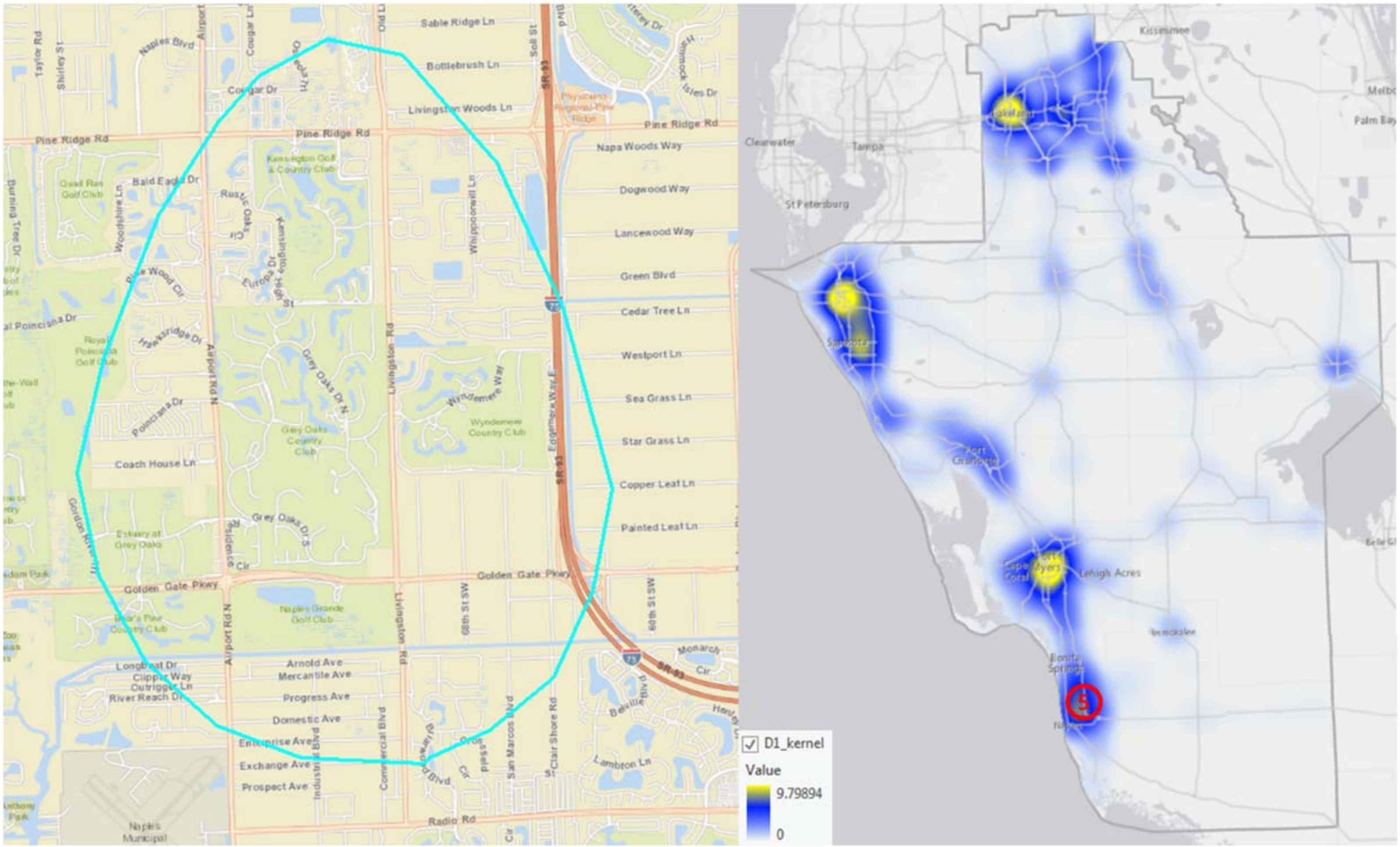


Figure 62 **The 5th high crash density location for large truck crashes from the kernel density map - District 1**

The 6th High crash density Location

The intersection of US-92 and SR-559, and the surrounding areas within about 2.5 miles rank the 6th place in the 10 most high crash density locations based on the kernel density map. The place locates in the city of Auburndale. Several major roads intersect in this area such as US-92, SR-544, SR-559 and SR-655. Large quantities of retails and services with a mixture of residential areas are located in this location, as well as several commercial warehouses.

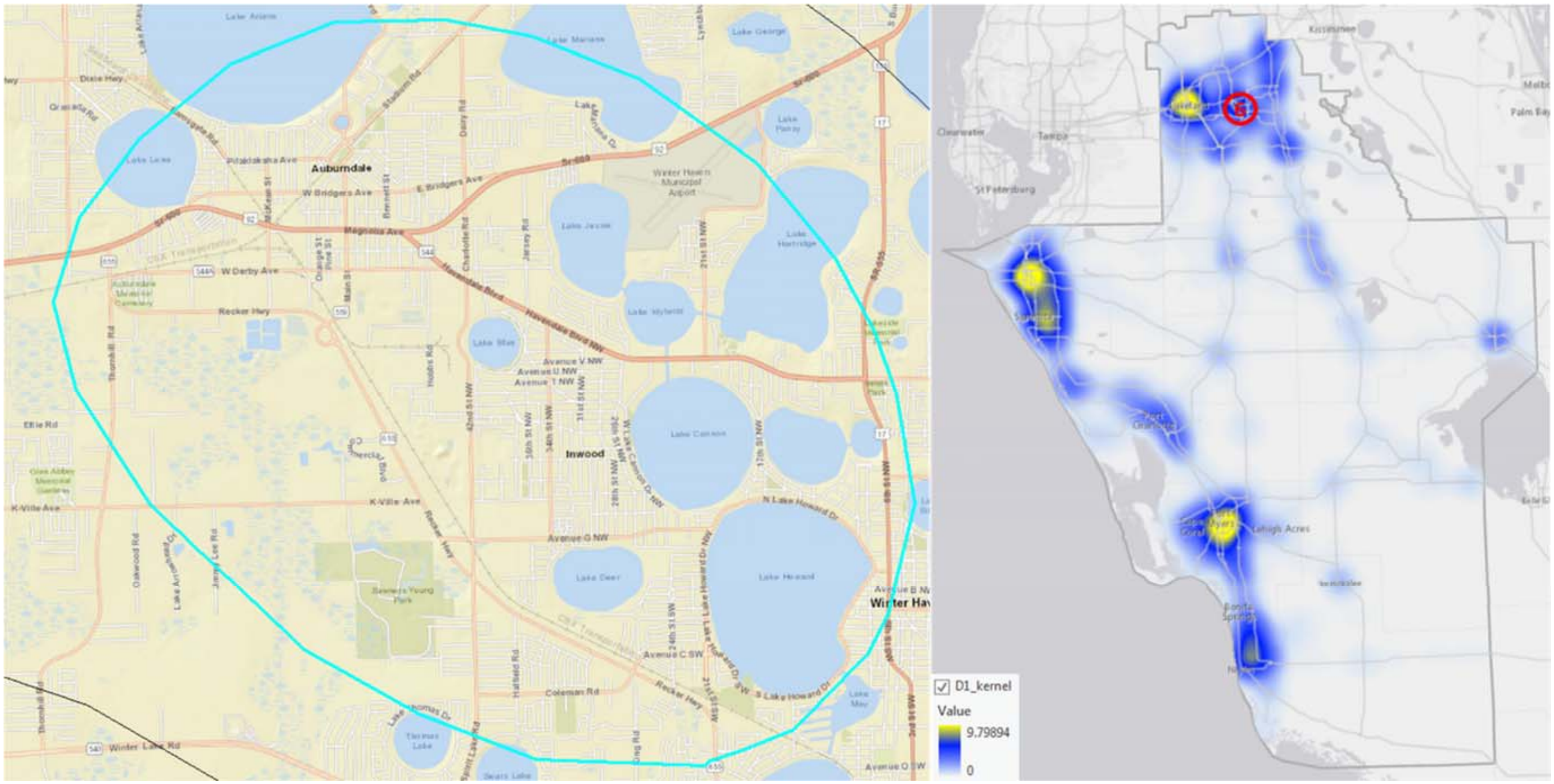


Figure 63 The 6th high crash density location for large truck crashes from the kernel density map - District 1

The 7th High crash density Location

The intersection of US-98 and SR-60, and the surrounding areas within about 1.5 miles rank the 7th place in the 10 most high crash density locations based on the kernel density map. The place locates in the north of Bartow downtown. Several major roads intersect in this area such as US-98, SR-60, and SR-555. The area has various land use, such as the office buildings, retails and residential buildings.

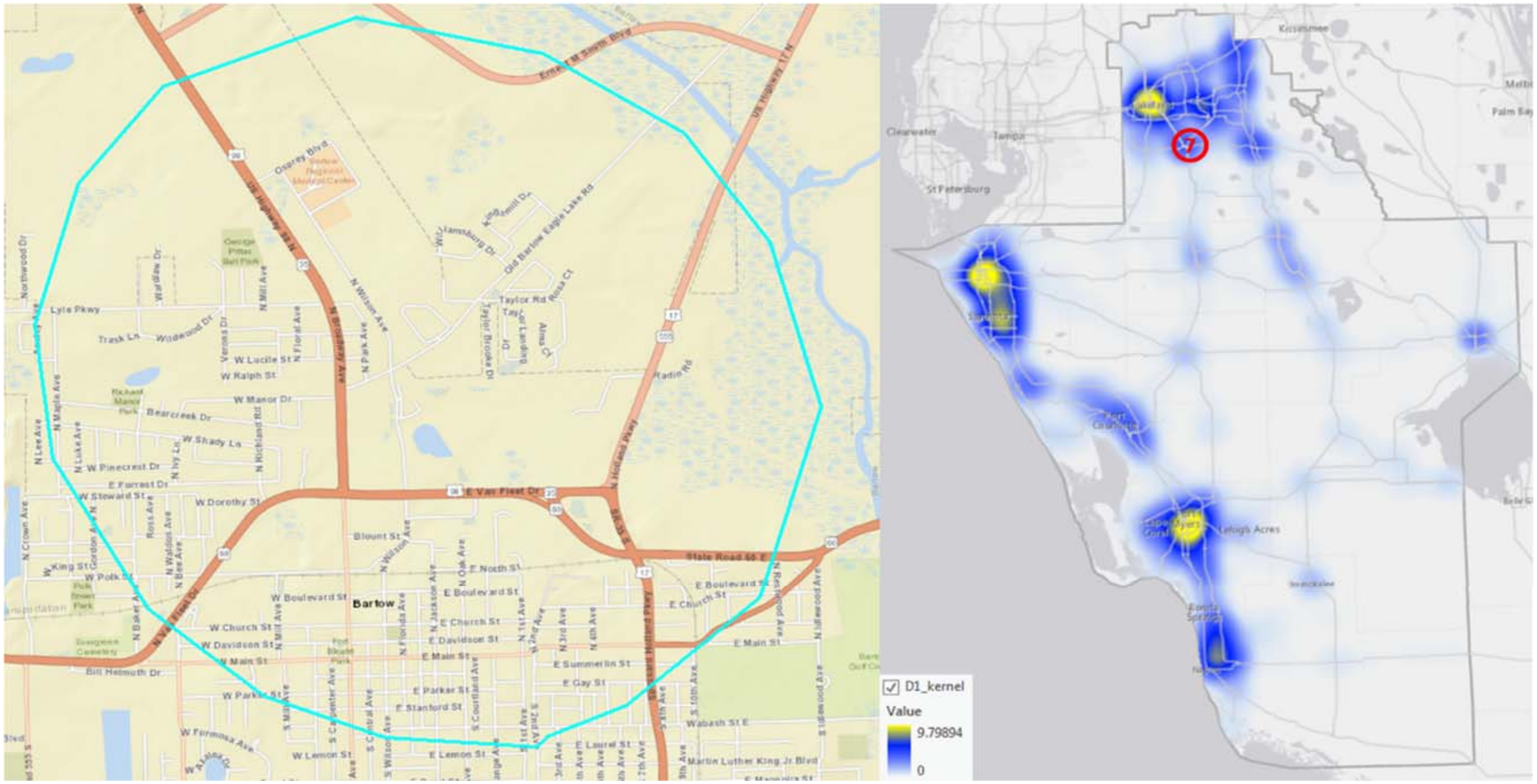


Figure 64 **The 7th high crash density location for large truck crashes from the kernel density map - District 1**

The 7th High crash density Location

The interchange of SR-27 and SR-60, and the surrounding areas within about 1.5 miles also rank the 7th place in the 10 most high crash density locations based on the kernel density map. The place locates in the west of Lake Wales downtown. Several major roads intersect in this area such as SR-17, SR-27, and SR-60. The area is a mixture with retails and residential buildings.

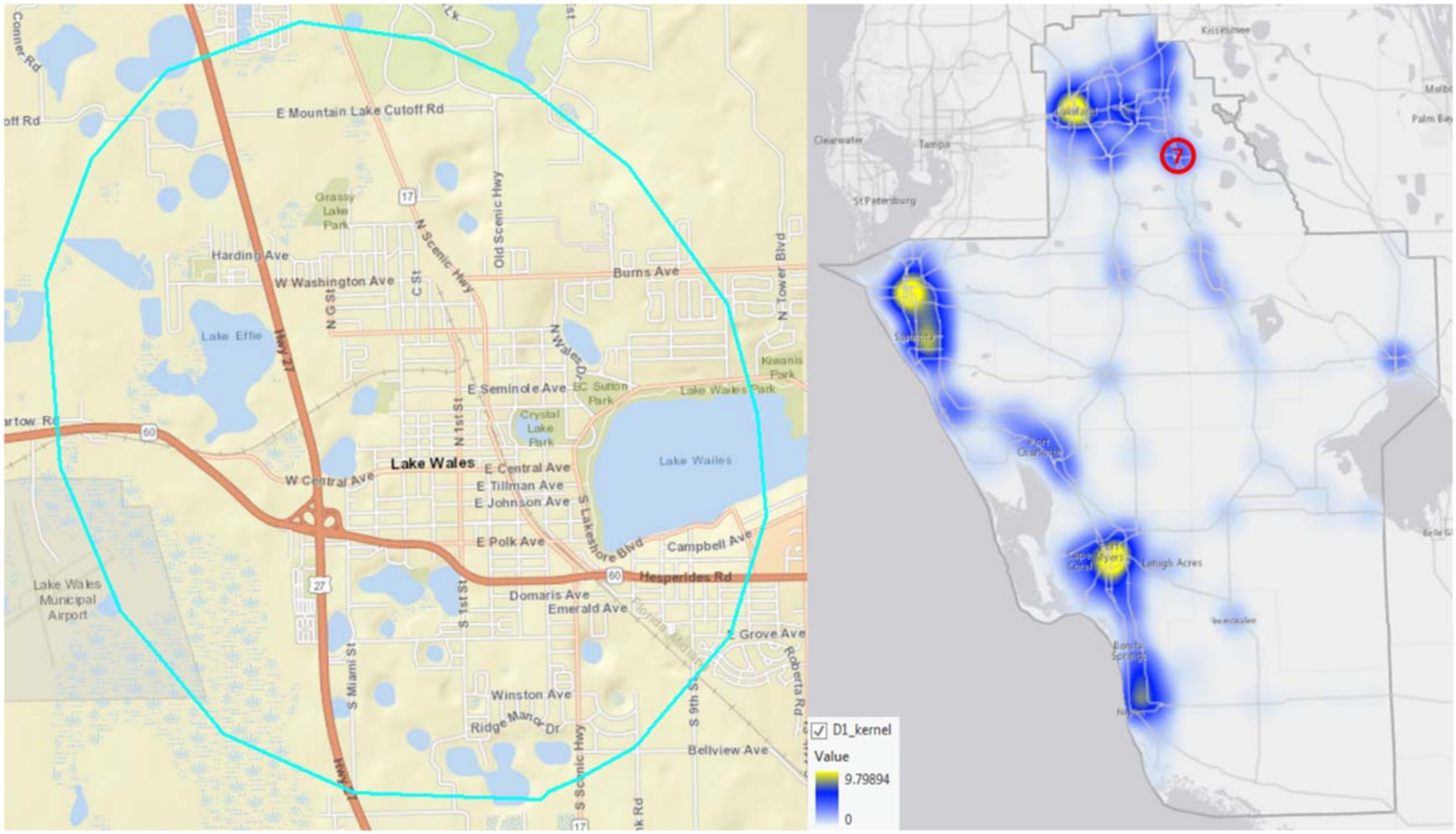


Figure 65 The 7th high crash density location for large truck crashes from the kernel density map - District 1

The 7th High crash density Location

The interchange of SR-27 and SR-17, and the surrounding areas within about 2 miles also rank the 7th place in the 10 most high crash density locations based on the kernel density map. The place locates in the southwest of Haines city downtown. The area is mainly covered by residential buildings with several retails.

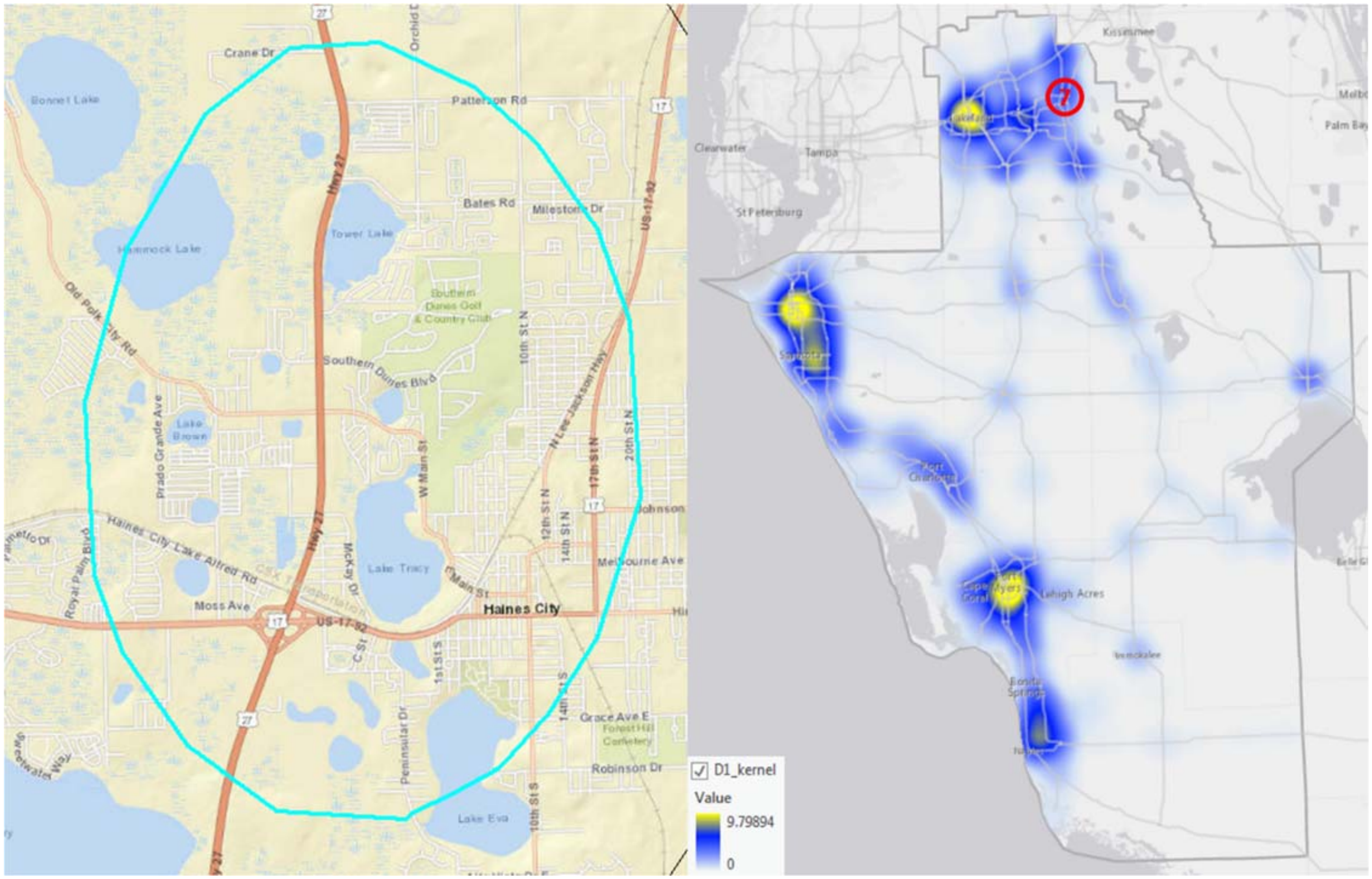


Figure 66 The 7th high crash density location for large truck crashes from the kernel density map - District 1 (Area 1)

The 7th High crash density Location

The interchange of SR-27 and I4, and the surrounding areas within about 2 miles also rank the 7th place in the 10 most high crash density locations based on the kernel density map. The place locates to the north of the Posner Park, a mixed-use development. The area is mainly covered by retails and residential buildings.

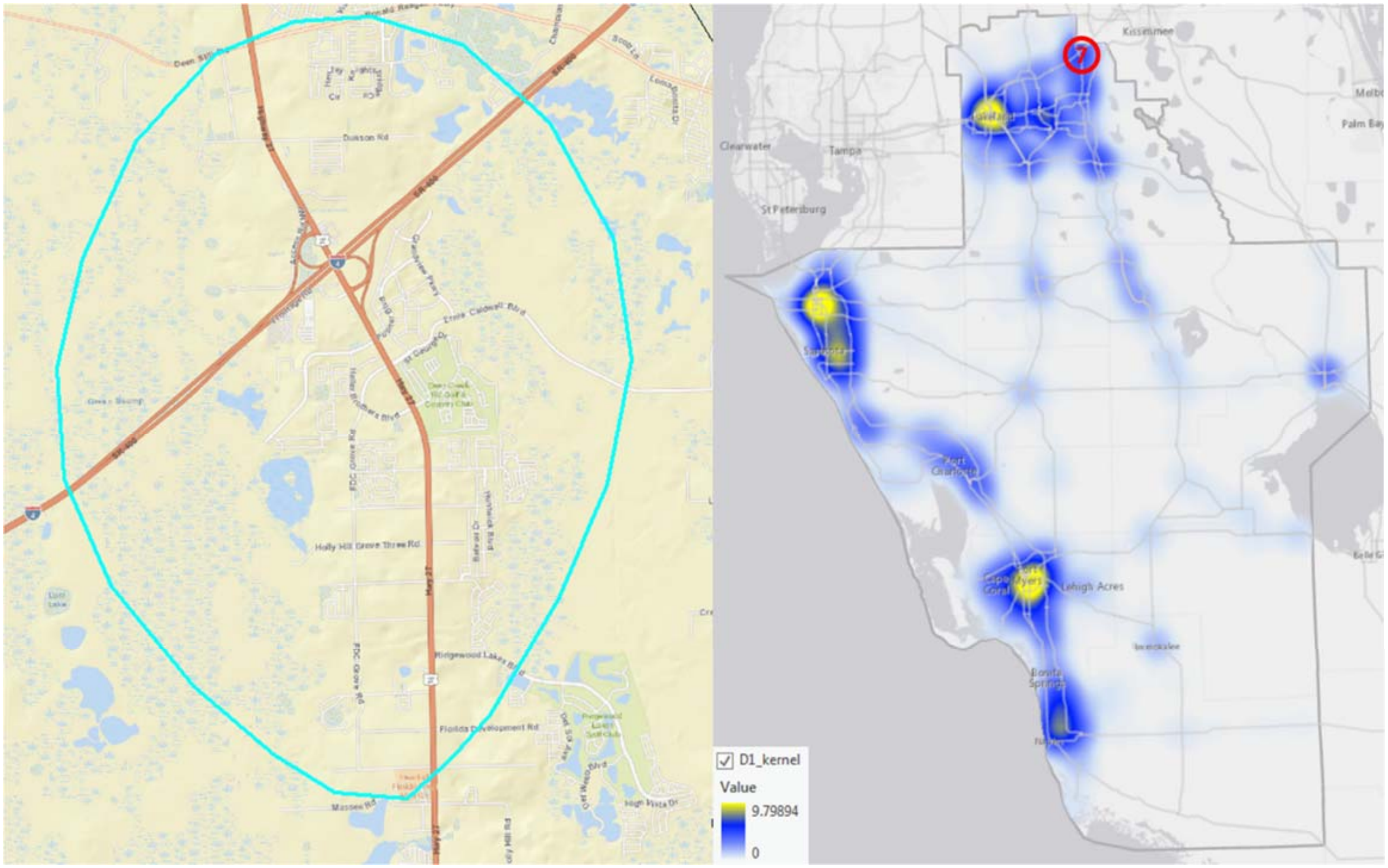


Figure 67 The 7th high crash density location for large truck crashes from the kernel density map - District 1 (Area 2)

7.2. Density Map for District 2

Figure 68 below shows the kernel density map for District 2.

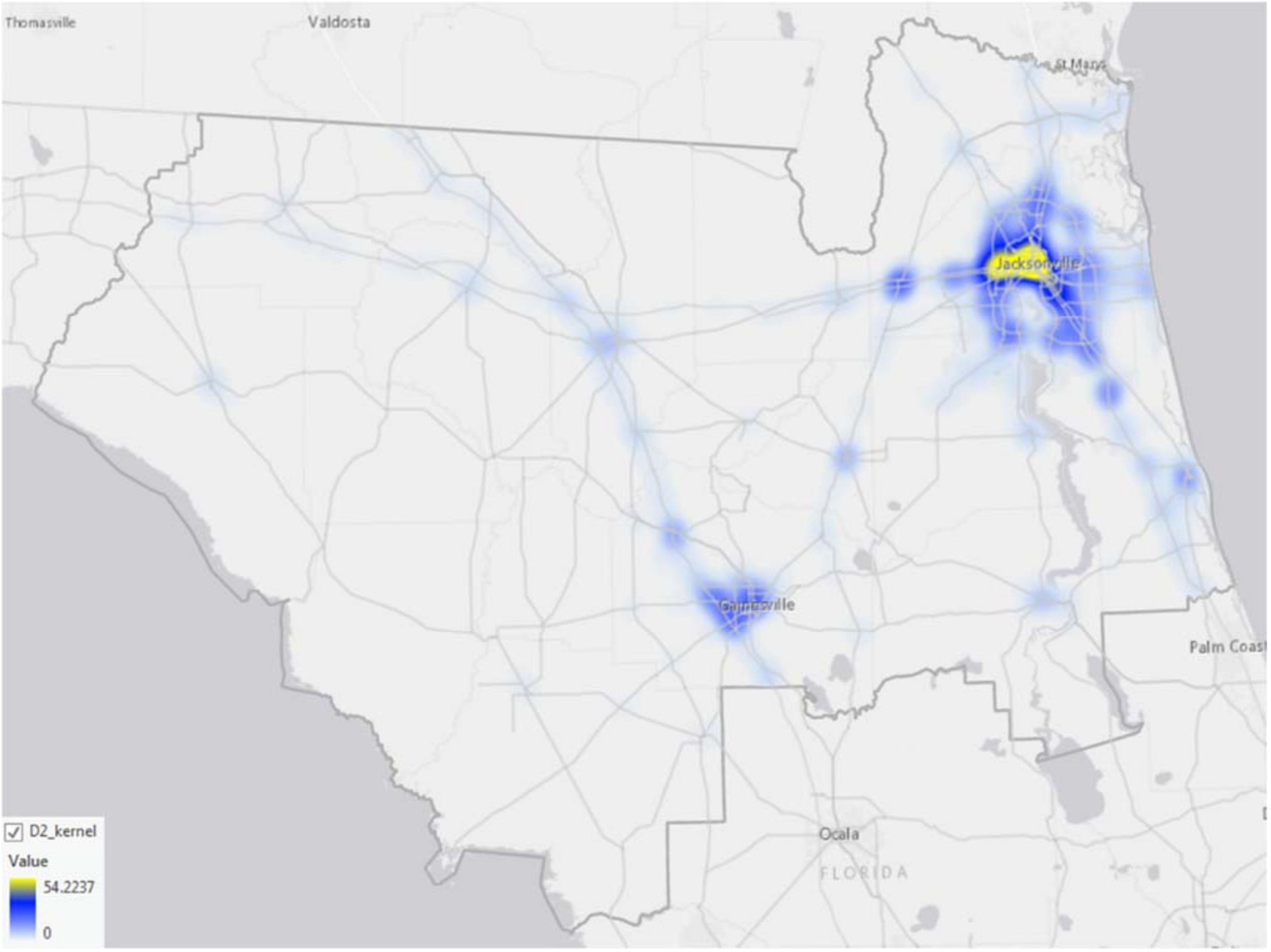


Figure 68 Kernel density mapping of all large truck crashes in District 2

Figure 69 presents the locations with the top 10 highest kernel density value. Jacksonville dominates the high-density area in the district.

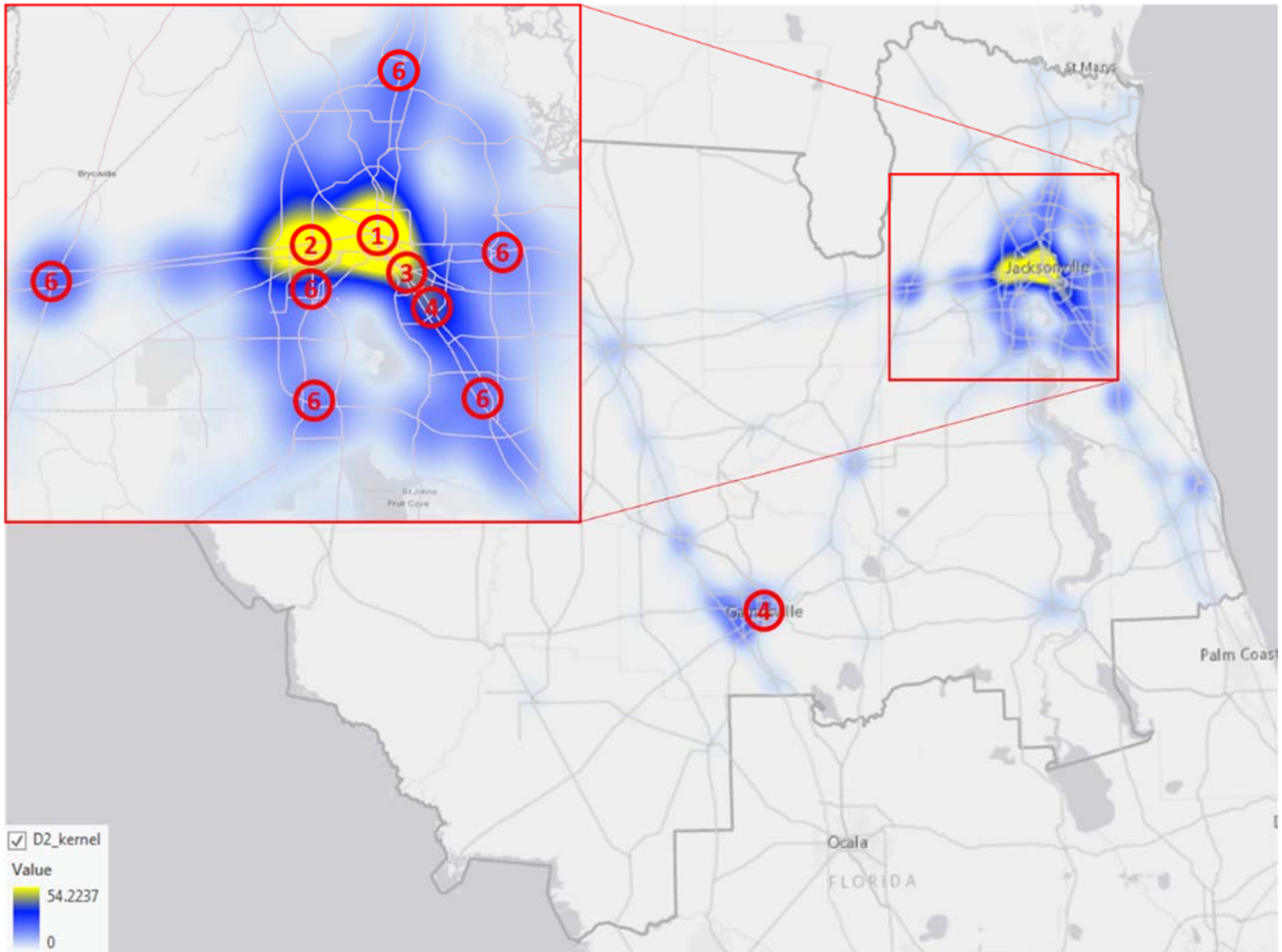


Figure 69 Top 10 locations selected from kernel density mapping of all large truck crashes in District 2

The 1st High crash density Location

Downtown Jacksonville, specifically the interchange of I10 and I95, and the surrounding areas within about 2 miles, rank the 1st place in the 10 highest crash density locations based on the kernel density map. Several major roads intersect in this area, such as I10, I95, US-90, SR-10 and SR-228. Large quantities of retails, entertains, conventional center and medical services with a mixture of residential areas are located in this location.

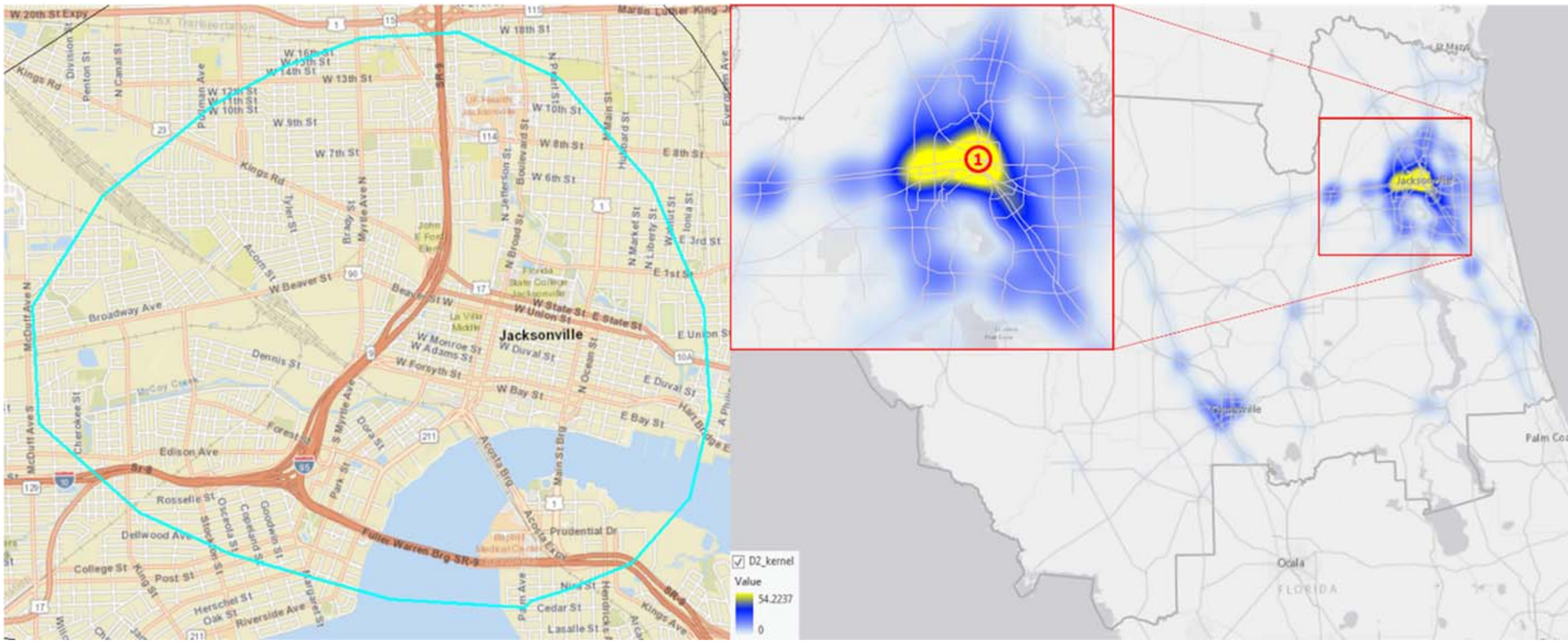


Figure 70 The 1st high crash density location for large truck crashes from the kernel density map - District 2

The 2nd High crash density Location

The west area of Jacksonville downtown ranks the 2nd place in the 10 most high crash density locations based on the kernel density map. Major roads I10, I295, SR-10, SR-103 and SR-111 intersect in this area. Large quantities of warehouses are in this area, with a mixture of residential areas.

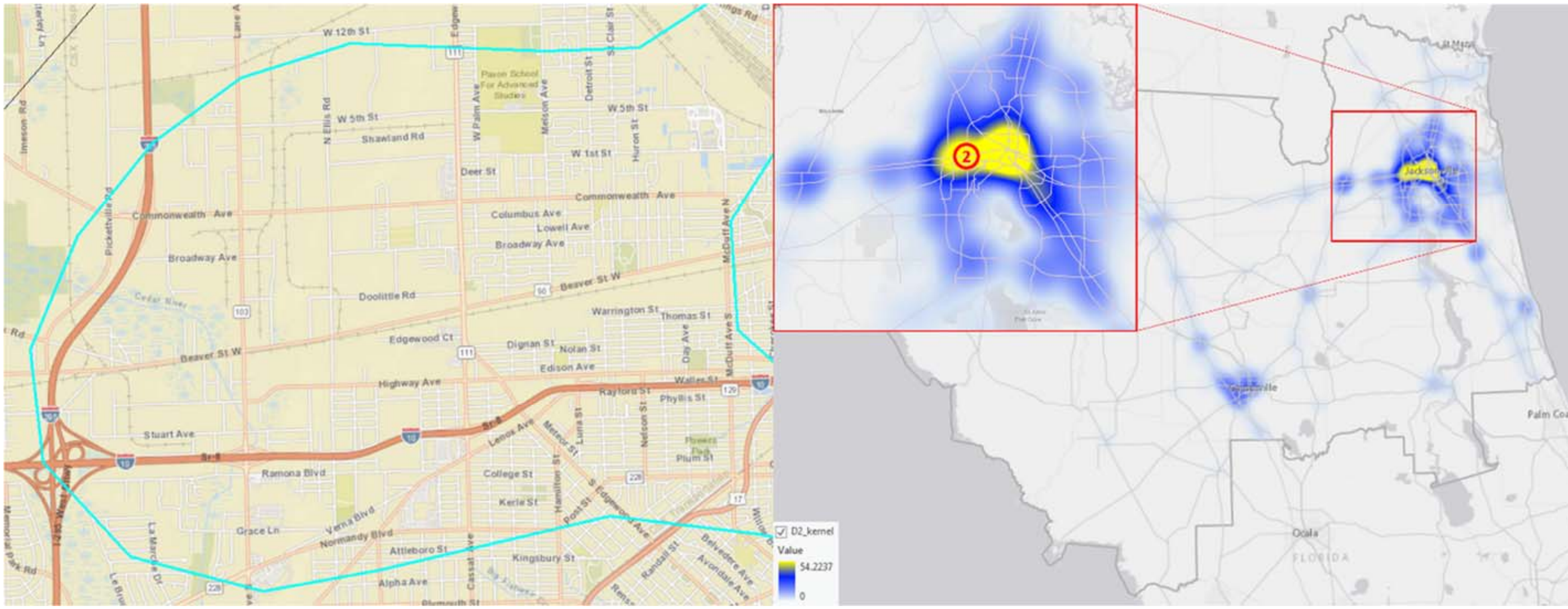


Figure 71 The 2nd high crash density location for large truck crashes from the kernel density map - District 2

The 3rd High crash density Location

The interchange of the I95 and the SR-126, and the surrounding areas within about 2 miles ranks the 3rd place in the 10 most high crash density locations in the district. The place locates to the southeast side of Jacksonville downtown. The sports center, retails, with a mixture of residential buildings are at this location.

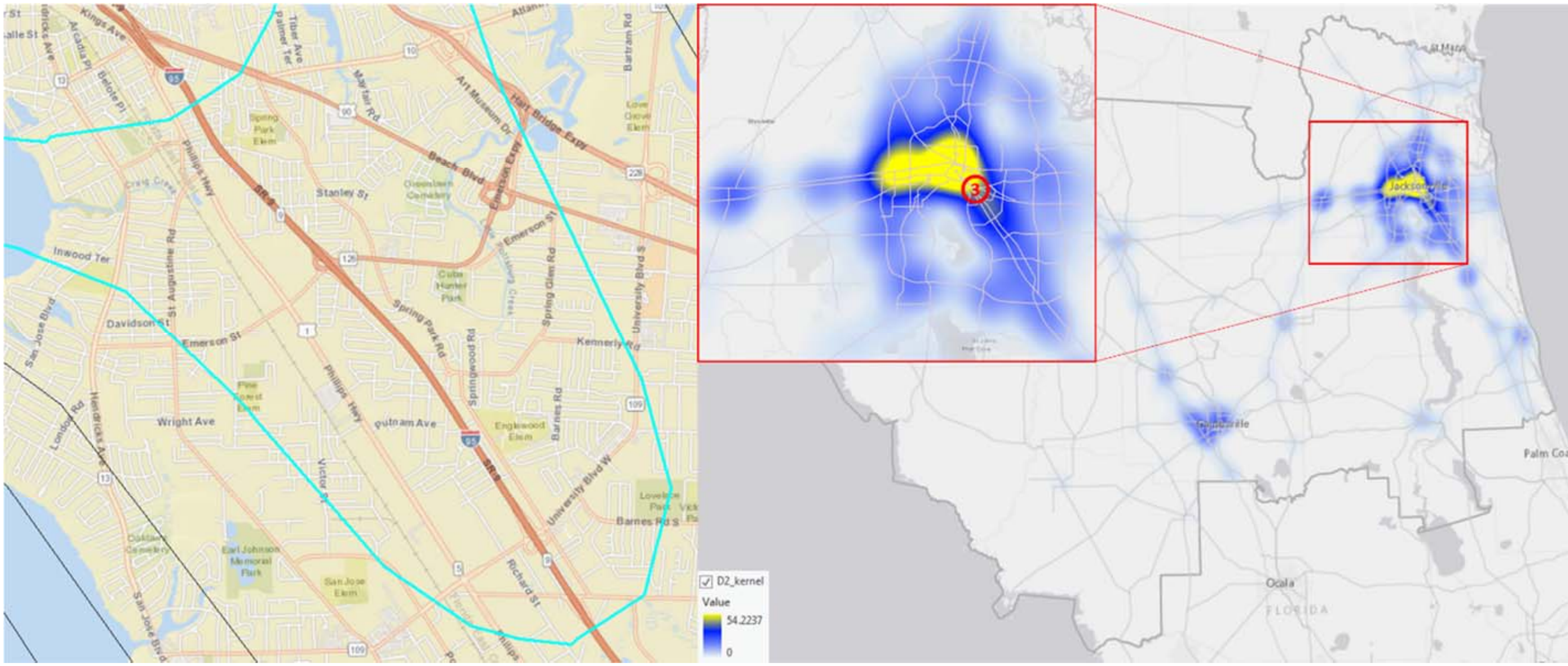


Figure 72 The 3rd high crash density location for large truck crashes from the kernel density map - District 2

The 4th High crash density Location

The interchange of the I95 and the SR-202, and the surrounding areas within about 1 mile ranks the 4th place in the 10 most high crash density locations in the district. The place locates to the southeast side of Jacksonville downtown. The sports center, the medical center, retails, with a mixture of residential buildings are at this location.

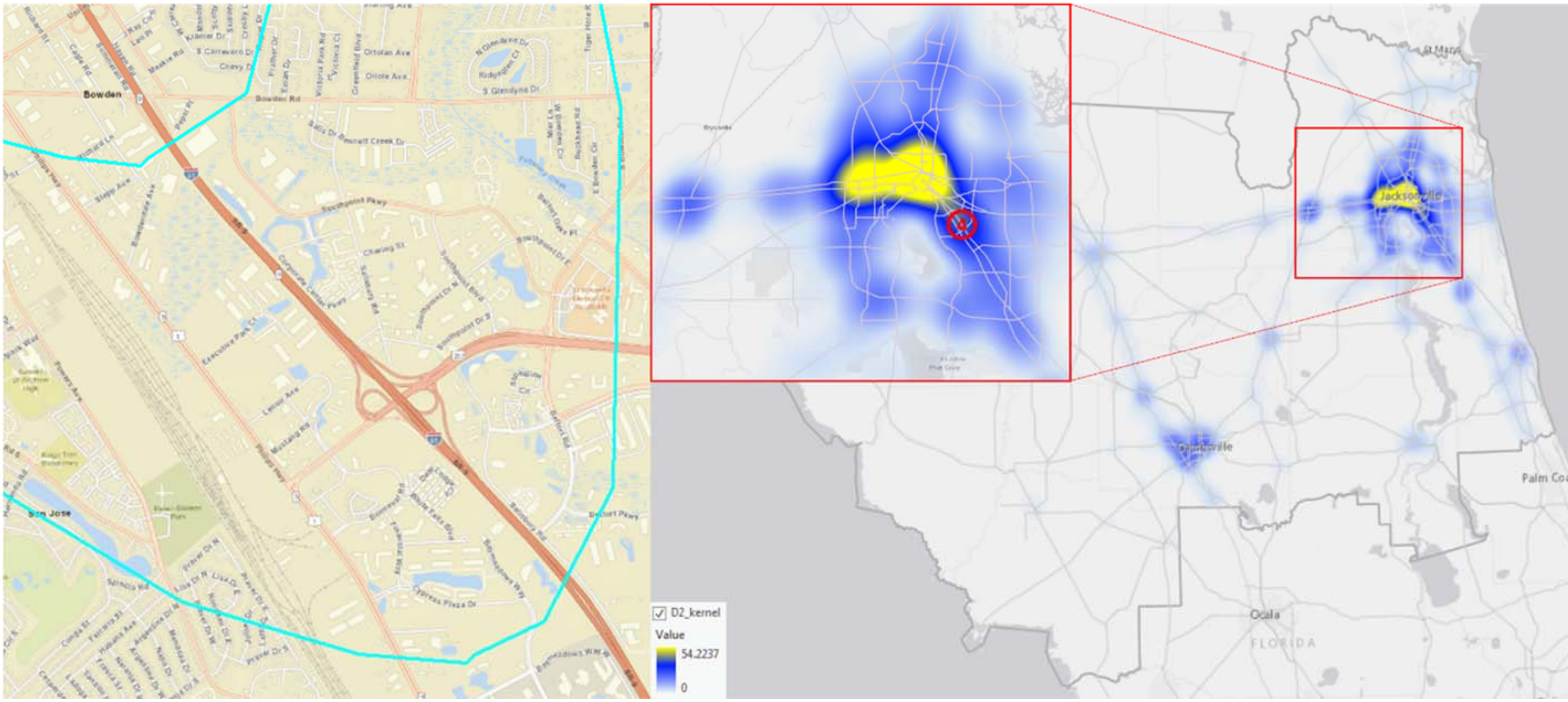


Figure 73 The 4th high crash density location for large truck crashes from the kernel density map - District 2

The 4th High crash density Location

The west area of downtown Gainesville also ranks the 4th place in the 10 most high crash density locations in the district. The area is at the intersection of US-441 and SR-26, and the surrounding area of about 0.5 mile. A mixture of retails, residential buildings and educational buildings are in this area.

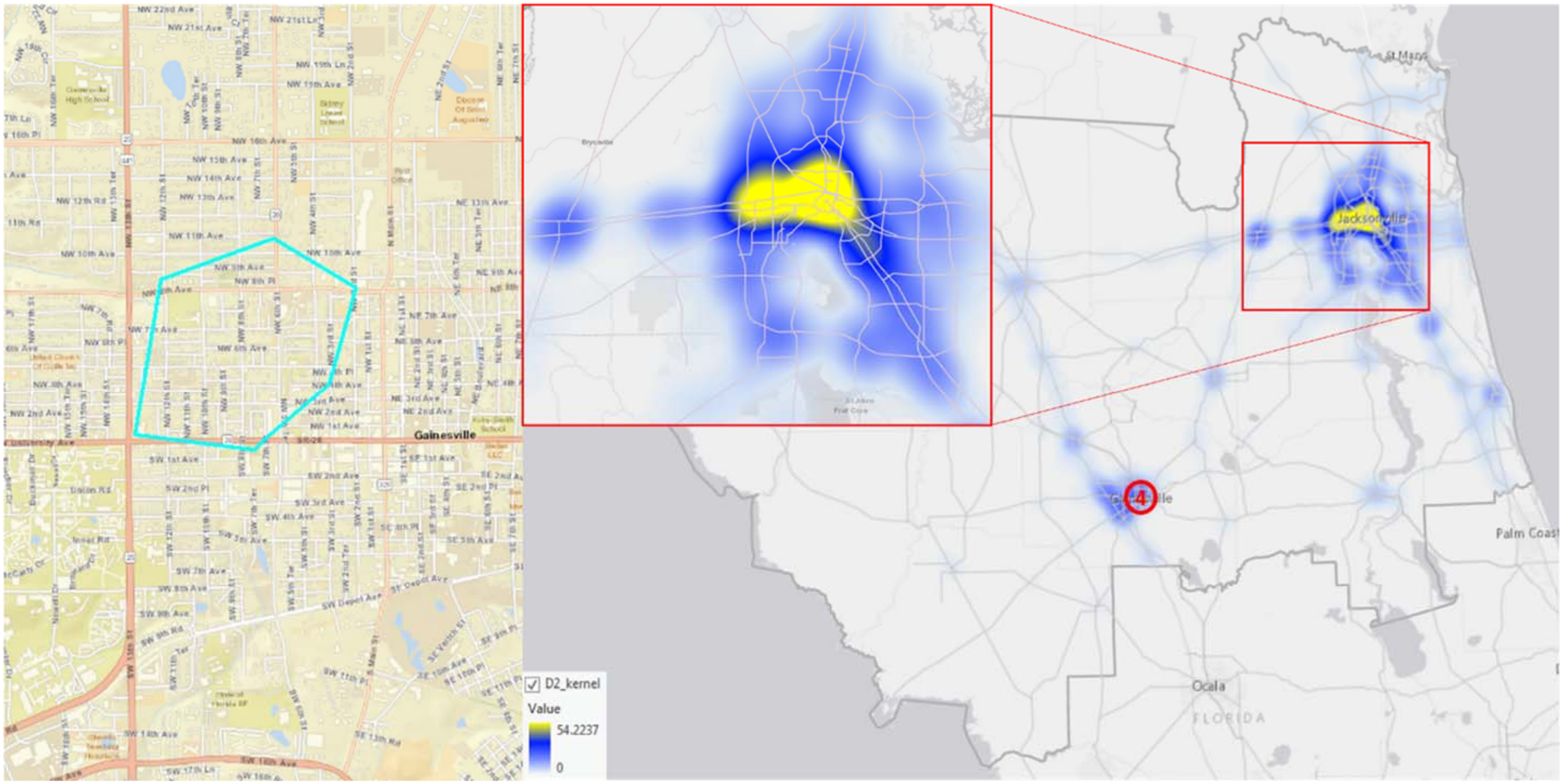


Figure 74 The 4th high crash density location for large truck crashes from the kernel density map - District 2

The 6th High crash density Location

The interchange of I295 and SR-134, and the surrounding areas within about 1.5 miles rank the 6th place in the 10 most high crash density locations based on the kernel density map. The place locates in the southwest of Jacksonville. Several major roads intersect in this area such as I295, SR-134 and SR-208. The place is mostly covered by residential buildings, with a mixture of retails and schools.

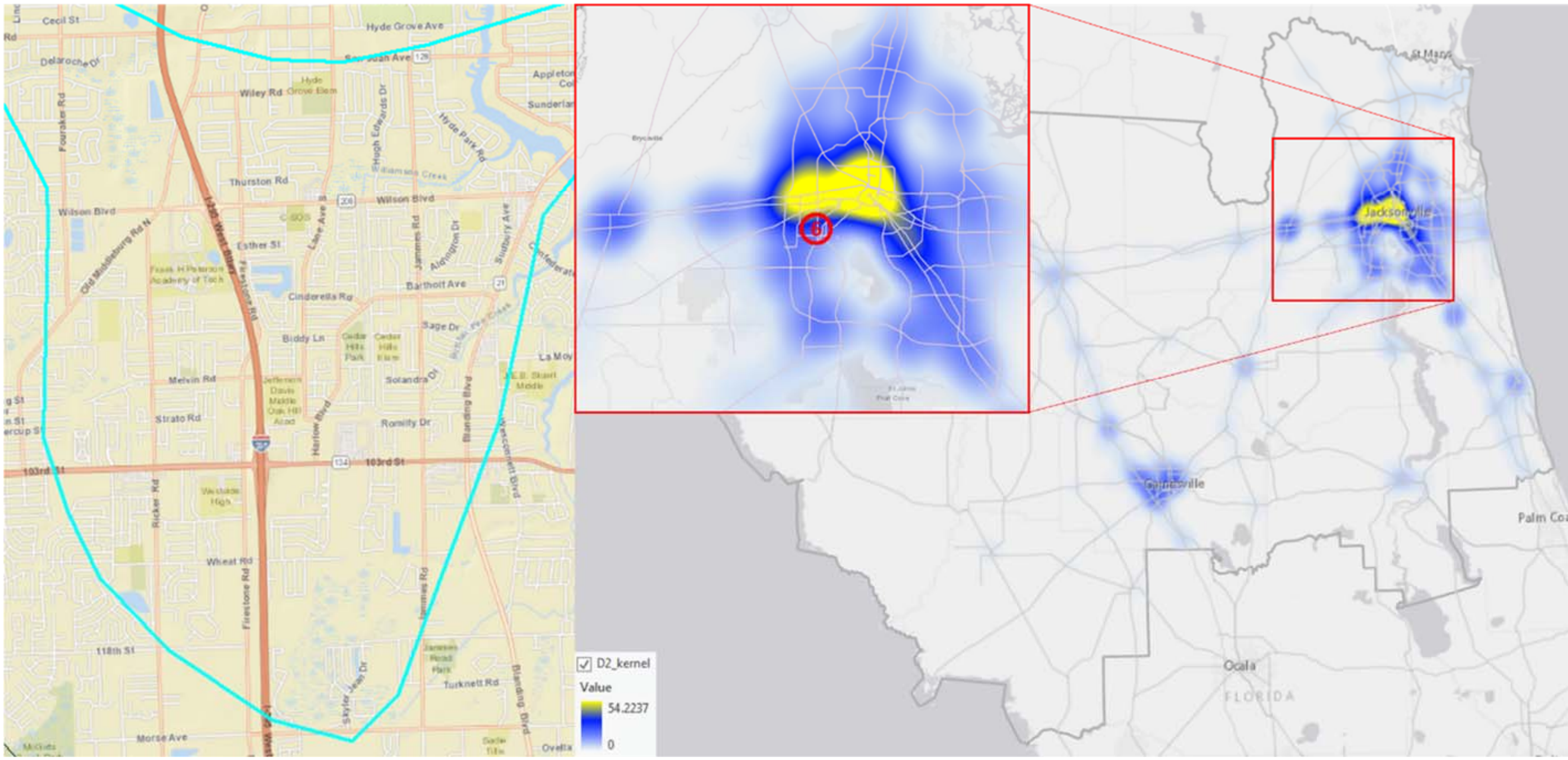


Figure 75 The 6th high crash density location for large truck crashes from the kernel density map - District 2

The 6th High crash density Location

The interchange of SR-10, SR-10A and SR-113, and the surrounding areas within about 2 miles also rank the 6th place in the 10 most high crash density locations based on the kernel density map. The place locates in the east of Jacksonville. Several major roads intersect in this area such as I295, SR-10, SR-10A and SR-113. Large quantities of shopping centers, retails are in this area, with a mixture of residential areas.

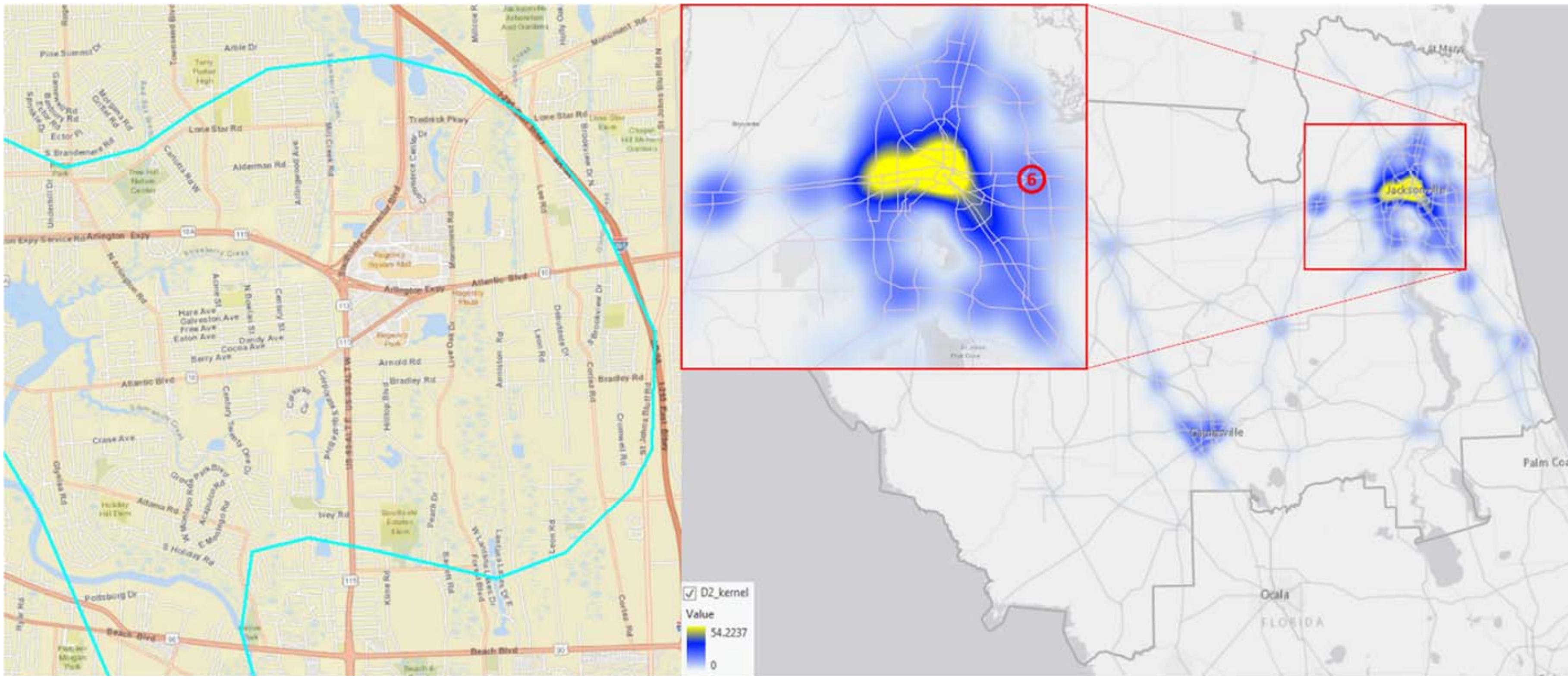


Figure 76 The 6th high crash density location for large truck crashes from the kernel density map - District 2

The 6th High crash density Location

The interchange of I95 and SR-5, and the surrounding areas within about 3 miles also rank the 6th place in the 10 most high crash density locations based on the kernel density map. The place locates in the southeast of Jacksonville. Several major roads intersect in this area such as I95, I295, SR-10A and SR-115. Large quantities of shopping centers, retails are in this area, with a mixture of residential areas.

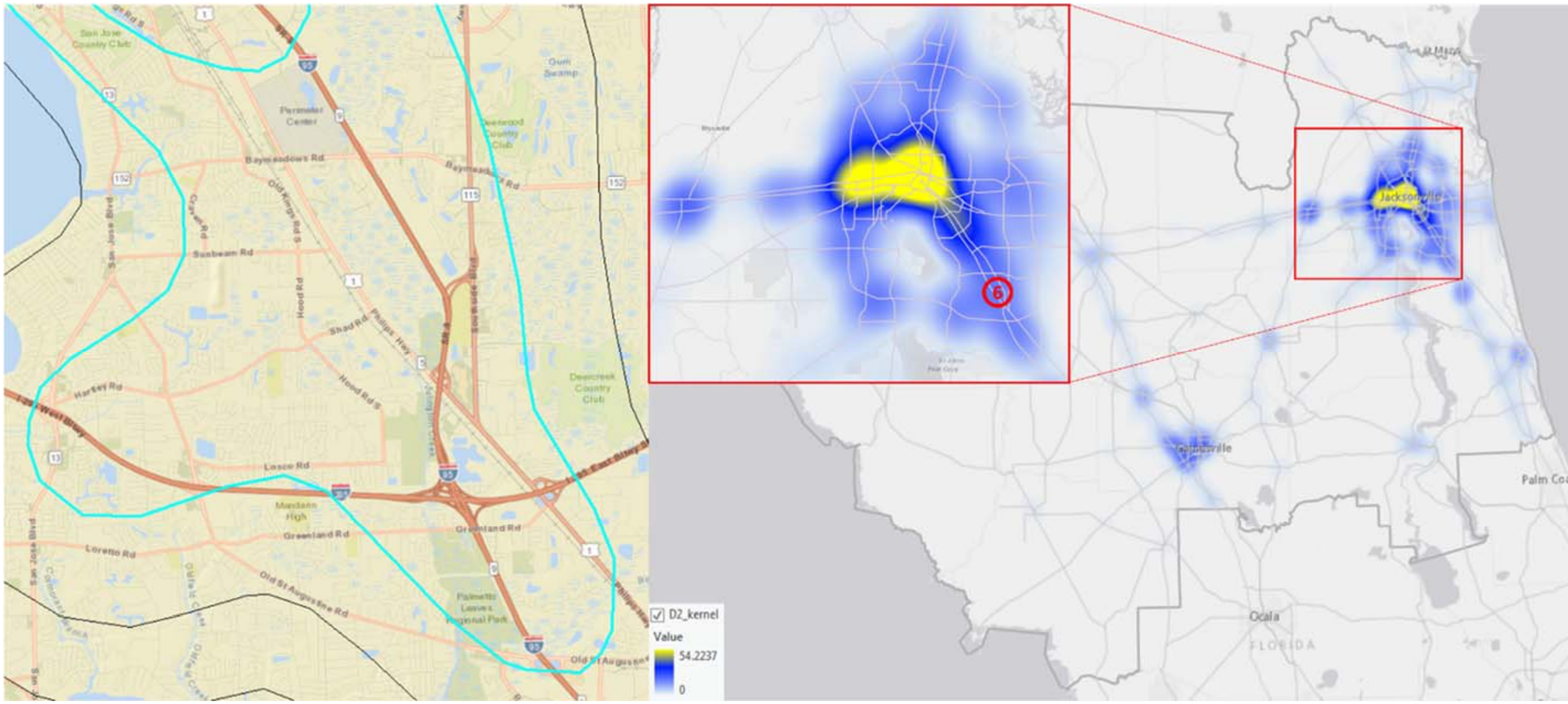


Figure 77 The 6th high crash density location for large truck crashes from the kernel density map - District 2

The 6th High crash density Location

The interchange of I295 and SR-21, and the surrounding areas within about 1 mile also rank the 6th place in the 10 most high crash density locations based on the kernel density map. The place locates in the southwest of Jacksonville. Several major roads intersect in this area such as I295, SR-17 and SR-21. Large quantities of shopping centers, retails are in this area, with a mixture of residential areas.

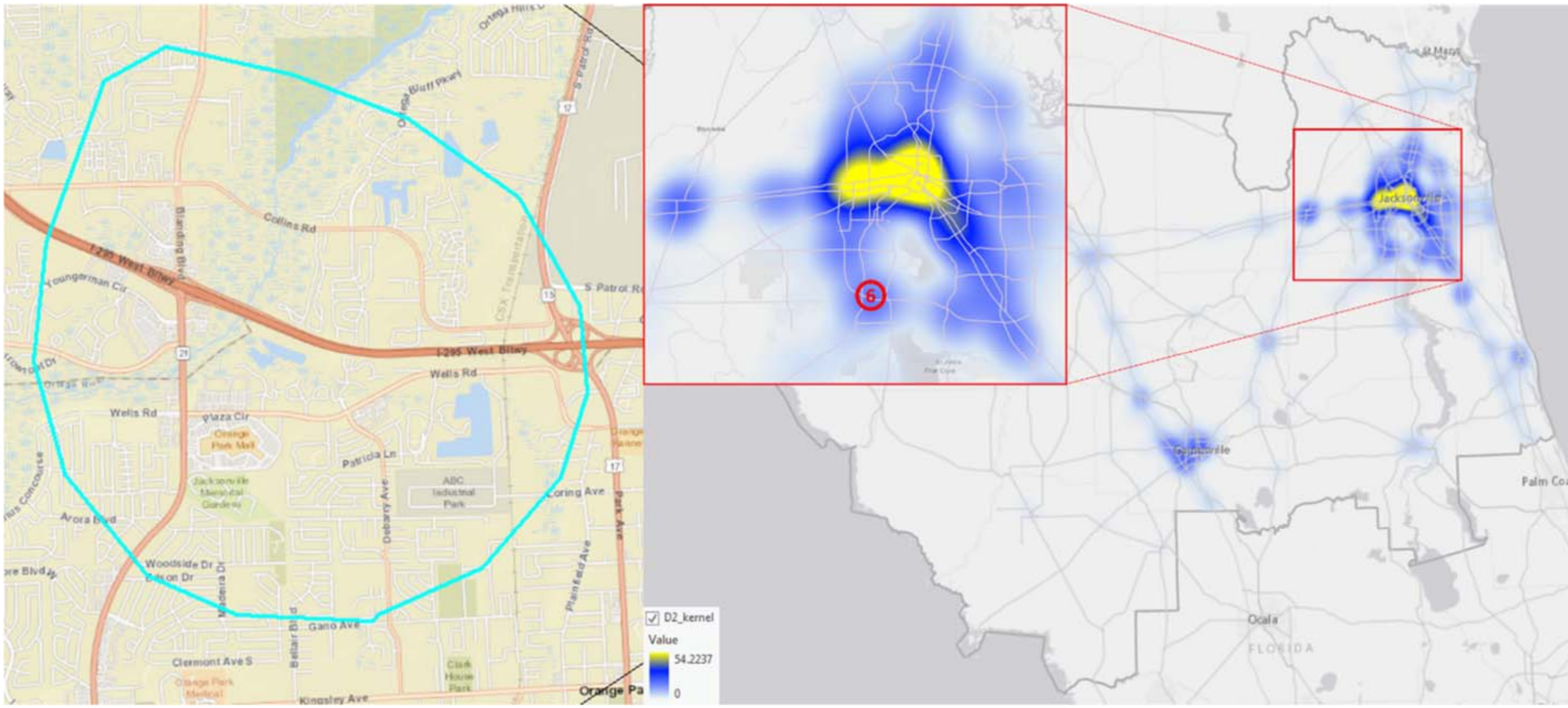


Figure 78 The 6th high crash density location for large truck crashes from the kernel density map - District 2

The 6th High crash density Location

The interchange of I10 and US-301, and the surrounding areas within about 1.5 miles also rank the 6th place in the 10 most high crash density locations based on the kernel density map. The place locates in the south of Baldwin. Several major roads intersect in this area such as I10, US-301, SR-10 and SR-200. A truck travel service (TA-Petro) locates in this area, with a scatter of residential buildings.

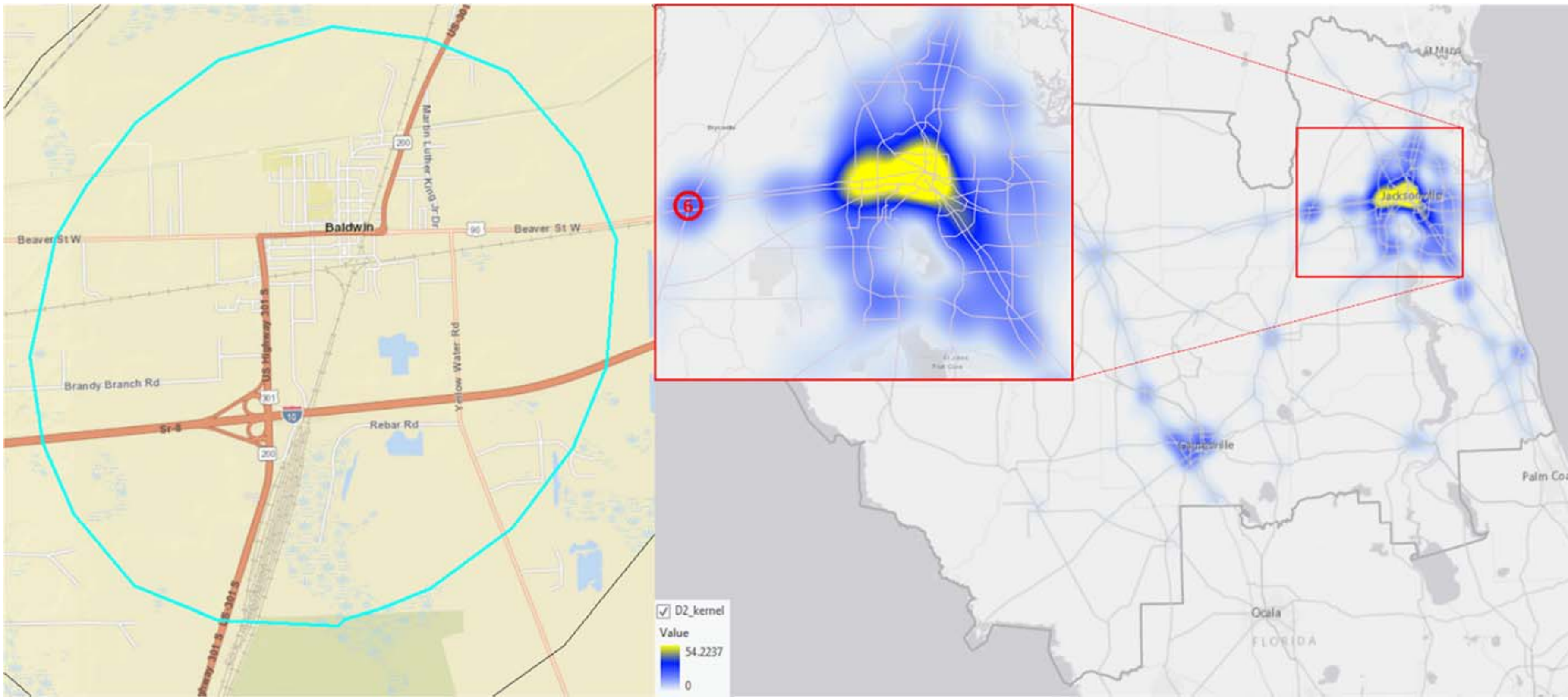


Figure 79 The 6th high crash density location for large truck crashes from the kernel density map - District 2

7.3. Density Map for District 3

Figure 80 shows the kernel density map of the large truck crashes density locations in District 3.

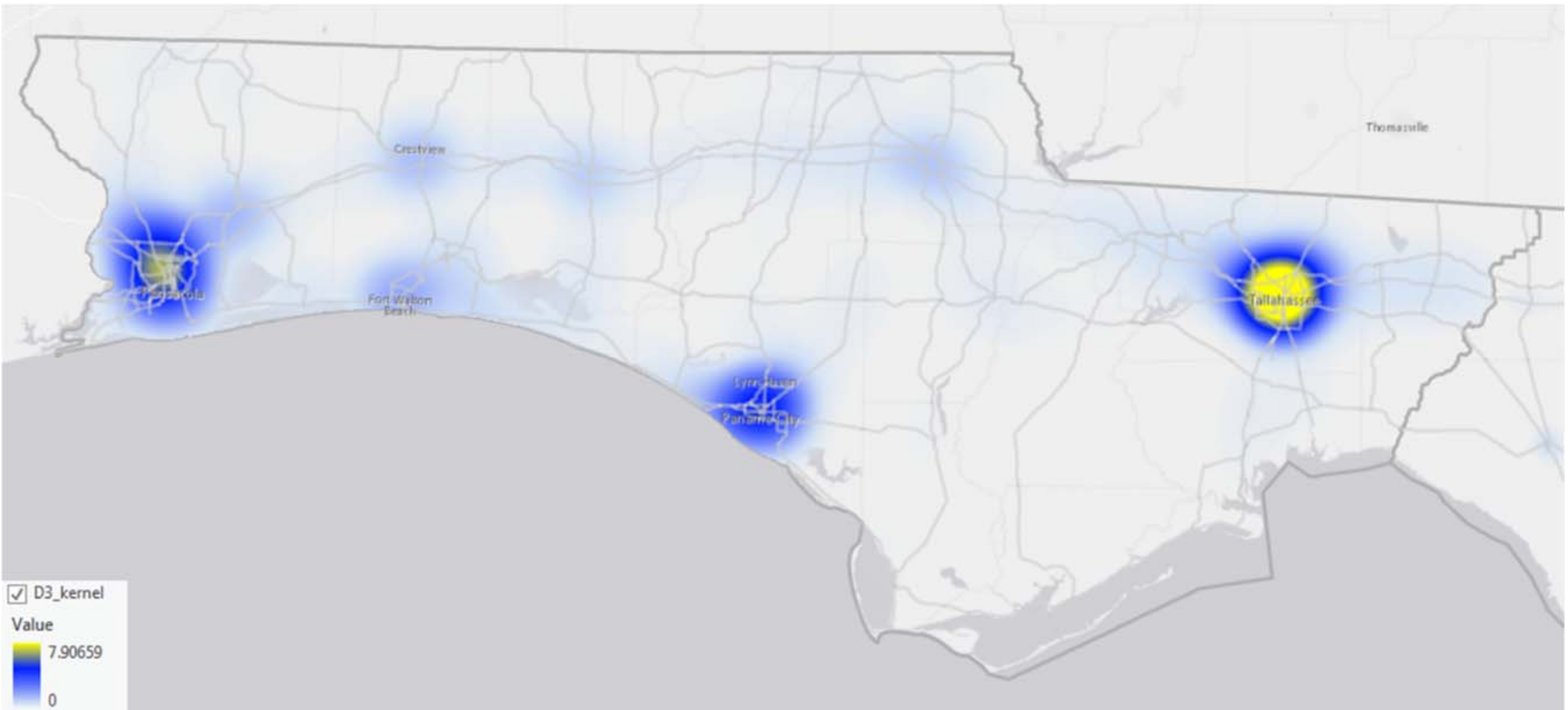


Figure 80 Kernel density mapping of all large truck crashes in district 3

Figure 81 shows the locations with the top 10 highest kernel density value. The highest crash density areas are located in the major cities in the district such as Tallahassee, Pensacola and Panama City.

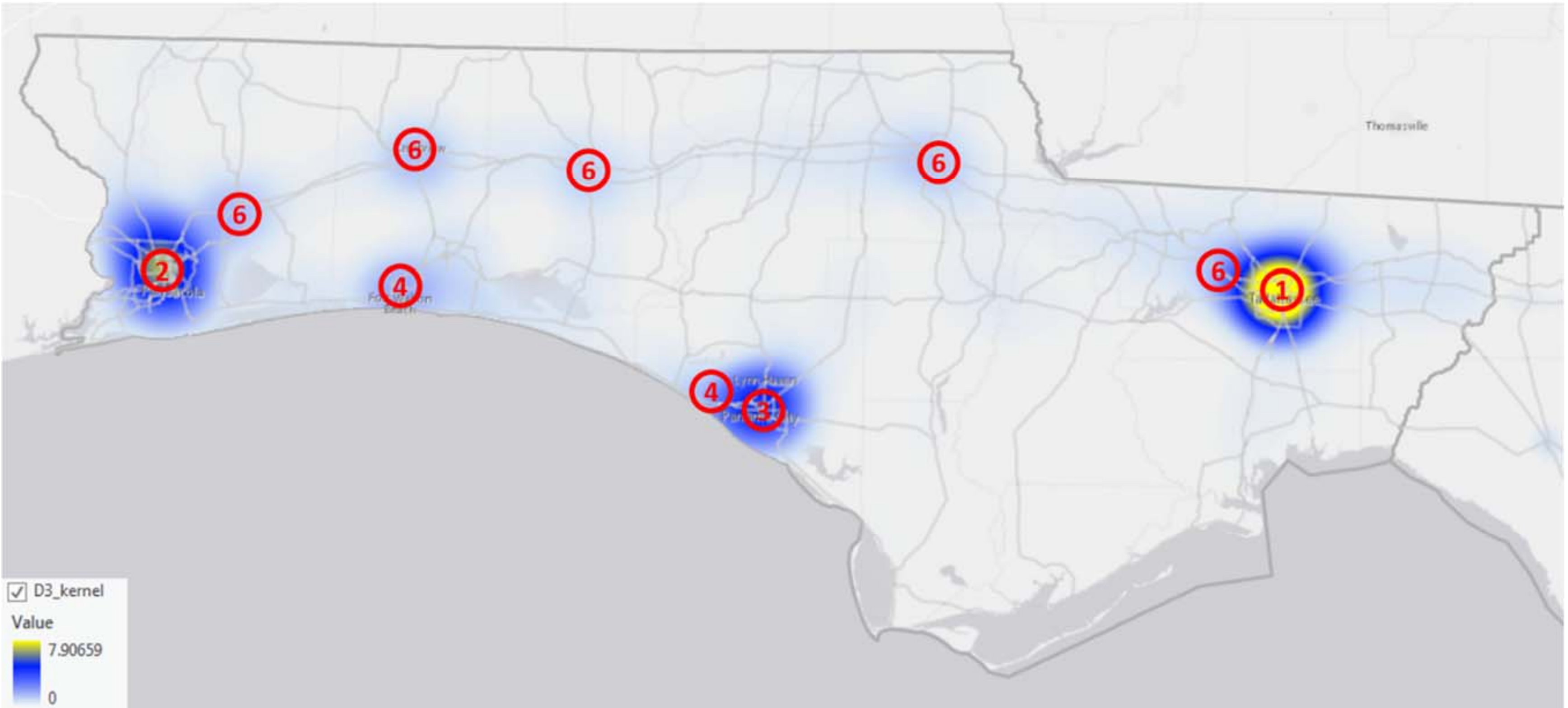


Figure 81 Top 10 locations selected from kernel density mapping of all large truck crashes in District 2

The 1st High crash density Location

Downtown Tallahassee, specifically the interchange of US-90 and SR-61, and the surrounding areas within about 3 miles, rank the 1st place in the 10 highest crash density locations based on the kernel density map. Several major roads intersect in this area, such as I10, US-90, SR-20, SR-61, SR-63, SR-265, SR-366 and SR-371. Large quantities of retails, entertains, conventional center, stadium, and university campus with a mixture of residential areas are located in this location.

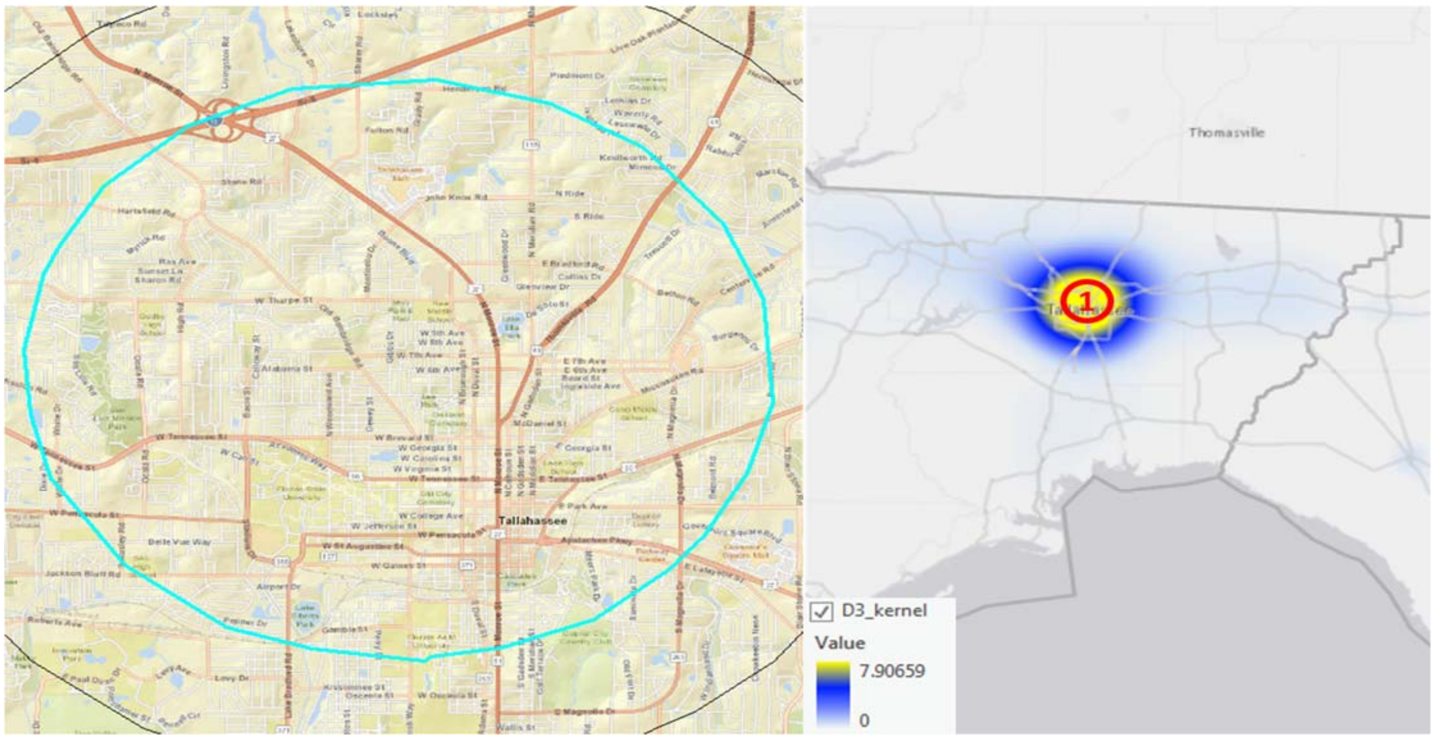


Figure 82 The 1st high crash density location for large truck crashes from the kernel density map - District 3

The 2nd High crash density Location

The west area of Pensacola ranks the 2nd place in the 10 most high crash density locations based on the kernel density map. Major roads I110, I10, US-29, SR-291, SR-292, SR-296, and SR-742 intersect in this area. Large quantities of retails and entertains are in this area, with a mixture of residential areas.

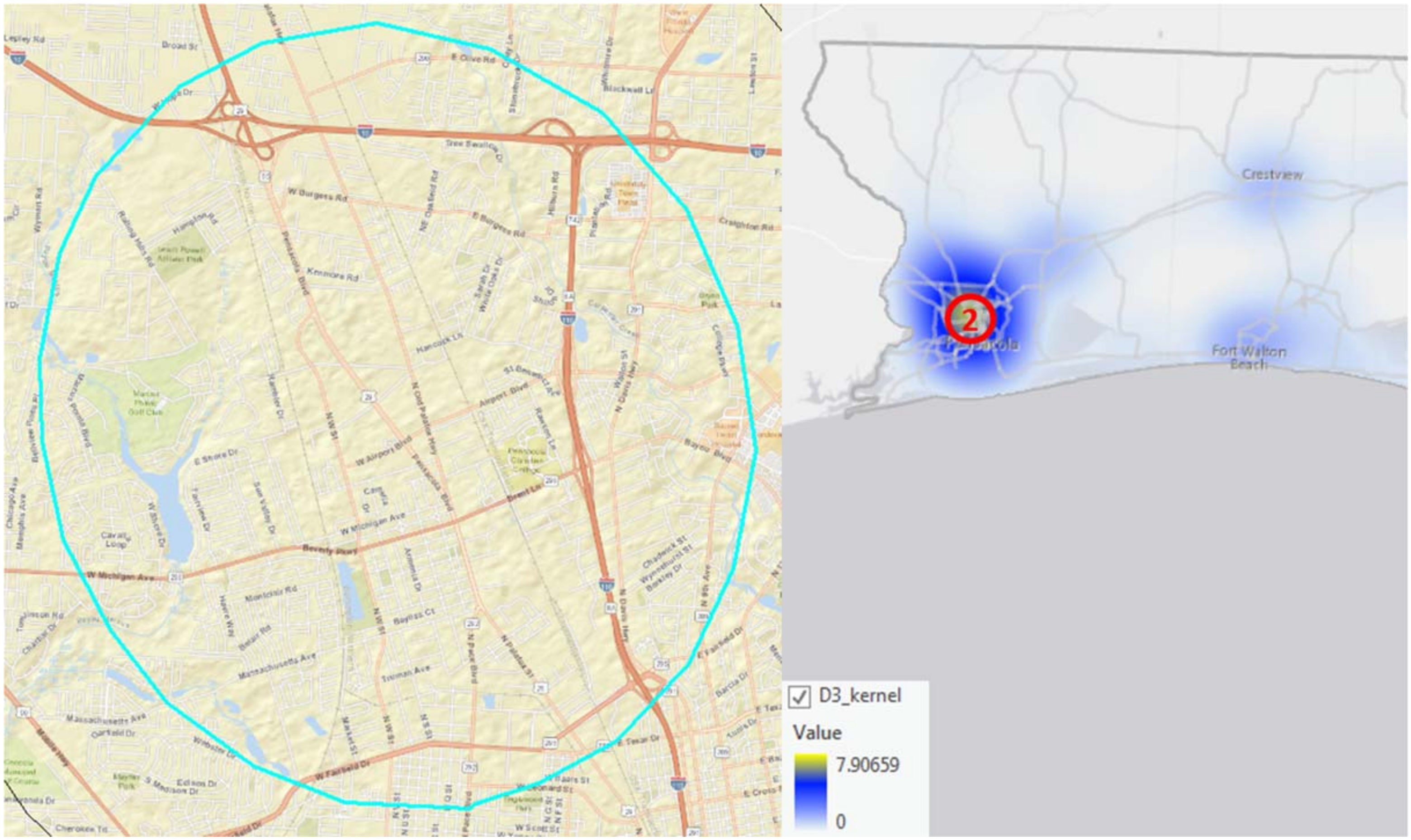


Figure 83 The 2nd high crash density location for large truck crashes from the kernel density map - District 3

The 3rd High crash density Location

The west area of Panama City ranks the 3rd place in the 10 highest crash density locations based on the kernel density map. The major intersection of US-98, SR-75 and SR-391, and the surrounding areas within about 2.5 miles has the very high crash density. Other major roads such as SR-30, SR-77, SR-389 and SR-390 also intersect in this area. Large quantities of retails and entertains are in this area, with a mixture of residential areas.

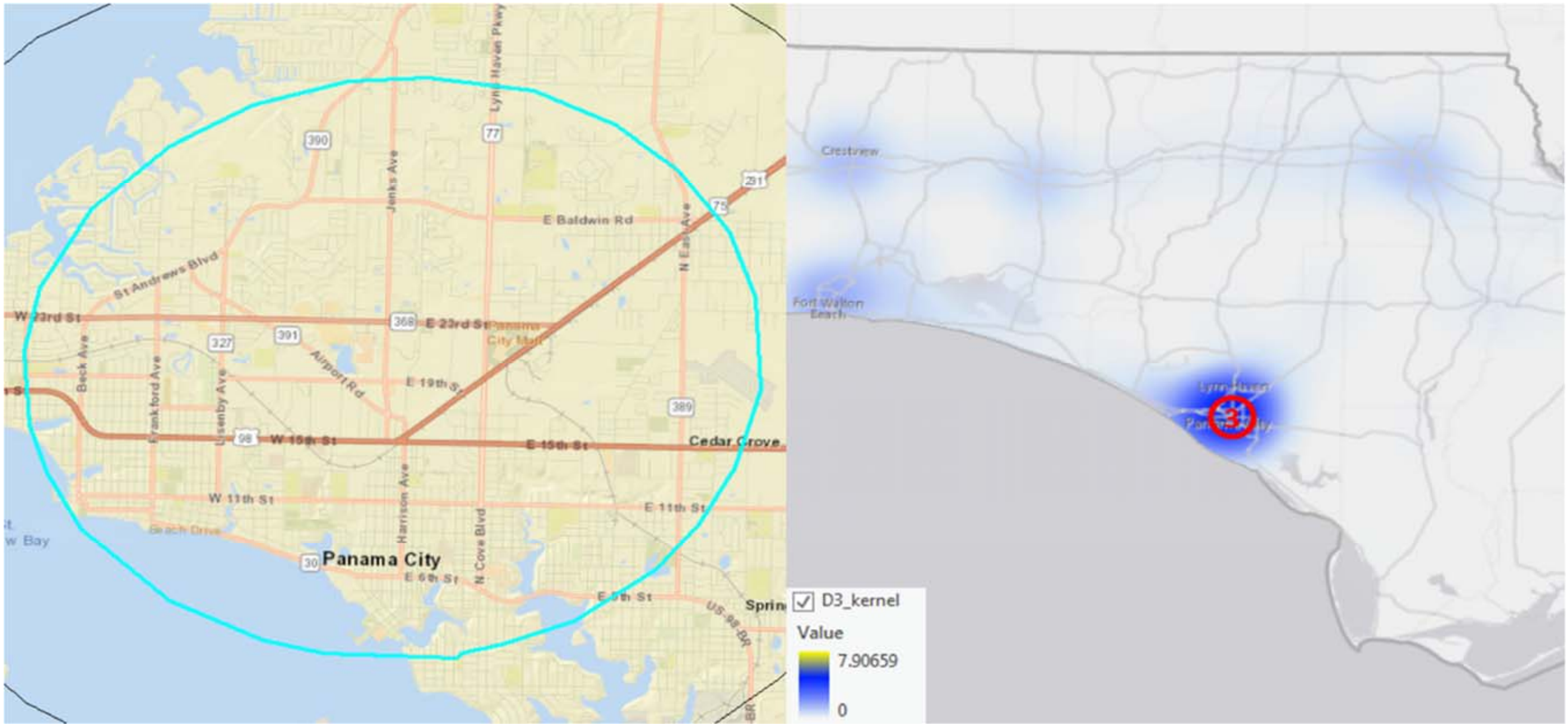


Figure 84 The 3rd high crash density location for large truck crashes from the kernel density map - District 3

The 4th High crash density Location

The area of Fort Walton Beach and Ocean City ranks the 4th place in the 10 highest crash density locations based on the kernel density map. Major roads SR-85, SR-189 and SR-393 intersect in this area. The majority of the location are covered with residential areas, with a mix of retails and recreational buildings.

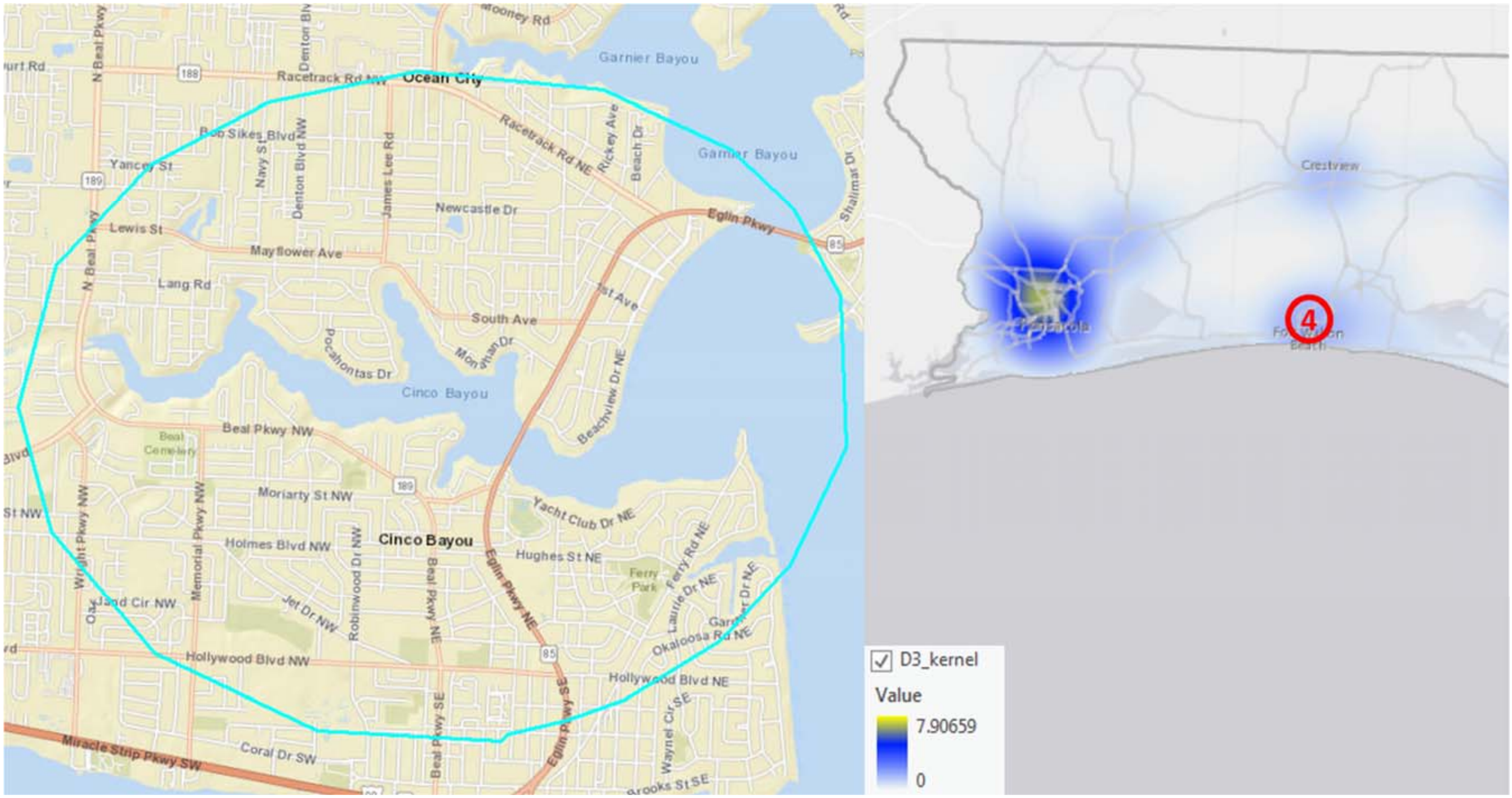


Figure 85 The 4th high crash density location for large truck crashes from the kernel density map - District 3 (Area 1)

The intersection of SR-30A and SR-79, and the surrounding areas within about 2 miles also rank the 4th place in the 10 most high crash density locations based on the kernel density map. The place locates in the Panama City Beach, at the south of Conservation Park. The location is covered with a mixture of retails, recreational buildings and residential buildings.

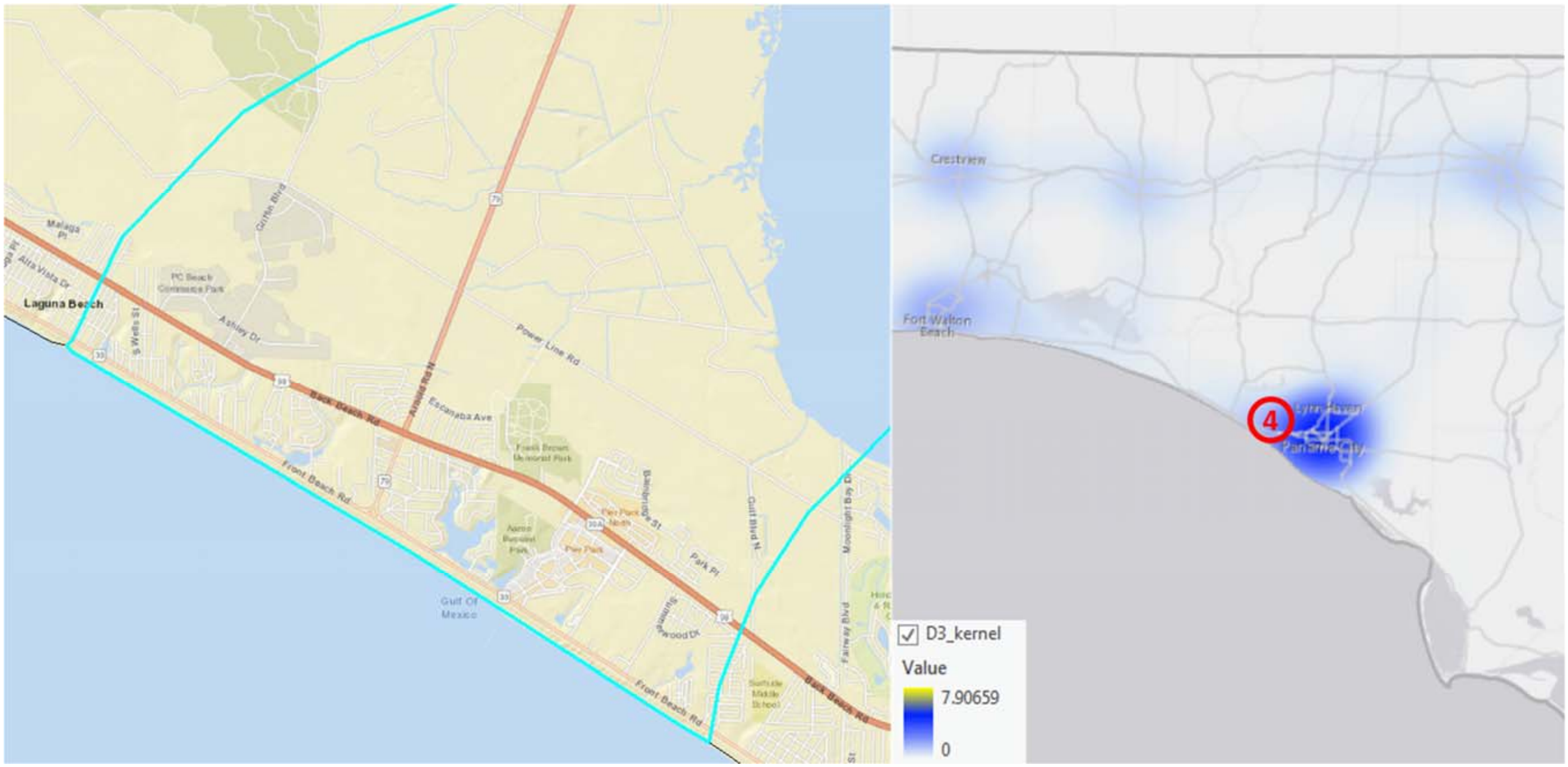


Figure 86 The 4th high crash density location for large truck crashes from the kernel density map - District 3 (Area 2)

The 6th High crash density Location

The interchange of the I10 and the SR-267, and the surrounding areas within about 3 miles ranks the 6th place in the 10 highest crash density locations in the district. The place locates to the south of Quincy. A scatter of retails, hotels, service buildings and residential buildings locate in this area.

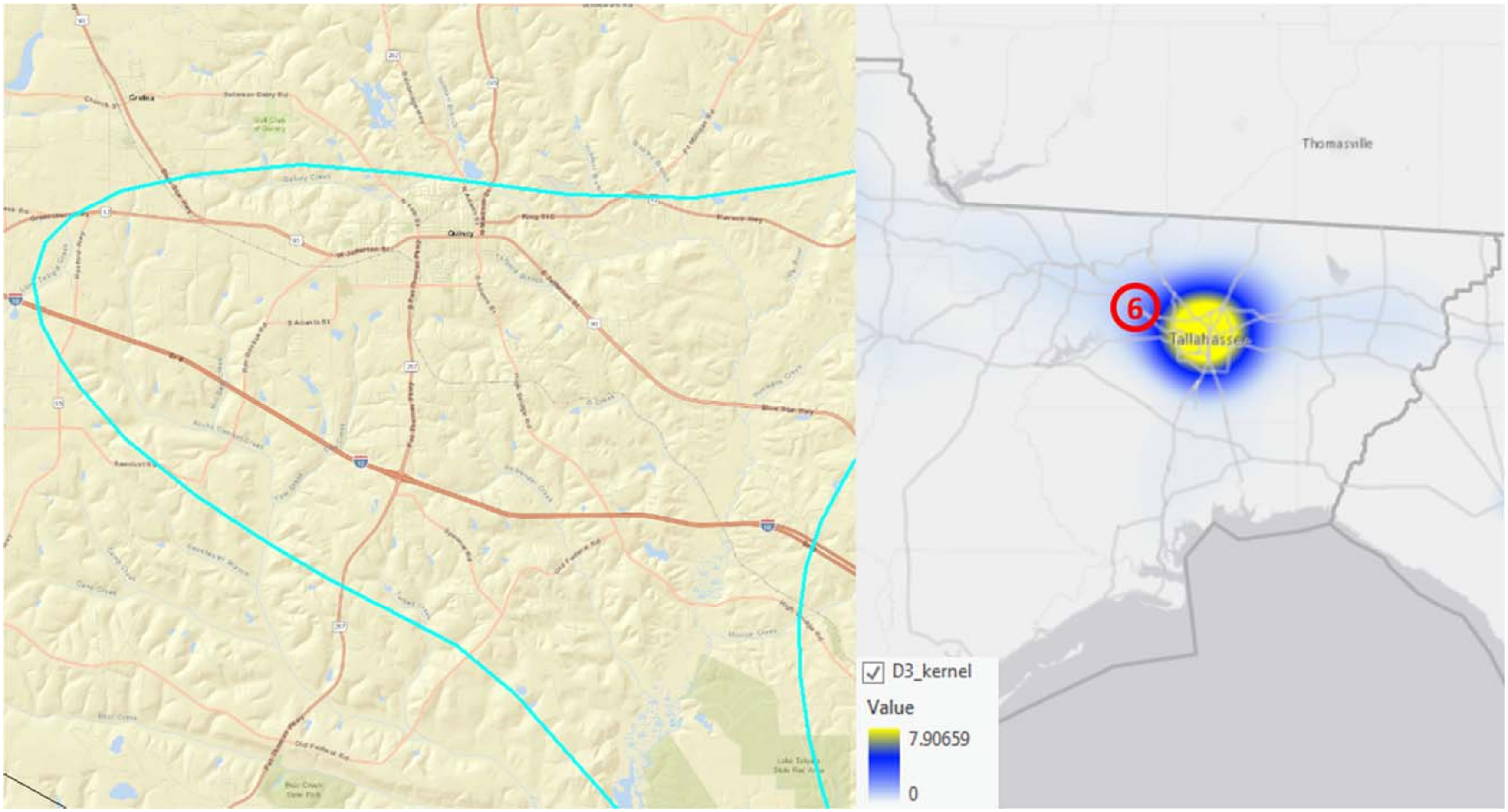


Figure 87 The 6th high crash density location for large truck crashes from the kernel density map - District 3

The 6th High crash density Location

The intersection of the US-90 and the SR-281, and the surrounding areas within about 3 miles also ranks the 6th place in the 10 highest crash density locations in the district. The place locates to the northeast of Pensacola, between Milton and Bagdad cities. The location is mostly covered by residential areas and educational areas such as schools.

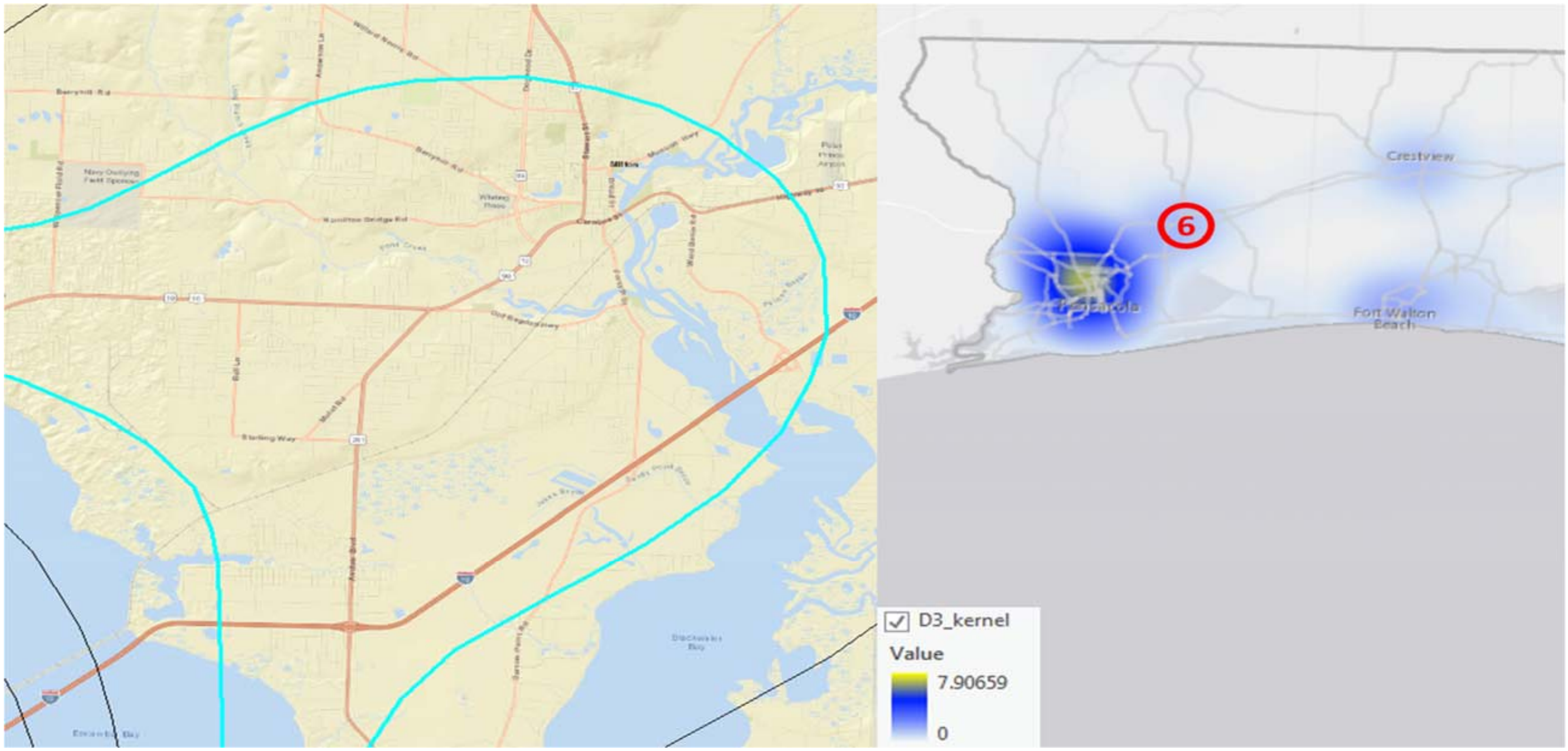


Figure 88 The 6th high crash density location for large truck crashes from the kernel density map - District 3

The 6th High crash density Location

The interchange of the I10 and the SR-85, and the surrounding areas within about 2.5 miles also ranks the 6th place in the 10 highest crash density locations in the district. The place locates in the south of Crestview. Major roads such as I10, SR-10 and SR-85 intersect in this area. The location is covered with a mixture of retails and residential buildings.

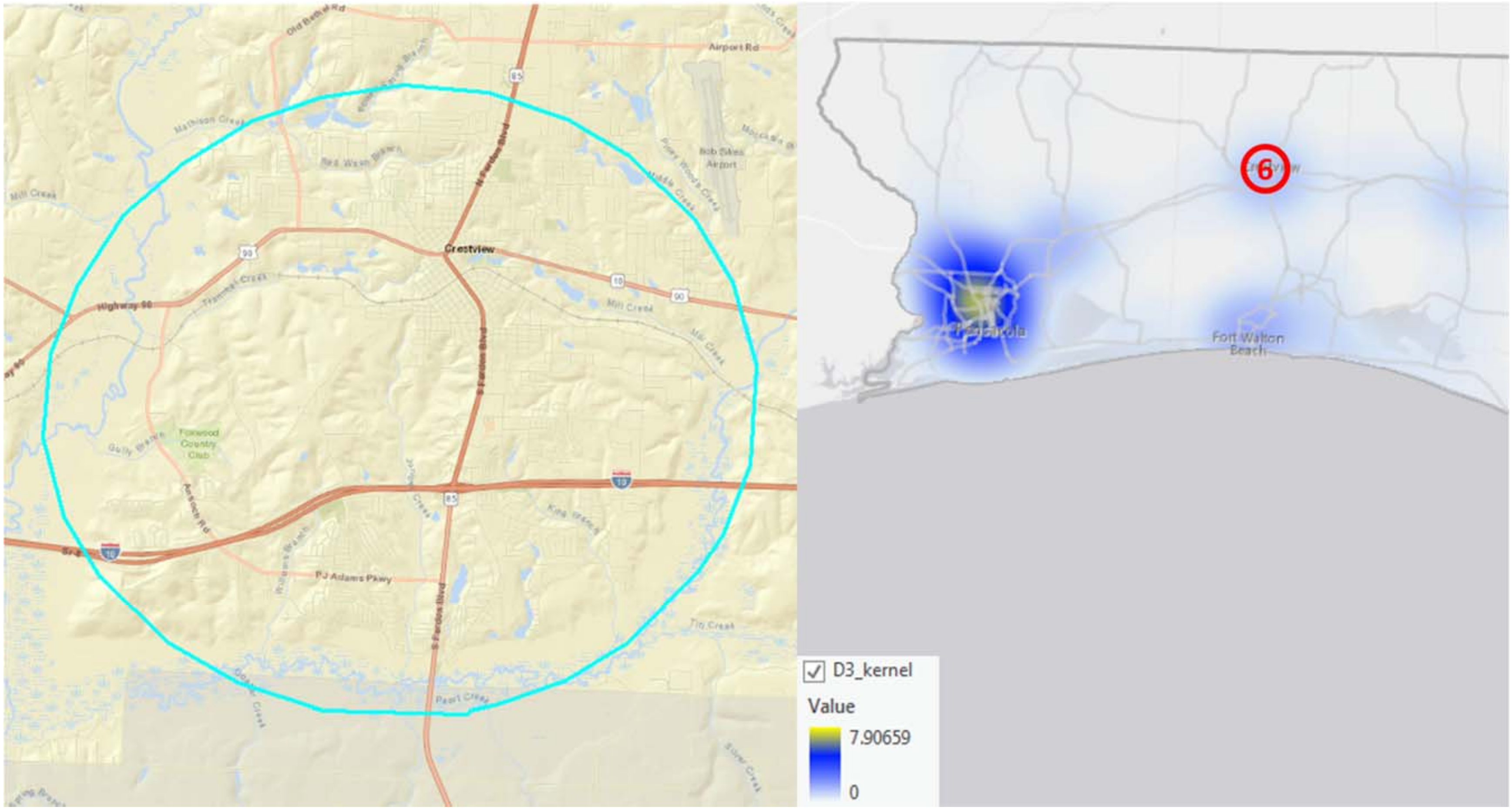


Figure 89 **The 6th high crash density location for large truck crashes from the kernel density map - District 3**

The 6th High crash density Location

The interchange of the I10 and the SR-83, and the surrounding areas within about 3 miles also ranks the 6th place in the 10 highest crash density locations in the district. The place locates in the DeFuniak Springs. Major roads such as I10, US-331, SR-10 and SR-83 intersect in this area. The location is covered with a mixture of retails and residential buildings.

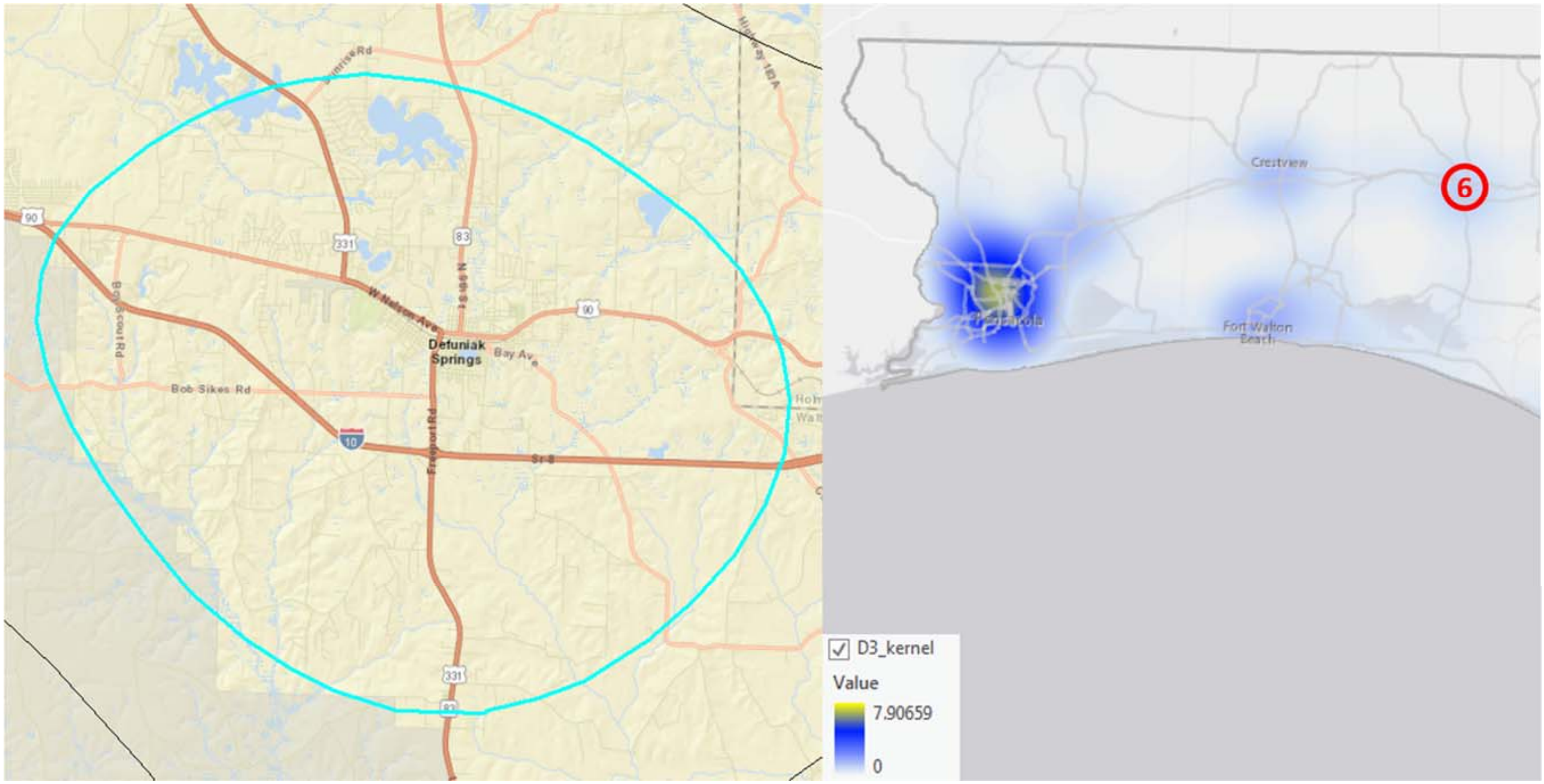


Figure 90 The 6th high crash density location for large truck crashes from the kernel density map - District 3

The 6th High crash density Location

The interchange of the I10 and the SR-71, and the surrounding areas within about 2 miles also ranks the 6th place in the 10 most high crash density locations in the district. The place locates in the southeast of Marianna city. Major roads such as I10, SR-10, SR-71, and SR-276 intersect in this area. A scatter of retails, hotels, service buildings and residential buildings locate in this area.

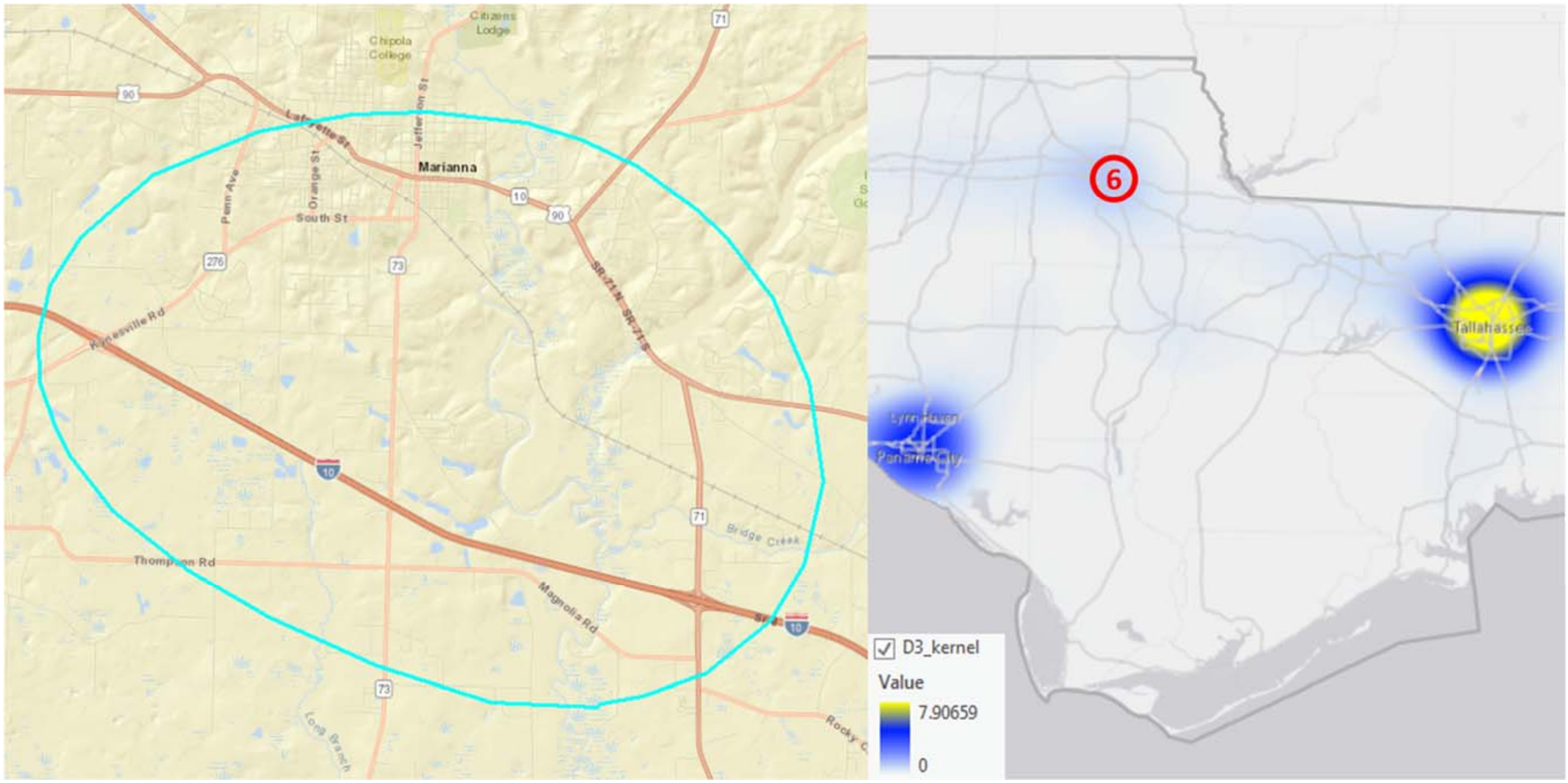


Figure 91 The 6th high crash density location for large truck crashes from the kernel density map - District 3

7.4. Density Map for District 4

Figure 92 shows the Kernel Density map of all large truck crashes in FDOT District 4.

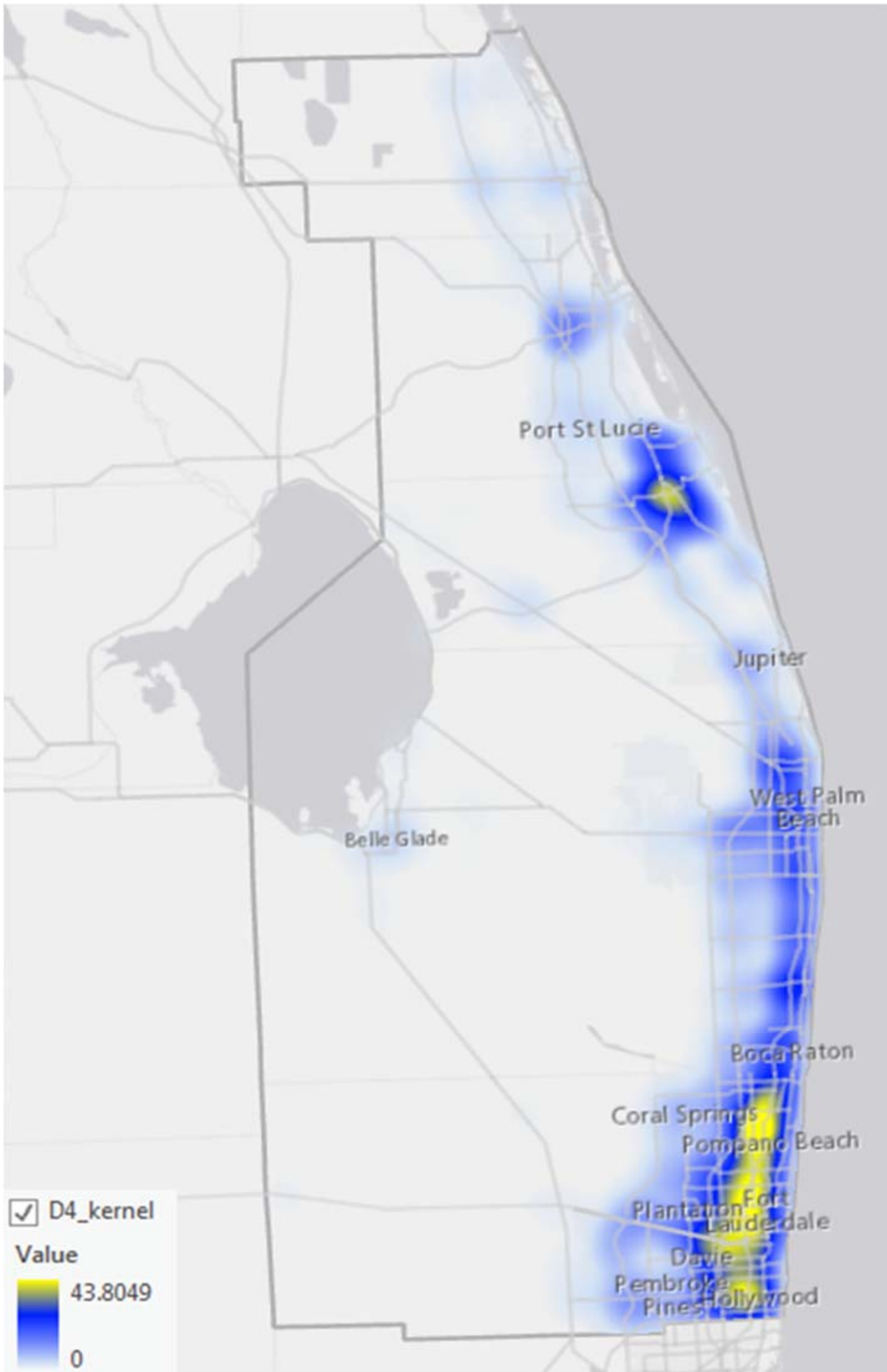


Figure 92 Kernel density mapping of all large truck crashes in District 4

Figure 93 identifies the top 10 locations that has the highest crash density. Most of the top locations are concentrated at the Southern part of District 4 in yellow color. The following map shows the selected top locations from the highest crash density to the lowest crash density.

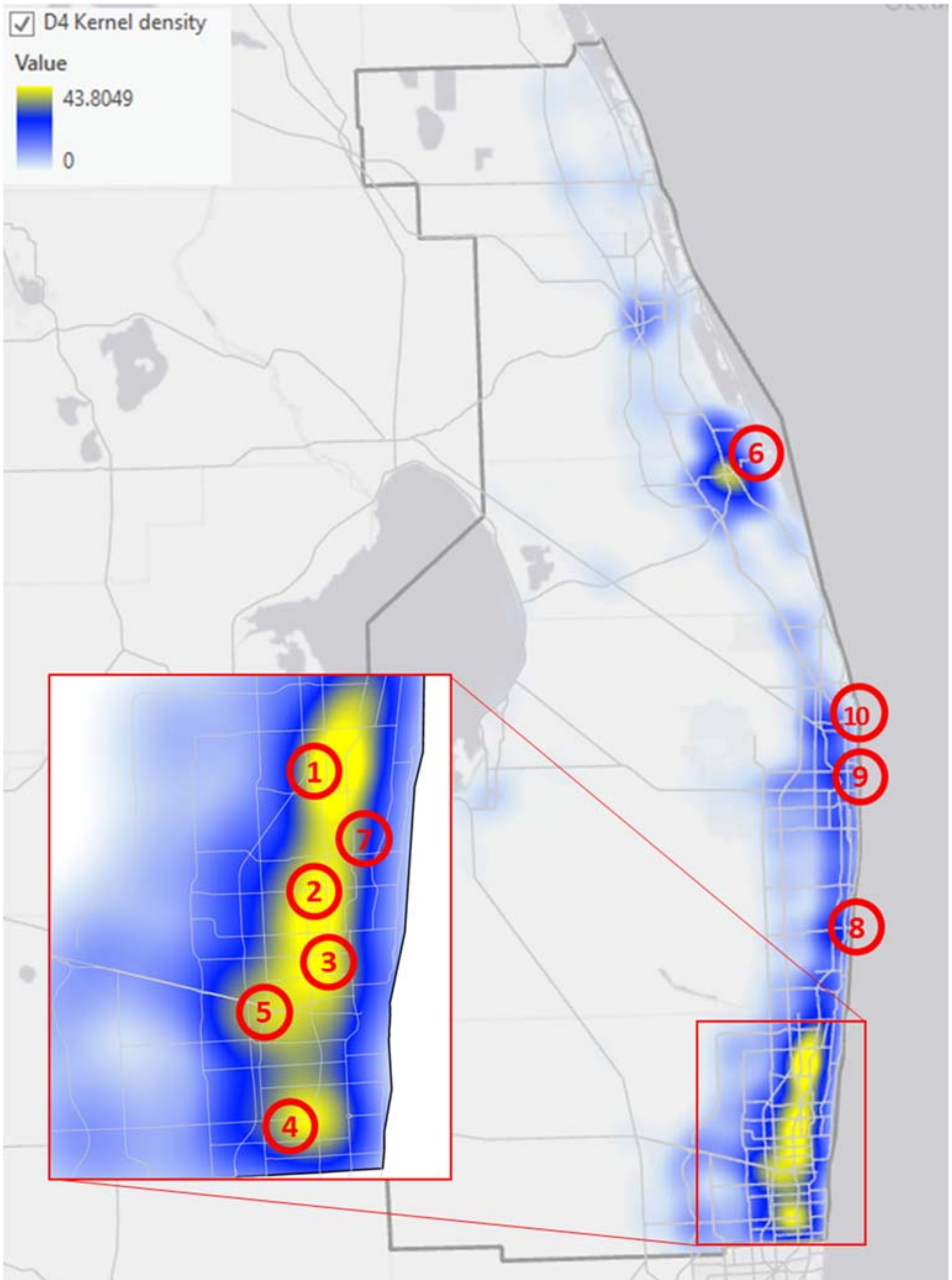


Figure 93 Top 10 locations selected from kernel density mapping of all large truck crashes in District 4

The 1st High crash density Location

The site with highest crash density is around the intersection of I-95/ W Copans Road and I-95 / W Atlantic Blvd. The area has residential, commercial land use. Most crashes happen on Interstate roads, turnpikes and local main roads. Since these roads have much higher traffic volume. These roads get concentrated in this area so they contribute the high density to this area.

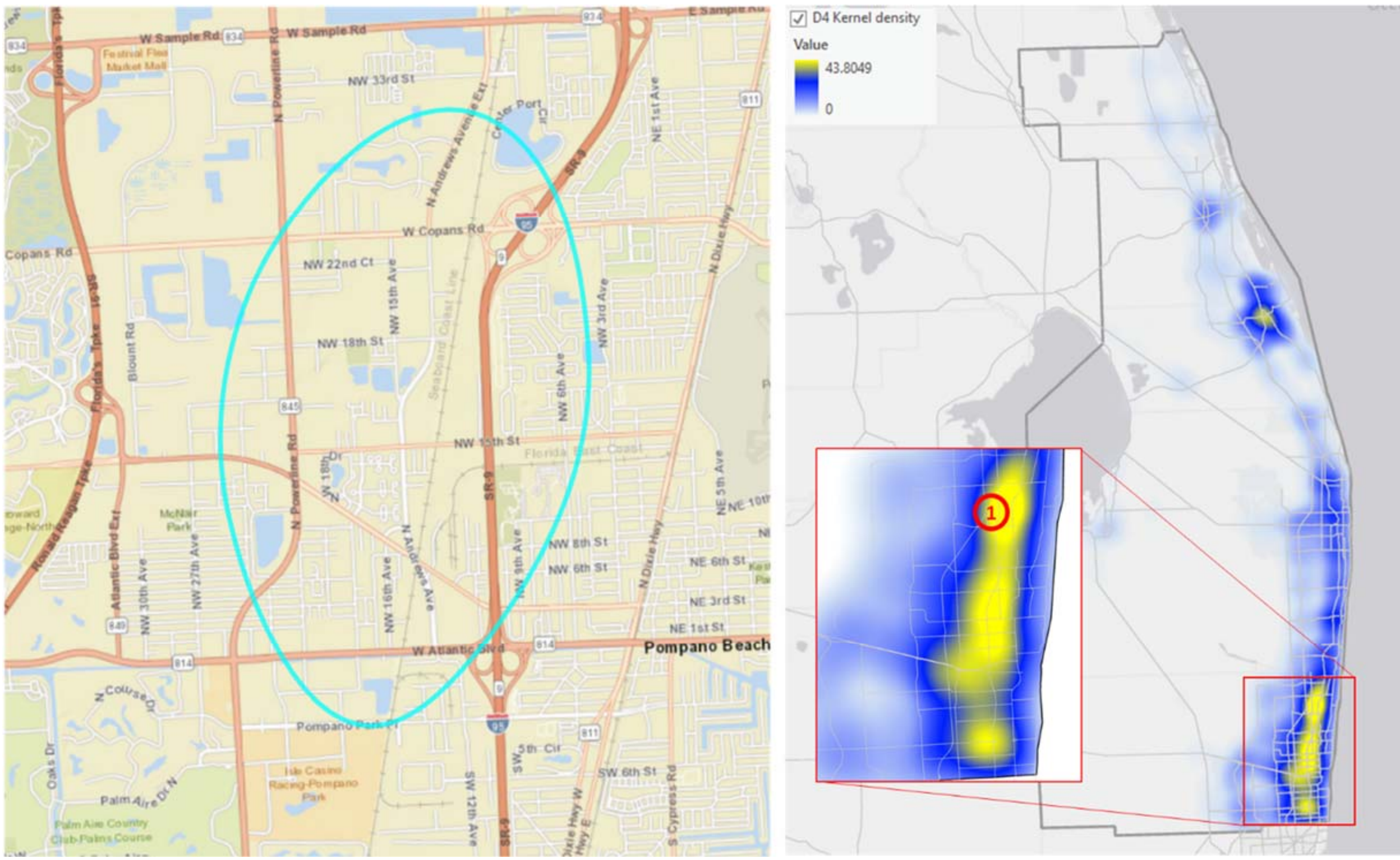


Figure 94 The 1st high crash density location for large truck crashes from the kernel density map - District 4

The 2nd High crash density Location

This site is around W Sunrise and I-95. The major land use in this place is residential and a little bit of commercial.

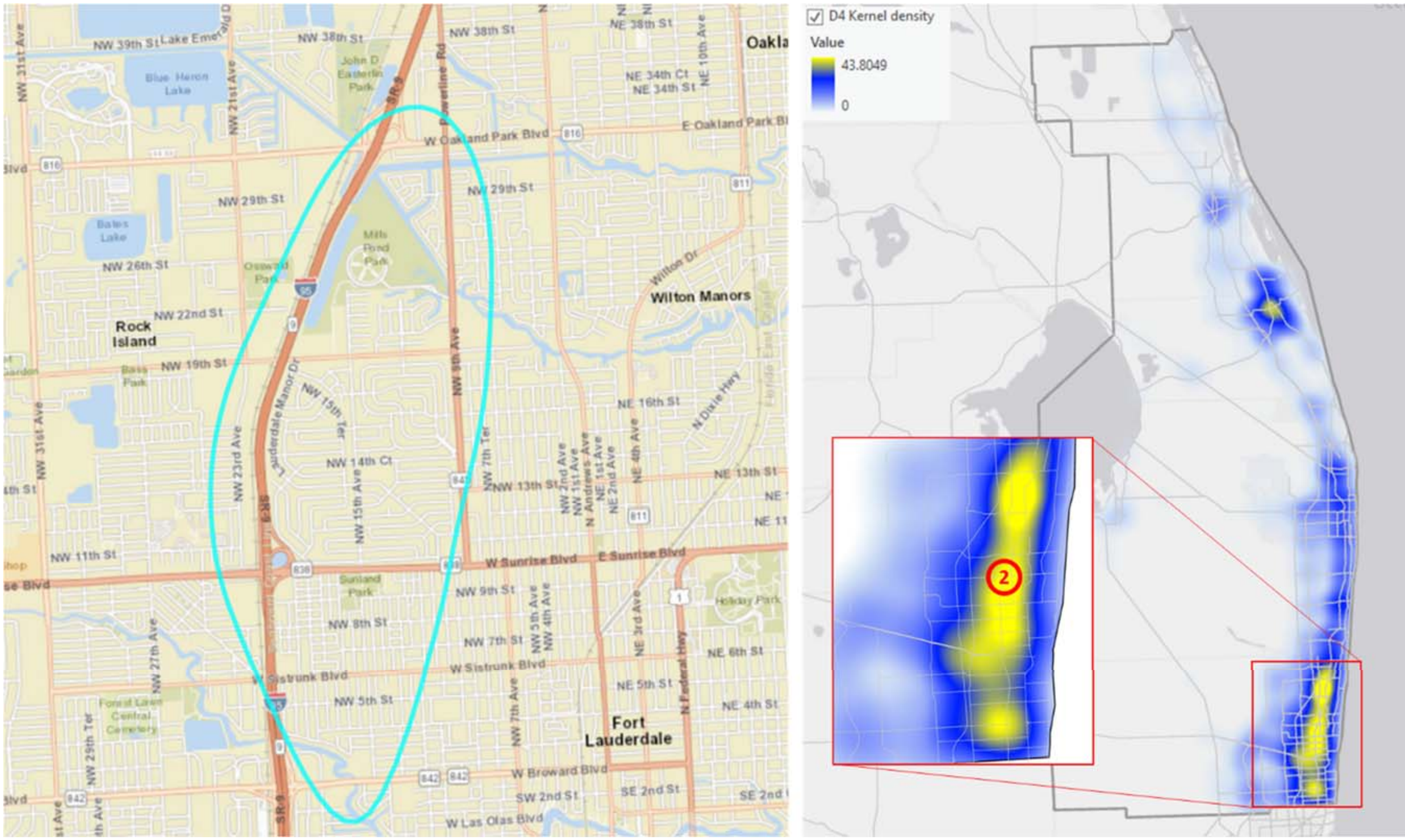


Figure 95 **The 2nd high crash density location for large truck crashes from the kernel density map - District 4**

The 3rd High crash density Location

The location is at the area within 1 mile of the intersection of W Broward Blvd and I-95. The major land use of this area is residential.

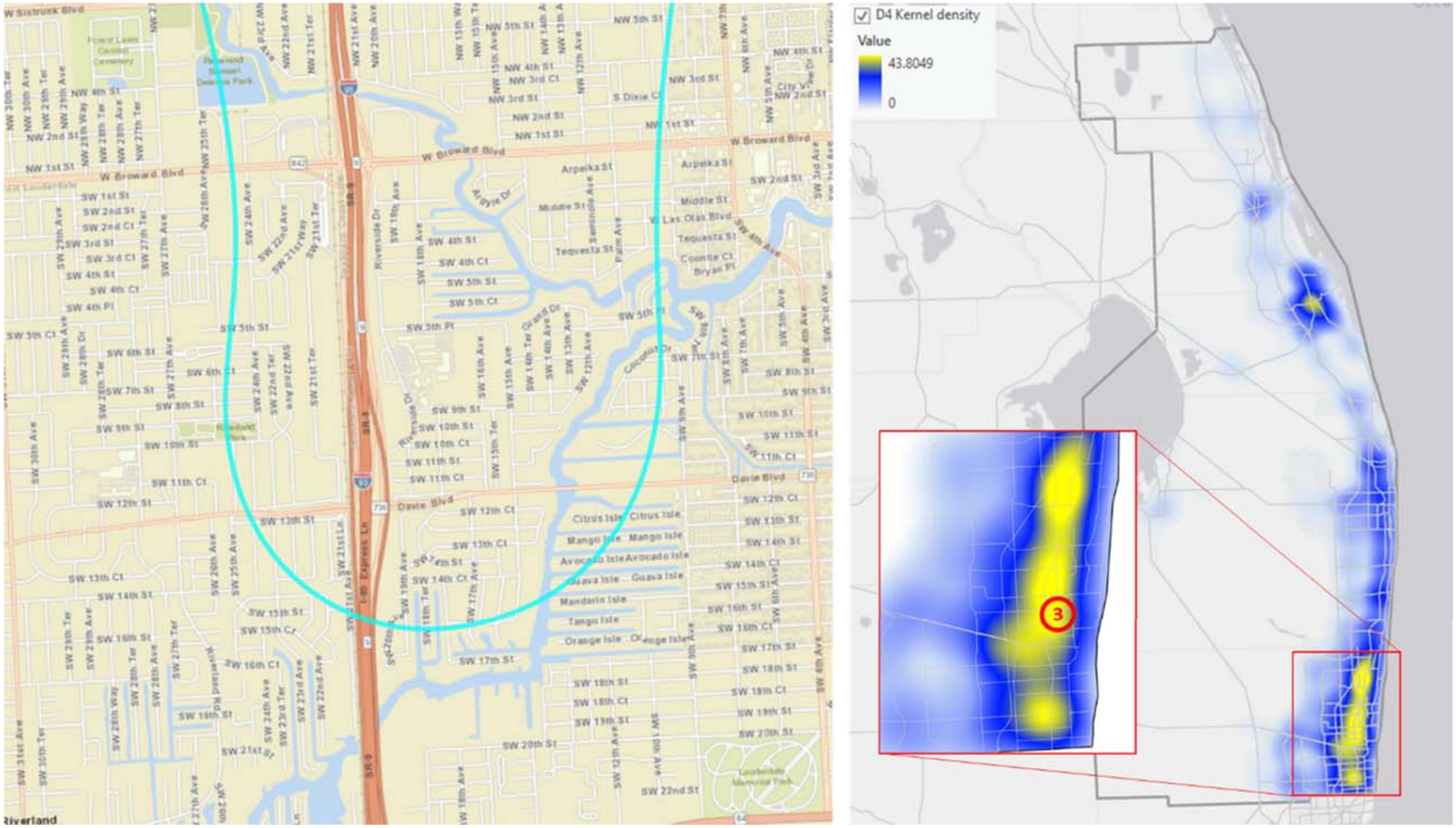


Figure 96 The 3rd high crash density location for large truck crashes from the kernel density map - District 4

The 4th High crash density Location

The location is at the intersection of Hollywood Blvd and I-95 and the surrounding areas within 1 mile. This area has residential, commercial land use, and parks.

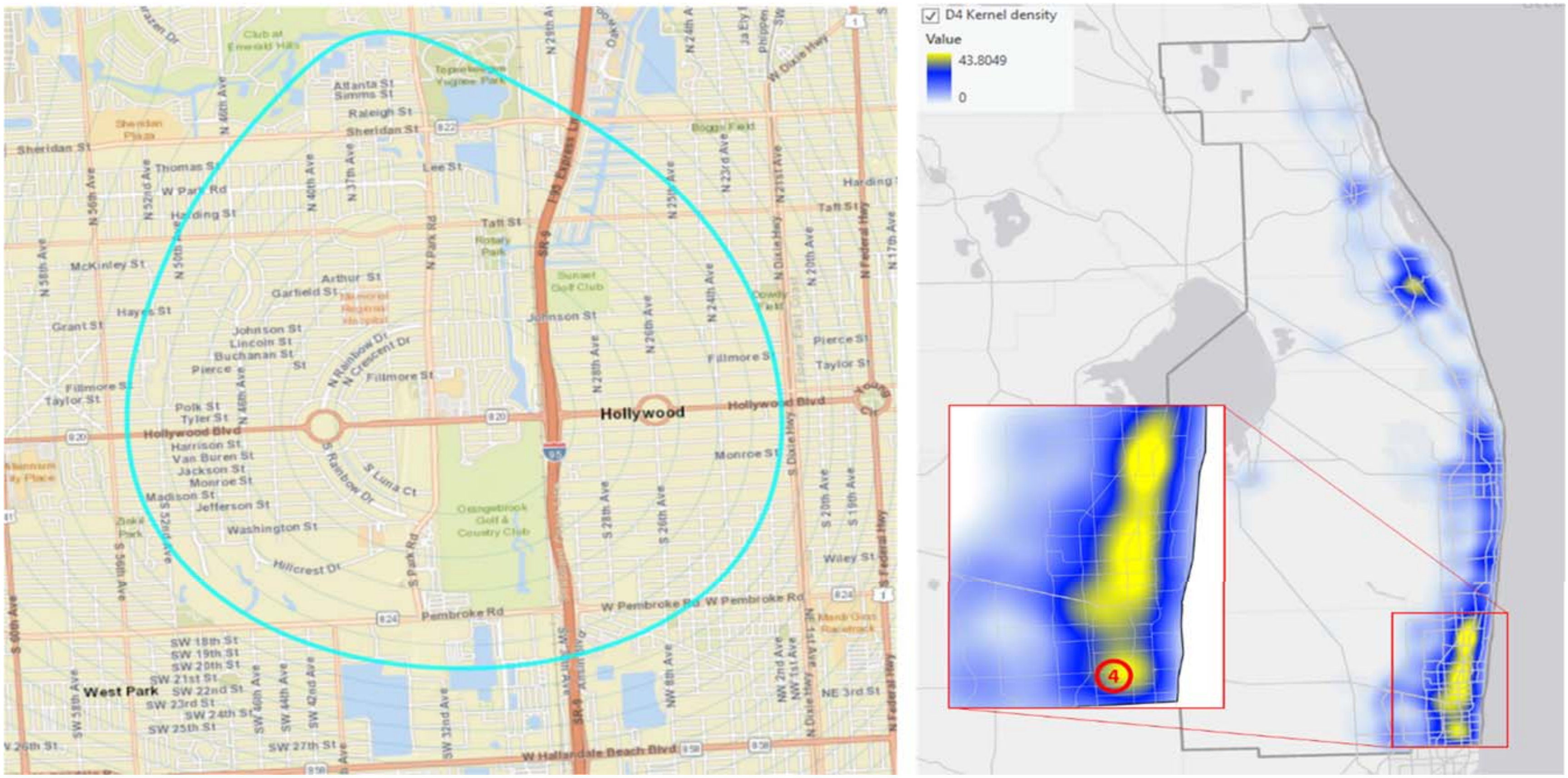


Figure 97 The 4th high crash density location for large truck crashes from the kernel density map - District 4

The 5th High crash density Location

This location includes the surrounding areas of four intersections: I-95 and I-595, I-95 and Marina Mile, Marina mile and I-595, I-95 and David Blvd. Residential is the major land use.

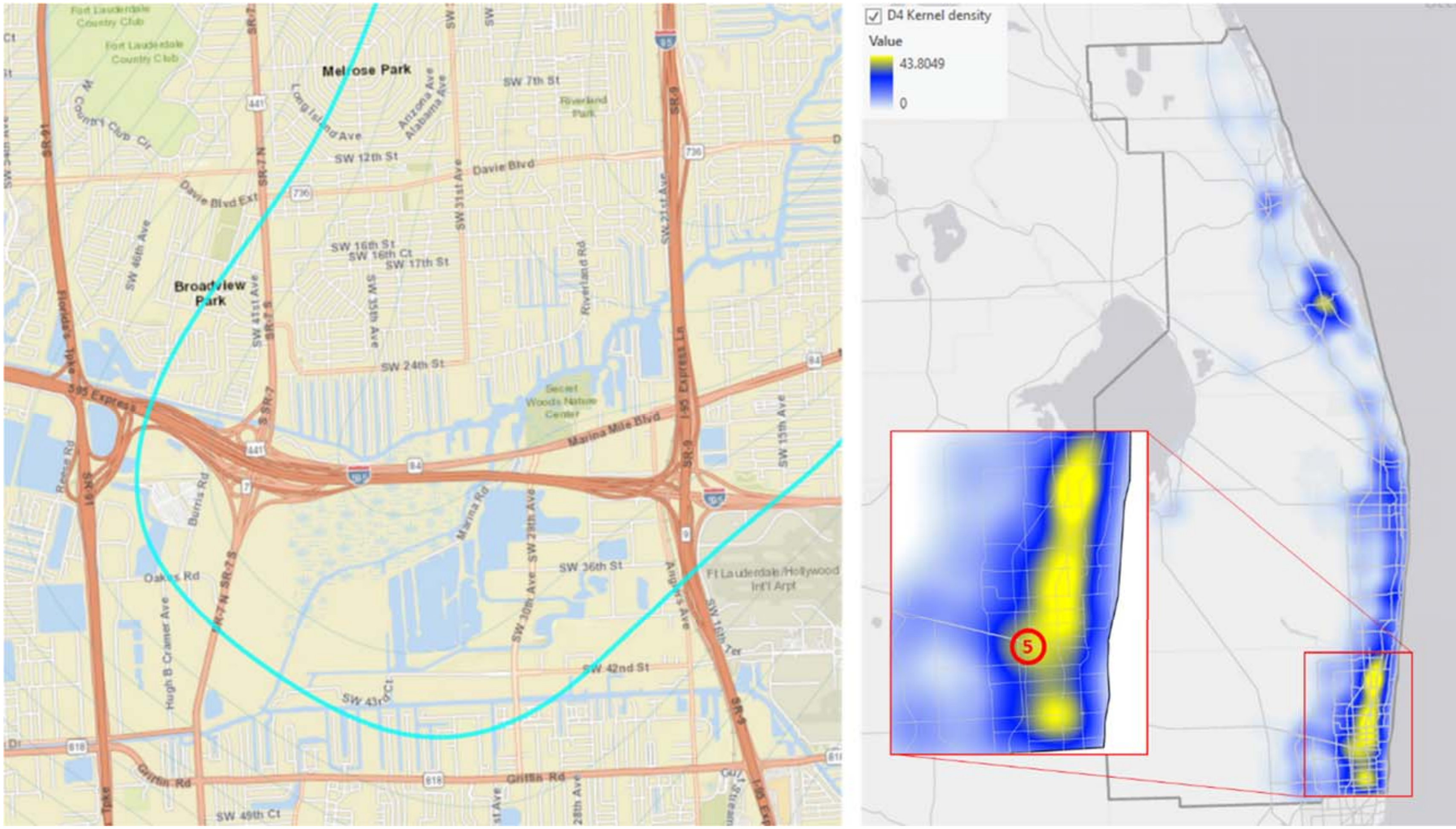


Figure 98 The 5th high crash density location for large truck crashes from the kernel density map - District 4

The 6th High crash density Location

This location is around the intersection of SE Monterey road and S Kanner Hwy and its 1 mile surrounding area. There are residential buildings, parks and business buildings.

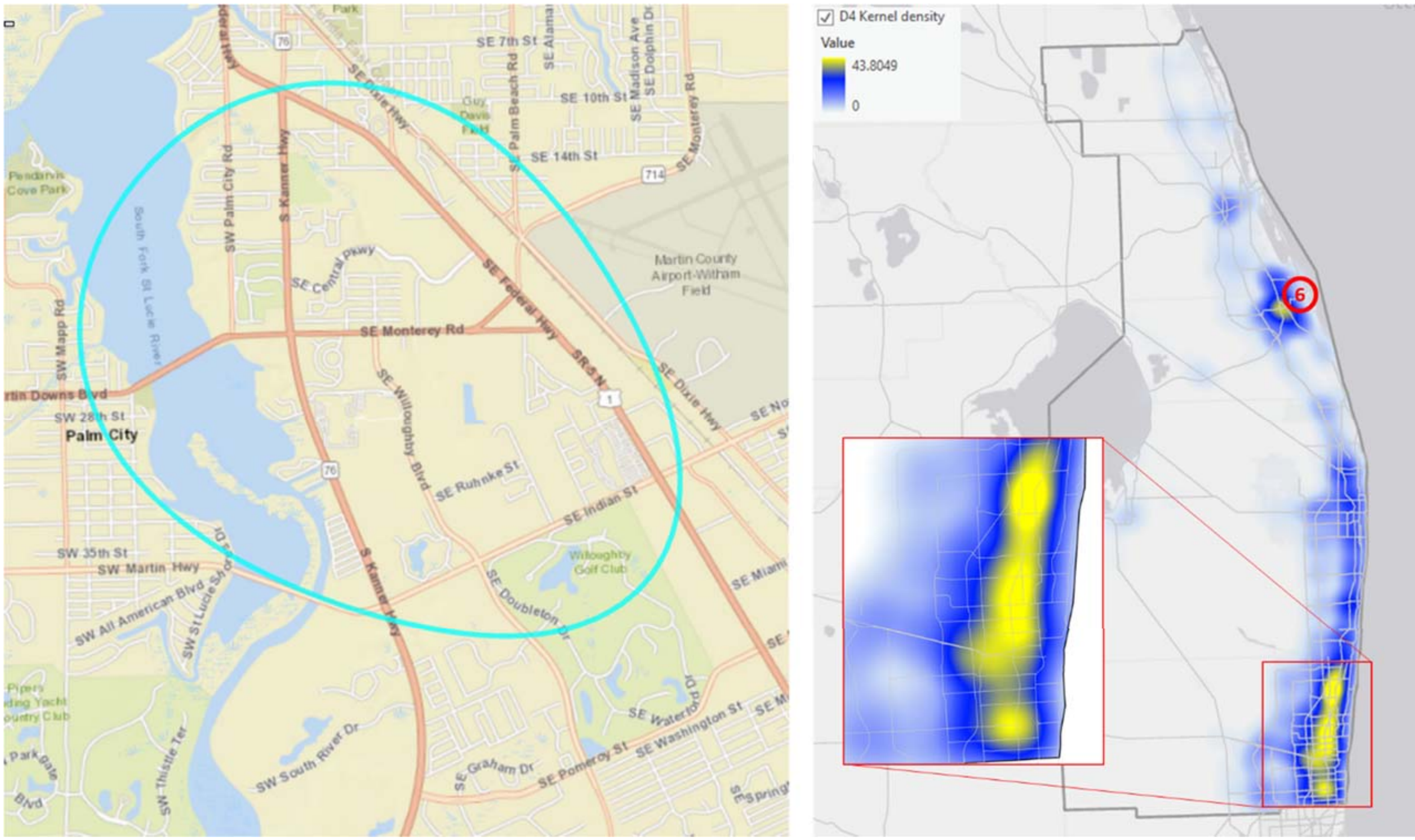


Figure 99 The 6th high crash density location for large truck crashes from the kernel density map - District 4

The 7th High crash density Location

This location is a 2000 feet buffer of I-95 and Powerline Road; the location is near the intersection of W Commercial Blvd as shown in the map. The land West of I-95 is for commercial use and on the East of I-95 there are residential buildings.

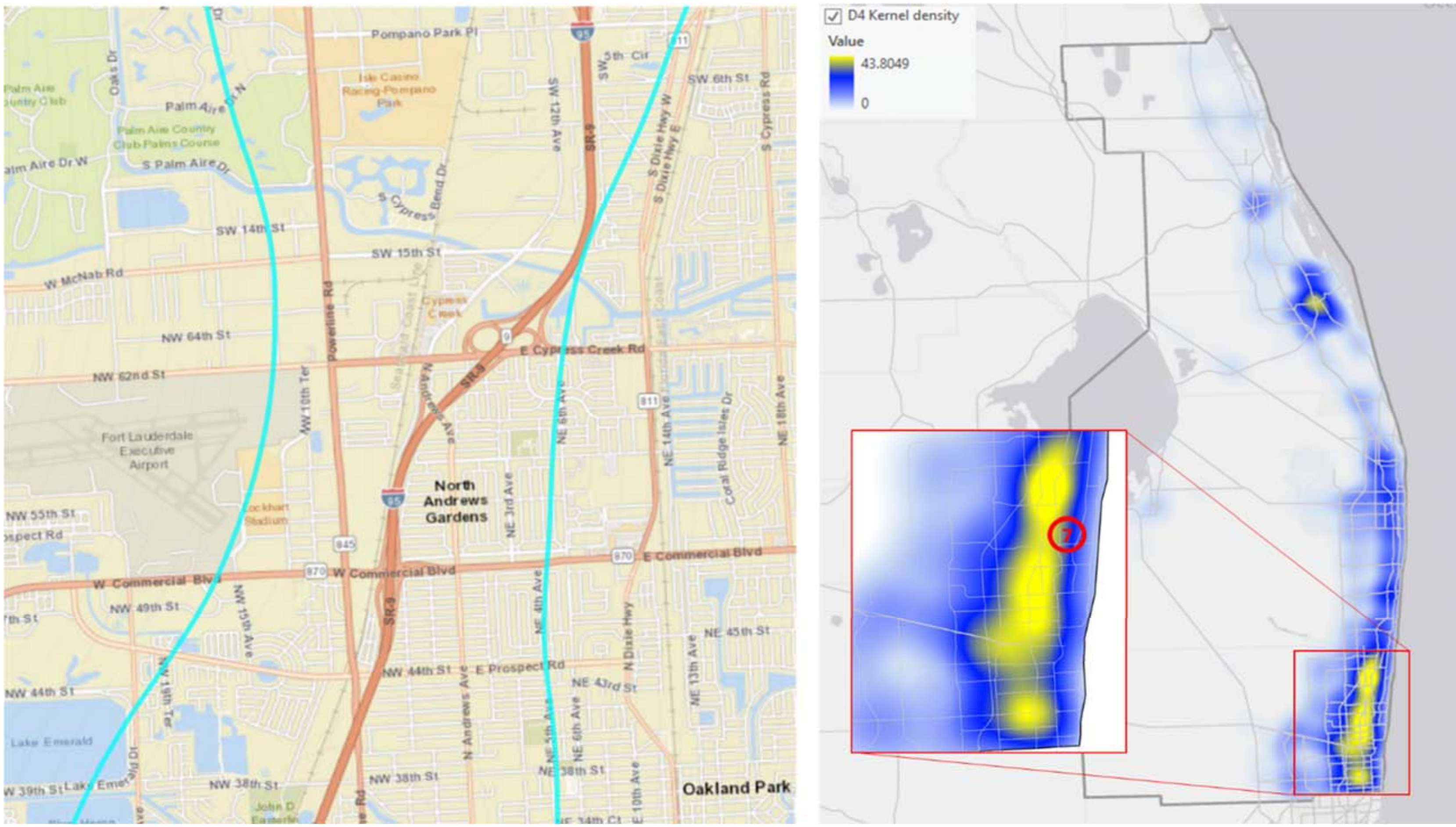


Figure 100 The 7th high crash density location for large truck crashes from the kernel density map - District 4

The 8th High crash density Location

The area is at South of I-95/W Atlantic Ave and North of I-95/Linton Road, and along the I-95. The land is for commercial use and residential use.

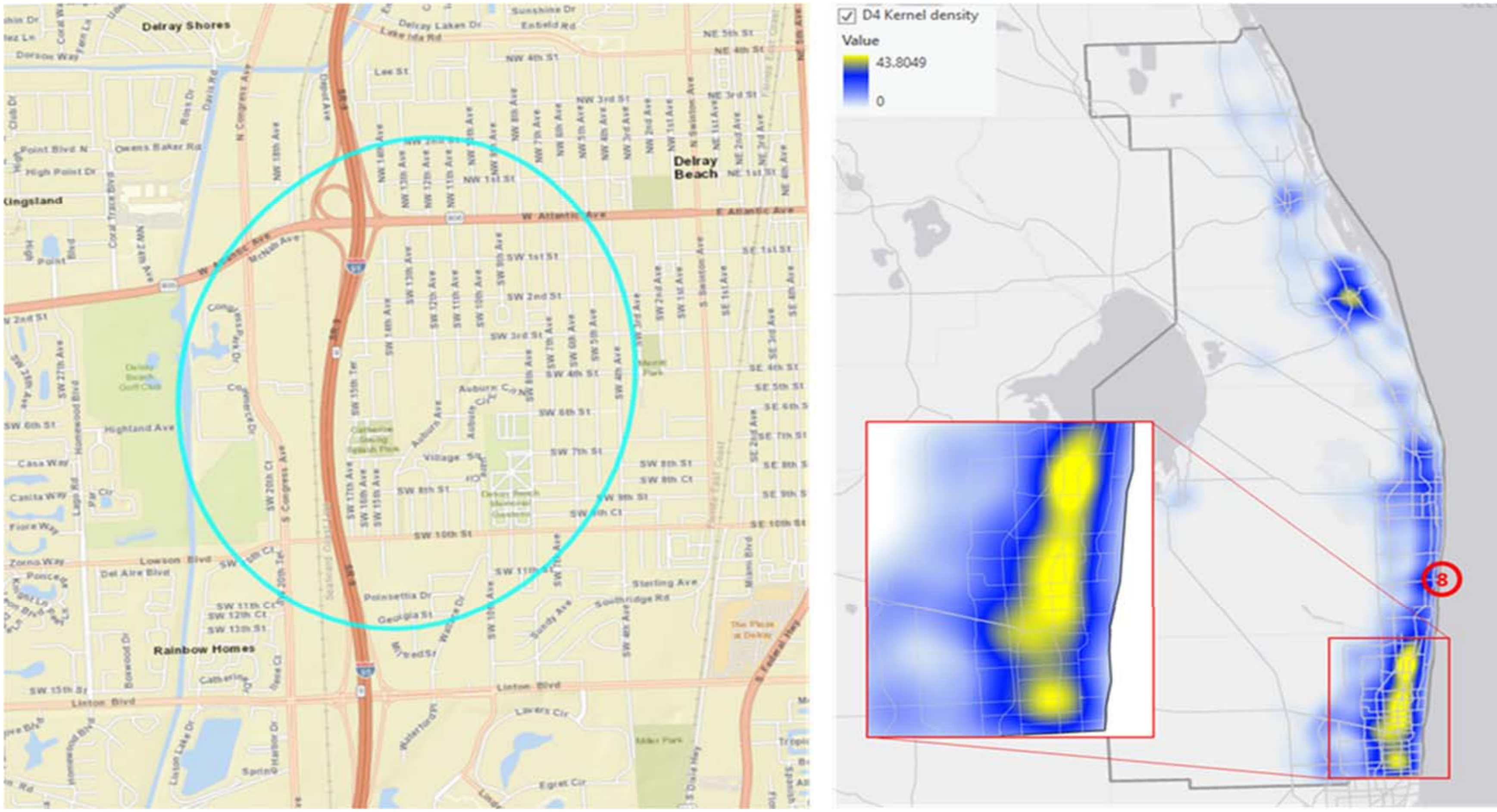


Figure 101 The 8th high crash density location for large truck crashes from the kernel density map - District 4

The 9th High crash density Location

The location is near the interchange of I-95 and Okeechobee Blvd as shown in the map. The North and middle part of the area have commercial buildings and mobile homes. South part of the area is Palm Beach International Airport.

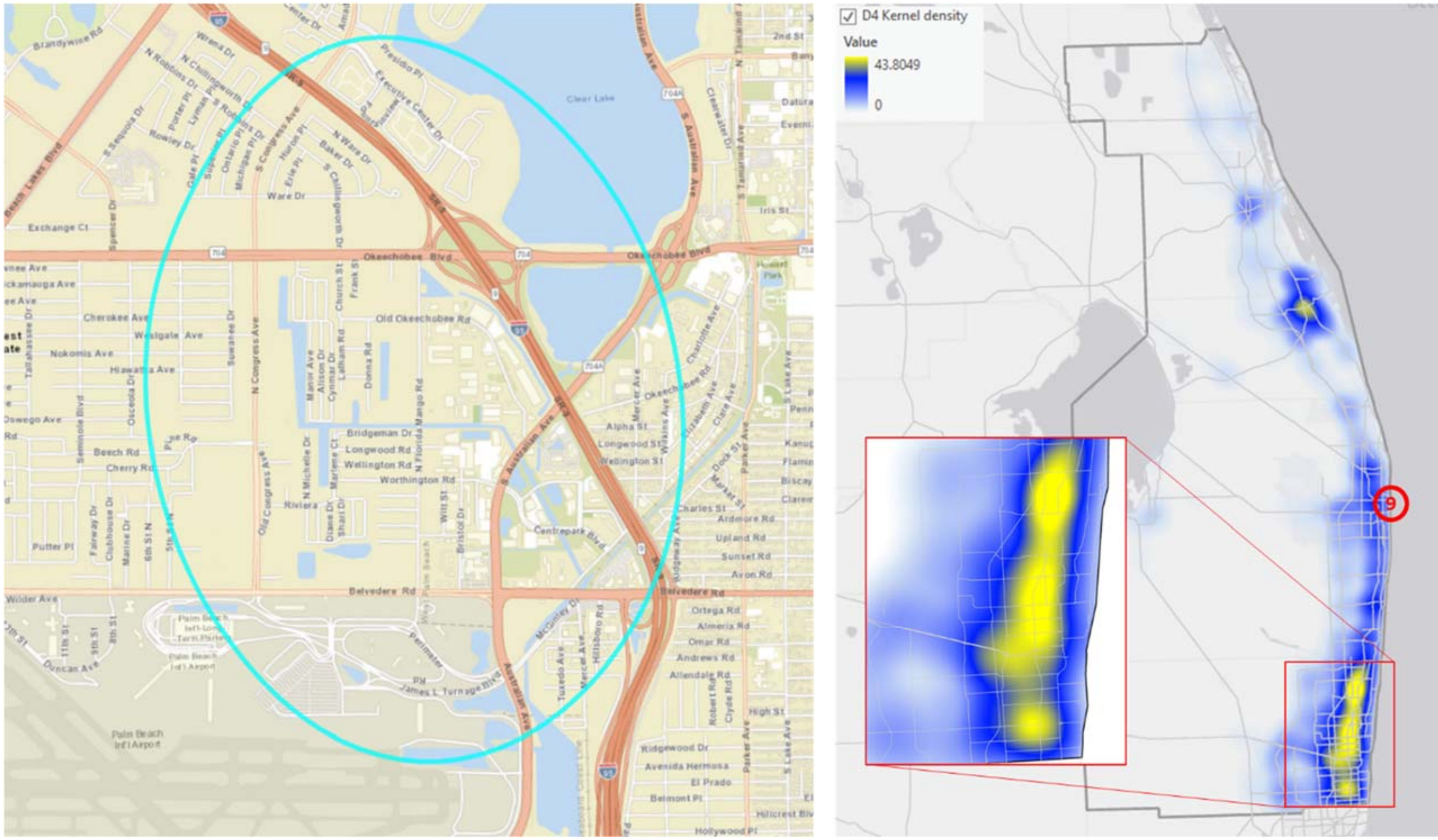


Figure 102 The 9th high crash density location for large truck crashes from the kernel density map - District 4

The 10th High crash density Location

This location is between the interchange of I-95/W Blue Heron Blvd and I-95/45th St. This area is mainly covered by industry building, commercial building, and mobile homes.

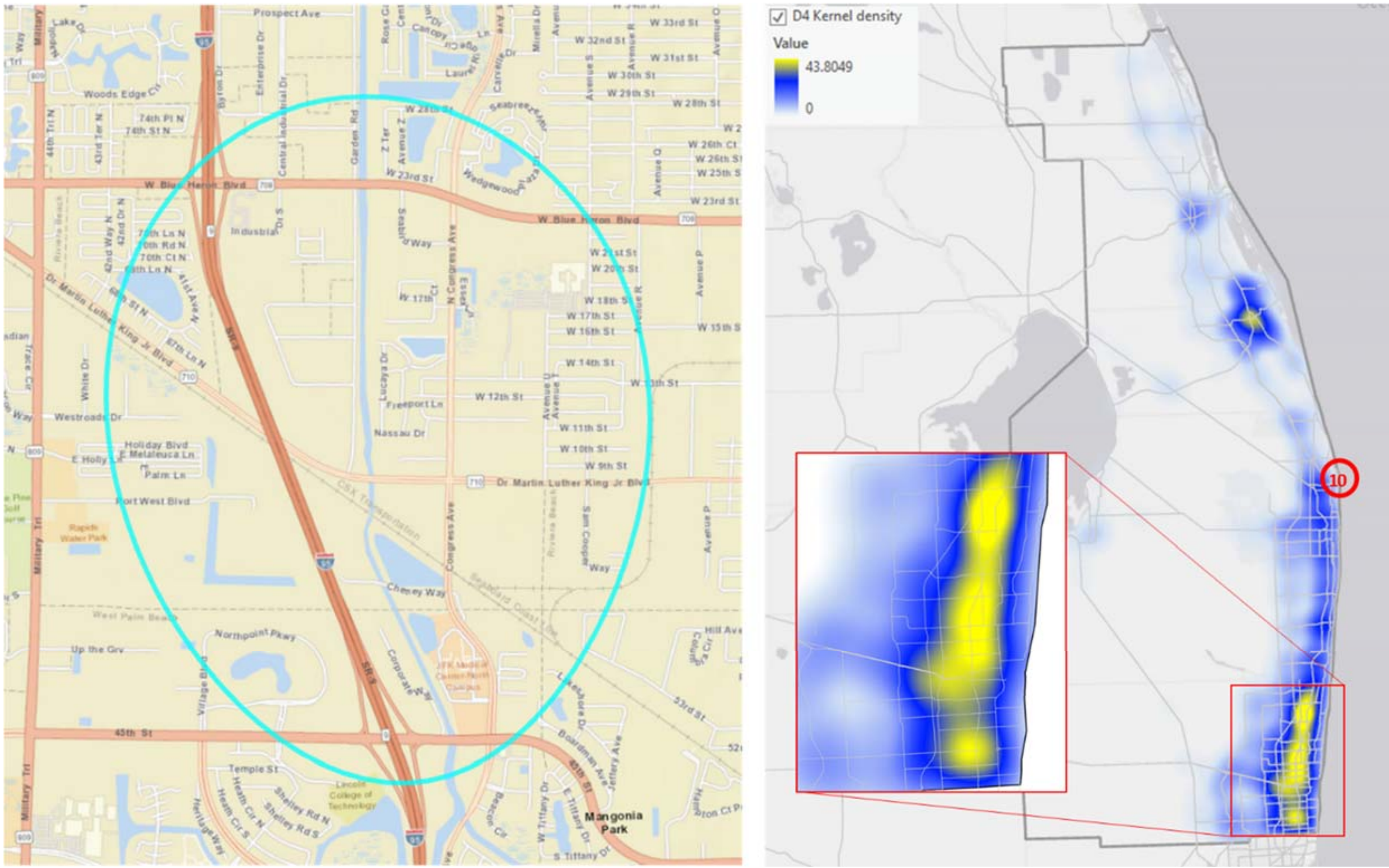


Figure 103 The 10th high crash density location for large truck crashes from the kernel density map - District 4

7.5. Density Maps for District 5

Figure 104 shows the kernel density map of the large truck crashes density locations in District 5.

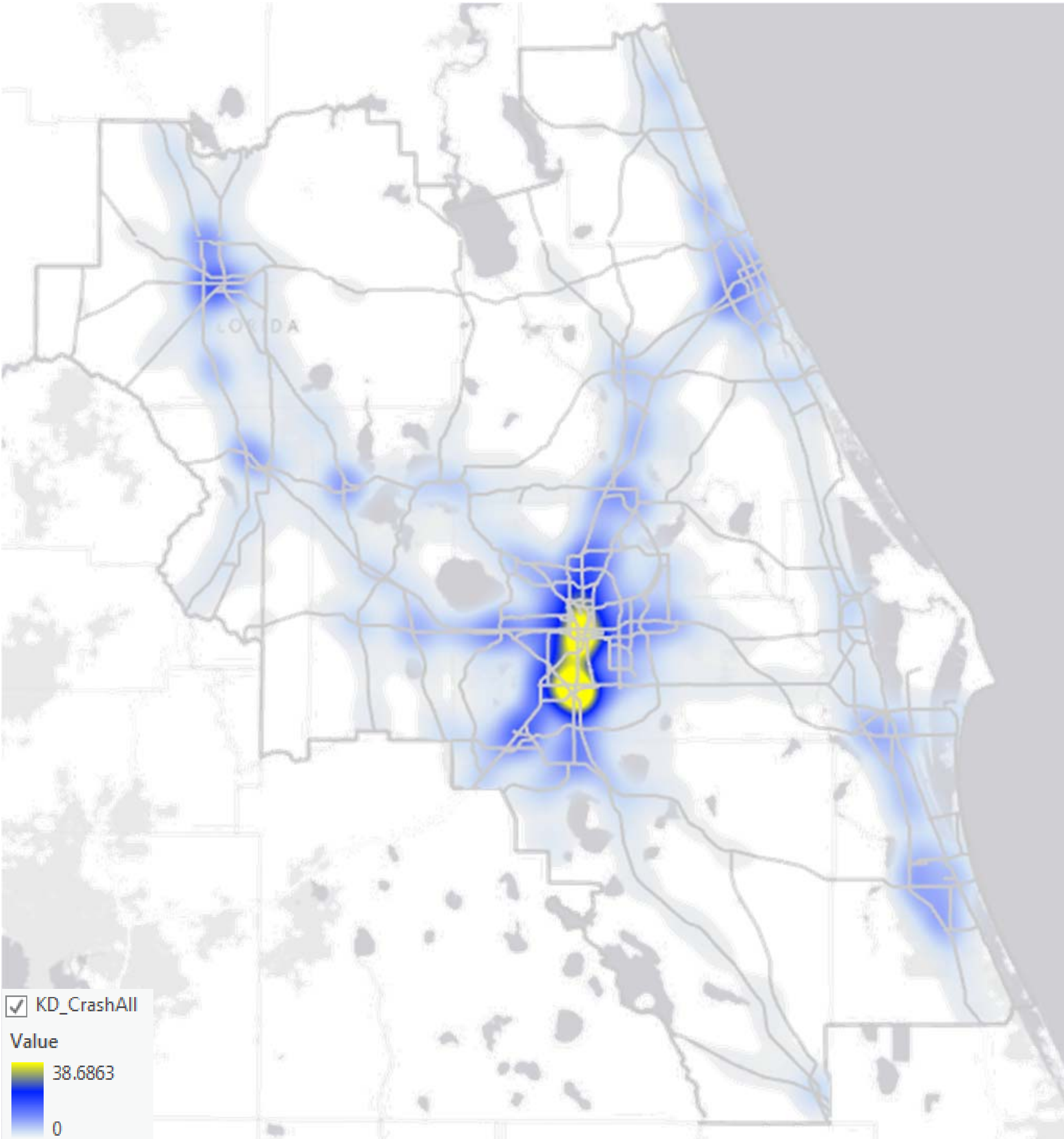


Figure 104 Kernel density mapping of all large truck crashes in District 5

Figure 105 shows the locations with the top 10 highest kernel density value. The city of Orlando in general dominates the high density area in the district. The top 2 locations and the areas between them (the yellow area in the Figure) cover the most parts of Orlando downtown. We selected the 2 most critical interchanges in the downtown as the top 2 high crash density locations. Then we selected the rest high crash density locations excluding the Orlando downtown area.

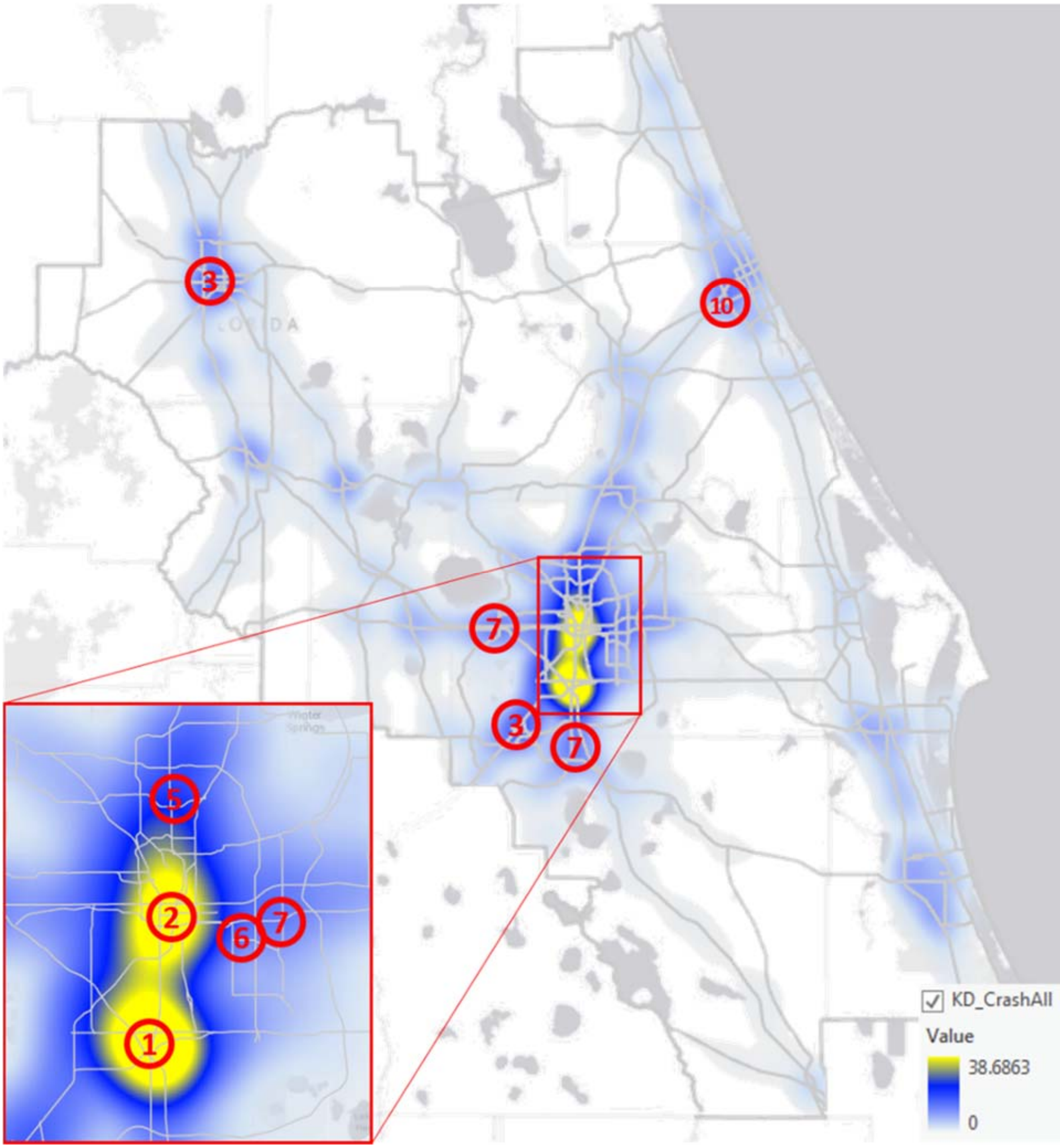


Figure 105 Top 10 locations selected from kernel density mapping of all large truck crashes in District 5

The 1st High crash density Location

The interchange of Florida's Turnpike, SR-528 and US-441 and the surrounding areas within about 1.5 miles rank the 1st place in the 10 most high crash density locations based on the kernel density map. The place locates in the south of Orlando downtown. Three major roads interchanges in this area of a variety of land use. Large quantities of retails and services with a mixture of residential areas are located in this location.

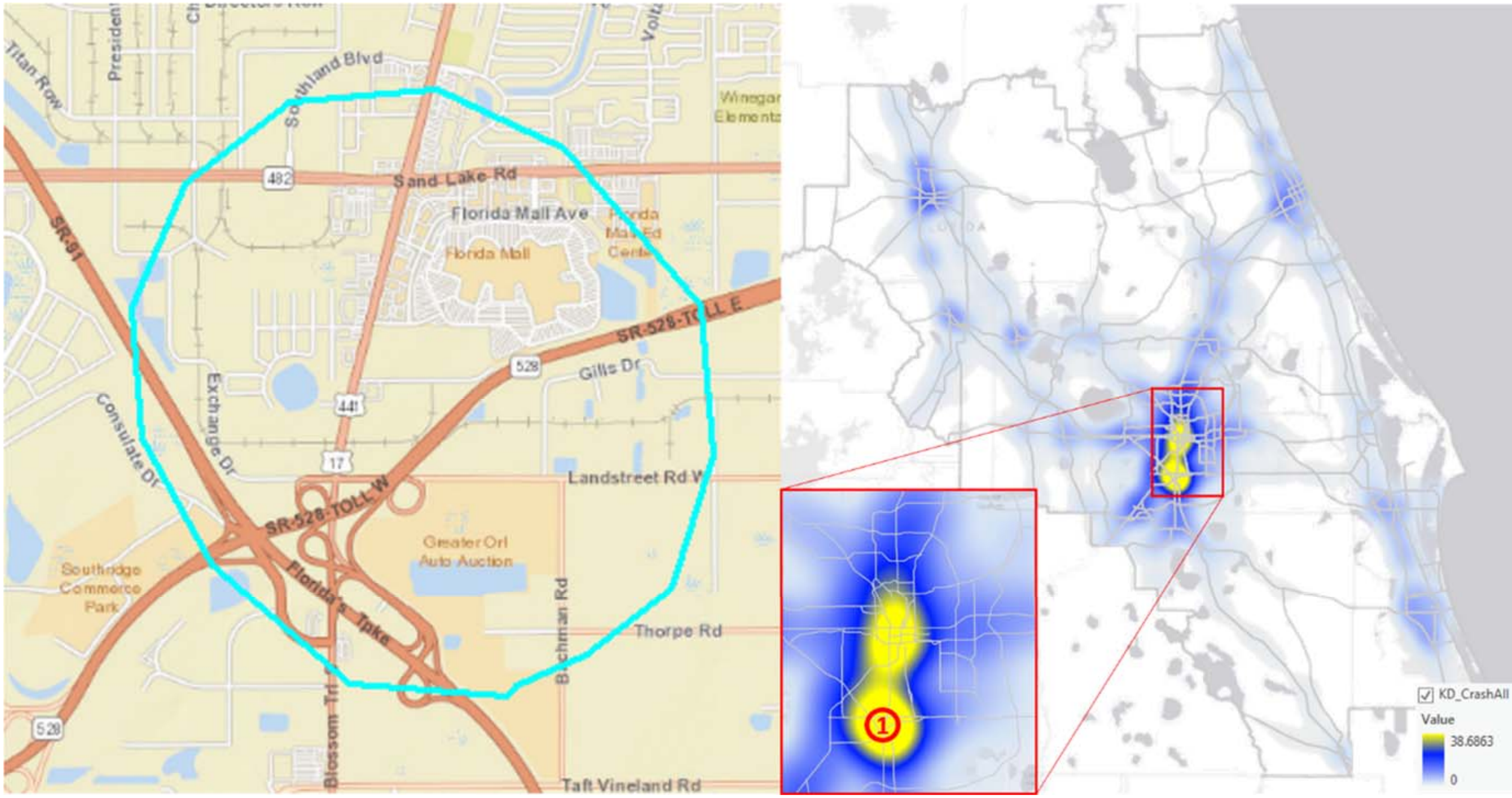


Figure 106 The 1st high crash density location for large truck crashes from the kernel density map - District 5

The 2nd High crash density Location

The interchange of the I4 and the SR-408, and the surrounding areas within about 1 mile ranks the 2nd place in the 10 most high crash density locations in the district. The place locates in the north of Orland downtown. Highly mixed-used lands exist at this location, such as the city hall, the stadium, the sports center, the retails and the residential buildings.

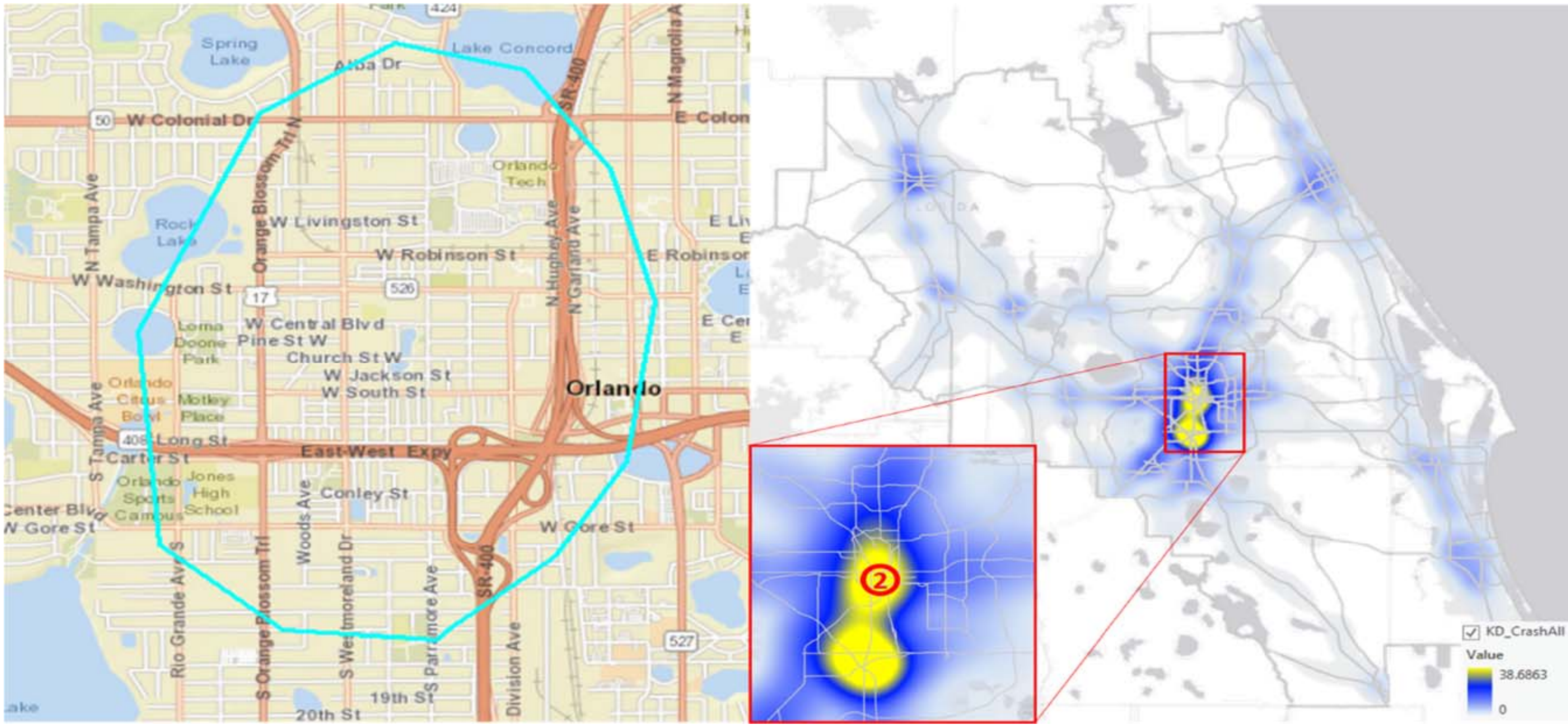


Figure 107 The 2nd high crash density location for large truck crashes from the kernel density map - District 5

The 3rd High crash density Location

The interchange of the I4 and the SR-536, and the surrounding areas within about 1 mile ranks the 3rd place in the 10 highest crash density locations in the district. The place locates to the southwest side of Orlando city, outside the Disney theme park. Resorts, hotels and other service buildings are at this location.

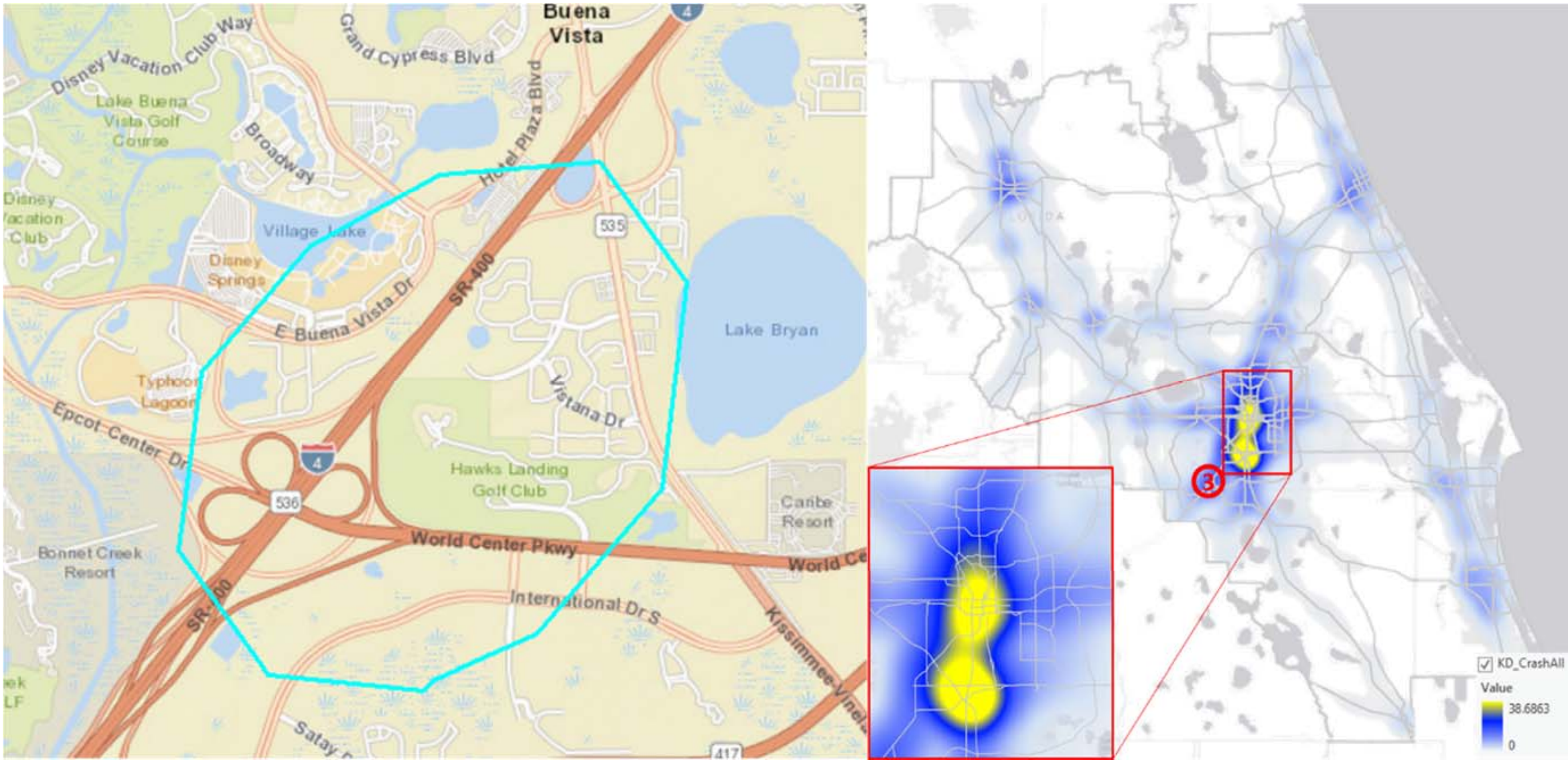


Figure 108 The 3rd high crash density location for large truck crashes from the kernel density map - District 5

The 3rd High crash density Location

The west area of Ocala also ranks the 3rd place. The place locates at the south of US-27, the north of SR-200, the east of I75, and the west of US-301. The majority of the location are covered with residential areas, with a mix of office buildings and retails.

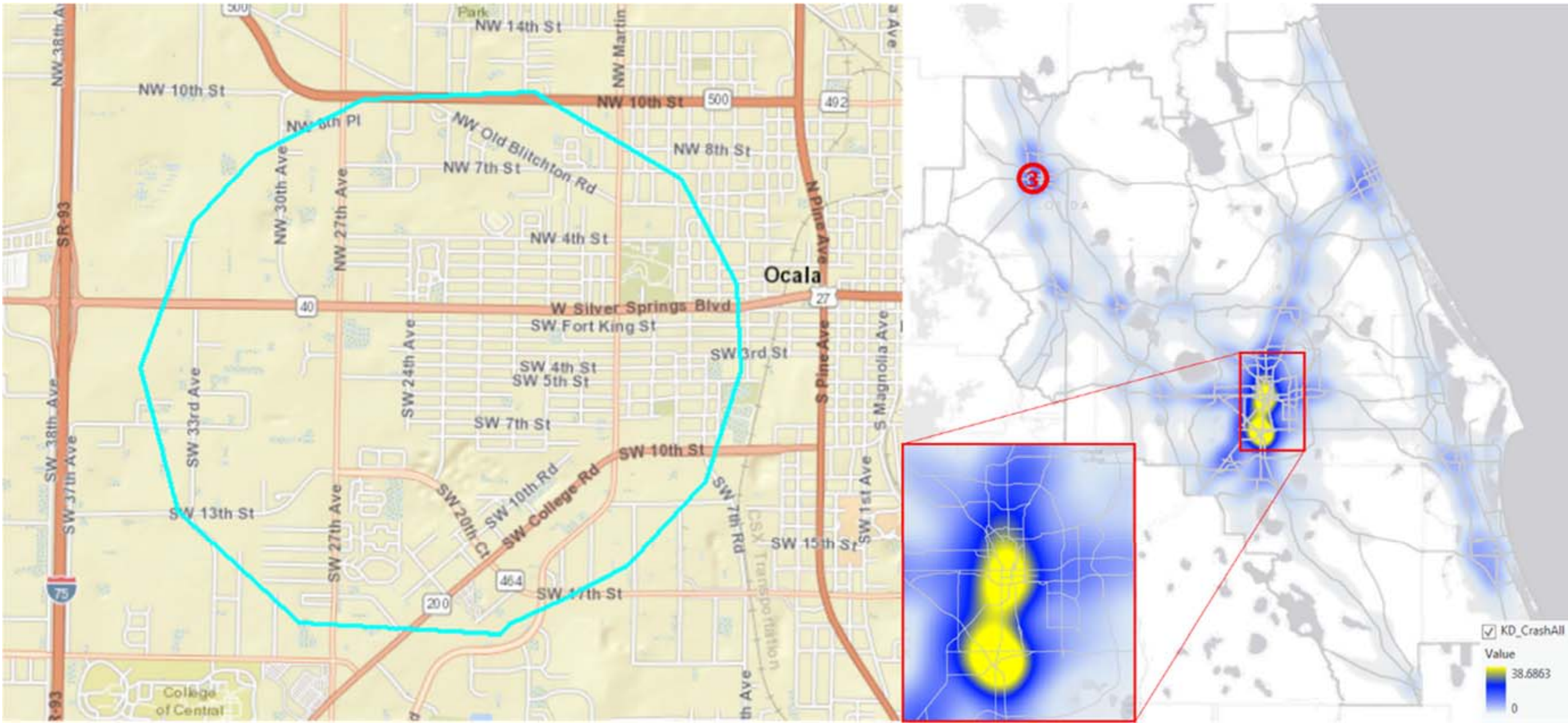


Figure 109 The 3rd high crash density location for large truck crashes from the kernel density map - District 5

The 5th High crash density Location

The interchange of the I4 and SR-436, and the surrounding areas within about 2 miles rank the 5th place. The place locates at the northeast of Orlando downtown. The area adjacent to the interchange is a mixture of recreational and shopping centers. The rest are mostly residential buildings.

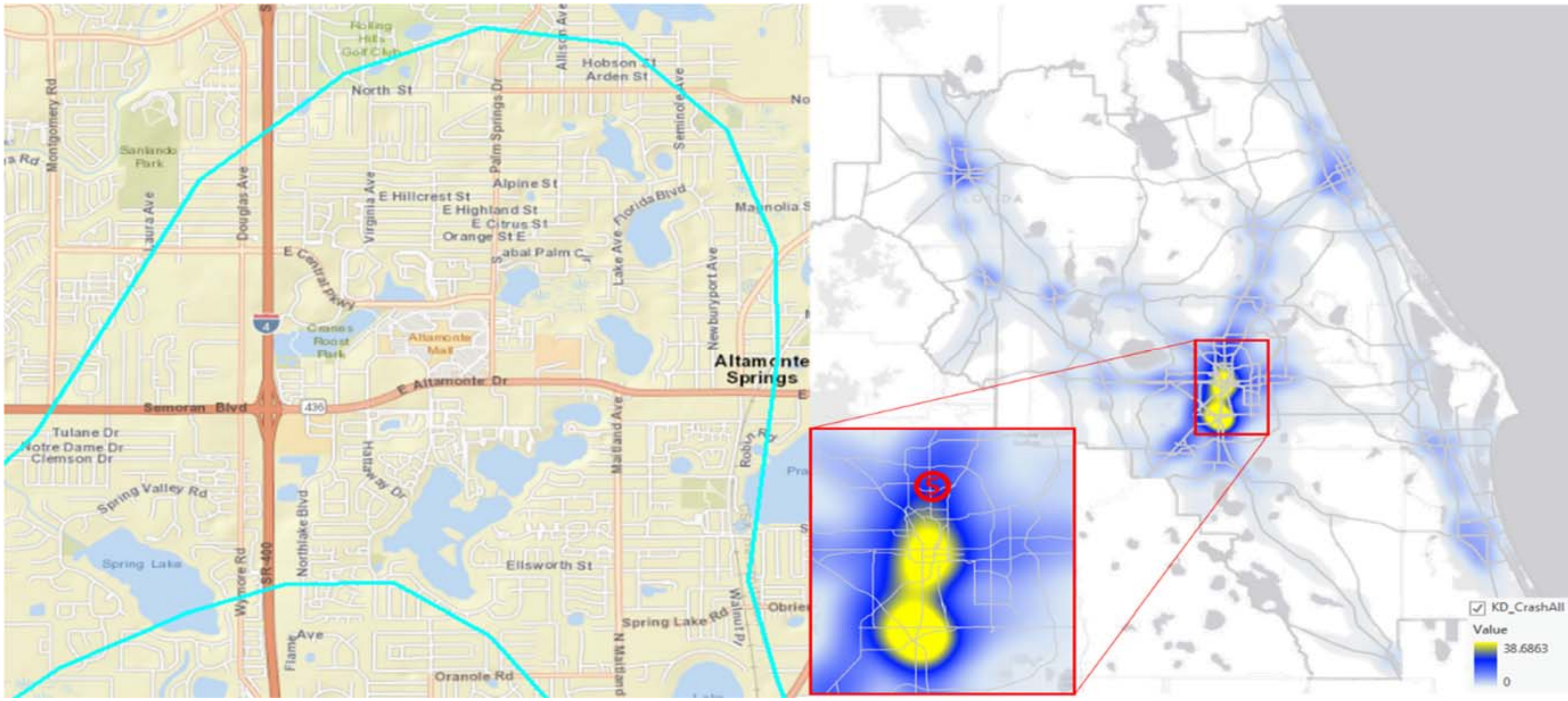


Figure 110 **The 5th high crash density location for large truck crashes from the kernel density map - District 5**

The 6th High crash density Location

The area between SR-408, SR-436, SR-50 and SR-551 ranks the 6th place. The place locates at the east side of Orlando downtown. The area covers 4 major intersections between the mentioned state roads. The location is mostly covered by residential areas and educational areas such as schools.

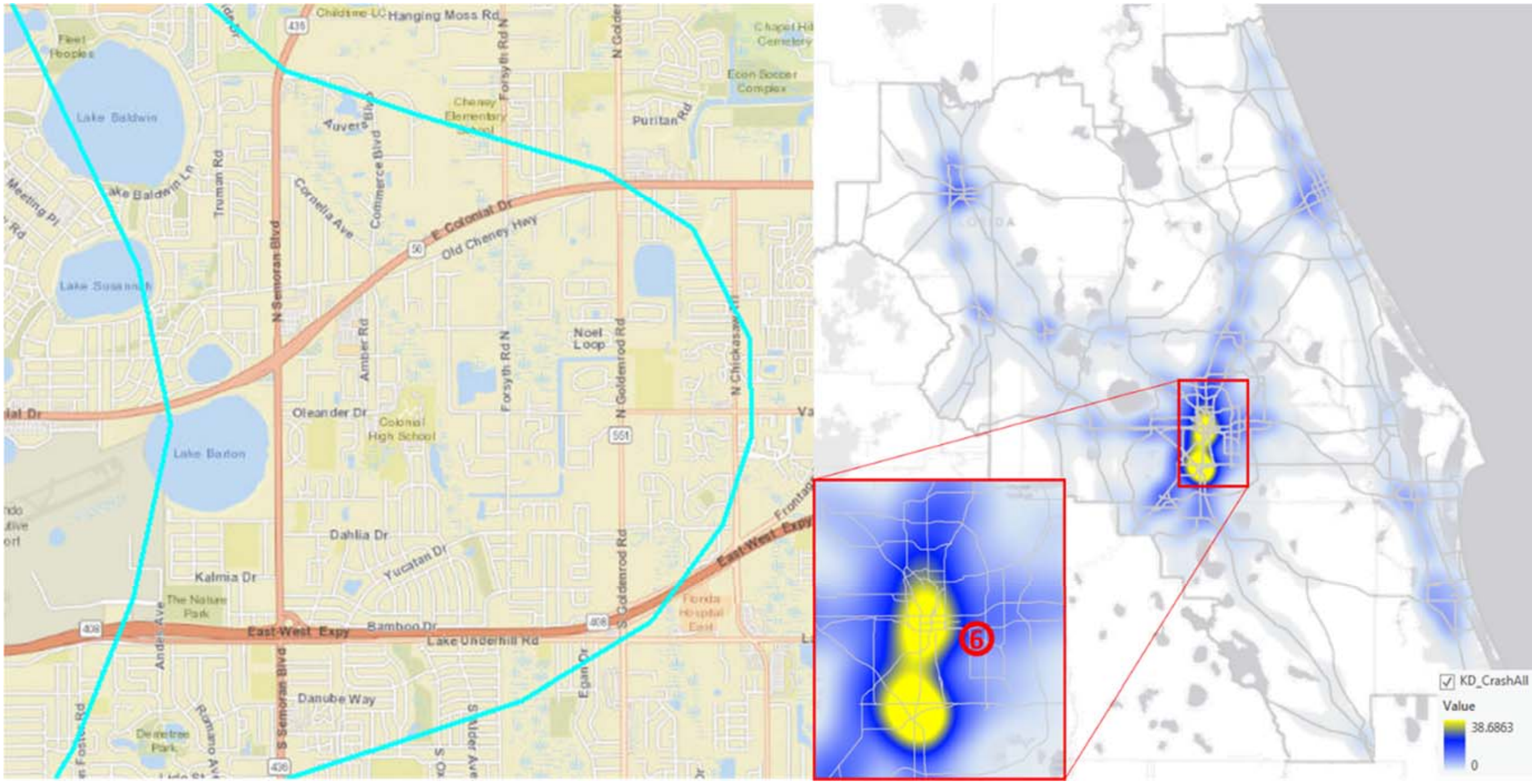


Figure 111 The 6th high crash density location for large truck crashes from the kernel density map - District 5

The 7th High crash density Location

The interchange of SR-429 with SR-91 and SR-50, and the surrounding areas within about 2 miles rank the 7th place. Three major roads interchange at the location. East of the interchange locates a large area of retail center. The rest parts of the area are mostly residential.

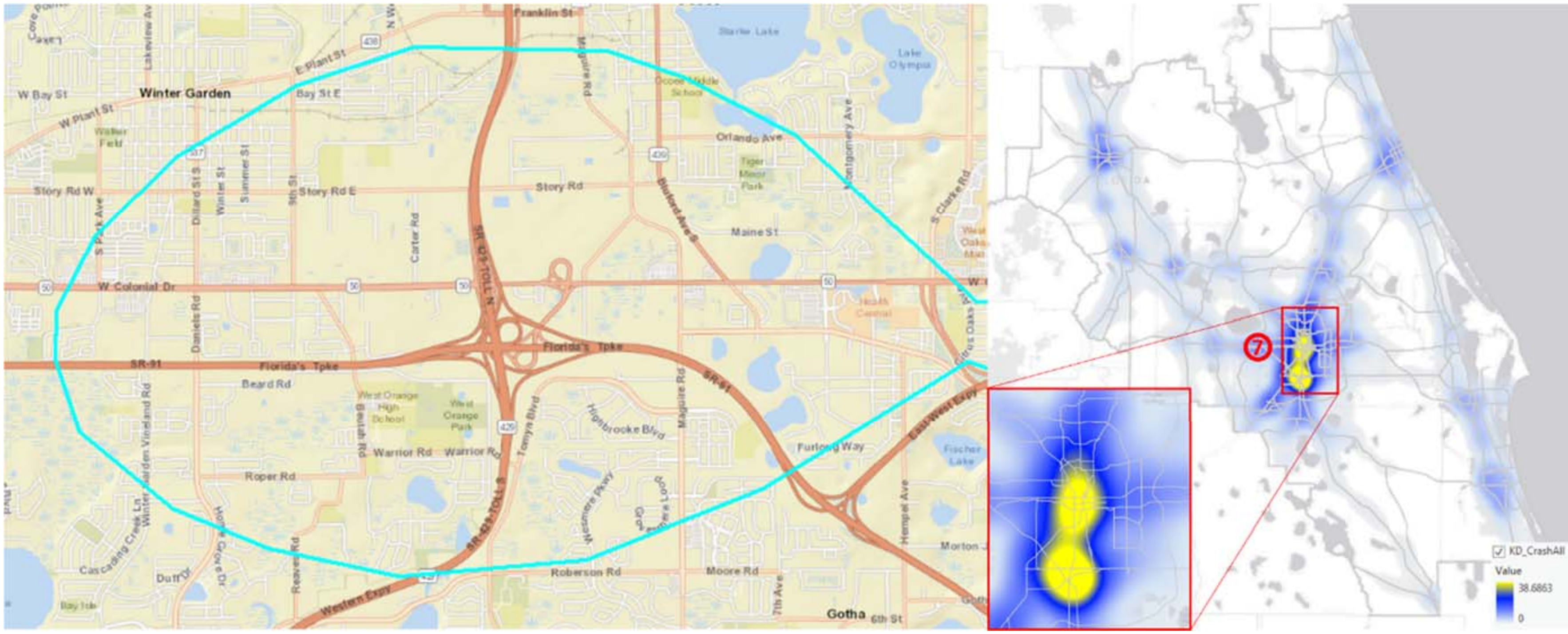


Figure 112 The 7th high crash density location for large truck crashes from the kernel density map - District 5

The 7th High crash density Location

The US-441 section between the intersection with the SR-417 and the intersection with the SR-500 and the SR-530, and the area within about 1.5 miles also ranks the 7th place. The place locates to the north of Kissimmee. Most parts of the area are residential with a mixture of retails.

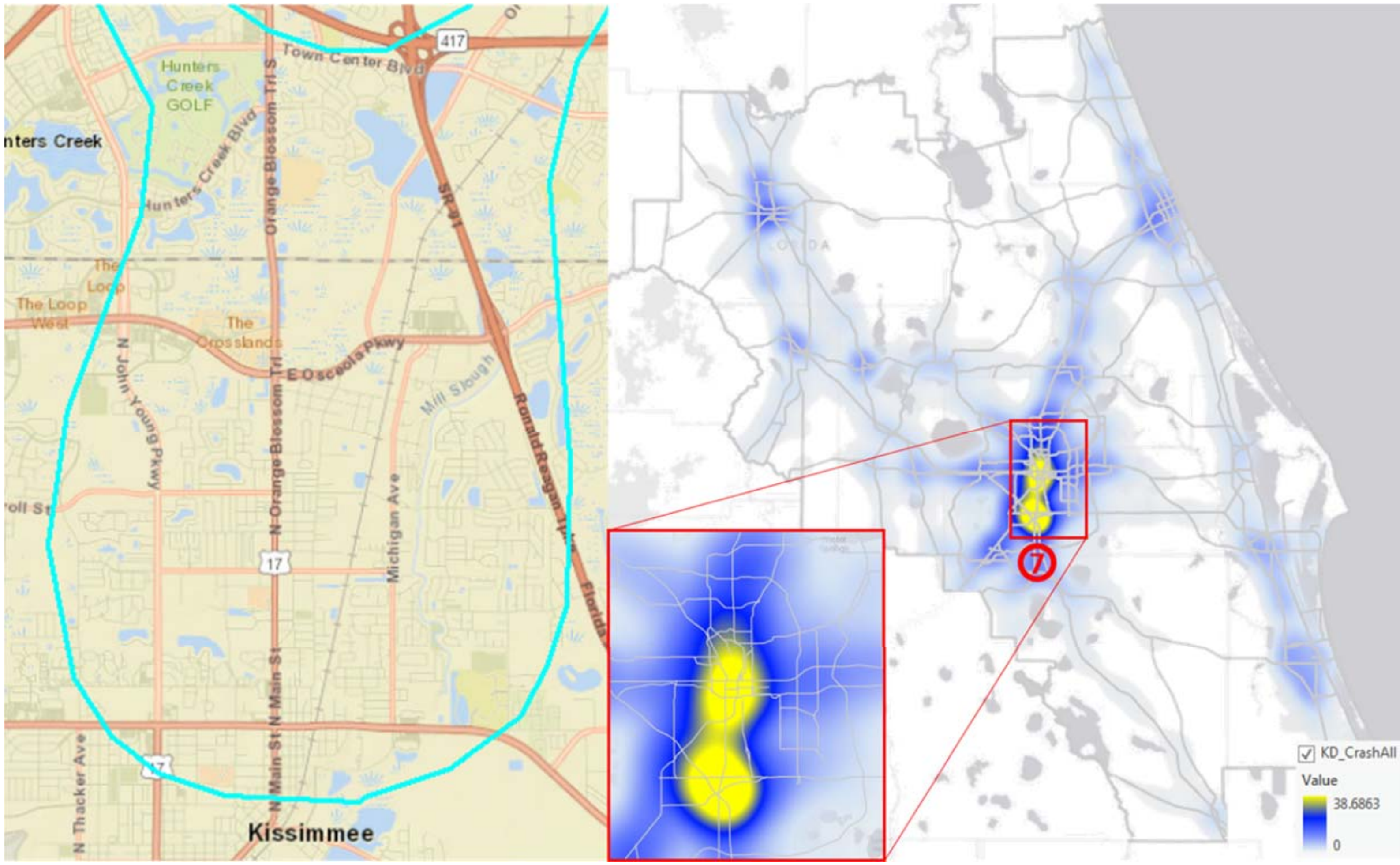


Figure 113 The 7th high crash density location for large truck crashes from the kernel density map - District 5

The 7th High crash density Location

The SR-417 section between the intersection with the SR-408 and the intersection with the SR-50, and the area within about 0.5 miles also ranks the 7th place. The place locates at the east side of Orland downtown. Most of the area are residential.

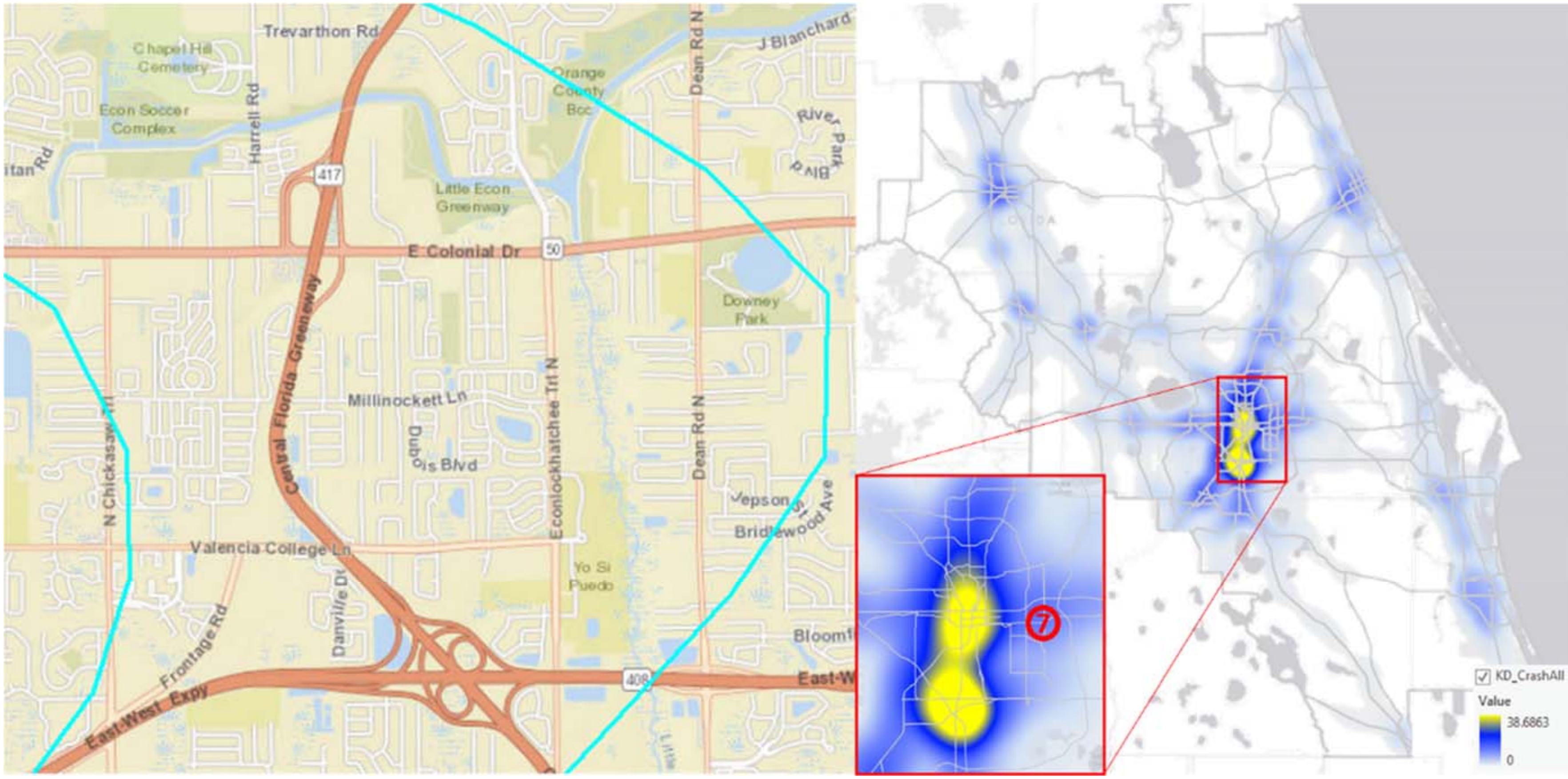


Figure 114 The 7th high crash density location for large truck crashes from the kernel density map - District 5

The 10th High crash density Location

The interchange of the I4 and the I95 and the surrounding 2.5 miles ranks the 10th place. The place locates to the west of Daytona Beach. Two major interchanges (I95 with i4, I95 with SR-600) exist within a distance of 1.2 miles. Most of the parts are rural, with a large recreational sports center.

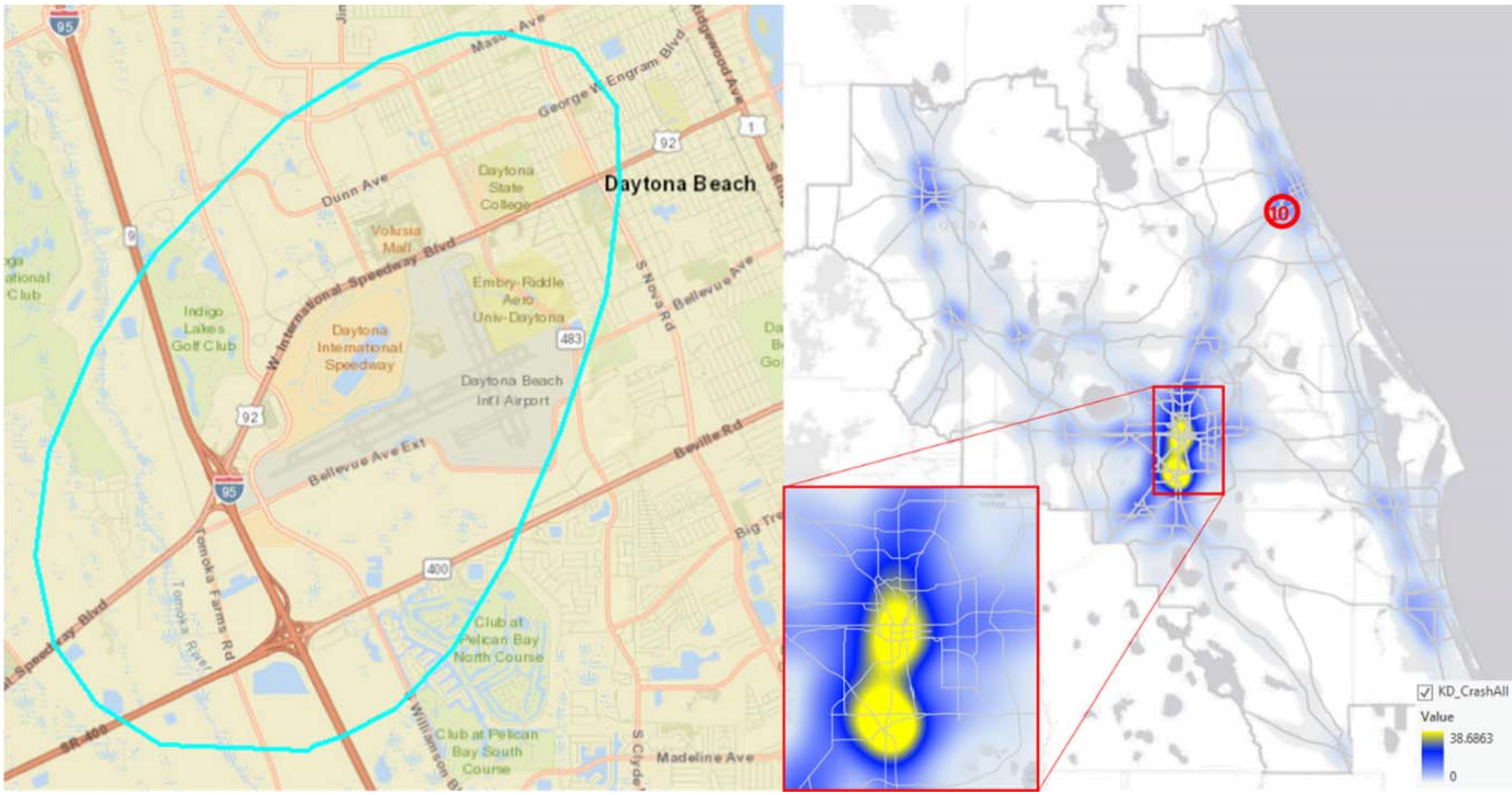


Figure 115 The 10th high crash density location for large truck crashes from the kernel density map - District 5

7.6. Density Maps for District 6

Figure 116 shows the kernel density map of large truck crashes for District 6.

Figure 116 Kernel density mapping of all large truck crashes in District 6

Figure 117 shows the top 10 locations with the highest density. The high large truck crash density locations of District 6 are all in Miami area, mostly due to its dense road network with high traffic volume.

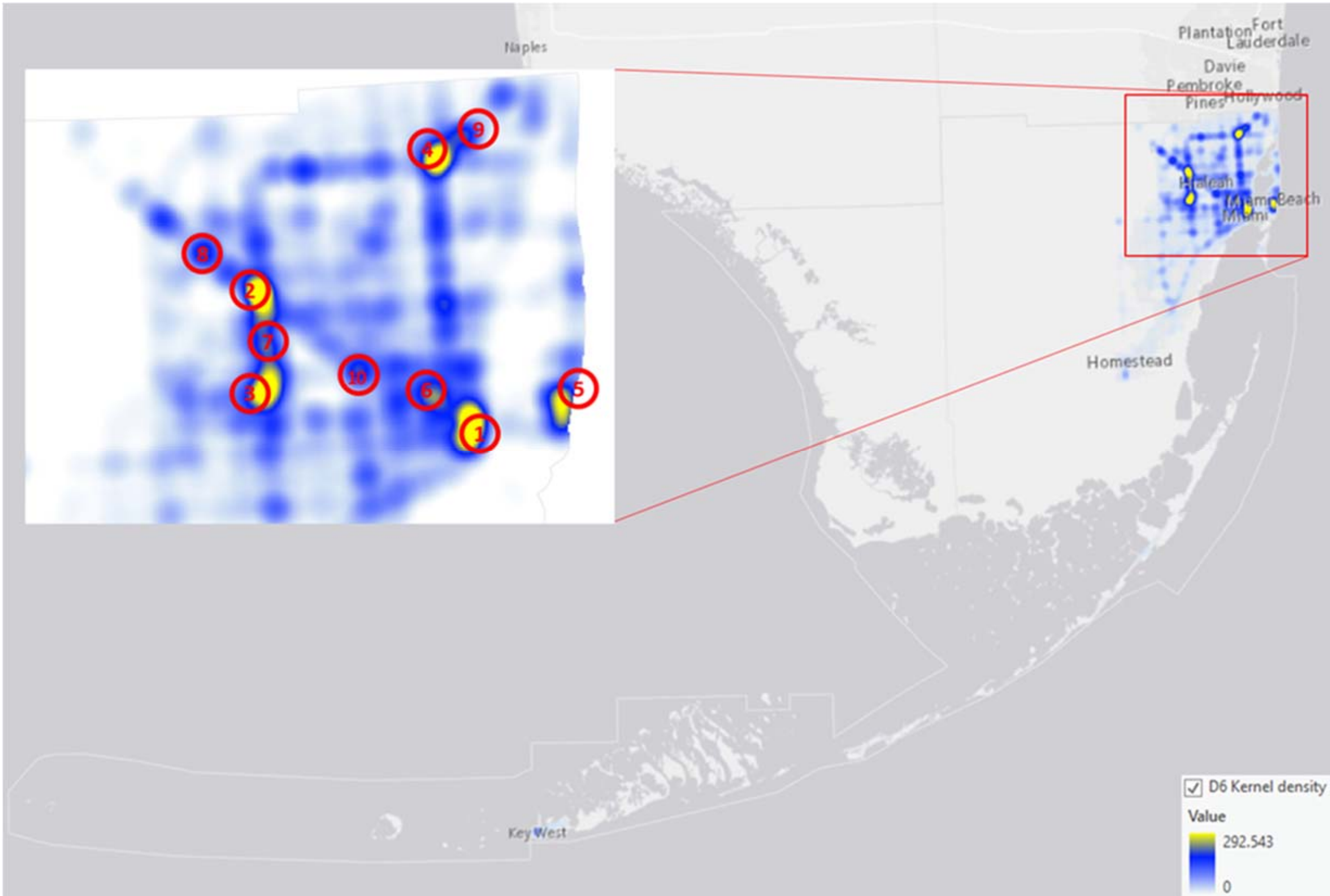


Figure 117 Top 10 locations selected from kernel density mapping of all large truck crashes in District 6

The 1st High crash density Location

This location is around N Miami Ave and NE 1st Street. I-95, N Miami Ave and Biscayne Blvd contributes a lot of crash density to the area. The land use for this location is mainly commercial.

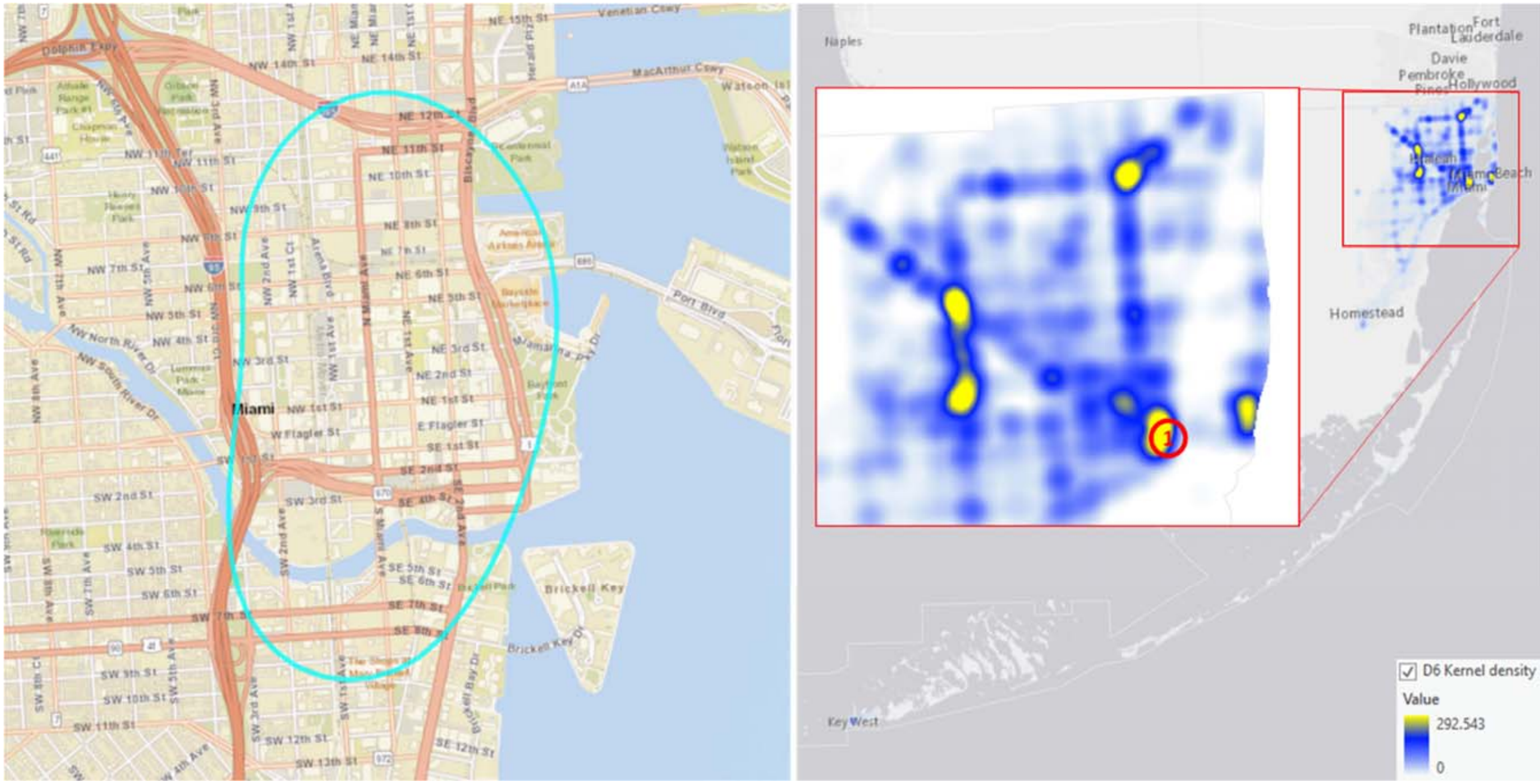


Figure 118 The 1st high crash density location for large truck crashes from the kernel density map - District 6

The 2nd High crash density Location

This location is around the interchange of W Okeechobee Rd and Palmetto Express way. The land is mainly for commercial use.

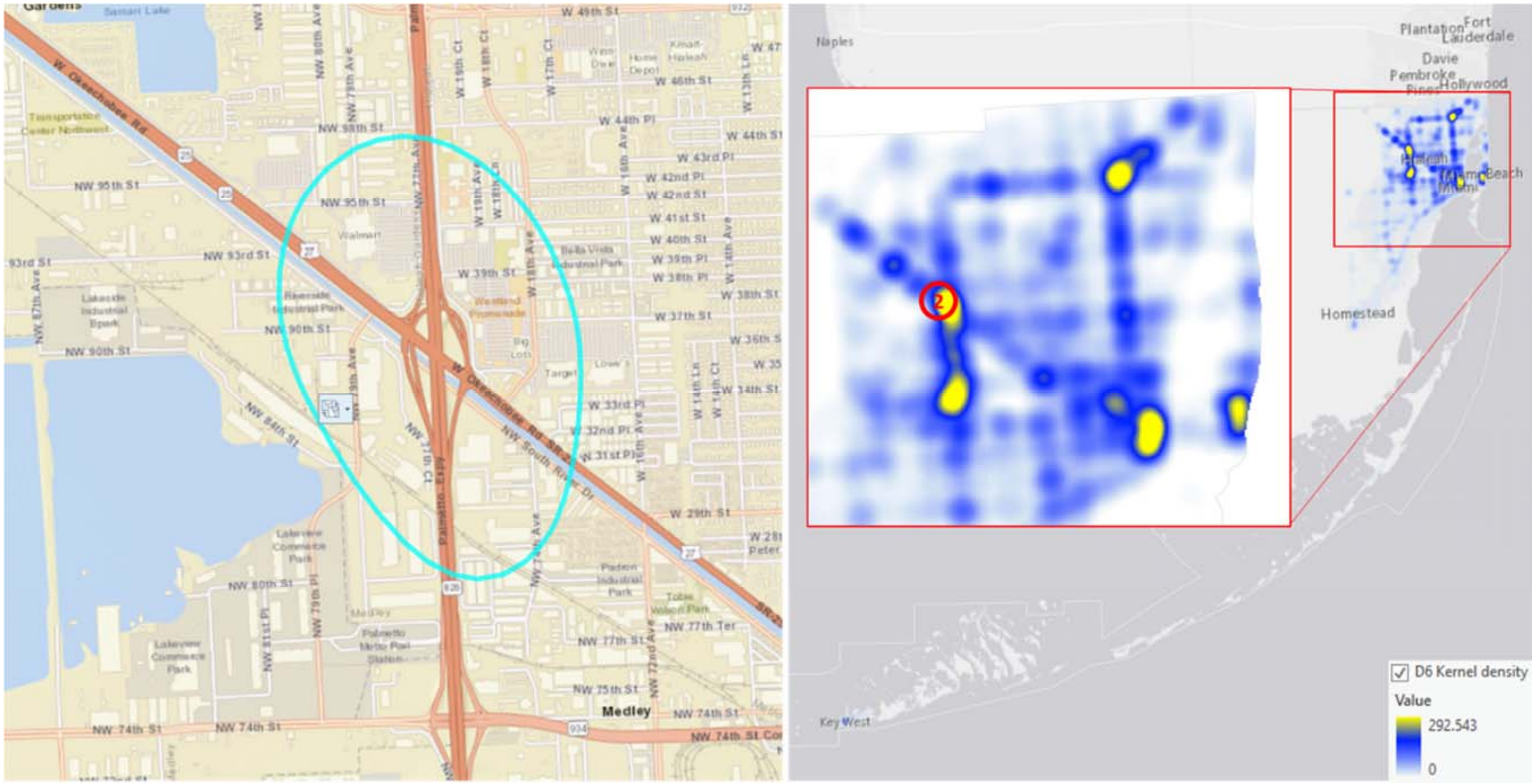


Figure 119 The 2nd high crash density location for large truck crashes from the kernel density map - District 6

The 3rd High crash density Location

This location is at the South of Palmetto Express way and NW 36th Street interchange as shown in the map. The area is for commercial use.

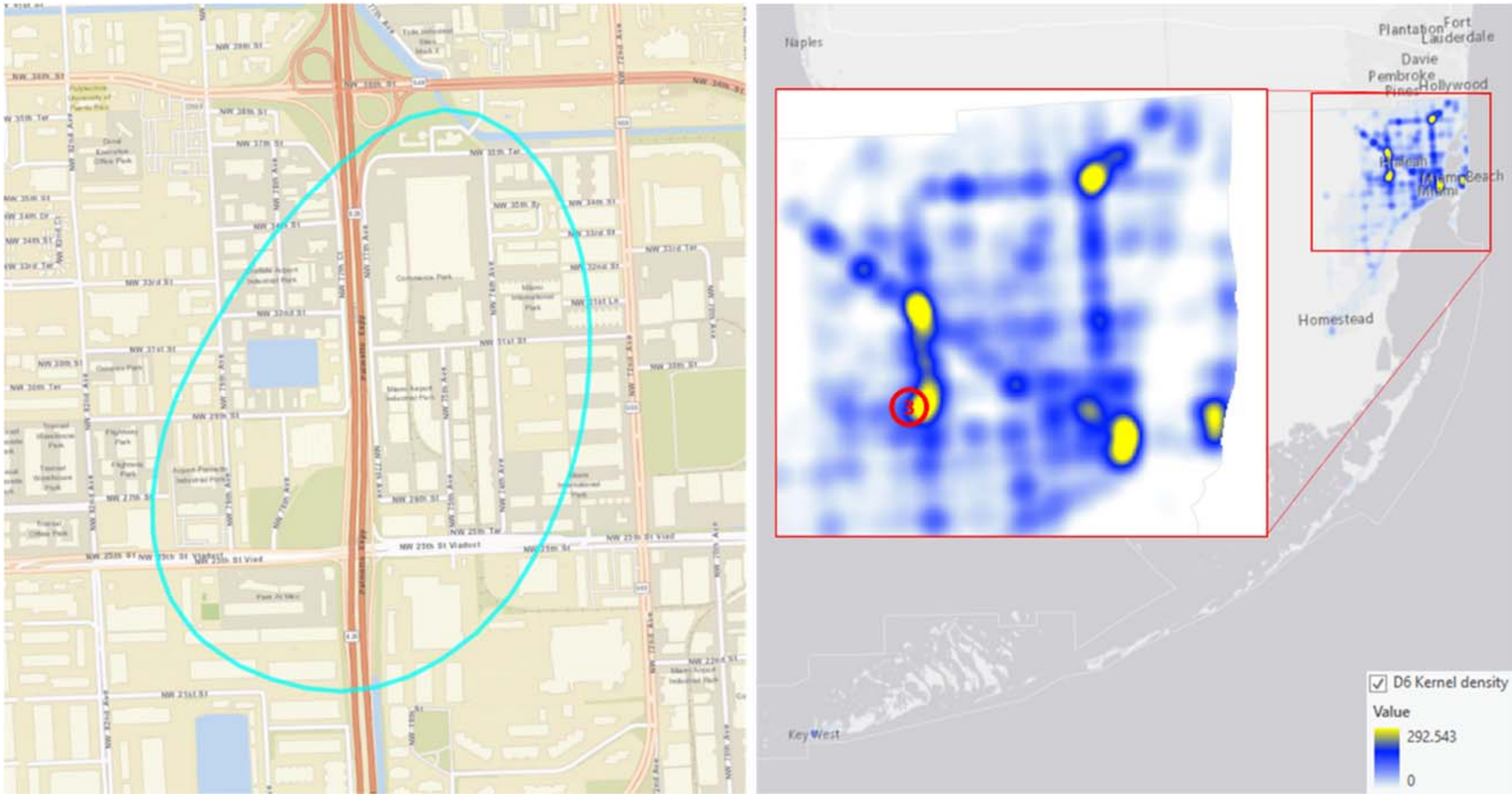


Figure 120 The 3rd high crash density location for large truck crashes from the kernel density map - District 6

The 4th High crash density Location

This location is at the interchange of I-95, Florida Turnpike and Palmetto Express way. The land is mainly used for this big interchange.

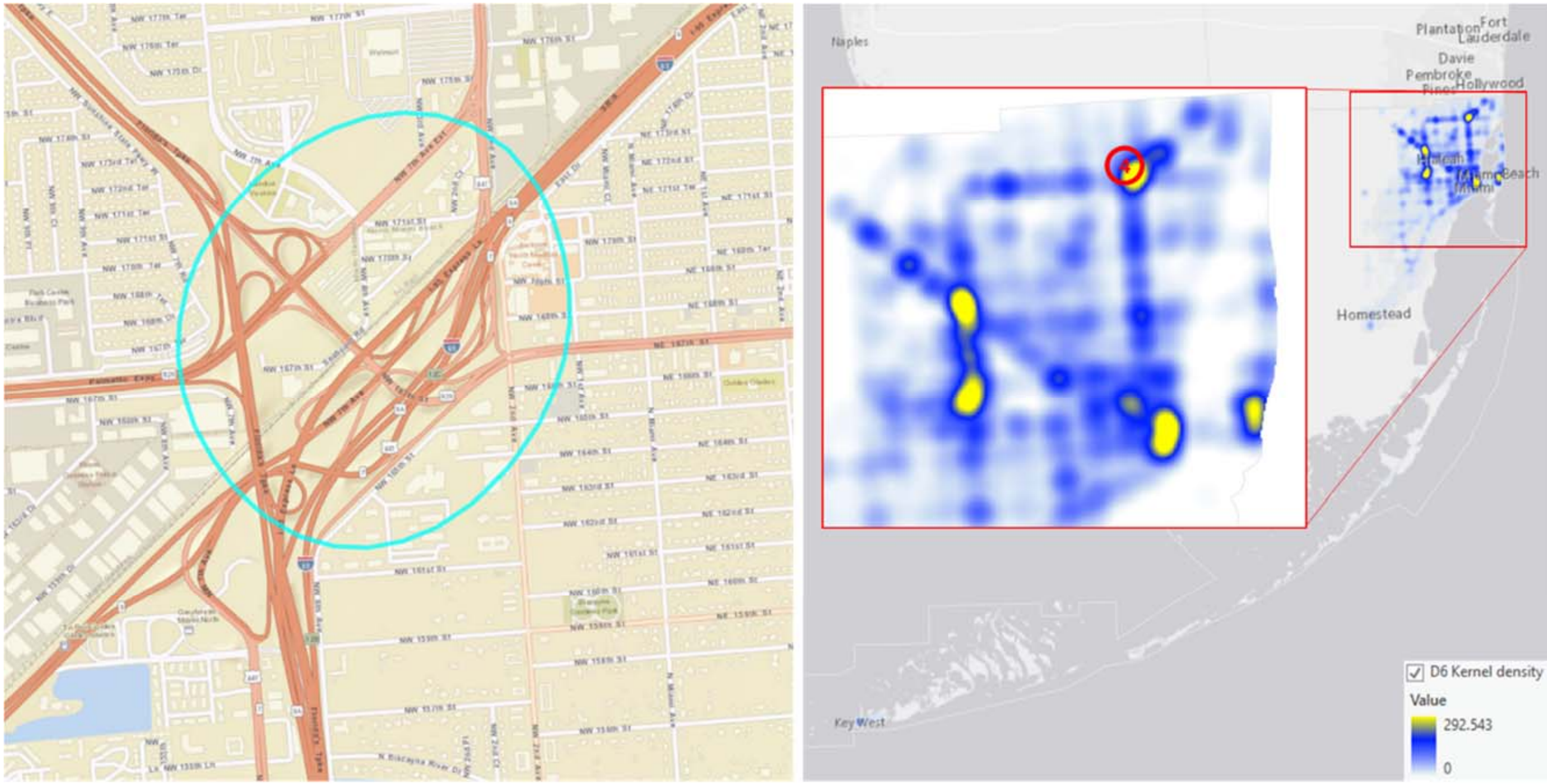


Figure 121 The 4th high crash density location for large truck crashes from the kernel density map - District 6

The 5th High crash density Location

The location is in Miami Beach. This area is selected because the three major roads surround it contribute crash density to it. The three roads are Washington Ave, 17th St and Alton Rd. This area is mainly for residential use.

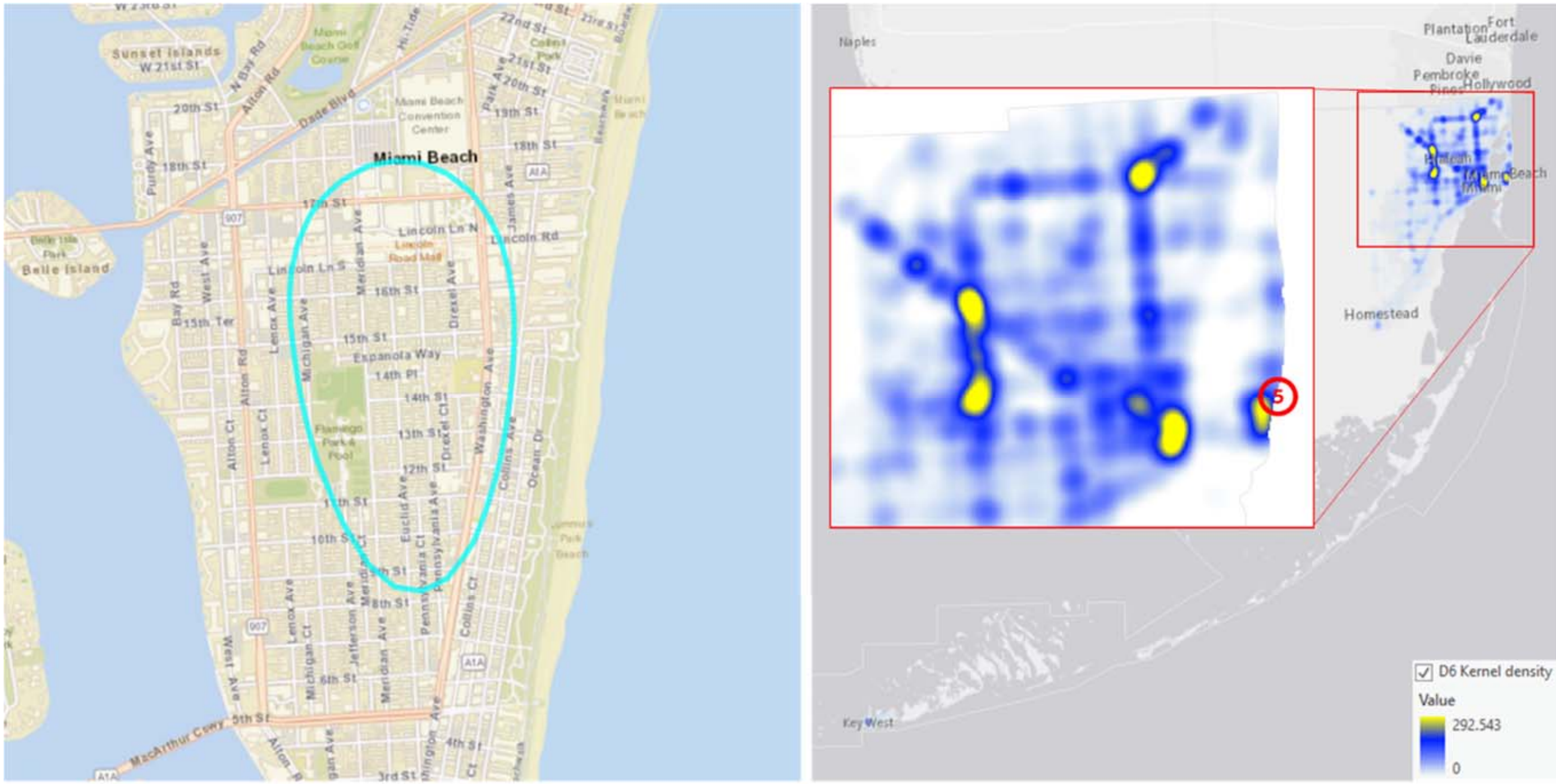


Figure 122 The 5th high crash density location for large truck crashes from the kernel density map - District 6

The 6th High crash density Location

This location is around the intersection of NW 20th St and NW 12th Ave. The location has some public facilities such as Miami Healthcare System and Jackson Memorial Hospital.

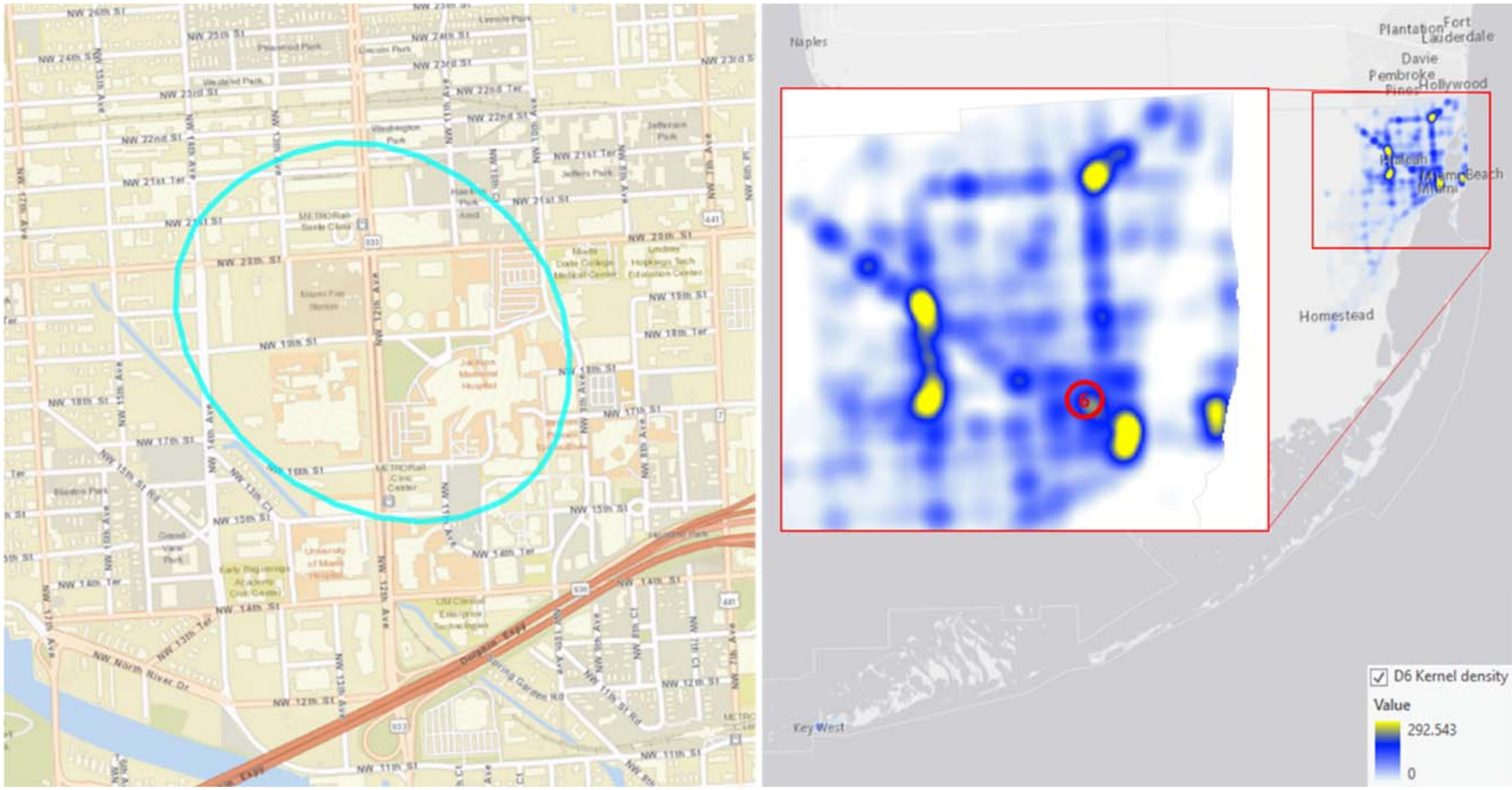


Figure 123 The 6th high crash density location for large truck crashes from the kernel density map - District 6

The 7th High crash density Location

This location is on the South East of the interchange of Palmetto Express way and NW 58th St. The area is relative small with a radius about 1000 feet. Its land use is commercial.

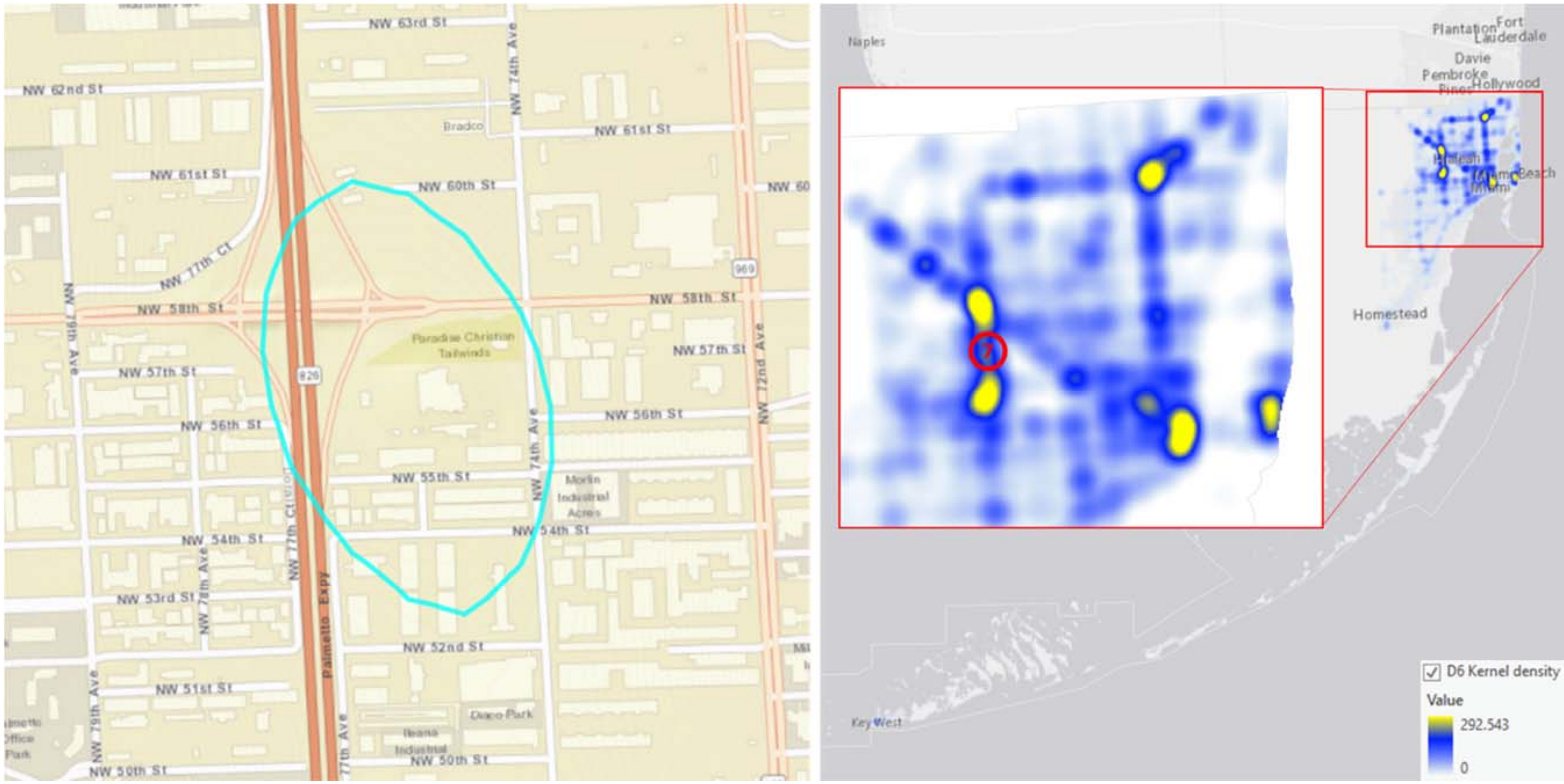


Figure 124 The 7th high crash density location for large truck crashes from the kernel density map - District 6

The 8th High crash density Location

The location is at the intersection of W Okeechobee Rd and NW 115th Way (Hialeah Garden Blvd). The radius of the area is about 600 feet. The land use is commercial. There are a few truck related businesses nearby such as Aljoma Lumber, Inc.

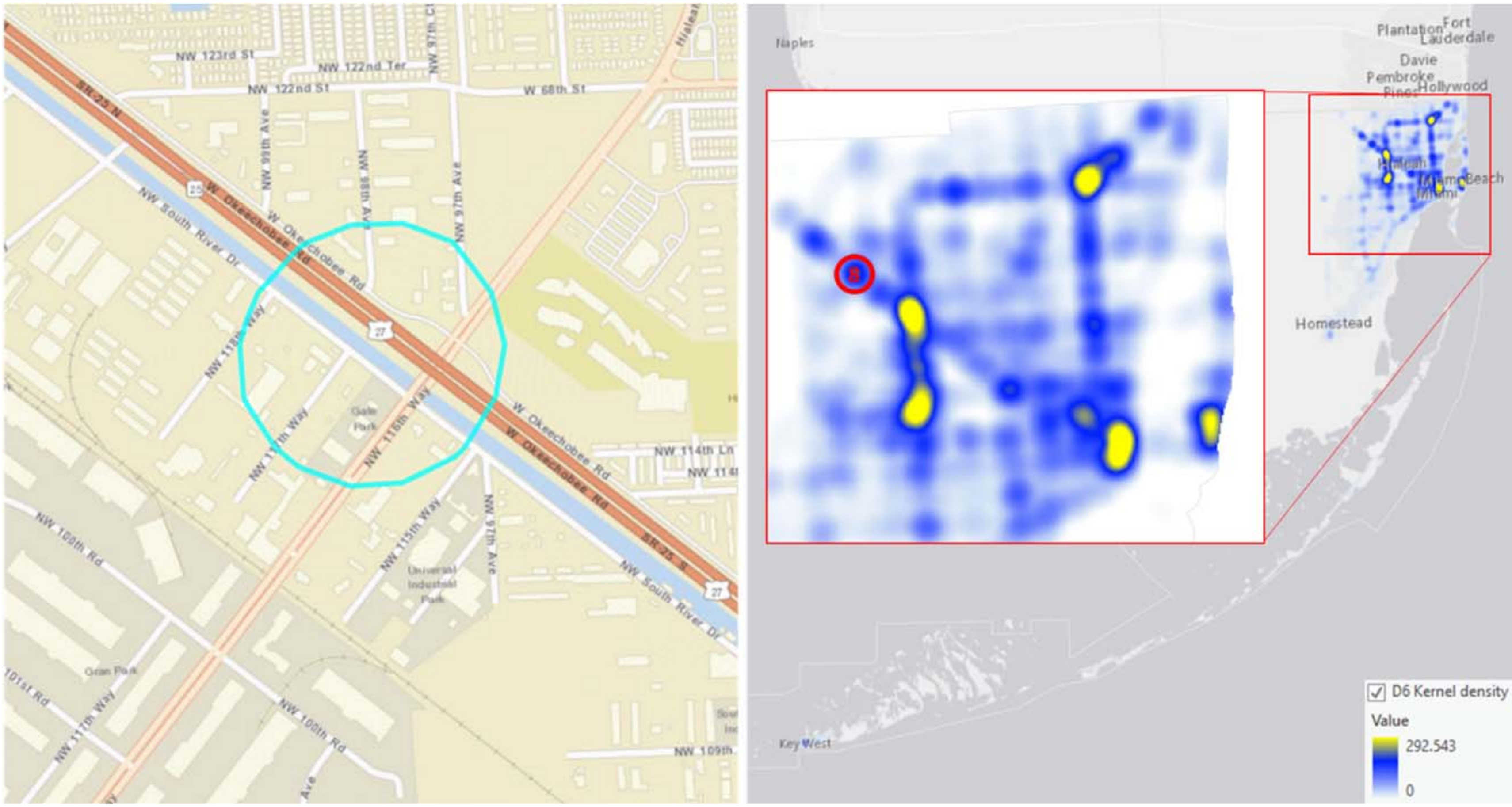


Figure 125 The 8th high crash density location for large truck crashes from the kernel density map - District 6

The 9th High crash density Location

The location is at the interchange of I-95 and NE Miami Gardens Drive. The area is picked since the crashes on I-95 and NE Miami Gardens Drive contributes a lot density to this area. The area is for commercial use and has truck related business such as Borden Dairy Co of Florida.

Figure 126 The 9th high crash density location for large truck crashes from the kernel density map - District 6

The 10th High crash density Location

The location is at the interchange of Airport Expressway, NW 36th St and NE Okeechobee Rd. The radius of the area is about 700 feet. It has Hotels, airport, residential buildings and commercial buildings.

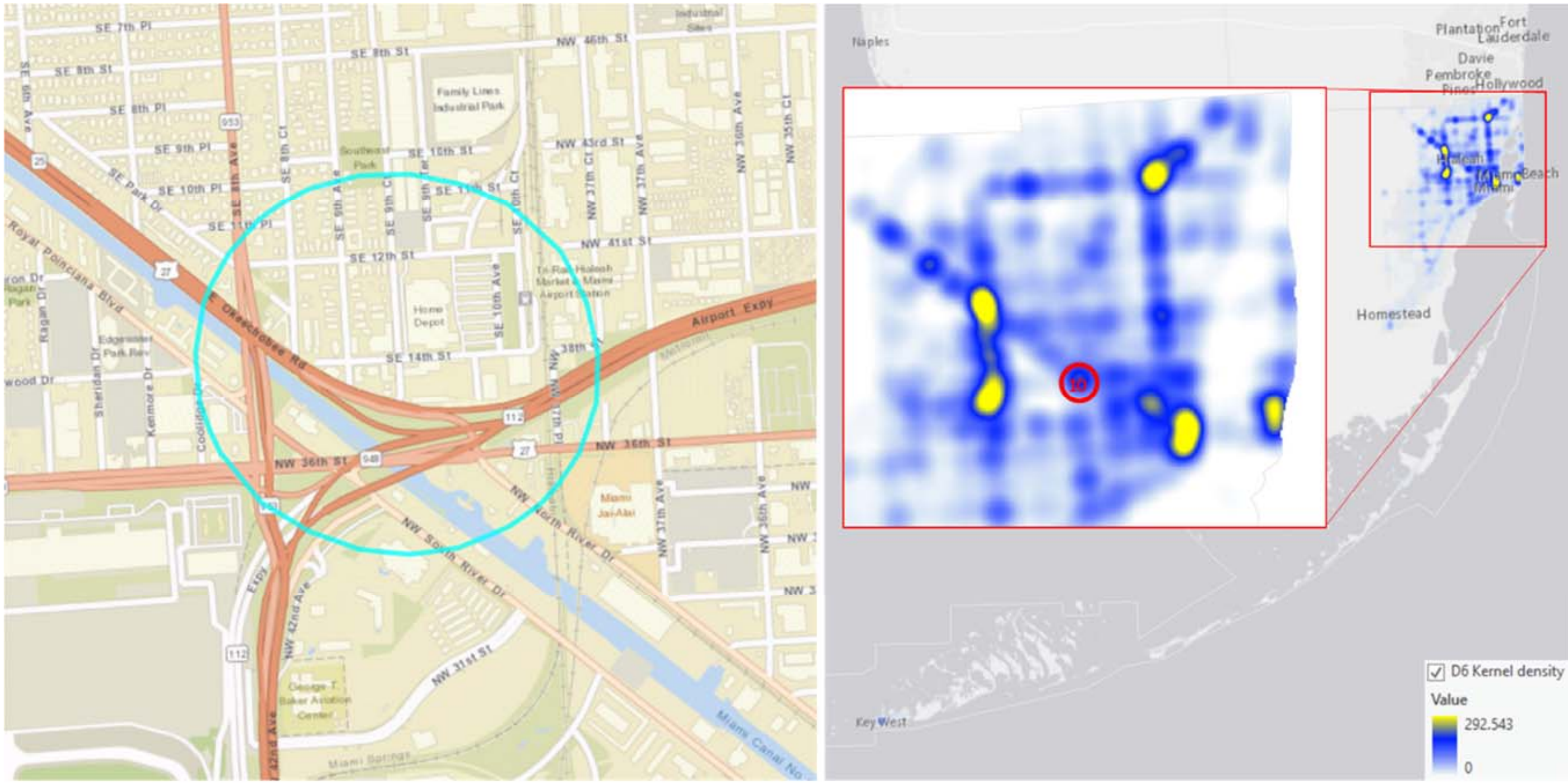


Figure 127 The 10th high crash density location for large truck crashes from the kernel density map - District 6

7.7. Density Maps for District 7

Figure 128 shows the kernel density map of large truck crashes for District 7.

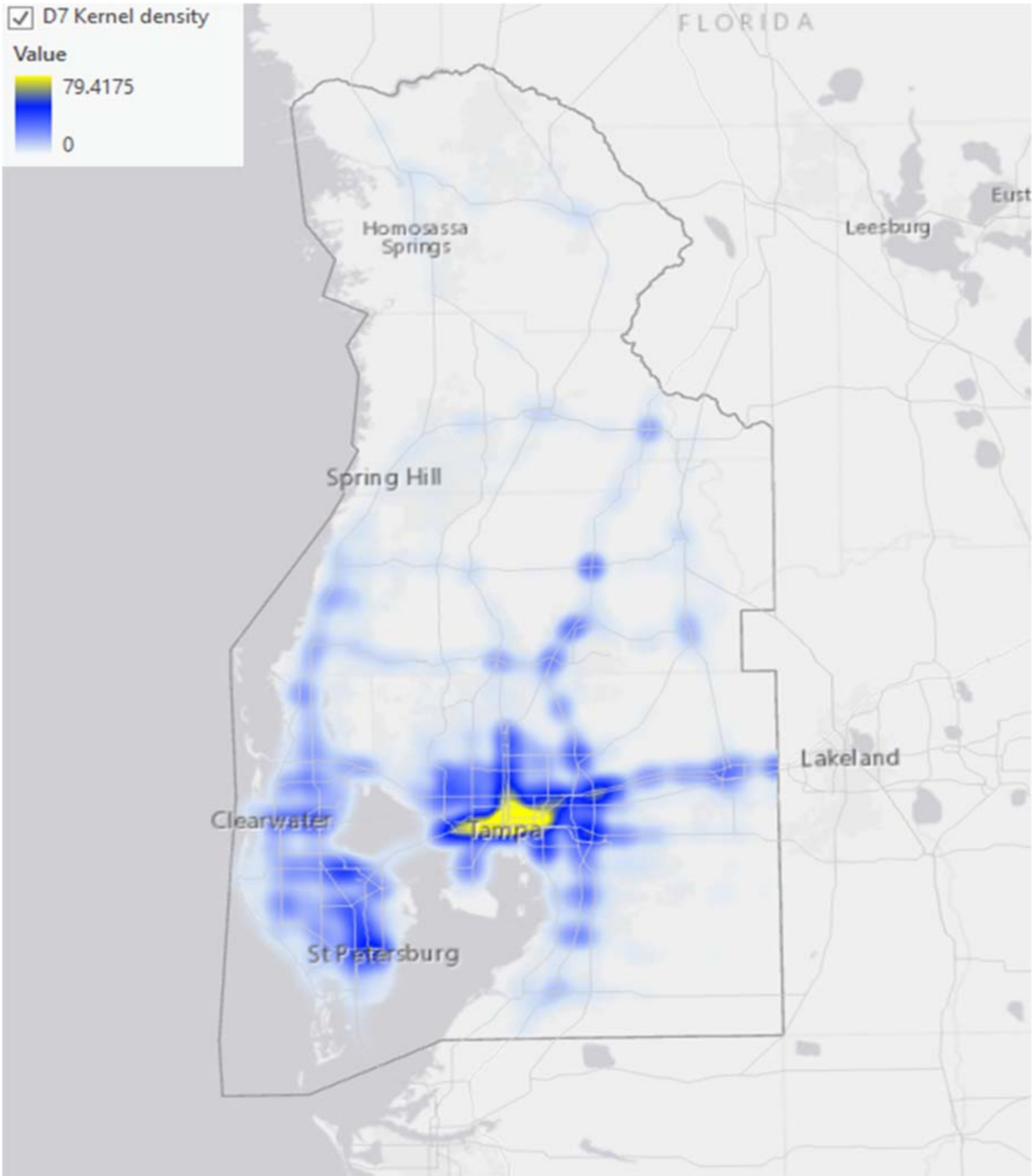


Figure 128 Kernel density mapping of all large truck crashes in District 7

Figure 129 identifies the top 10 locations with the highest density. The highest density in District 7 is concentrated in Tampa, St Petersburg. The top 7 locations with high truck crash density are from Tampa.

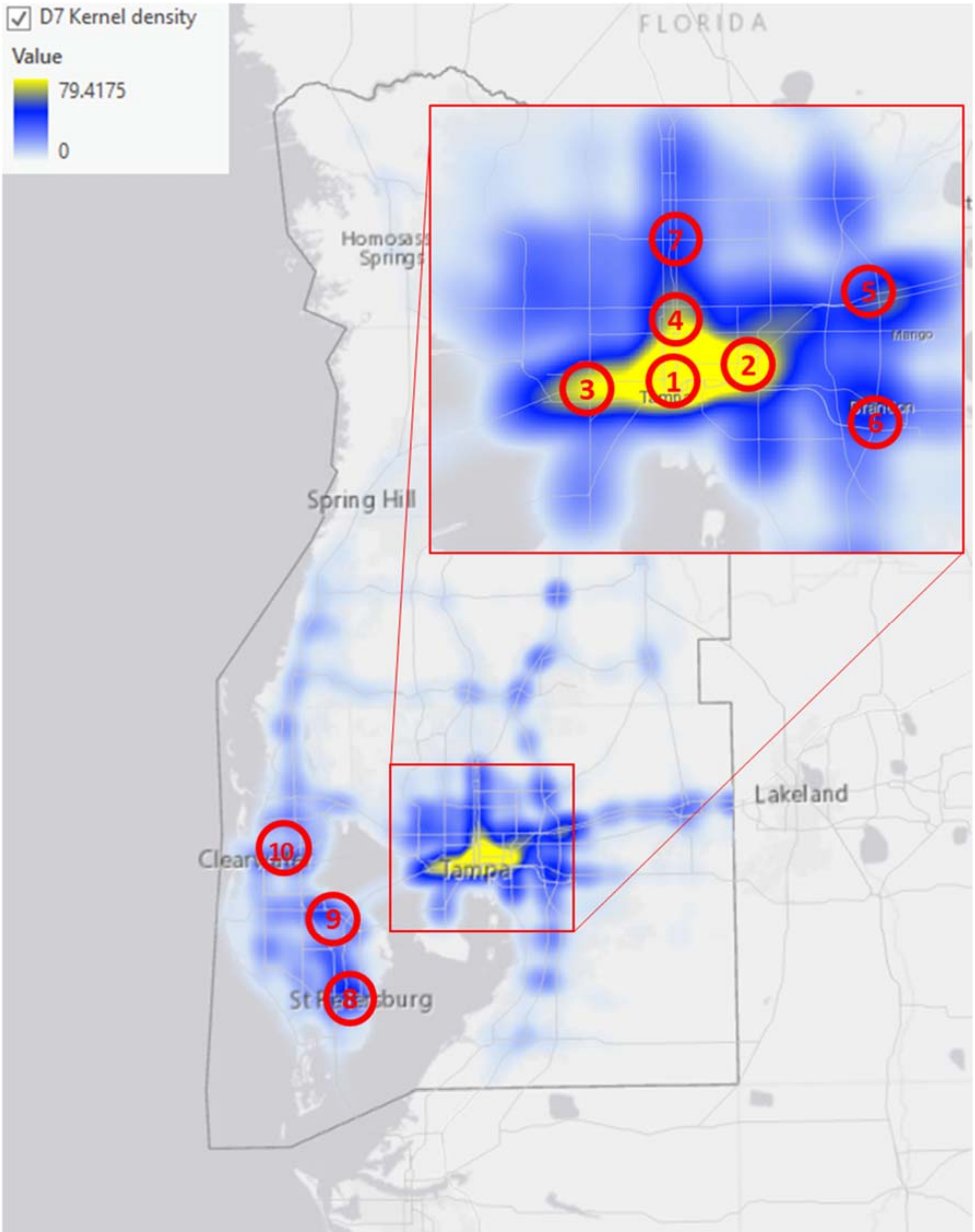


Figure 129 Top 10 locations selected from kernel density mapping of all large truck crashes in District 7

The 1st High crash density Location

The location is around the interchange of I-4 and I-275. This location is selected because the major roads (I-4, I-275 and Selmon Expressway) contribute a lot crash density to the area. The radius of the area is about 2000 feet. Most of the buildings are residential.

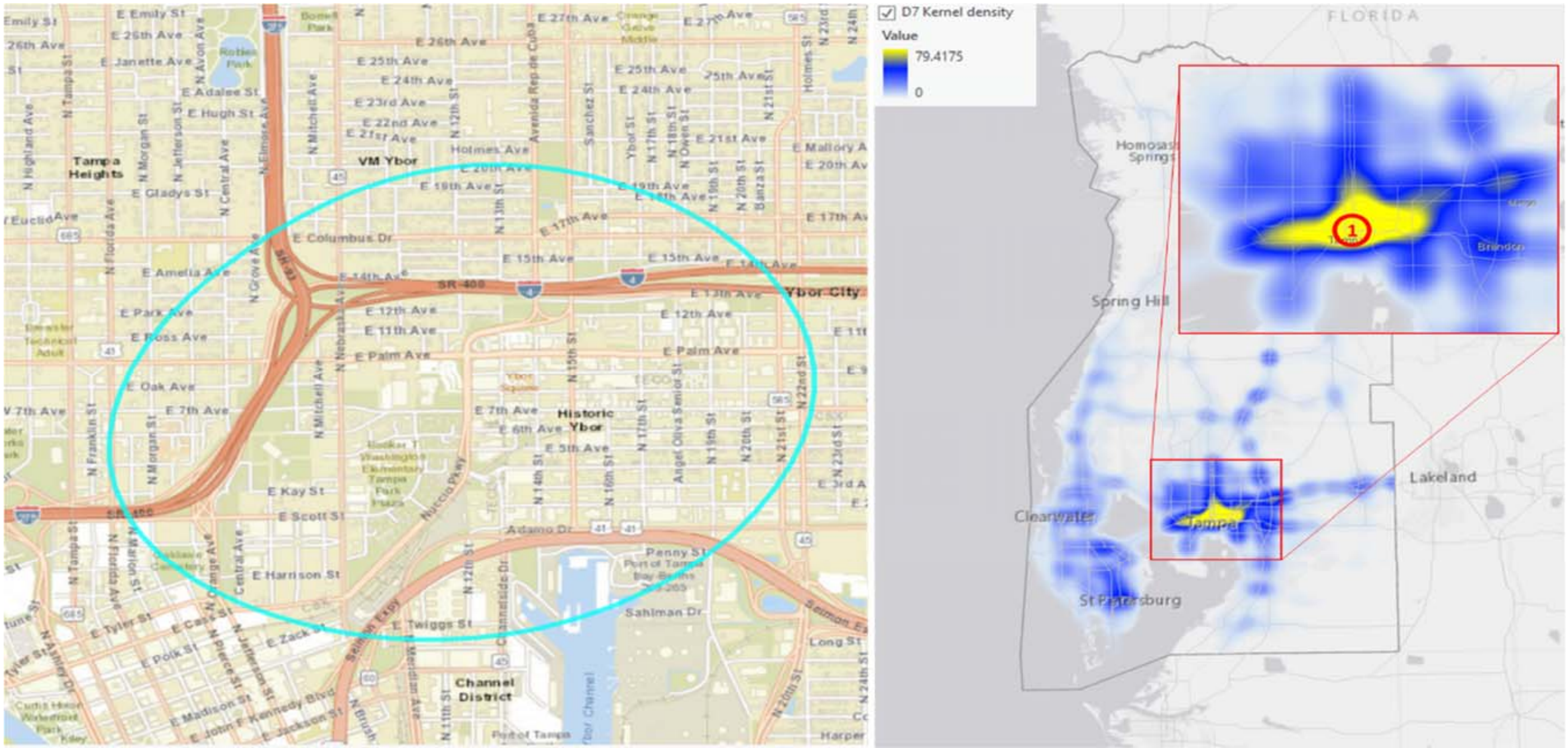


Figure 130 The 1st high crash density location for large truck crashes from the kernel density map - District 7

The 2nd High crash density Location

The location is around the interchange of I-4 and N 50th Street. There are commercial and residential land uses. The radius of the area is about 4000 feet.

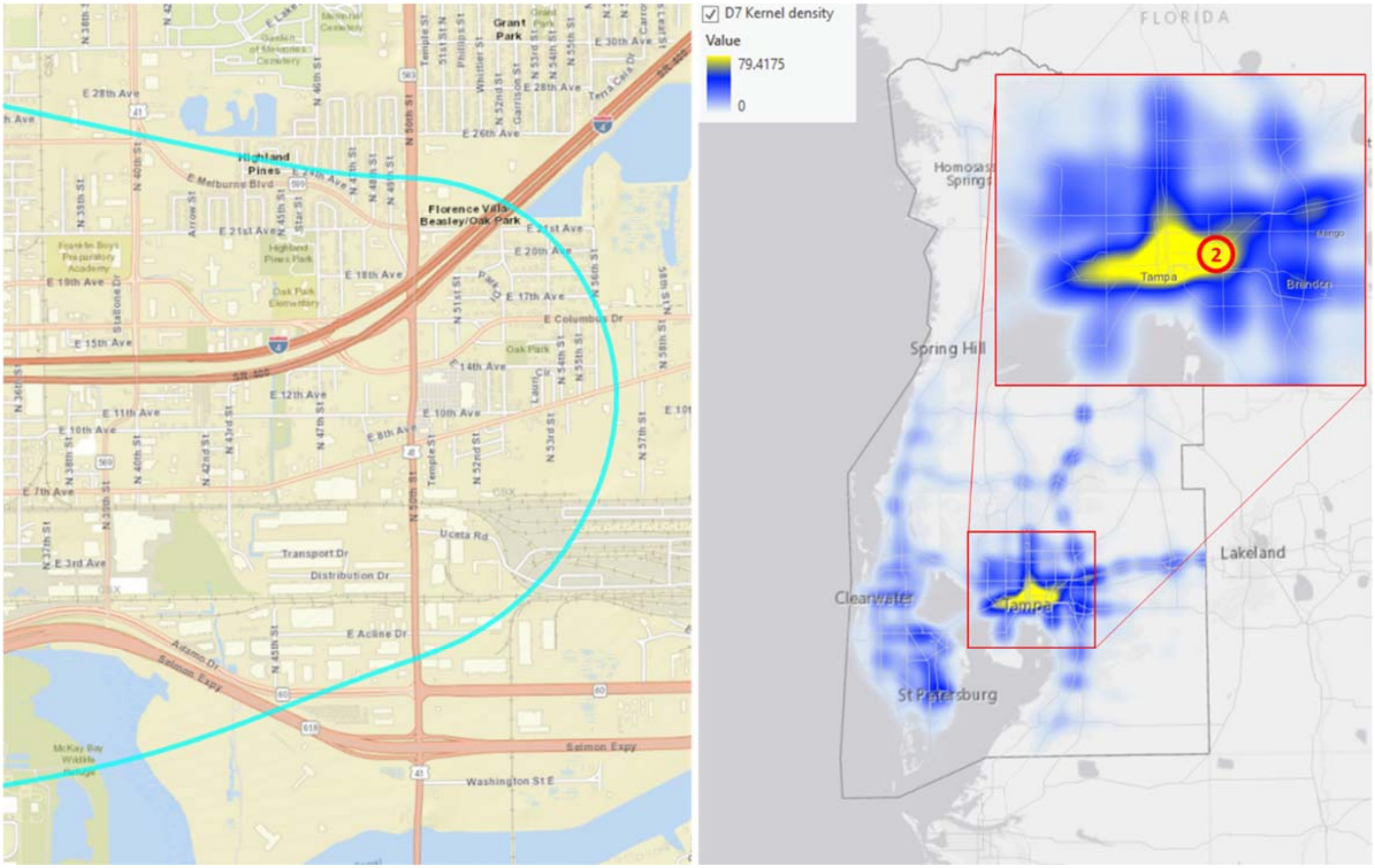


Figure 131 The 2nd high crash density location for large truck crashes from the kernel density map - District 7

The 3rd High crash density Location

The location starts around the interchange of I-275 and N Dale Mabry Hwy, and the area goes East along on I-275 since there are more crashes on this road. The major land use of this area is residential but it also has commercial buildings at the North of the interchange.

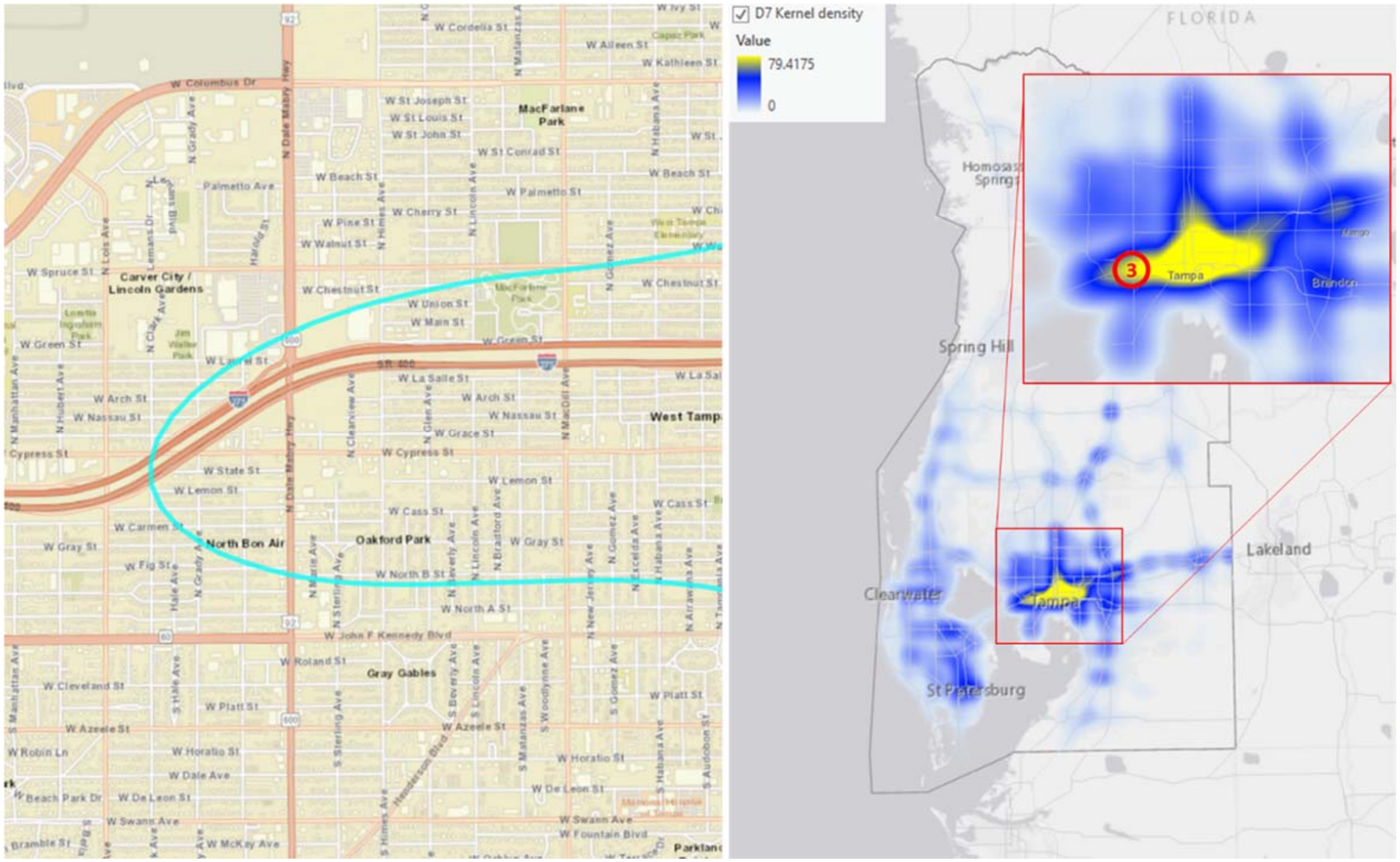


Figure 132 The 3rd high crash density location for large truck crashes from the kernel density map - District 7

The 4th High crash density Location

This location is around the interchange of East Hillsborough Avenue and I-275. The area is mainly covered with residential buildings.

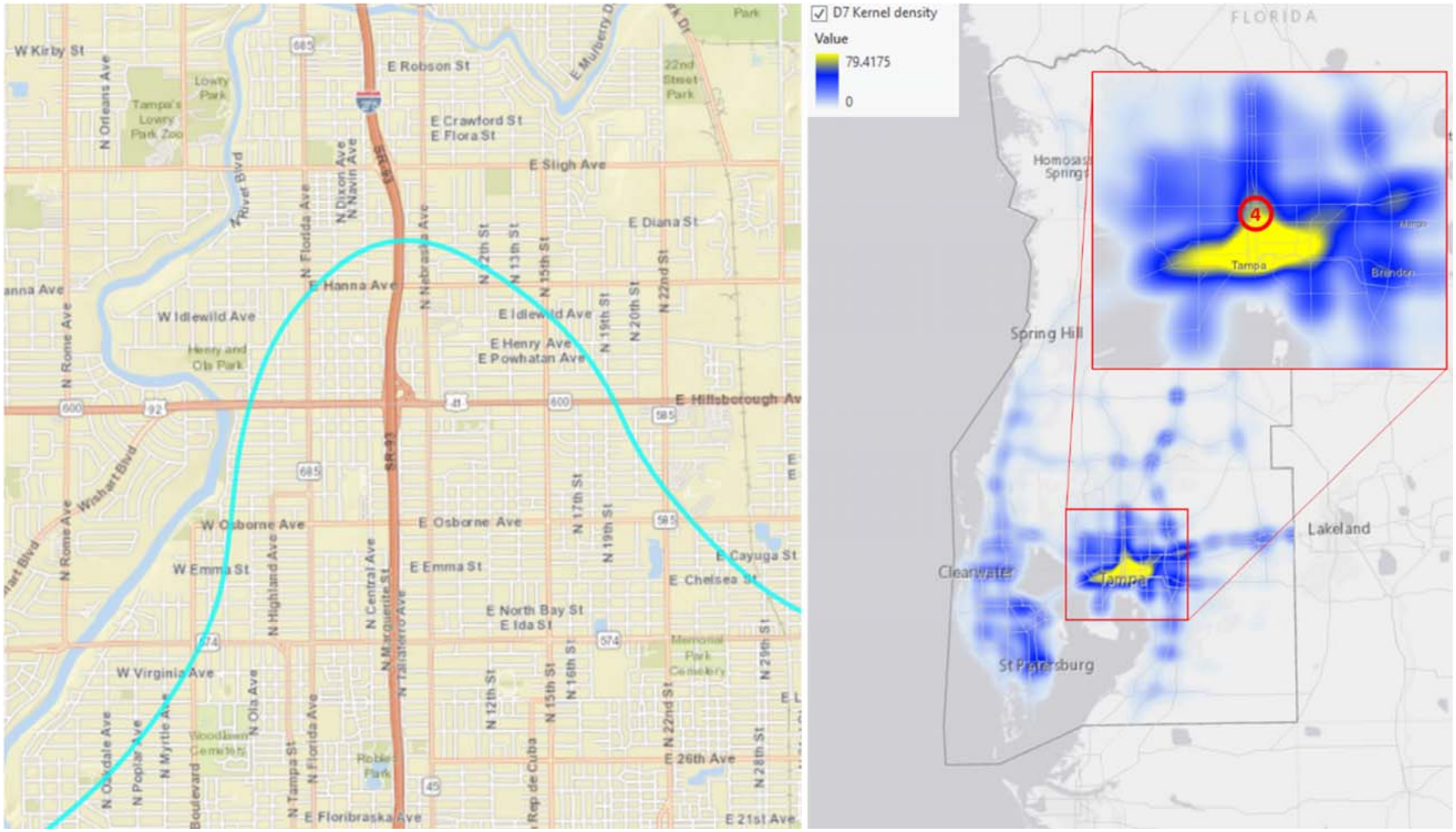


Figure 133 The 4th high crash density location for large truck crashes from the kernel density map - District 7

The 5th High crash density Location

The location is around the interchange of I-75 and I-4. The area is for residential, commercial and open space.

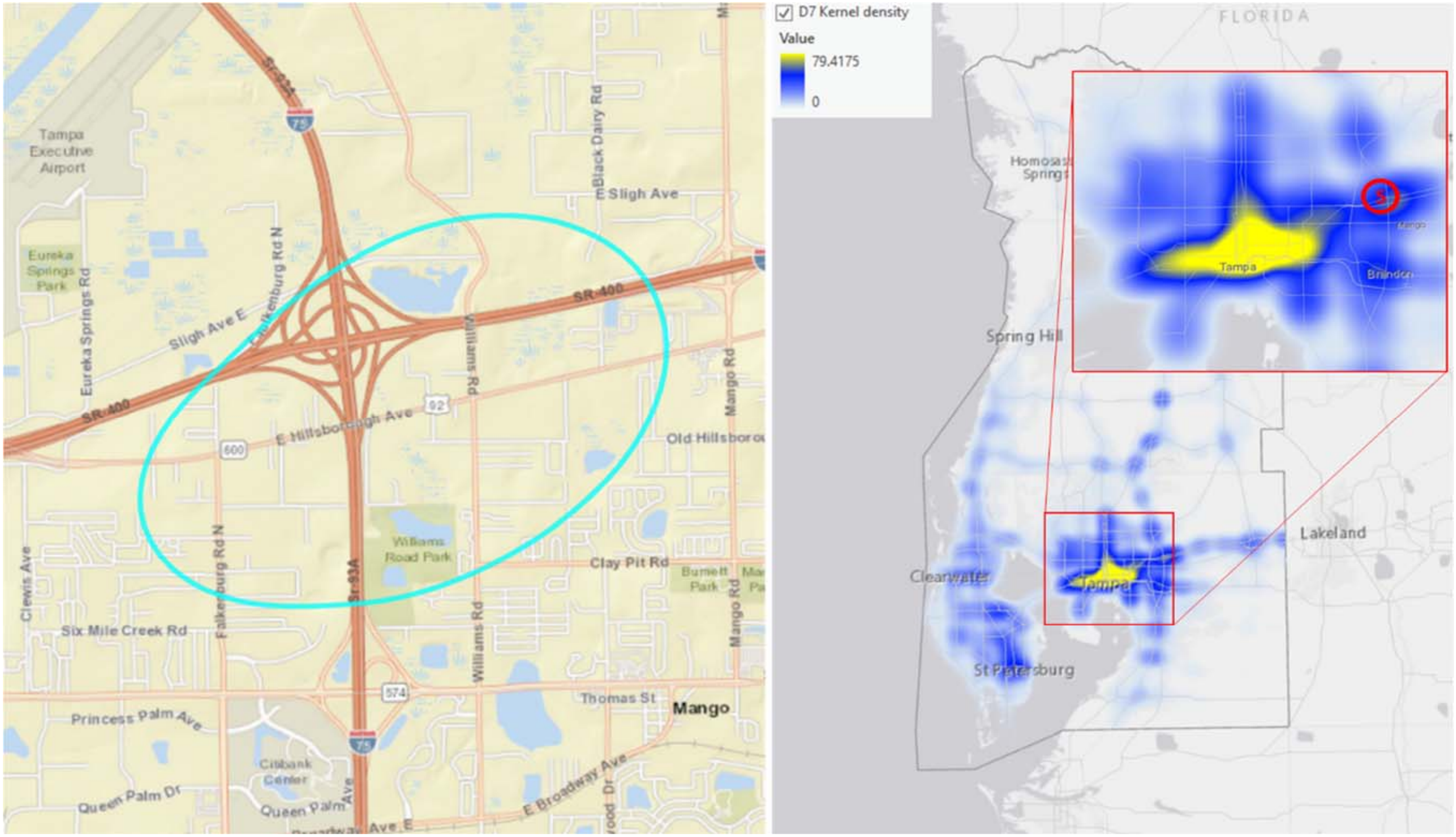


Figure 134 The 5th high crash density location for large truck crashes from the kernel density map - District 7

The 6th High crash density Location

The location is around the interchange of I-75 and E Adams Drive. It covers the Western area about 1 mile from the interchange. The land is mainly for commercial use.

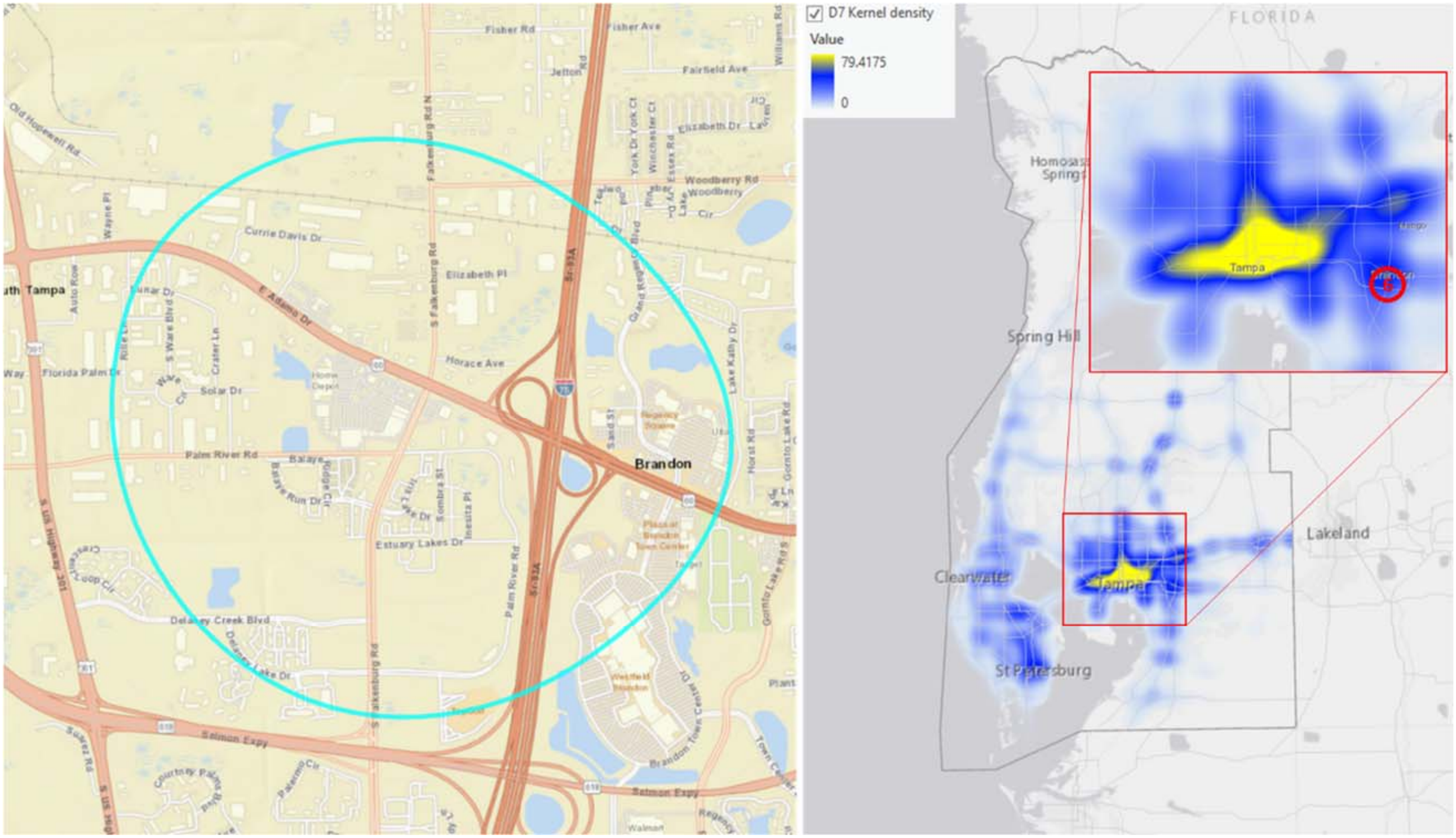


Figure 135 The 6th high crash density location for large truck crashes from the kernel density map - District 7

The 7th High crash density Location

The location is at the South of the interchange of East Busch Boulevard and I-275. The area is a 2000 feet buffer zone along the I-275. The area is mainly for residential but also has some big commercial centers such as The Home Depot and Sears.

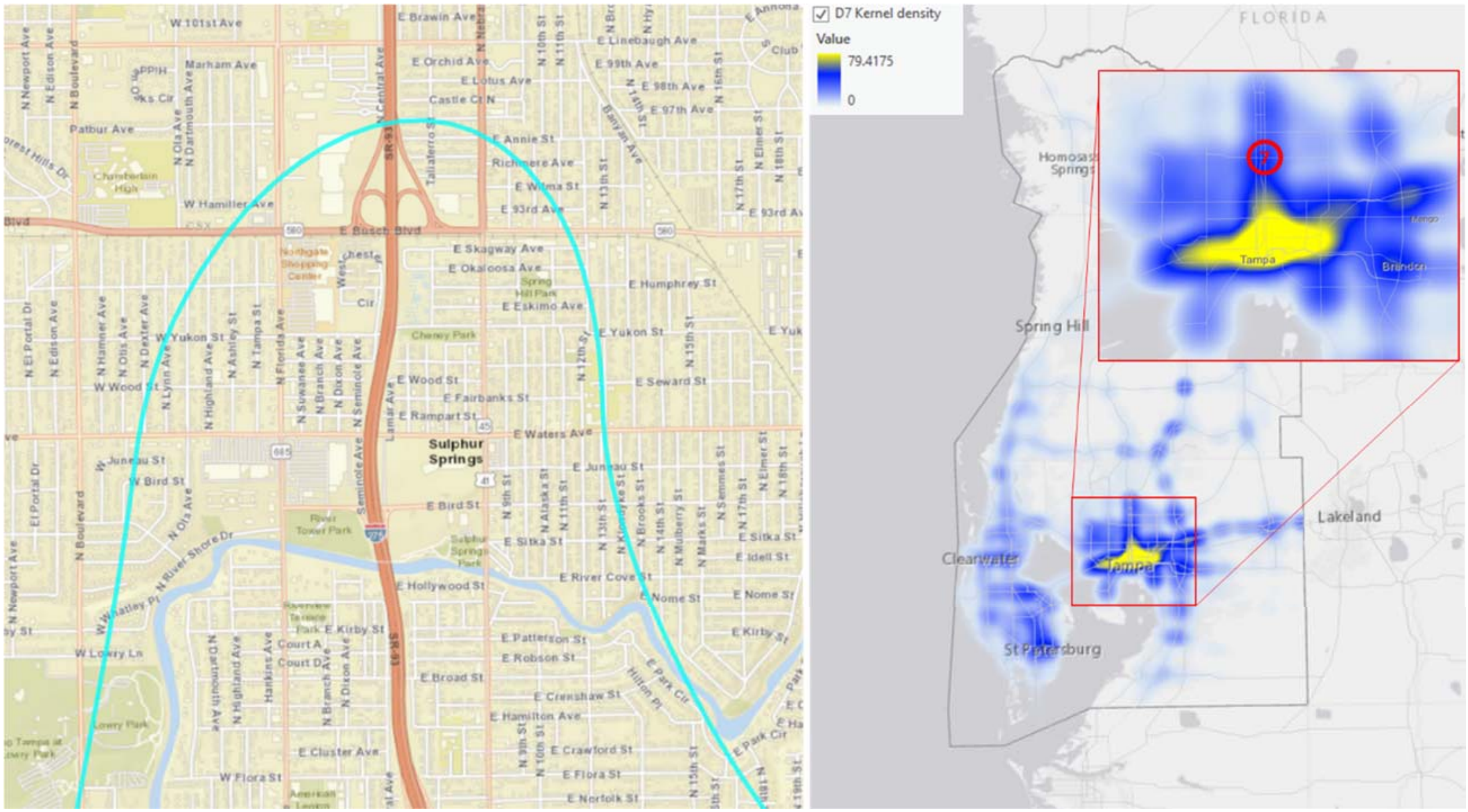


Figure 136 The 7th high crash density location for large truck crashes from the kernel density map - District 7

The 8th High crash density Location

The location is around the interchange of I-375 and I-275. The West part is residential and the East part is commercial and residential.

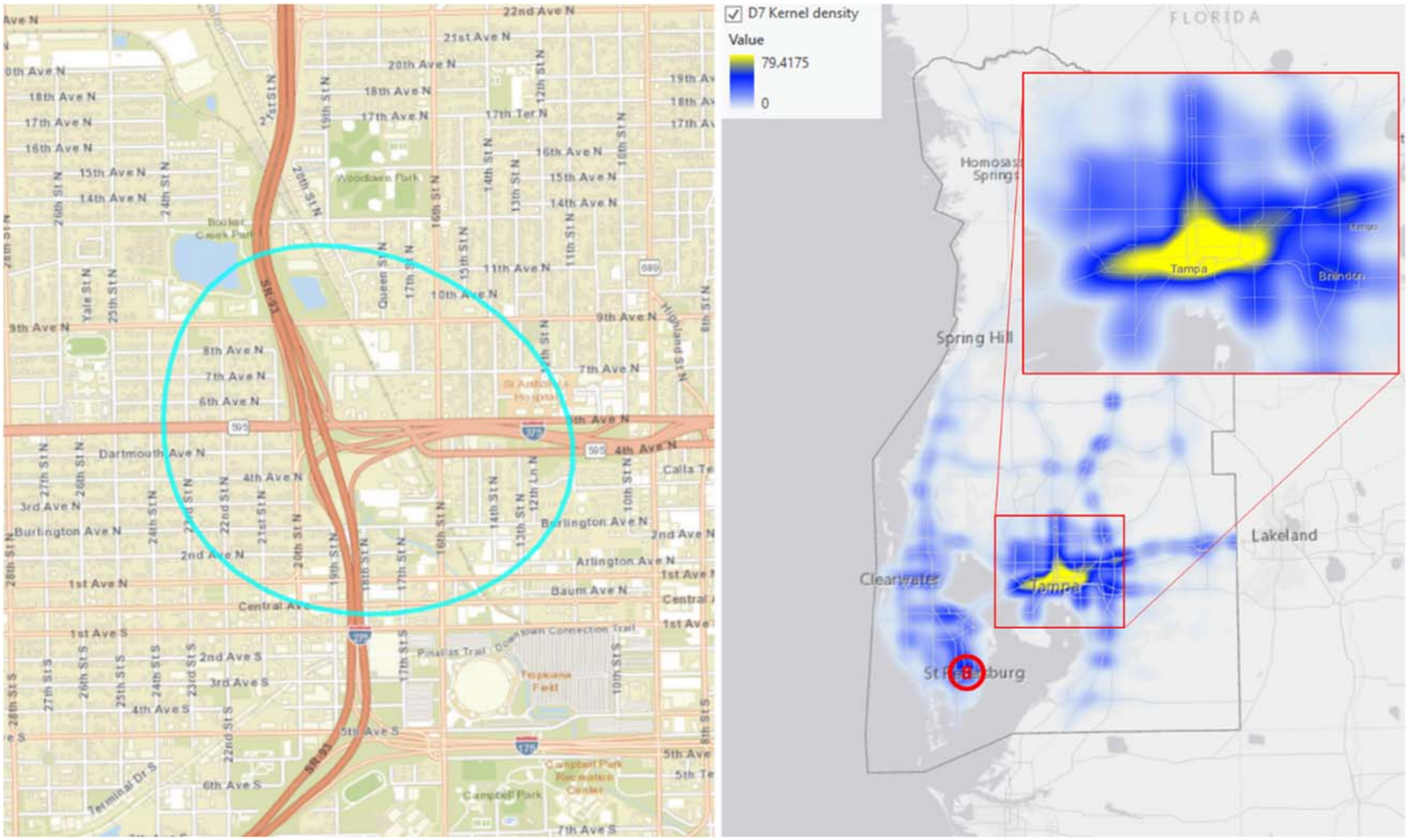


Figure 137 The 8th high crash density location for large truck crashes from the kernel density map - District 7

The 9th High crash density Location

The location is around the intersection of Ulmerton road and Roosevelt Blvd. The area is about 8000 feet long. There are a lot of commercial buildings and an airport no the North.

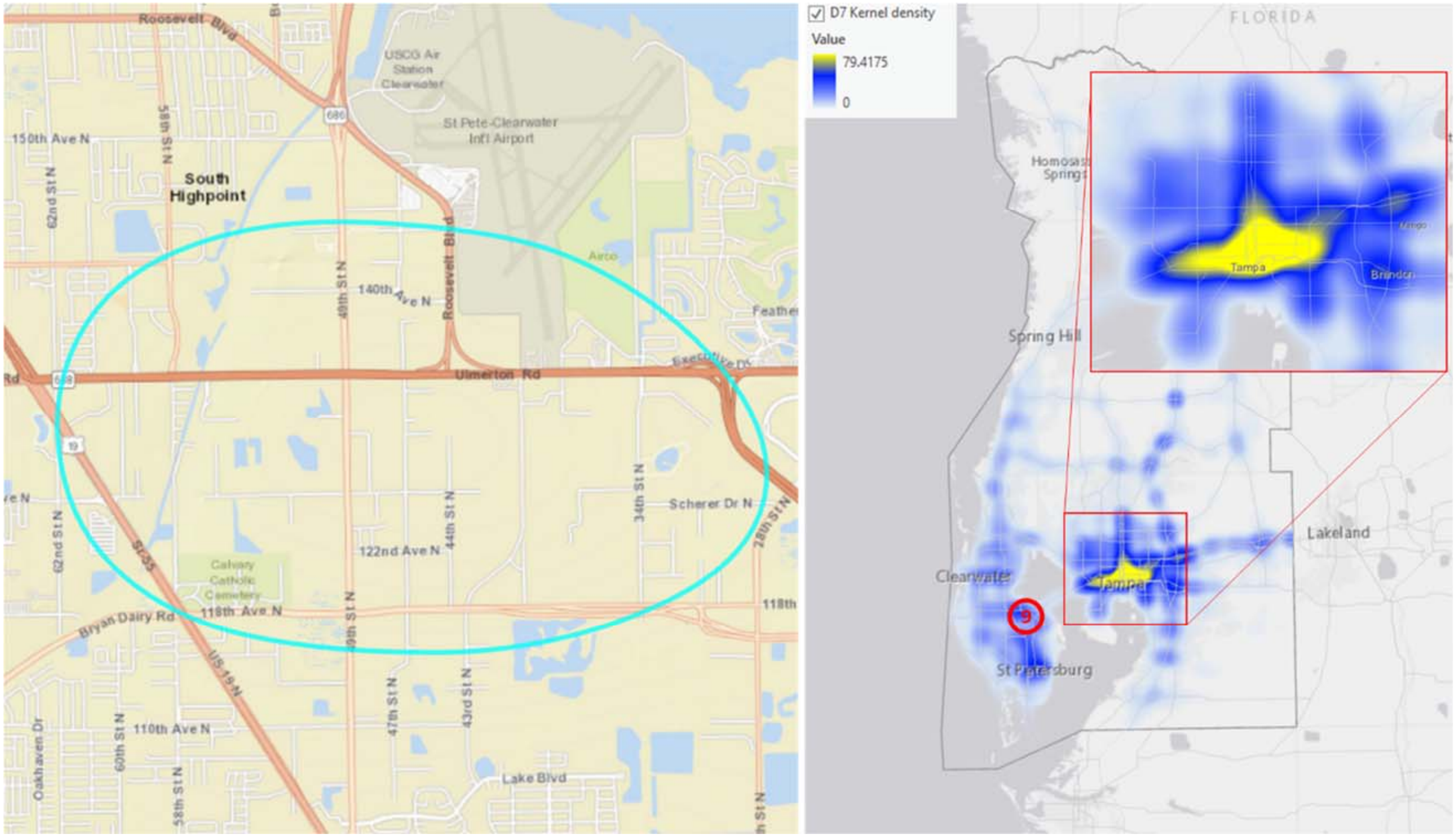


Figure 138 The 9th high crash density location for large truck crashes from the kernel density map - District 7

The 10th High crash density Location

The location is around the intersection of Gulf to bay Blvd and Belcher Road. The selected area is about 4000 feet long. This area covered with residential homes and shopping malls in the center.

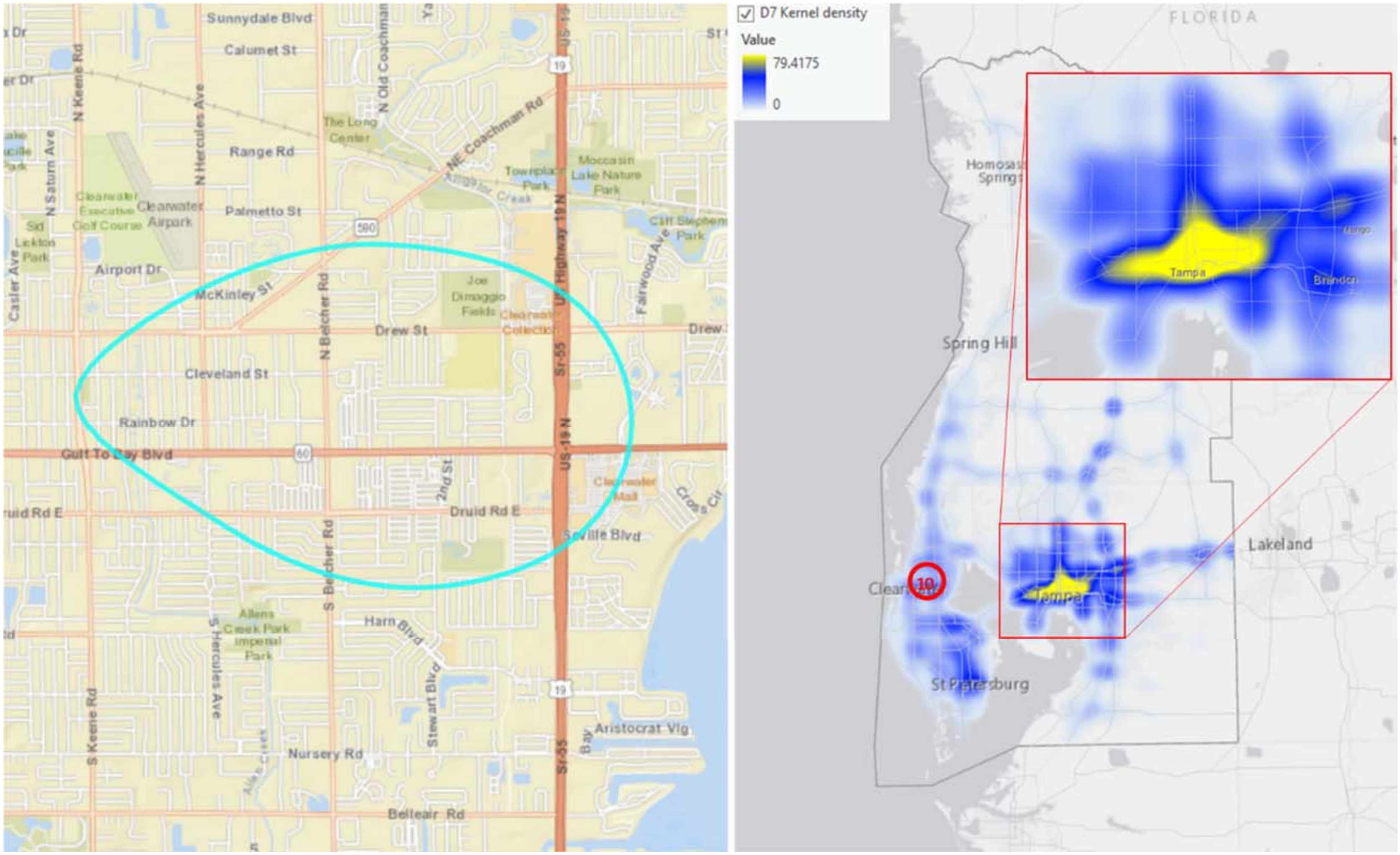


Figure 139 The 10th high crash density location for large truck crashes from the kernel density map - District 7

8. COUNTERMEASURES

This chapter shows the development of a data-driven, evidence-based set of countermeasures that target the behavioral factors and critical locations gleaned from historical crash data presented in the previous chapters. The traditional "3 E's" approach to countermeasure development is a logical way to approach recommendations for safety interventions. Engineering, enforcement, and education have proven to be effective treatments for safety-related issues. Sometimes mentioned as a "fourth E", emergency medical services are not included in this discussion of countermeasures because it generally speaks to mitigating the effects of injuries rather than crash causation.

A priori, the objective of this research was to use historical crash data to identify specific risk factors and locations for large truck and bus crashes. Ostensibly, such an effort would result in a targeted application of treatments to target those crashes. The results of crash analysis and spatial analysis have illuminated those factors and locations where treatments might be most needed.

For purposes of this project, the introductory discussion of countermeasures is not intended to be exhaustive, given the purpose, constraints, and needs of the project. It is intended to provide an overview of potential countermeasures that are most applicable to the factors and locations identified.

8.1. Approach

This effort is structured in a way that plans for the application of countermeasures to reduce crashes involving commercial motor vehicles (CMV). In the following pages, a review of literature describes past work that has contributed to countermeasures for truck crashes. Subsequently, a discussion of systemic approaches is undertaken, including a grouping of select countermeasures along the lines of the aforementioned 3 E's. Next, we describe the formation of targeted countermeasures, applied to the factors and locations gleaned from the crash severity analysis and spatial analysis. It is hoped that the combination of systemic and targeted treatments will create a comprehensive approach that will improve the current commercial vehicle safety picture.

While research literature centered on traffic safety countermeasures is quite extensive, that which is specifically focused on CMV crashes is more limited.

To guide implementation of the American Association of State Highway Transportation Officials (AASHTO) strategic plan, the Transportation Research Board (TRB) sponsored a National Cooperative Highway Research Project (NCHRP) entitled *A Guide for Reducing Collisions Involving Heavy Trucks* (NCHRP, 2004). The guide is a set of recommended objectives for CMV crashes that range from roadway improvements to administrative measures like improving safety data and strengthening Commercial Driver License (CDL) laws. There are 15 strategies presented in the publication.

In a report to Congress, the US DOT noted that there are a range of infrastructure improvements that can lead to fewer CMV crashes and safer roadways (FHWA, 2016). With an infrastructure focus, most of the recommendations focus on engineering/roadway improvements to mitigate large truck and bus crashes. The report highlights 3 categories of improvement; infrastructure safety, communications infrastructure, and innovative CMV practices.

Infrastructure safety describes roadway improvements like roadway geometry, surfaces and roadside features. Communication infrastructure encompasses devices to communicate information to help CMV and other drivers safely navigate the roadway network, like warnings about congestion or incidents. Innovative CMV safety practices like roadside intelligent transportation systems (ITS) that increase compliance with safety regulations or increase safety by providing for better separation of the larger and smaller vehicles.

The report highlights a myriad of roadway treatments like truck restricted lanes, oversize corridors, virtual weigh stations, rumble strips, high friction surfaces, cross-slope breaks, passing lanes, static and dynamic signs, and work zone systems. Similar to the work of Blower, the report notes the value of targeted enforcement and high visibility enforcement (NHTSA, 2019d). The FHWA Office of Operations website adds commentary on traffic incident management systems (FHWA, 2019b), traveler information, and enhanced truck parking facilities (FHWA, 2019c).

The FHWA also published a report entitled, "Manual for Selecting Safety Improvements on High Risk Rural Roads" that provides a inventory of general engineering safety investments for rural roads (FHWA, 2014). While not specifically intended for CMV, it includes treatments that would be beneficial to trucks operating on rural roadways.

Vehicle treatments to assist drivers or mitigate driver error were noted in research by Blower and Kostyniuk (Blower et al. 2010). These systems include backup cameras, side object detection, driver monitoring, forward collision avoidance, and adaptive cruise control. The systems were noted as moderate to high cost, though most did not have an empirical basis like those derived from crash modification factors (CMF). The research also highlighted targeted enforcement as a potential solution for reducing CMV crashes.

The research team engaged State and Federal CMV enforcement organizations to better understand the perspective of enforcement in countermeasure development. Through these contacts, the team is able to understand the historical context and current state of the practice for CMV enforcement philosophy, techniques, and tactics.

The Federal Motor Carrier Safety Administration (FMCSA) was established in 2000 as separate administration under the U.S. Department of Transportation (DOT). The FMCSA is the lead federal government agency responsible for regulating and providing safety oversight of CMVs. The primary mission of the FMCSA is to reduce crashes, injuries and fatalities involving large trucks and buses.

The Chief Safety Officer and Assistant Administrator for FMCSA was engaged as part of this research and he iterated the value of non-CVE officers engaging in CMV enforcement. Most recently, the FMCSA deployed the Truck and Bus Traffic Enforcement Training (TBTET), again designed to enhance officers' knowledge about the dangers of unsafe truck and bus driving behaviors.

The Florida Highway Patrol, Office of Commercial Vehicle Enforcement is the lead agency for administering the Federal Motor Carrier Safety Assistance Program Grant. More than 200 FHP Troopers have specialized training, equipment, and National certifications necessary to conduct inspections and issued Federal enforcement actions. The FHP CVE Troops conduct vehicle weight inspections at 20 fixed FDOT weigh station locations and mobile enforcement with portable scales statewide. Troopers conduct more than 110,000 commercial vehicle inspections annually, placing more than 14,000 vehicles and more than 5,000 drivers out of service for critical safety violations. The Chief of the FHP Office of Commercial Vehicle Enforcement was contacted as part of this project and insights into agency activities were gleaned from discussions about enforcement practices.

The Commercial Vehicle Safety Alliance (CVSA) is a non-profit organization that supports both public and private commercial vehicle organizations to advance achieve uniformity, compatibility and reciprocity of commercial motor vehicle inspections and enforcement by certified inspectors. The CVSA Director of Crash Data Programs was engaged to better understand CMV enforcement. Nationally, safety is advanced as a partnership between industry and the enforcement community. The role of both enforcement officers, industry, and drivers were highlights of the discussion.

8.2. Systemic Countermeasures

Traditional approaches to reducing crashes have centered on identifying problem locations or "hot spots" in an attempt to direct resources. Problem locations typically manifest themselves in crash data, through higher frequency of crashes. Similarly, identification of risk factors holds the promise to understand crash causation so that treatments might be applied in a targeted way. The dominant risk factor for CMV crashes is not so different from the larger traffic crash experience for all vehicles, driver error accounts for the vast majority of crashes. Therefor countermeasures aimed at driver error seek to either change the behavior or drivers, or to mitigate the consequence of their errors.

The systemic approach relies on a broader view of treatments, targeting a greater geography and range of risk factors. Systemic approaches may involve prioritizing where investments may be made, which is common in the infrastructure/engineering solutions. In the case of enforcement and education, they imply a more general application of the treatment, 7 like agency-wide enforcement programs and area-wide media coverage.

For purposes of this Task, systemic countermeasures will describe generalized approaches that might be applied anywhere. This section also provides an opportunity for the three E's to be presented, along with some examples representing the more common applications.

8.2.1. Engineering Countermeasures

Engineering countermeasures are generally associated with the built environment. While there are numerous engineering countermeasures, there are a handful that are best suited for improving large truck and bus safety. Lane restrictions, differential speed limits, truck parking programs, traffic incident management, geometric design, median barriers, and surface treatments are approaches that have been used in an attempt to impact CMV safety.

8.2.1.1. Lane Restrictions

Truck lane restrictions are an engineering countermeasure that seeks to reduce interactions between large trucks and other vehicles on the roadway. Where trucks are restricted to use of certain freeway lanes, or restricted from use of certain freeway lanes, the technique is an effective way to maintain vehicle headways and reduce said interactions. Lane restrictions have found to be most effective when there are 3 or more directional lanes of travel (Cate et al. 2004). They have been viewed as an effective safety treatment that reduces crashes (Zeitz 2003).

Florida has prohibited trucks from using the left lane on a number of 3-lane rural freeway segments in the state (FDOT, 2019).

8.2.1.2. Differential Speed Limits

Speed and severity of crashes are undeniably linked, and speed and stopping distance for the CMV are equally inseparable. Having different speeds for trucks and other traffic introduces speed variance that may contribute to rear end and lane change type of crashes. A number of studies have found that differential speed limits (DSL) do not produce safety benefits (Wilmot and Khanal, 1999; Garber et al. 2003; Garber et al. 2006). DSL is a seldom-used treatment in Florida and one that likely only has specific and limited applications, based on unique roadway conditions.

8.2.1.3. Truck Parking Program

Given the fact that driver fatigue is often associated with CMV crashes, providing for adequate opportunity for rest is a key component of truck parking programs. Florida is a national leader in the area of truck parking, and several FDOT projects have enhanced truck parking along Florida Interstates and at rest areas as well as public and private facilities. The innovation inventories available parking at various locations and informs truck operators of availability via roadway signs, smart device applications, and the state 511 system. Coupled with electronic logging devices that monitor operator hours, parking programs have the potential to boost opportunities for driver rest.

8.2.1.4. Traffic Incident Management

Large trucks are disproportionately represented in secondary crashes. Traffic incident management (TIM) programs that focus attention on safe, quick clearance and advanced warning are ways to mitigate the dangers associated with trucks approaching roadway incidents. Queues that form at freeway incident scenes are among the most dangers situations for large vehicles because of stopping distance requirements.

The FDOT Rapid Incident Scene Clearance (RISC) is a program that is designed to expedite the clearance of roadways to mitigate congestion and queues that are often the breeding areas for secondary crashes. Additionally, the FDOT Road Ranger service patrol program is a strategy that provides temporary traffic control and advance warning.

Advance warning via 511 and roadway changeable message signs (CMS) are effective TIM strategies. Efforts to monitor queue lengths are emerging technologies, but certainly worthwhile to reduce the most serious injury and fatal crashes involving CMV. The Tennessee Highway Patrol and Tennessee DOT have created a queue monitoring program that expedites resources to protracted freeway incident scenes, specifically to warn approaching vehicles at the back of a queue (TDOT, 2019). Traffic incident management is an effective engineering countermeasure and should be used whenever possible, particularly on higher speed rural freeway segments where truck traffic is dominant.

8.2.1.5. Geometric design changes

Geometric design changes are likely among the costliest treatments. Flattening curves, changing cross slope breaks, or truck by-pass routes are some of the changes that can improve truck safety. Passing lanes, climbing lanes, and dedicated truck lanes require right of way and expensive capital outlay. The opposite of climbing lanes escape routes allow drivers to divert away from traffic in the case of brake failure.

8.2.1.6. Barriers

Physical barriers help prevent vehicle median crossover crashes, as well as crashes involving roadside objects. Research indicates that concrete walls, guardrails, and cable barrier systems are all effective treatments at reducing serious injury crashes. Some systems like high-tension cable barrier systems are actually more effective and less costly than alternatives (Zou et al. 2014). Even where barrier systems are not specifically designed for large trucks, evidence shows that such systems prevent truck penetration about half of the time (Gabauer 2012).

8.2.1.7. Signs, Signals, and Markings

Among the most cost-effective treatments are signs, signals, and markings. Ensuring that retroreflective properties of signs remain effective maximizes the chances that large truck drivers can see those signs given the level of their vehicle lights. Duplicating warning signs or increasing their size can help the drivers of high-profile vehicles notice them better.

Signal treatments might be detection control that can extended green phases by identifying the speed and distance of approaching trucks, or intelligent transportation systems (ITS) that detects a vehicle's speed on a curve or exit ramp and warns the driver with flashing lights. Another ITS treatment is warning signs that provide speed feedback when entering areas where speeds are reduced, or special hazards exist. Road weather information systems (RWIS) and work zone systems are other ways that technology provides drivers with information and warning about changing road conditions.

Roadway markings are among the most cost-effective treatments. Wider edge lines help drivers identify lanes and avoid shoulder drop-offs. Horizontal signs painted on the roadway eliminate the competition of roadside or overhead signs on driver attention. Using contrasting markings is an effective way to increase the effectiveness of white pavement markings.

8.2.1.8. Surface treatments

Surface treatments encompass a range of engineering countermeasures to improve the friction, drainage, markings, or edges. Increasing roadway surface friction is a sound way to mitigate the effects of weather and improve braking for CMVs. Similarly, making changes to roadway pavement or drainage can reduce the amount of water on the roadway, increasing tire adhesion and improving braking efficiency. On roadway edges, increasing the width of edge lines can help drivers identify travel lanes, and adding rumble strips can warn drivers when those edges are crossed.

8.2.1.9. Driver Assist Systems

Given the fact that more than 90 percent of crashes involving CMV are attributed to human factors, an important area of engineering is dedicated to vehicle systems that assist drivers. Many of these technologies are now available to consumers of passenger vehicles, as well as the CMV. Lane departure warning systems, automatic braking, backup warning devices, drowsy driver alerts, and parking assist technology are just a few vehicle-based engineering solutions. Side view cameras and detection systems hold great promise in reducing truck crashes, and it is estimated that forward-facing detection systems could reduce rear end collisions by 37 percent (IIHS, 2019). Electronic stability control systems are another area where technology can assist CMV drivers. While these technologies and treatments are beyond the scope of implementation as a CMV countermeasure, they are worthy of mention here and potential support by public policy-makers.

8.2.2. Enforcement Countermeasures

Manual traffic enforcement is the familiar process of a police officer in a marked cruiser observing a traffic violation and subsequently executing a traffic stop of a vehicle along the side of a roadway. The subsequent contact with the driver provides an opportunity to discuss the observed violation, potentially issue a citation or warning, and thereby correct the violation. The visible enforcement also serves as a general deterrent for other drivers who might see the police vehicle with the violator vehicle positioned on the shoulder of the roadway in the traffic stop scenario. An officer stopping a truck or bus is highly noticed by other CMV traffic.

Traffic enforcement is viewed as a valuable countermeasure that includes an opportunity to educate the individual who has been contacted through the stop. While typically viewed as a negative encounter by most motorists, the enforcement contact can provide positive outcomes that advance safety. The following sections highlight enforcement activities and related topics.

8.2.2.1. Legal Basis for Enforcement of Common Violations

Title 49 USC 31102, motor carrier safety assistance program, outlines the responsibilities of states to plan and execute safety programs for trucks and busses. States are required to have plans, include CMV safety in driver manuals, and engage in high visibility enforcement activities.

The Federal Motor Carrier Safety Administration is responsible for ensuring full compliance with all Federal Motor Carrier Safety Regulations (FMCSR) required of truck, bus and motor coach companies regulated by the U.S. Department of Transportation. Officers who have specialized training from the Federal Motor Carrier Safety Administration can conduct inspections of commercial vehicles and issue Federal enforcement actions in addition to Florida Uniform Traffic Citations. The North American Standard Inspection is the type of specialized activity that these offices conduct under Federal regulations. Officers with this training are sometimes referred to as MCSAP officers (Motor Carrier Safety Assistance Program). Additional certifications for hazardous materials are available to those officers who hold the appropriate levels of training.

The commercial vehicle enforcement paradigm in Florida has left most contact with commercial vehicles to specialists within the Florida Highway Patrol Commercial Vehicle Enforcement (CVE) troops. Notwithstanding this specialization, any law enforcement officer in Florida has legal authority to stop commercial vehicles for observed violations of the state's motor vehicle and licensing codes, typically found in Florida Statute Chapters 316, 318, 320, and 322.

> *316.302 Commercial motor vehicles; safety regulations; transporters and shippers of hazardous materials; enforcement.*
>
> *(9) (a) Any member of the Florida Highway Patrol or any law enforcement officer employed by a sheriff's office or municipal police department authorized to enforce the traffic laws of this state pursuant to s. 316.640 who has reason to believe that a vehicle or driver is operating in an unsafe condition may, as provided in subsection (11), enforce the provisions of this section.*
>
> *(11) Any traffic enforcement officer or any person otherwise authorized to enforce this section may issue a traffic citation as provided by s. 316.650 to an alleged violator of any provision of this section.*

8.2.2.2. Roadside Inspection

Where CMV are concerned, specially trained enforcement personnel typical engage the drivers of large truck in roadside inspections and enforcement stops. As mentioned, the North American Standard Inspection is typical among CVE/MCSAP officers. CVSA is the official body responsible for the development and distribution of the North American Standard Part A (Driver), Part B (Vehicle), Passenger Carrier Vehicle, Cargo Tank, Hazardous Materials/Dangerous Goods and Other Bulk Packaging.

This highly visible activity is a prominent part of traffic safety, though one which is difficult to measure quantitatively. The FMCSA has created the roadside intervention effectiveness model (REIM) in an attempt to quantify the benefits of enforcement and inspection activities (FMCSA, 2019). The model seeks to attribute a potential reduction in crashes with those activities. Unlike the crash modification factors (CMF) in the highway capacity manual (HCM), the REIM is an aggregated estimate that is not intended for use at specific locations.

8.2.2.3. Truck and Bus Traffic Enforcement Training

Given there are only about 200 Florida officers who have the training and certification needed to sanction drivers under Federal CMV regulations, enforcement of state laws by state and local patrol officers is a critical component of a CMV safety effort. With thousands of certified officers in Florida, a familiarity with CMV operations provides those officers with the tools to engage in truck enforcement activities for violations of Florida statutes. Relevant statutes that might be enforced are those that contribute to crash reduction and safety, such as, following too closely, changing lanes, wireless device use, occupant restraint, loads on vehicles, vehicle equipment, and loads on vehicles.

Since driver behavior is a chief issue in CMV crash causation, enforcement of moving traffic violations is a very important part of the enforcement countermeasure. Non-inspection enforcement can be accomplished by any officer and it advances CMV safety in a significant way. Similarly, enforcement of non-CMV vehicles that commit violations around the CMV, creating a hazard is also an important role for both CVE and non-CVE enforcement officers. The FMCSA has developed a specialized training program entitled, “Truck and Bus Traffic Enforcement Training” to promote CMV enforcement among non-CVE officers (FMCSA, 2018a). This might be a good program to bring to Florida to be a force multiplier for the FHP CVE effort.

8.2.2.4. Fair game rules

In commercial vehicle enforcement, “fair game rules” describe enforcement actions that target all road users as potentially contributing to crashes involving commercial vehicles. It is understood that many commercial vehicle crashes involve passenger automobiles and often those vehicles or their drivers are contributing causes of the crashes. Similarly, other road users like pedestrians and bicyclists are also involved in collisions with large trucks and their culpability would also be appropriate to consider in the enforcement scenario.

Neglecting the role of non-commercial vehicle road users in targeted enforcement would be miss a significant factor in the safety equation, therefore any effort to reduce crashes should consider enforcement actions for all road users for relevant violations. Fair game rules denote an enforcement philosophy whereby law enforcement officers might stop any road user that commits an infraction of the traffic laws that might lead to a collision involving a CMV.

8.2.2.5. High Visibility Enforcement (HVE)

High visibility enforcement (HVE) is a traffic enforcement strategy that seeks to create a general deterrence among drivers through highly publicized and visible police activity using marked patrol vehicles. HVE is often accomplished with a surge of marked patrol vehicles in a geographic area for a short period of time, actively engaged in traffic stops with emergency lights activated for increased visibility. The HVE typically targets a particular type of traffic violation in a concentrated way. Press releases announcing the purpose and location of the activity can generate additional awareness by the public when included in print or electronic media. Transportation agencies sometimes use changeable message signs (CMS) or portable CMS to tailor enforcement or safety messages in the general area of the HVE deployment.

In Florida, CVE Troopers typically drive large SUVs, further identifying their purpose to a discerning public who might be familiar with their operations, like CMV operators. Actively stopping CMV and informing them of the HVE as a safety initiative typically results in word of mouth sharing with other operators, again amplifying the value of the enforcement.

HVE is a proven traffic enforcement strategy that has been used by Florida agencies for speeding, belt use, impaired driving, and other violations. Though seldom used for CVE, there is a potential for the tactic to be an effective tool in an overall enforcement strategy.

8.2.2.6. Following too closely

Perception-reaction time, and the capabilities of vehicle braking systems combine to form a total stopping distance for all vehicles. The laws of mass and motion dictate that large trucks require longer distances to stop. This is one of the reasons that Florida law specifically mentions following distance restrictions for trucks and combination vehicles. In conversations with enforcement experts, following too closely is a principal driver behavior that contributes to crashes. Following too closely is a common violation that enforcement stop and cite drivers for. Florida's following too closely statutes states:

> *316.0985 Following Too Closely*
>
> *(1) The driver of a motor vehicle shall not follow another vehicle more closely than is reasonable and prudent, having due regard for the speed of such vehicles and the traffic upon, and the condition of, the highway.*
>
> *(2) It is unlawful for the driver of any motor truck, motor truck drawing another vehicle, or vehicle towing another vehicle or trailer, when traveling upon a roadway outside of a business or residence district, to follow within 300 feet of another motor truck, motor truck drawing another vehicle, or vehicle towing another vehicle or trailer. The provisions of this subsection shall not be construed to prevent overtaking and passing nor shall the same apply upon any lane specially designated for use by motor trucks or other slow-moving vehicles.*

(3) Motor vehicles being driven upon any roadway outside of a business or residence district in a caravan or motorcade, whether or not towing other vehicles, shall be so operated as to allow sufficient space between each such vehicle or combination of vehicles as to enable any other vehicle to enter and occupy such space without danger. This provision shall not apply to funeral processions.

8.2.2.7. Changing lanes

Similar to stopping distance, large trucks are decidedly less capable of taking evasive maneuvers. When the drivers of non-CMV change lanes abruptly, or too close in front of a large truck, it creates a dangerous condition that can cause the CMV to lose control or strike the offending vehicle. Enforcement personnel often observe this type of violation, jeopardizing the CMV vehicle/driver. Fair game rules recognize that the drivers of non-CMV should be stopped and cited when committing infractions that cause hazards to large trucks and busses. While CMV make lane change judgement errors because of blind spots, non-CMV are the focus of lane change violations because of aggressive maneuvers that create hazards.

316.083 Overtaking and passing a vehicle. —The following rules shall govern the overtaking and passing of vehicles proceeding in the same direction, subject to those limitations, exceptions, and special rules hereinafter stated:

(1) The driver of a vehicle overtaking another vehicle proceeding in the same direction shall give an appropriate signal as provided for in s. 316.156, shall pass to the left thereof at a safe distance, and shall not again drive to the right side of the roadway until safely clear of the overtaken vehicle.

8.2.2.8. Wireless communications

Florida law contains a prohibition on the use of handheld wireless devices. As a secondary violation, the driver must be stopped for a separate infraction in order for wireless device use to be cited. Federal law however, stipulates that CMV operators cannot use wireless devices and prohibits use in a more restrictive way (FMCSA, 2012). Under Federal rules, the violation is a primary offense.

316.305 Wireless communications devices; prohibition. —

(3)(a) A person may not operate a motor vehicle while manually typing or entering multiple letters, numbers, symbols, or other characters into a wireless communications device or while sending or reading data on such a device for the purpose of novice interpersonal communication, including, but not limited to, communication methods known as texting, e-mailing, and instant messaging.

The Federal rule for prohibits holding a mobile device and pressing or dialing more than a single touch of the device. Reaching for a device is also viewed as a distraction and guidance from the Federal Motor Carrier Safety Administration encourages no reaching, holding, dialing, texting, or reading. Compliance encourages close proximity, use of hands-free listening, and voiceactivated dialing. Penalties can be up to $2,750 in fines for drives and potential disqualification for a commercial driving license (FMCSA, 2012).

8.2.2.9. Vehicle Equipment

Commercial motor vehicles are disproportionately represented in historical crash data for faulty equipment that contributes to the crash. A key part of truck enforcement centers on inspection and identification of equipment violations. The roadside inspection that is part of the multi-level certification for CVE specialists. Again, any Florida enforcement officer can stop and cite a CMV for common equipment violations like lights, tires, mirrors, etc. Florida State Statute 316.215 and 316.610 specify the requirements for safe vehicle equipment and inspection thereof:

> *316.215 Scope and effect of regulations. —*
>
> *(1) It is a violation of this chapter for any person to drive or move, or for the owner to cause or knowingly permit to be driven or moved, on any highway any vehicle, or combination of vehicles, which is in such unsafe condition as to endanger any person, which does not contain those parts or is not at all times equipped with such lamps and other equipment in proper condition and adjustment as required in this chapter, or which is equipped in any manner in violation of this chapter, or for any person to do any act forbidden, or fail to perform any act required, under this chapter.*
>
> *316.610 Safety of vehicle; inspection. —*
>
> *It is a violation of this chapter for any person to drive or move, or for the owner or his or her duly authorized representative to cause or knowingly permit to be driven or moved, on any highway any vehicle or combination of vehicles which is in such unsafe condition as to endanger any person or property, or which does not contain those parts or is not at all times equipped with such lamps and other equipment in proper condition and adjustment as required in this chapter, or which is equipped in any manner in violation of this chapter, or for any person to do any act forbidden or fail to perform any act required under this chapter.*

There are other statutes applicable to specific vehicle equipment that may also be used.

8.2.2.10. Loads on Vehicles

By their nature, many large trucks carry loads either within or on their chassis or trailer. When those loads shift, spill, or drop, it creates a dangerous situation for the CMV as well as other traffic and road users. In the CMV scenario, truck weight limitations are also a significant part of operations with FDOT weigh stations and portable scales used by enforcement officers. Vehicle weight plays an important role in vehicle stability and stopping distance, and therefore is another aspect of vehicle equipment and enforcement that are important to reducing crashes.

Florida law contains great detail about weigh restrictions and limitations. Enforcement is typically undertaken at weigh stations and by CVE certified officers with the expertise and equipment necessary to detect violations.

316.545 Weight and load unlawful; special fuel and motor fuel tax enforcement; inspection; penalty; review. —

316.525 Requirements for vehicles hauling loads. —

(1) It is the duty of every owner, licensee, and driver, severally, of any truck, trailer, semitrailer, or pole trailer to use such stanchions, standards, stays, supports, or other equipment, appliances, or contrivances, together with one or more lock chains, when lock chains are the most suitable means of fastening the load, or together with nylon strapping, when nylon strapping is the most suitable means of securing the load, so as to fasten the load securely to the vehicle.

8.2.2.11. Seat Belt Use

Florida's seat belt law has provisions that exclude commercial motor vehicles, however Federal Regulations do impose restrictions on the CMV driver. Section 392.16 of the Federal Motor Carrier Safety Regulations (FMCSAR), requires that, "...a CMV which has a seat belt assembly installed at the driver's seat shall not be driven unless the driver has properly restrained himself/herself with the seat belt assembly." (FMCSA, 2017) While seat belts do not have any effect on crash causation, they do represent a means by which injuries are reduced when a collision does occur. A number of states have implemented enforcement programs where officers positioned on overpasses and other vantage points observe violations and radio fellow officers who are positioned downstream to engage in the enforcement stop of the vehicle.

8.2.3. Education Countermeasures

Public information and safety education are the typical activities that describe the education countermeasure group. It is often difficult to measure the effectiveness of education countermeasures in traffic safety. Paid media, earned media, and social media are the typical ways in which traffic safety communication is achieved.

A strategic communication plan is typically created to ensure that a targeted approach is undertaken, with specificity about who, where, and how the audience will be engaged. While a coordinated media effort might originate in a central office for public affairs or communications, safety education often relies on organizational champions to get the word out.

Paid media is synonymous with the advertising that we see every day. As its name implies, paid media requires funding to purchase exposure. While radio, television, and print are the most recognizable medium, innovative purchases like movie theaters, sporting events, and promotional items can also get traffic safety messages out.

Unlike paid media, earned media involves messaging with little or no monetary investment. Public service messages, press events, website links/banners, marquee signs, and workplace/school programs are just a few examples of "free" advertising.

Social media is an emerging arena of communication, and one that is particularly used by younger audiences. Social media relies on people helping to spread the word about a idea, product, or service. The seeds of social media can be planted by organizations or champions, and their networks are challenged to help generate interest.

The following sections describe the topical basis for education efforts as they relate to CMV crashes.

8.2.3.1. No Zone/Blind spots

Large trucks have blind spots on all four sides, making the ability to see surrounding traffic a complicate task for CMV drivers. The public information objective for blind spot programs is to make motorists aware of these blind spots so that they might avoid driving in those areas. Some of the most effective ways to convey the dangers of blind spots are images and info graphics that graphically depict their location around an image of a truck (FMCSA, 2018b). Another effective strategy for educating the public is the use of a tractor trailer, painted with special graphics depicting those no zones. When taken to public events, the trailer becomes a highly visible focal point, reinforcing the need to share the road and stay out of blind spots. The Florida Highway Patrol uses a no zone trailer for public outreach (FLHSMV, 2016). Blind spots for trucks and busses are also very dangerous for bicyclists and pedestrians, given they are smaller and more challenging to see. Public outreach should inform all road users of the dangers near large profile vehicles.

8.2.3.2. Stopping distance

Trucks and busses require longer distances to stop. Public information aimed at reminding drivers of those vehicles is important to insure they manage their speed and following distance. Reminding other road users is also important because it prevents them from placing the CMV driver in a dangerous situation that they may not be able to stop for. Like other vehicles, rain, snow, and ice can increase stopping distance significantly. When fully loaded, a bus or truck and take up to the length of two football fields to stop at 65 miles per hour.

8.2.3.3. Lane changes

When the drivers of other vehicles pass and cut in front of a large truck it brings together a number of truck safety factors. At some point during the maneuver, the offending vehicle is likely operating in a truck’s blind spot. It also implicates the truck’s ability to stop, given the fact that buses and trucks can take up to 40 percent longer to stop. Large vehicles are also less agile and evasive maneuvers are more challenging. Share the road programs are aimed at making the public aware of the dangers of changing lanes abruptly around large vehicles. The Florida Trucking Association uses a “Road Team” of experienced drivers and safety professionals to make public presentations about sharing the road with trucks. They often appear at civic organizations and schools, encouraging other road users to recognize the dangers of operating CMV (FTA, 2018). The CVSA has a tri-fold brochure on the topic (CVSA, 2019).

8.2.3.4. Following too closely

The Large Truck Crash Causation Study (LTCCS) found that 5 percent of large truck crashes were the result of the CMV following too closely (CVSA, 2019). Stopping distance and blind spots are complicated by following too closely. When trucks are platooning, this becomes a critical scenario. Because of vehicle heights, following too closely also complicates slowing or stopping for unexpected events like traffic queues or incidents.

8.2.3.5. Anticipate wide turns/Intersections

Like other aspects of driving a large dimension vehicle, making turns is not the same as passenger cars. Because of the distance between axles, trucks and busses off-track, meaning they require a wider turning radius. It is important for the public to understand wide turns so that they can avoid the pitfalls of trucks that are preparing for, or executing a wide turn at an intersection or in a parking lot. With a turning radius of 55 feet or more, drivers and pedestrians must be careful not to move into the space created by a CMV that is setting up to turn right or left. Truck drivers must be care to use signals well ahead of intended turning situations

8.2.3.6. Driver fatigue

Driver fatigue among truck and bus drivers is a common problem. Research indicates that about 13 percent of CMV drivers were fatigued at the time of crash (CVSA, 2019). Where public information and safety education are concerned, it is critical to continually reminder CMV operators of the dangers associated with drowsy driving. While hours of operation limits are designed to prevent drivers from driving too long, research indicates that the time of day may actually be more important (FMCSA, 1996). Drivers need to understand that a combination of time of day and the duration of the driving activity may be compounding.

8.2.3.7. Occupant restraint use

National campaigns for occupant restraint use like "Click it or Ticket" have boosted the national belt use average in passenger cars from about 85 percent in 2010 to 90 percent in 2017 (NHTSA, 2018). According to the most recent statistics from the Federal Motor Carrier Safety Administration, the compliance rate for CMV is about 86 percent (FMCSA, 2017). Despite progress, 34 percent of large truck occupants killed in the U.S. are unrestrained (FMCSA, 2006).

The FMCSA has created a suite of educational and promotional materials to promote the use of seat belts among CMV operators (FMCSA, 2014c).

8.2.3.8. Distracted driving

Like all drivers, CMV operators are subject to many in-vehicle distractions. Using electronic devices like cell phones or smart devices are readily associated with driver distraction, but there are other forms of driver distraction that are equally problematic. Evidence from a naturalistic driving study found that using calculators, looking at maps, reading, personal grooming, reaching for an object, and putting on sunglasses were other types of activities that take a CMV driver's attention away from driving (Olson et al., 2009). Outreach on the topic of driver distraction centers on educating CMV operators about the dangers of distracted driving and providing them with strategies and techniques for minimizing distractions. The CVSA has created a video training program and related materials to inform drivers about the topic (Defeat Distracted Driving Materials 2019). A tri-fold brochure accompanies the 16-minute video.

8.2.3.9. Officer/Driver Exchange Programs

A number of states have created programs where CMV drivers might meet or ride with an enforcement officer to gain a different perspective on their job. Conversely, an enforcement officer might ride with a truck driver to better understand their profession.

8.3. Targeted Countermeasures

While systemic countermeasures describe generalized treatments for enforcement and education, targeted countermeasures are aimed at specific locations including hot spot areas and intersection. Where engineering countermeasures are concerned, a systemic application might prioritize locations, while targeted efforts would identify with greater specificity the treatment that is needed. Targeted engineering solutions would involve a more in-depth safety analysis given the potential investment required.

This chapter first presents the available countermeasures from the literature organized in tabular form and categorized by engineering countermeasures for vehicles, engineering countermeasures for roadway, enforcement countermeasures, and education countermeasures. Next this chapter presents 35 critical locations in the state of Florida. For each location we present applicable countermeasures that can be applied as necessary. For each critical location, we highlight the notable reasons for both large trucks and other vehicles involved in the large truck-related crashes. The final part of this chapter ranks the recommended countermeasures by cost level for each most notable critical reason.

The countermeasures discussed in this chapter are organized using the critical reason framework presented in Chapter 5. The framework includes the following six general categories:

- Driving Error
- Non-Driving Error
- Driver Distraction or Vision Obstruction
- Vehicle Defect
- Roadway Conditions
- Weather Conditions

8.3.1. The countermeasure Summary Tables

This section summarizes truck crash countermeasures from the literature. There are four summary tables of countermeasures: 7 engineering countermeasures for vehicles, 34 engineering countermeasures for roadway, 9 enforcement countermeasures, and 7 education countermeasures. The first column of each table contains the ID of each specific countermeasure. The Name column records the names of the countermeasures. The Usage column provides a brief description of the countermeasure. The detailed information of the countermeasure can be found in the corresponding literature shown in the Source column. Target Critical Reason column contains the critical reasons targeted by the countermeasure. Cost-Effectiveness column indicates the cost level (low, medium, or high) of a countermeasure, and whether the countermeasure is proven to be effective, tried, or just an experimental measure. Some countermeasures also have a crash modification factor (CMF). The primary source of the CMF values is the CMF clearinghouse and other online sources are also used to estimate the CMF values if the countermeasure was not found in the CMF Clearinghouse. These CMF values are determined for all vehicle types unless otherwise noted in the table, and the values are usually provided as a range since multiple studies on the same countermeasure may result in several different CMF values.

Table 66 **Engineering Countermeasures: Vehicle**

No.	Name	Usage	Target critical reason	Cost-effectiveness	Source	CMF Name[1]	CMF Value[2]
Eng1	Lane Departure Warning Systems (virtual rumble strips)	Detect lane departures and give feedback to drivers through vibration, audio or light. It can reduce crashes caused by driver inattention and fatigue	Driving Error; Driver Distraction /Vision Obstruction	Proven, low cost	FHWA, 2016		
Eng2	Back-up camera systems	Add back-up camera systems to large trucks	Driving Error; Driver Distraction /Vision Obstruction	Moderate to high cost	Blower, 2007		
Eng3	Side-object detection	Add mirrors or light alert systems that allows truck drivers to notice side-object	Driving Error; Non-Driving Error; Driver Distraction /Vision Obstruction	Moderate to high cost	Blower, 2007		
Eng4	Driver monitoring systems	Detect and alert drowsy/distracted drivers through a camera	Non-Driving Error	High cost	Blower, 2007		
Eng5	Forward collision avoidance systems	Use radar/ laser to detect imminent crash and take brake action autonomously.	Driving Error	High cost	Blower, 2007	Forward collision warning system	0.8 (estimated)[3]
Eng6	Adaptive cruise control	Adjusts speed automatically to maintain a safe distance from the vehicle ahead	Driving Error; Non-Driving Error	High cost	Blower, 2007		
Eng7	Enhanced seat belt warning system	Visual and audible warning activates when the large truck driver or other occupants fail to use seat belt.	Driving Error	Moderate cost	Woodrooffe and Blower, 2015		

[1] Crash modification factor (CMF) names are found in CMF clearinghouse. (http://www.cmfclearinghouse.org/)
[2] The value indicates the proportion of crashes would happen after implementing the named countermeasure.
[3] 'Estimated' means this CMF value is not from CMF clearinghouse, it is estimated based on https://cmvdrivingsafety.org/modules/safety-systems/

Table 67 Engineering Countermeasures: Roadway

No.	Name	Usage	Target critical reason	Cost- effectiveness	Source	CMF Name	CMF Value
Eng8	Truck restricted lanes	Restrict truck on certain lanes using signs can separate slow moving truck from other fast-moving vehicles during a certain time. This countermeasure has proven to be effective in reducing number of crashes and crash severity.	Driving Error	Proven, low cost	FHWA, 2016	Implement truck lane restrictions on 4-lane freeways (truck crashes)	0.73 – 1.12 [4]
Eng9	Oversize/Overweight Corridors	Designate, construct corridors specifically for oversize/overweight trucks. The geometric changes of the road and impact fees on the road pavement and structures can be designed more suitable for oversize/overweight trucks.	Driving Error	Experimental, high cost	FHWA, 2016		
Eng10	Virtual Weigh Stations	Add to places where traditional enforcement operations may be difficult to deploy	Driving Error	Proven, Moderate cost	FHWA, 2016		
Eng11	Flatten Curve	Reconstruct the curve by increasing the curve length so that the drivers need less severe maneuver. This countermeasure can reduce the number of crashes and crash severity.	Driving Error; Non-Driving Error; Roadway Condition	Proven, high cost	Huang et. al, 2001	Flatten horizontal curve	0.315 - 0.584
Eng12	Rumble Strips	Apply at center lines, edge lines or shoulders. It can reduce crashes caused by driver inattention and fatigue.	Driving Error; Driver Distraction /Vision Obstruction	Proven, low cost	FHWA, 2016	Install centerline and shoulder rumble strips	0.34 - 1.021

[4] CMF value vary by crash type, crash severity, roadway type, and area type. A CMF value great than 1 indicates an expected increased crash count.

Table 67 Engineering Countermeasures: Roadway (Continued)

No.	Name	Usage	Target critical reason	Cost- effectiveness	Source	CMF Name	CMF Value
Eng13	High-Friction Surface Treatments (HFST)	This countermeasure is appropriate at intersection, curves, and ramps to increase the surface friction.	Roadway Condition, Weather Condition	Proven, low to moderate cost	FHWA, 2016	Install high friction surface treatment (HFST)	0 - 0.36
Eng14	Cross-slope Breaks	Use of a rounded shoulder may alleviate vehicle stability issue associated with large cross-slope breaks. Personals who are responsible for the construction and maintenance need education not to create large cross-slope breaks.	Driving Error, Non-Driving Error, Roadway Condition	Tried, moderate cost	FHWA, 2016		
Eng15	Enhanced Drainage	Drainage structures need to be calibrated to local weather conditions.	Roadway Condition	Tried, moderate cost	FHWA, 2016		
Eng16	Higher-Performance Barriers	Could be designed at high severe crash locations.	Reduce severity	Proven, moderate to high cost	FHWA, 2016		
Eng17	Adding Escape Ramps	Designed at the downhills of sharp curves, allow large truck drivers to divert away from main traffic and dissipate the energy once the break system fails.	Vehicle Defects, Roadway Condition	Proven, high cost	FHWA, 2016	Install truck escape ramp (CMF ID 868)	0.25

Table 67 Engineering Countermeasures: Roadway (Continued)

No.	Name	Usage	Target critical reason	Cost- effectiveness	Source	CMF Name	CMF Value
Eng18	Climbing Lanes	Mitigate the risk of passing behavior with limited sight climbing hills.	Driving Error; Driver Distraction / Vision Obstruction	Proven, high cost	FHWA, 2016	Provide passing lane or climbing lane	0.58 - 0.75
Eng19	Alternate Passing Lanes	Provide a third passing lane in the middle for two-lane opposite direction road.	Driving Error	Proven, high cost	FHWA, 2016	Provide passing lane or climbing lane	0.58 - 0.75
Eng20	Exclusive Truck Roadways	Build outer roadways for trucks and also allow passenger cars to travel on it.	Driving Error	Experimental, high cost	FHWA, 2016		
Eng21	Interchange Truck bypass	It facilitates the trucks merge safely to the main traffic at the interchange. An example can be find at I-405 and I-5, Irvine, CA	Driving Error	Tried, high cost	FHWA, 2016		
Eng22	Static Warning Signs	Duplicated warning signs (stop, yield, rollover, curve and so on) on both side of the road to prevent blocked sight by other larger vehicles. Increase the size of the warning signs.	Driving Error; Driver Distraction / Vision Obstruction; Roadway Condition	Proven (static) or experimental/promising (oversized static), low cost	FHWA, 2016	Advance static curve warning signs	0.7 – 0.92
Eng23	Updating retroreflective traffic signs	Since the angle of large truck headlamps to the sign and the light back to large truck drivers' eye is greater, it is critical to keep retroreflective signs visible for these drivers at night	Driving Error; Roadway Condition	Proven, moderate cost	FHWA, 2016		

Table 67 Engineering Countermeasures: Roadway (Continued)

No.	Name	Usage	Target critical reason	Cost- effectiveness	Source	CMF Name	CMF Value
Eng24	Updating signs to MUTCD standards	Follow the Manual on Uniform Traffic Control Devices to inform the drivers with consistent messages when they drive on roadways operated by different agencies.	Driving Error; Roadway Condition	Proven, moderate cost	FHWA, 2016		
Eng25	Dynamic warning signs	Showing the CMV speed and the suggested speed before entering high risk areas, such as high roller risk area, signalized intersection area. This countermeasure is not affective to frequent drivers.	Driving Error; Non-Driving Error; Driver Distraction / Vision Obstruction	Proven, low to moderate cost	FHWA, 2016	Install dynamic advance intersection warning system	0.1 - 0.46
Eng26	Truck rollover warning system	Intelligent Transportation System installed on freeway exit ramps notifying drivers about the excessive speed or road conditions to prevent rollover crashes on sharp curves.	Driving Error; Driver Distraction /Vision Obstruction; Roadway Condition	Proven, moderate cost	Pigman, 1999	Install dynamic advance intersection warning system	0.1 - 0.46
Eng27	Contrast marking	Apply black marking horizontally after the white marking. This countermeasure increases the visibility of the marking.	Driving Error; Non-Driving Error; Driver Distraction / Vision Obstruction	Tried, moderate cost	FHWA, 2016, Carlson et al., 2007		
Eng28	Horizontal Signing	These signs on the road pavement draw more attention of the drivers in addition to other roadside signs and overhead signs at a location. This countermeasure is beneficial at interchanges since it reduces the last minute lane changes of passenger vehicles in front of large trucks.	All critical reasons	Tried, low cost	FHWA, 2016		

Table 67 Engineering Countermeasures: Roadway (Continued)

No.	Name	Usage	Target critical reason	Cost- effectiveness	Source	CMF Name	CMF Value
Eng29	Detection-Control Systems for Traffic Signals	With this system, traffic signals stop green phase by detecting the speed, length of the approaching large truck, to prevent it from running red light or failing to stop after other vehicles.	Driving Error; Non-Driving Error; Roadway Condition	Proven, moderate to high cost	FHWA, 2016		
Eng30	Wider Edge Lines	Wider edge lines over the 4-inch minimum MUTCD standard communicate better.	Driving Error; Non-Driving Error; Distraction / Vision Obstruction	Proven, low cost	FHWA, 2016	Install wider edgelines	0.341 - 0.962
Eng31	Work Zone and Incident Notification Systems	Large truck driver receives notification about work zone or incident ahead through telecommunication, or portable signs to prevent failing to stop. For example, portable dynamic signs showing stopped traffic ahead whenever the portable radar system detects queued traffic at the work zone.	Driving Error	Proven, high cost	FHWA, 2016		
Eng32	Visibility and Wind Detection Systems	Road Weather Information Systems are used at high weather risk locations (wind, fog) to inform large truck drivers to take certain actions (reduce speed, stop driving).	Weather Condition	Proven, moderate to high	FHWA, 2016		
Eng33	Traffic Incident Management (TIM)	Traveler information, advance warning, and queue protection strategies to reduce rear end collisions	Driving Error	Proven, low cost	FHWA, 2019b		
Eng34	Truck Parking Availability Systems (TPAS)	Enhancements to facilitate truck parking, facilitating rest	Driving Error	Proven, moderate cost	FHWA, 2019b		

Table 68 Enforcement Countermeasures

No.	Name	Usage	Target critical reason	Cost-effectiveness	Source	CMF Name	CMF Value
Enf1	High Visibility Enforcement (HVE)	Increased and/or intensified generalized traffic enforcement on truck corridors or CMV	Driving Error	Proven, moderate cost	NHTSA		
Enf2	Targeted Enforcement – Truck Lane Restrictions	Increased or intensified enforcement where FDOT has implemented lane or roadway restrictions	Driving Error	Proven, moderate cost	FHWA, 2016		
Enf3	Targeted Enforcement - Oversize/Overweight	Increased or intensified enforcement of width, weight, and length limitations and permits	Driving Error; Vehicle	Proven, moderate cost	FHWA, 2016		
Enf4	Targeted Enforcement – Inspection/Equip.	Increased or intensified enforcement of vehicle equipment and safety	Vehicle	Proven, moderate cost	FHWA, 2016		
Enf5	Targeted Enforcement – Following Too Closely	Increased focus for enforcement of laws related to following too closely	Driving Error	Proven, moderate cost	Blower, 2007		
Enf6	Targeted Enforcement – General Patrol	Enforcement resources are limited and should be concentrated on the most problematic areas.	All critical reasons	Proven, moderate cost	Blower, 2007		
Enf7	Targeted Enforcement – CMV Electronic Device use	Enforcement resources use vantage points to observe CMV use of handheld electronic devices	Driving Error; Distraction	Proven, moderate cost			
Enf8	Strengthen Commercial Driver's License (CDL) Program	Comply with all of the provisions of the CDL, decrease the chance of fraudulent issuing of license	All critical reasons	Proven, moderate cost	Blower, 2007		
Enf9	Targeted Enforcement - HAZMAT	Specialized Enforcement of hazardous materials transport violations	Driving error; equipment	Proven, moderate cost			

Table 69 Education Countermeasures

No.	Name	Usage	Target critical reason	Cost- effectiveness	Source	CMF Name	CMF Value
Ed1	Increase Public Understanding of Driving with Trucks	Incorporate instructions on how to drive safely near large trucks into light vehicle driving courses and licensing process. This countermeasure can reduce hazardous car-truck interactions	Driving Error; Non-Driving Error; Distraction / Vision Obstruction	Proven, low to moderate cost	Blower, 2007		
Ed2	No Zone	Increase public understanding of large truck sight limitations	Driving error; Distraction / Vision Obstruction	Proven, low to moderate cost			
Ed3	Safe Passing	Increase public understanding of safe lane changes after passing large trucks	Driving error	Proven, low to moderate cost			
Ed4	Slow Traffic in Left Lane	Increase public and CMV understanding about limitations on driving in left lane – Don't hand out in the left lane and similar programs	Driving error	Proven, low to moderate cost			
Ed5	Distracted Driving	Increase CMV understanding of in-vehicle distractions – Put it down or similar programs	Driving error; distractions	Proven, low to moderate cost			
Ed6	Driver Fatigue	Increase CMV understanding of drowsiness, fatigue, and hours of operations laws; availability of truck parking systems, etc.	Driving error; fatigue	Proven, low to moderate cost			
Ed7	Bike/Ped safety	Increase public understanding of causes for bike/ped crashes	Driving error	Proven, low to moderate cost			

8.3.2. Critical Location Framework

This study identifies 35 statewide priority locations, most notable critical reasons for crashes in each location and the relevant countermeasures. The locations are organized in two categories:

a) hotspots or general geographic areas determined by the highest crash kernel density statewide, and
b) high priority intersections categorized by high crash severity or high crash rate.

Each hotspot area is explained through three maps: a kernel density and location map as shown in Figure 140, a close-up map of the area and the road network as shown in Figure 141, and crash location map as shown in Figure 142. Next, different critical reasons for crashes occurred in each area are shown in Table 70 and Figure 143.

Similar analysis for each problematic intersection is also presented, including: a map showing the location of the intersection in the state of Florida, a close-up map showing the road network, a satellite image showing the intersection and the intersection-related crashes (such as Figure 94), and a histogram chart of critical reasons (such as Figure 103).

The analysis divides the large truck-involved crashes into two categories: large truck as primary vehicle and non-large truck as the primary vehicle. The primary vehicle is usually the vehicle at fault in a traffic crash report. Separating crashes by primary vehicles could reveal the different problems related to large trucks and other vehicles. We summarized the occurrences of critical reasons for every location in several tables (from Table 70 to Table 104). The first column is the general category of critical reasons, and the second column is the subcategory of critical reasons. The third and fourth column contain the occurrences of each subcategory critical reason for large truck as primary vehicle crashes and non–large truck as primary vehicle crashes. Since one traffic crash could have multiple critical reasons, for example, aggressive maneuver and inattention at the same time, the total number of occurrences in a column is usually greater than the report count. After each table (from Table 70 to Table 104) there is a chart that visually illustrates critical reasons and highlights one or several notable critical reasons.

8.3.3. Ranked FDOT Districts by Kernel Density

To get a statewide understanding of hot spots and to rank them accordingly, we re-organized the host spot spatial analysis presented in Chapter 7. Figure 56 shows the resulting statewide kernel density map. 15 hotspot areas are selected by ranking the kennel density across all districts.

District 6 has five hotspot areas, District 4 has three hotspot areas, District 7 has three hotspot areas, District 2 has two hotspot areas, and District 5 has two hotspot areas. District 1 and District 4 have lower density values, so they are not considered in the analysis of top hot spots.

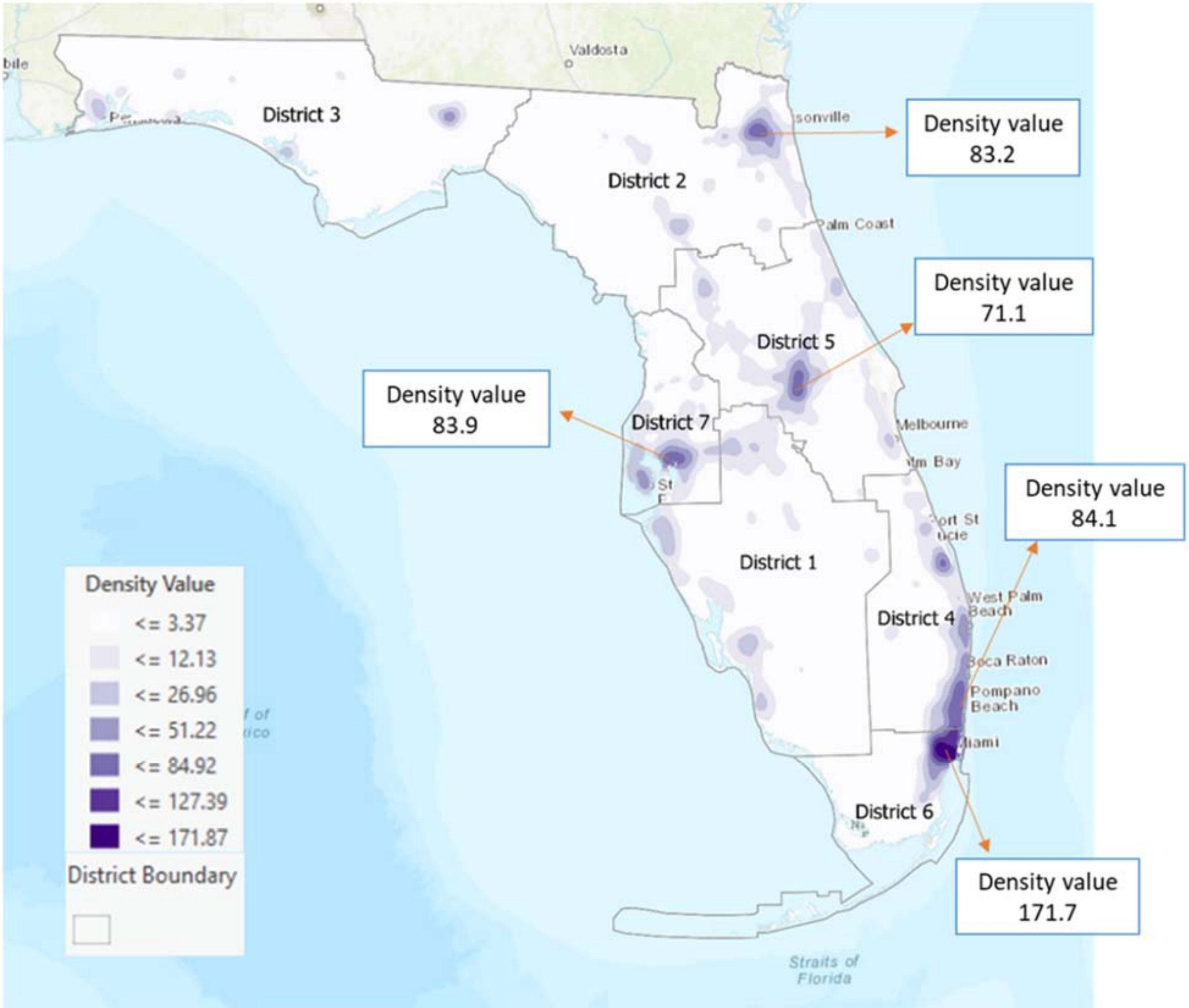


Figure 140 Kernel density in FDOT Districts

8.3.3.1. District 6 – five locations

4.2.1.1.1 Hotspot Area # 1 in District 6

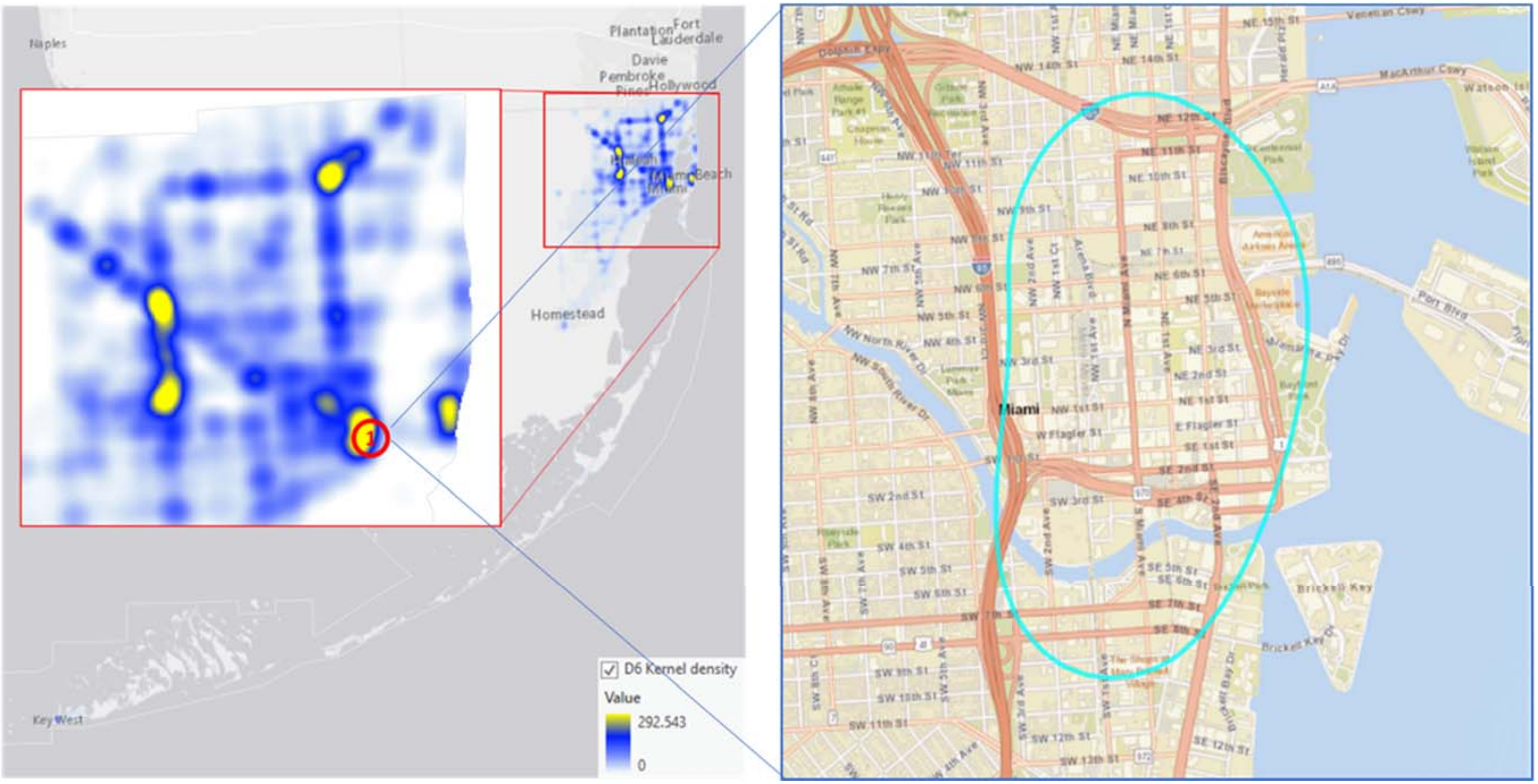


Figure 141 Hotspot area # 1 location and roads in District 6

Large Truck as Primary Vehicle: 592 crashes

Non – Large Truck as Primary Vehicle: 414 crashes

Figure 142 Crash locations by primary vehicle type in hotspot area # 1 in District 6

Table 70 Occurrence of Critical Reasons in District 6, Hotspot Area #1

D6, Hot Spot Area #1	Critical Reasons		Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	147	65
	2	Improper Maneuver	128	75
	3	Other Contributing Actions	124	91
	4	Illegal maneuver	22	46
Non-Driving Error	5	Other critical condition	1	3
	6	Asleep	0	1
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	0
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	9	2
	11	Other recognition	46	20
	12	Inattention	5	6
	13	External distraction	4	0
	14	Internal distraction	2	4
	15	Obstruction	4	2
Vehicle Defects	16	Vital defect	10	1
	17	Non-Vital Defect	8	4
Roadway Condition	18	Slick road	37	29
	19	Road geometry	36	15
	20	Work zone	7	3
	21	Rough road	1	1
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	1
	25	Wind gust	0	0
	26	Glare	0	0
	27	NA	141	118
Report Count			592	414

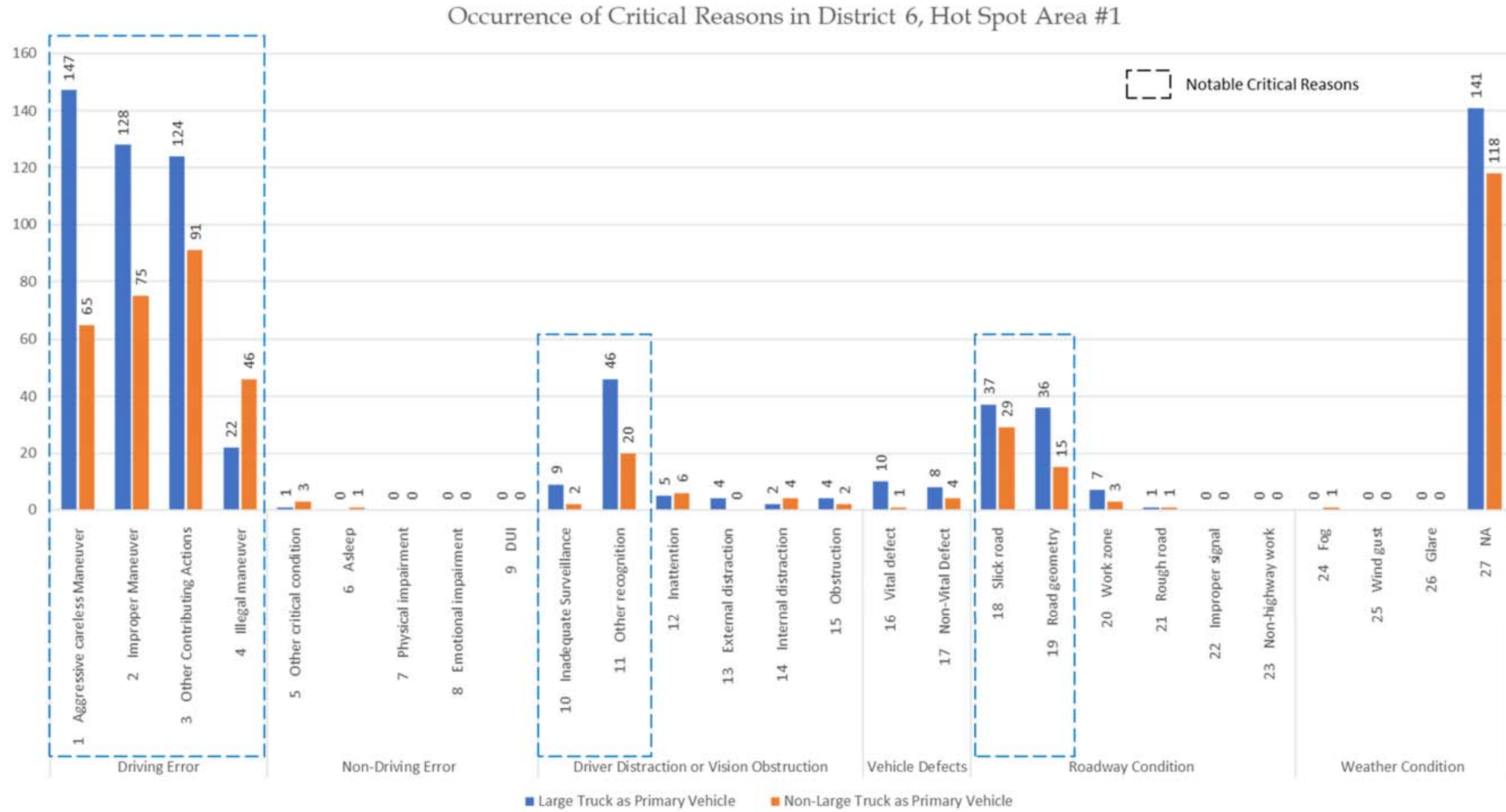


Figure 143 Occurrence of critical reasons in District 6, hotspot area #1

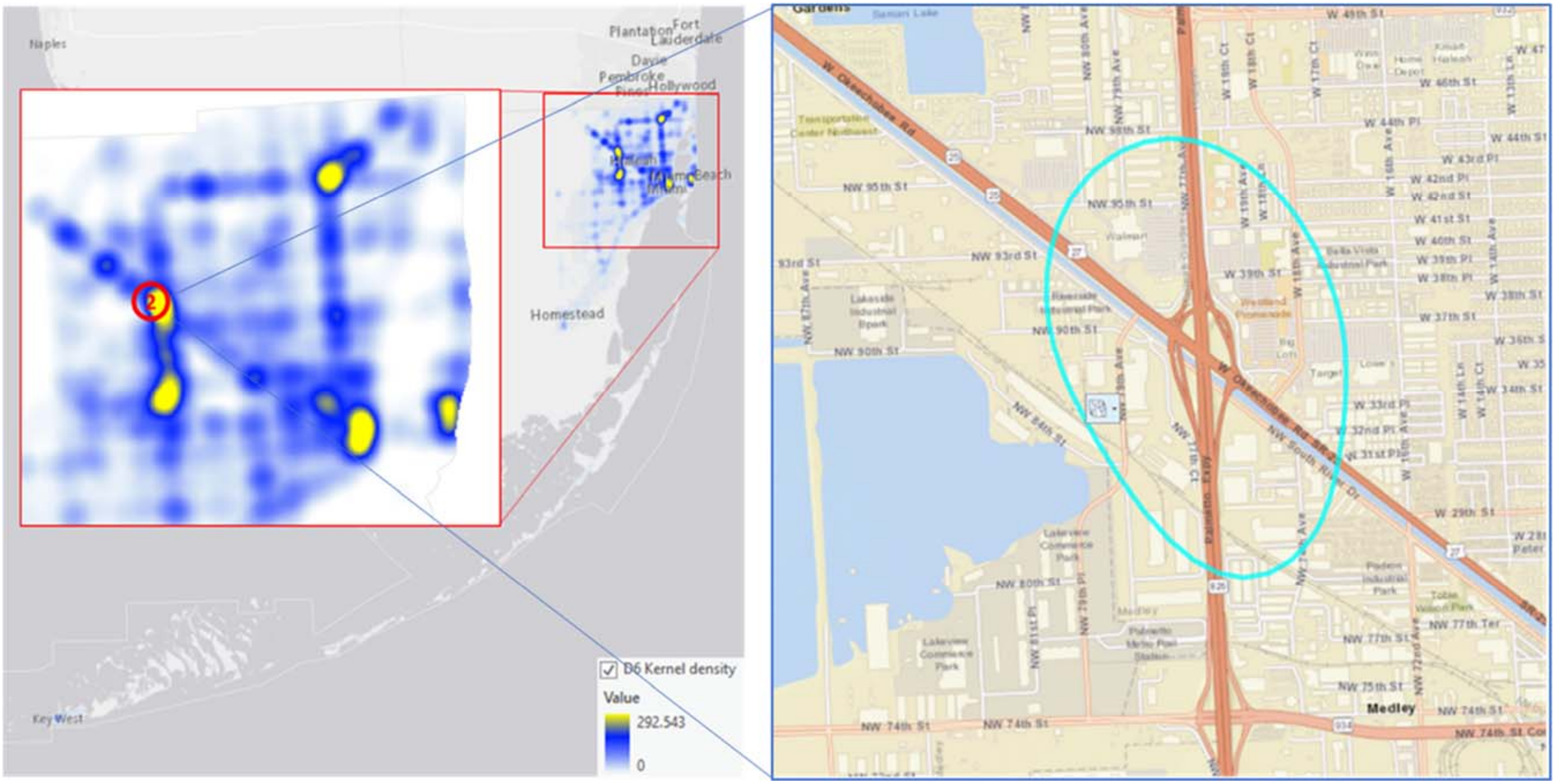
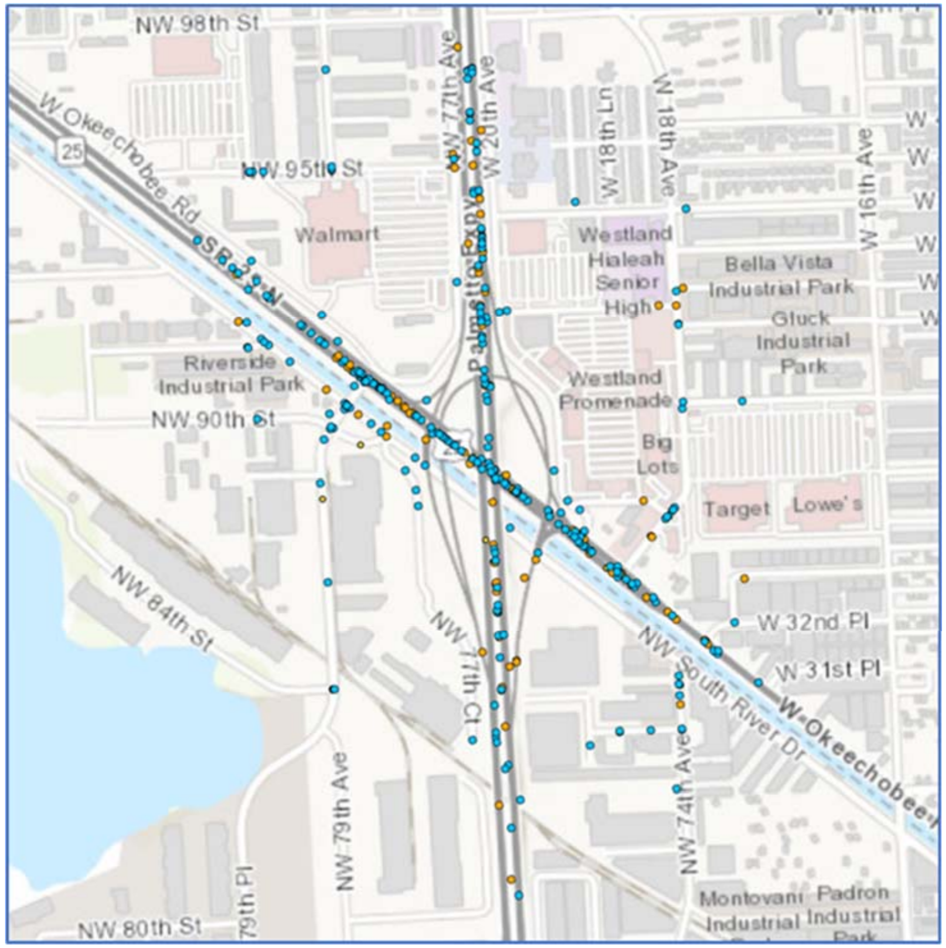


Figure 144 Hotspot area # 2 location and roads in District 6



Large Truck as Primary Vehicle: 405 crashes

Non – Large Truck as Primary Vehicle: 237 crashes

Figure 145 Crash locations by primary vehicle type in hotspot area # 2 in District 6

Table 71 Occurrence of Critical Reasons in District 6, Hotspot Area #2

D6, Hot Spot Area #2	Critical Reasons		Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	127	56
	2	Improper Maneuver	111	59
	3	Other Contributing Actions	47	39
	4	Illegal maneuver	28	23
Non-Driving Error	5	Other critical condition	0	1
	6	Asleep	0	2
	7	Physical impairment	0	1
	8	Emotional impairment	0	1
	9	DUI	0	3
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	15	6
	11	Other recognition	9	5
	12	Inattention	9	7
	13	External distraction	0	3
	14	Internal distraction	2	2
	15	Obstruction	0	0
Vehicle Defects	16	Vital defect	5	2
	17	Non-Vital Defect	4	1
Roadway Condition	18	Slick road	48	28
	19	Road geometry	24	8
	20	Work zone	4	3
	21	Rough road	0	0
	22	Improper signal	0	1
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	0
	25	Wind gust	0	0
	26	Glare	0	0
	27	NA	73	50
Report Count			405	237

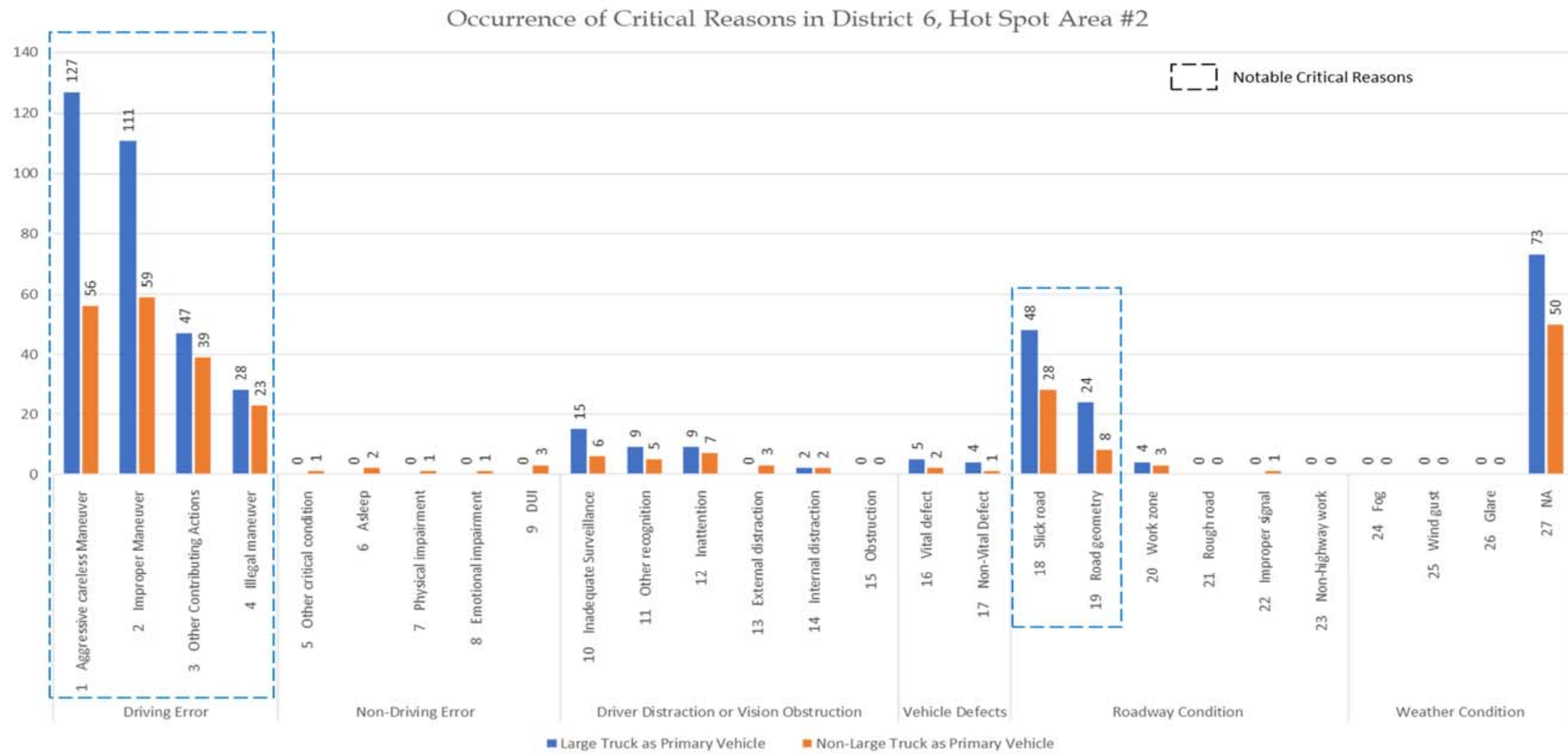


Figure 146 Occurrence of critical reasons in District 6, hotspot area #2

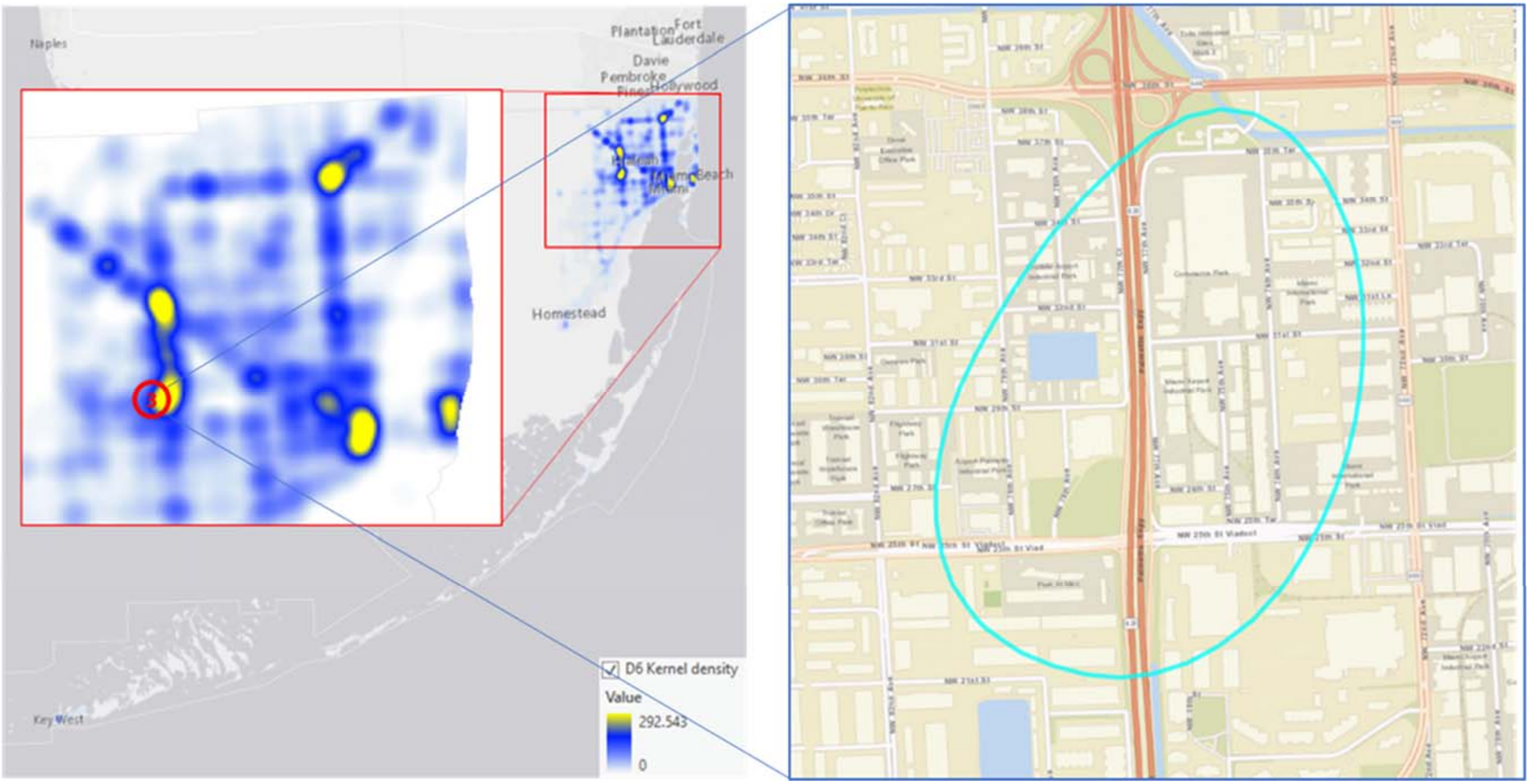
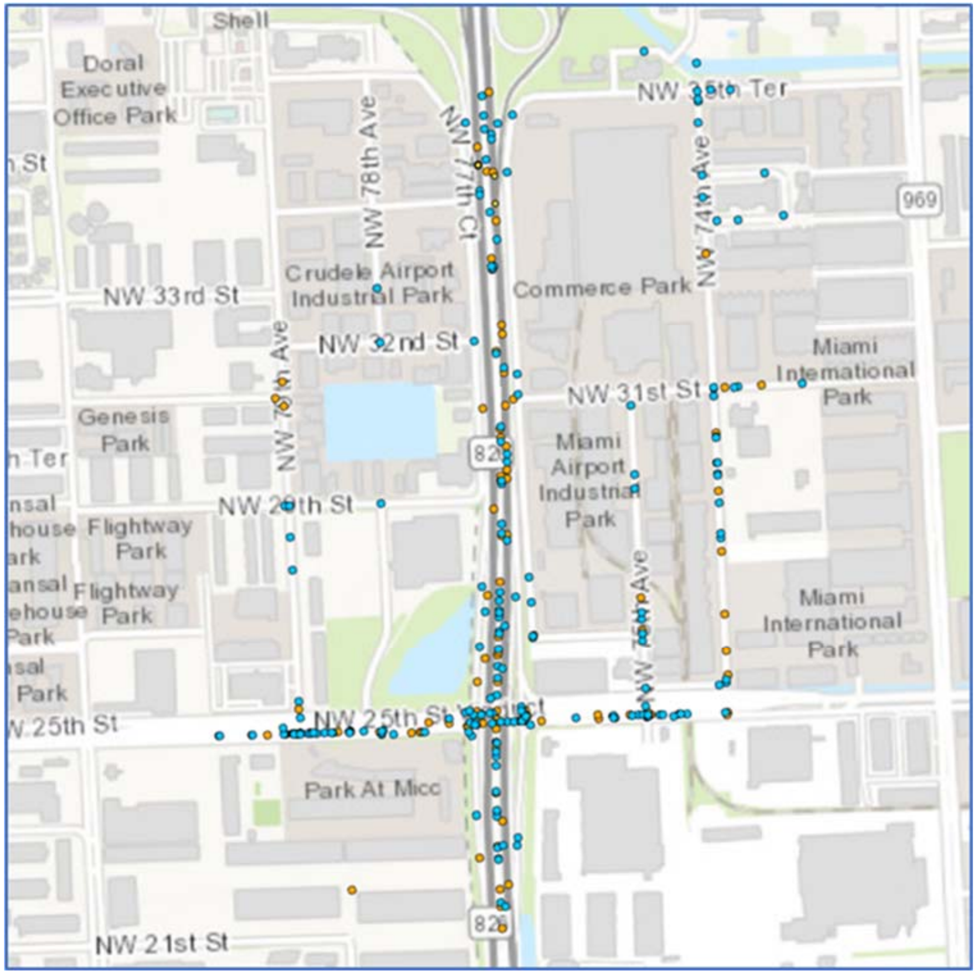


Figure 147 Hotspot area # 3 location and roads in District 6



● Large Truck as Primary Vehicle: 317 crashes

● Non – Large Truck as Primary Vehicle: 194 crashes

Figure 148 Crash locations by primary vehicle type in hotspot area # 3 in District 6

Table 72 Occurrence of Critical Reasons in District 6, Hotspot Area #3

D6, Hot Spot Area #3	Critical Reasons		Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	97	50
	2	Improper Maneuver	101	35
	3	Other Contributing Actions	37	26
	4	Illegal maneuver	17	23
Non-Driving Error	5	Other critical condition	0	0
	6	Asleep	1	0
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	0
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	10	3
	11	Other recognition	14	8
	12	Inattention	1	5
	13	External distraction	1	1
	14	Internal distraction	0	2
	15	Obstruction	1	0
Vehicle Defects	16	Vital defect	5	0
	17	Non-Vital Defect	1	1
Roadway Condition	18	Slick road	28	15
	19	Road geometry	16	10
	20	Work zone	10	4
	21	Rough road	0	1
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	0
	25	Wind gust	0	0
	26	Glare	0	1
	27	NA	51	50
Report Count			317	194

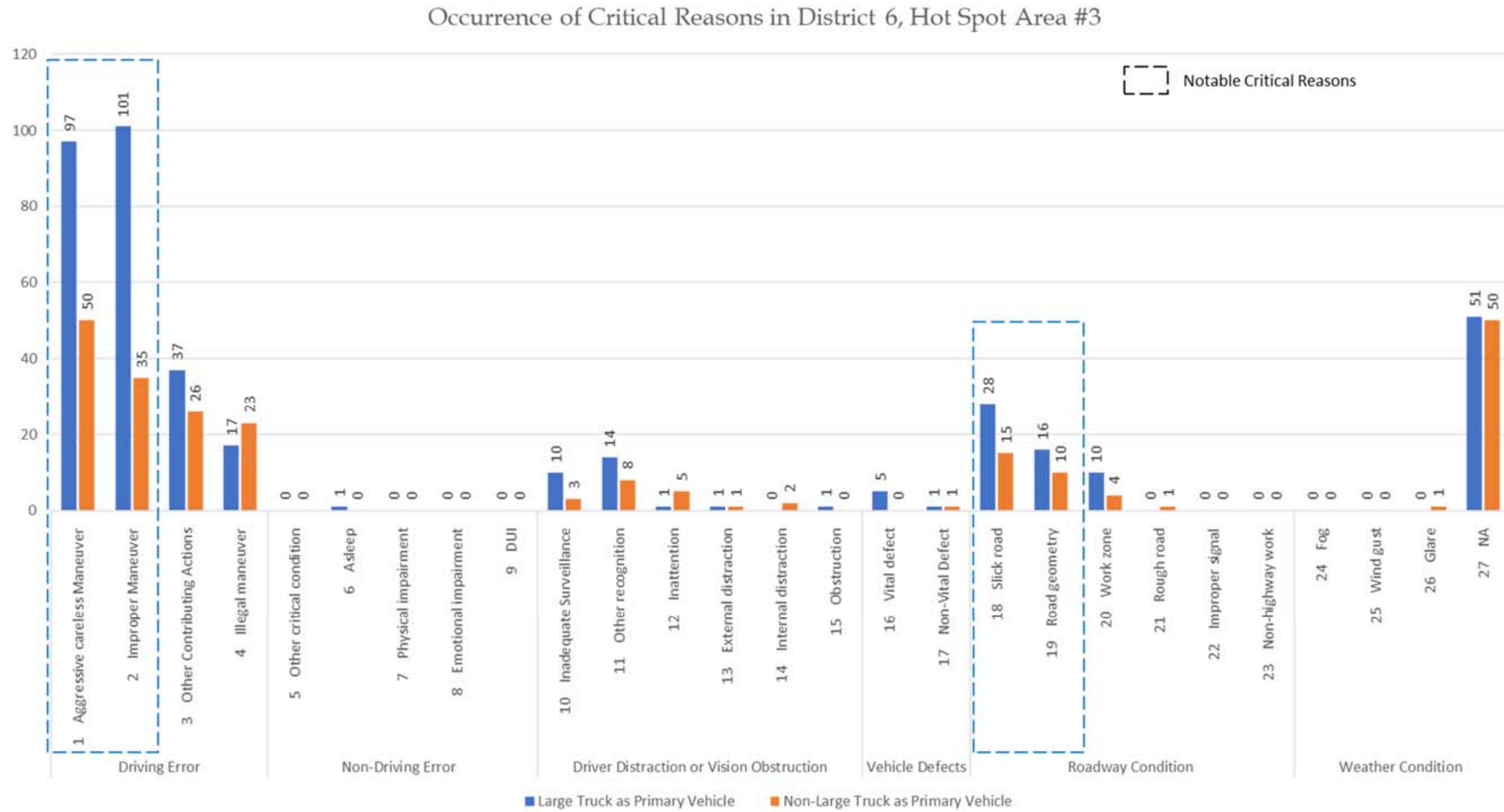


Figure 149 Occurrence of critical reasons in District 6, hotspot area #3

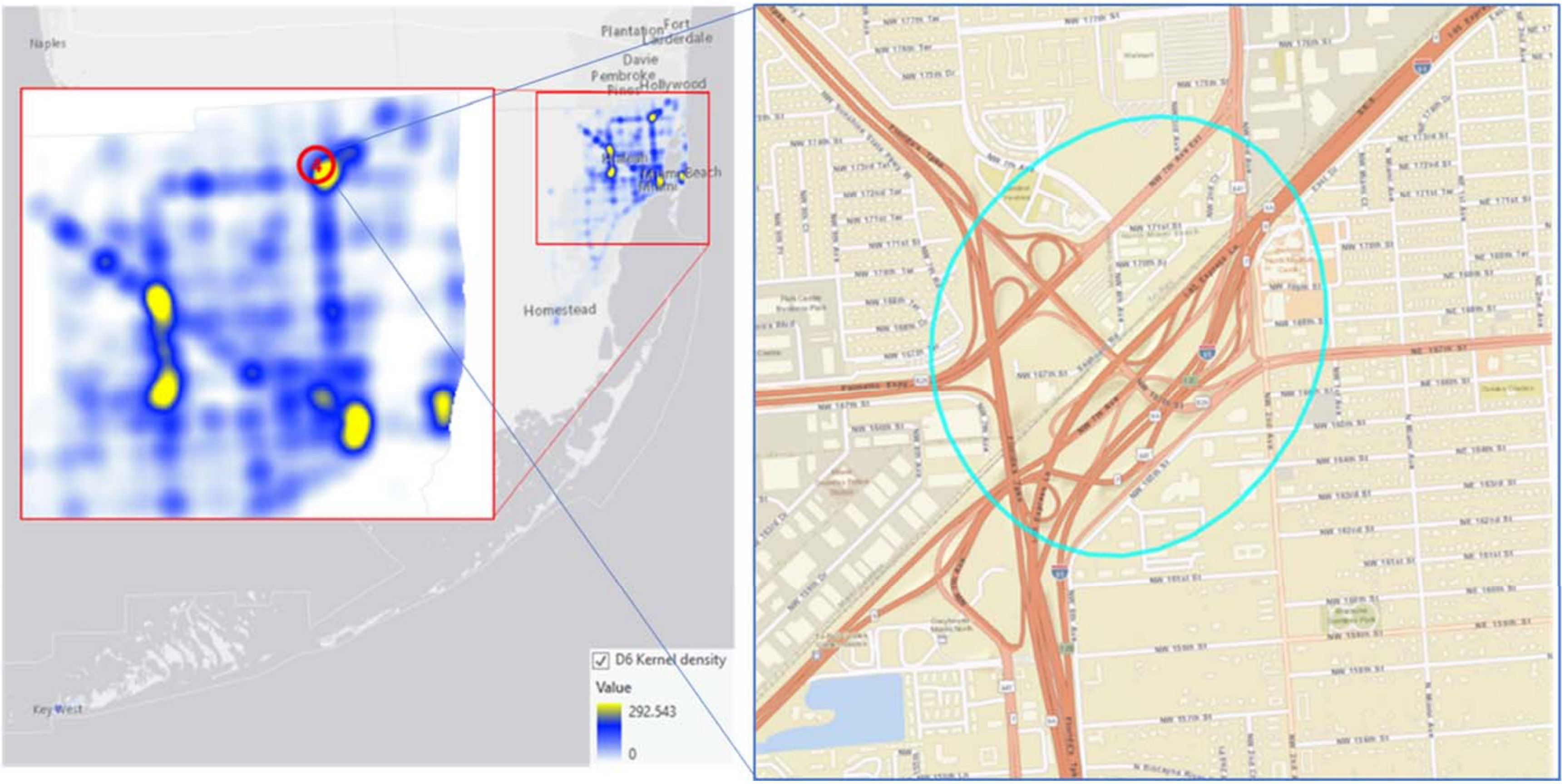


Figure 150 Hotspot area # 4 location and roads in District 6

Large Truck as Primary Vehicle: 312 crashes

Non – Large Truck as Primary Vehicle: 234 crashes

Figure 151 Crash locations by primary vehicle type in hotspot area # 4 in District 6

Table 73 Occurrence of Critical Reasons in District 6, Hotspot Area #4

D6, Hot Spot Area #4	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	117	52
	2 Improper Maneuver	53	60
	3 Other Contributing Actions	47	34
	4 Illegal maneuver	14	33
Non-Driving Error	5 Other critical condition	0	0
	6 Asleep	0	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	1	1
	11 Other recognition	4	2
	12 Inattention	16	12
	13 External distraction	0	0
	14 Internal distraction	0	1
	15 Obstruction	1	1
Vehicle Defects	16 Vital defect	9	0
	17 Non-Vital Defect	4	3
Roadway Condition	18 Slick road	39	29
	19 Road geometry	47	32
	20 Work zone	3	1
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	0	0
	25 Wind gust	0	0
	26 Glare	0	0
	27 NA	62	41
Report Count		312	234

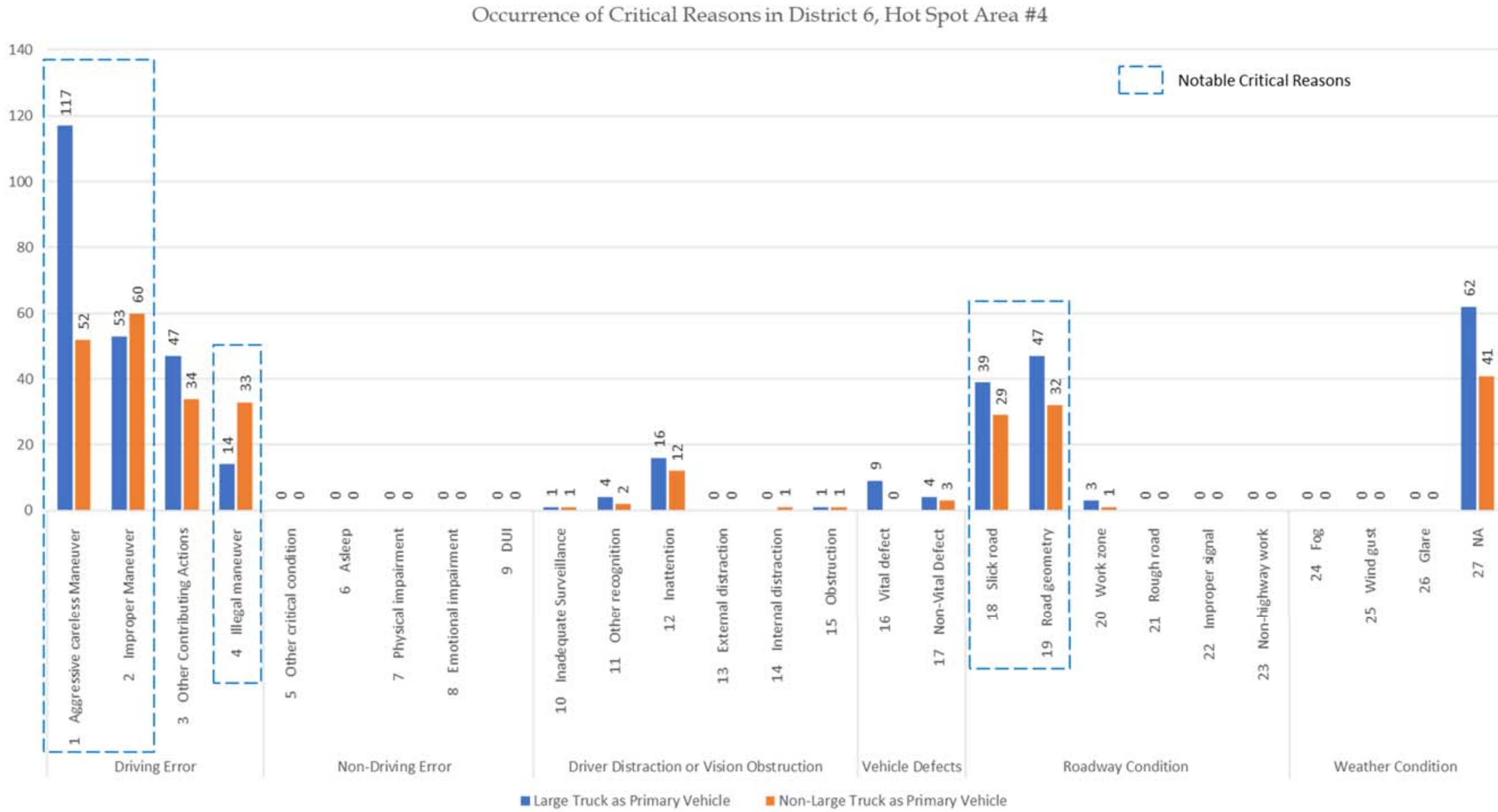


Figure 152 Occurrence of critical reasons in District 6, hotspot area #4

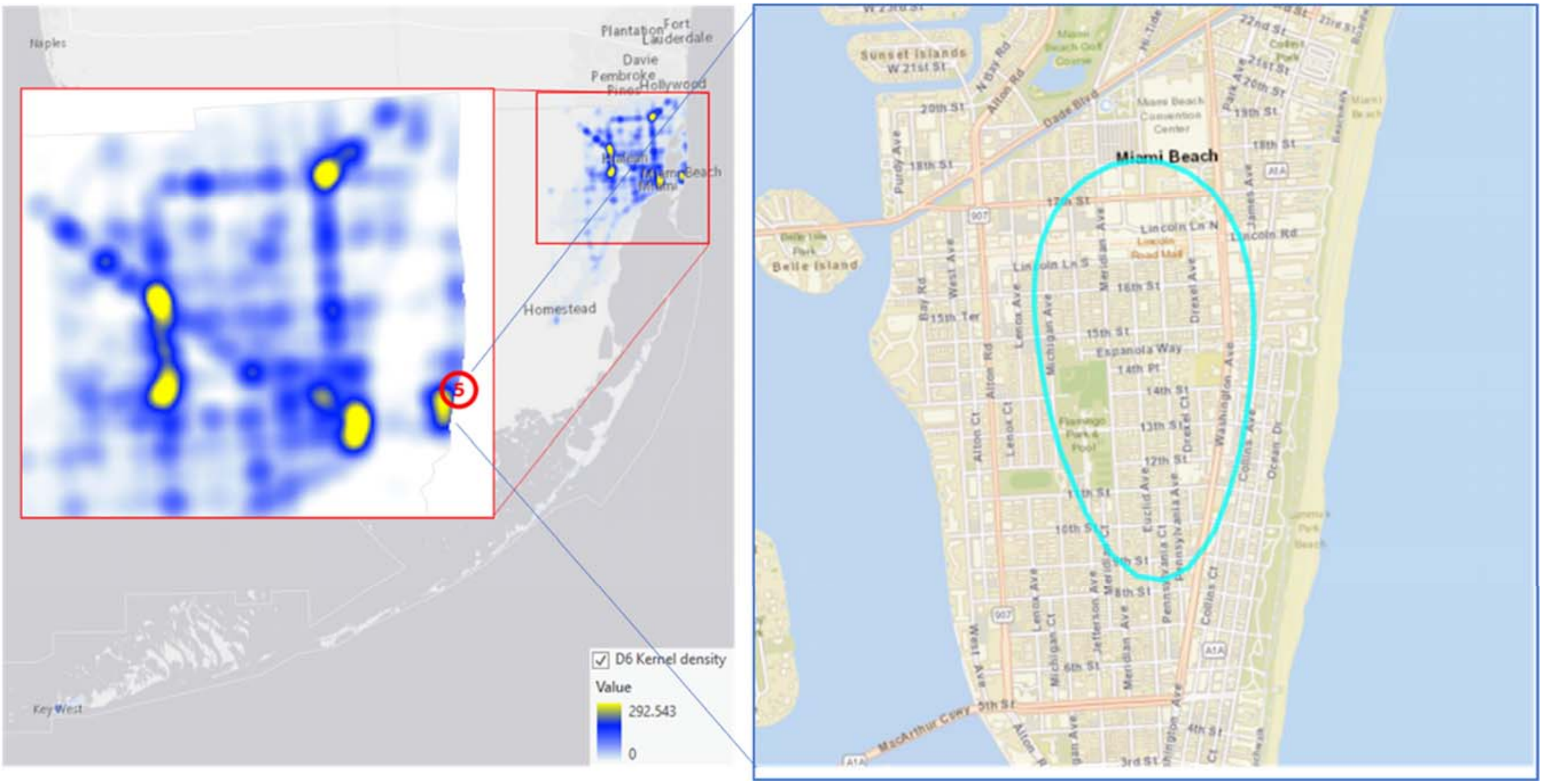
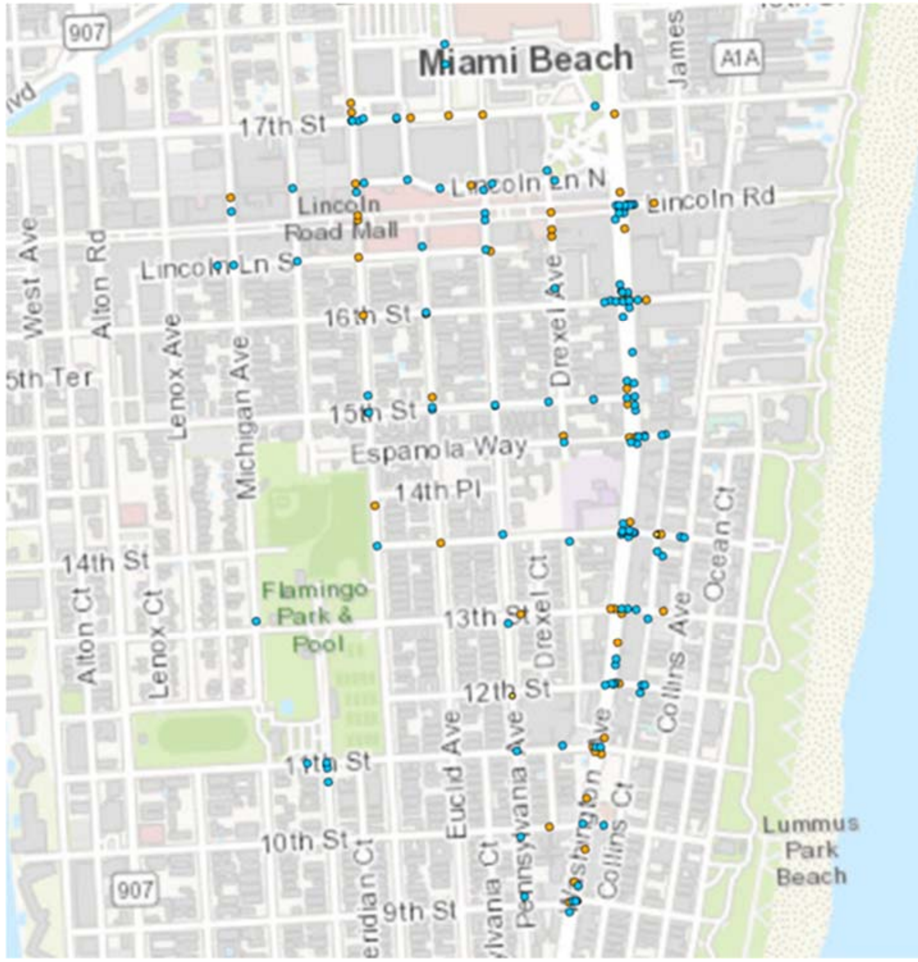


Figure 153 Hotspot area # 5 location and roads in District 6



Large Truck as Primary Vehicle: 140 crashes

Non – Large Truck as Primary Vehicle: 74 crashes

Figure 154 Crash locations by primary vehicle type in hotspot area # 5 in District 6

Table 74 Occurrence of Critical Reasons in District 6, Hotspot Area #5

D6, Hot Spot Area #5	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	60	13
	2 Improper Maneuver	11	3
	3 Other Contributing Actions	22	11
	4 Illegal maneuver	3	4
Non-Driving Error	5 Other critical condition	0	0
	6 Asleep	0	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	7	2
	11 Other recognition	9	6
	12 Inattention	2	0
	13 External distraction	0	0
	14 Internal distraction	0	0
	15 Obstruction	0	0
Vehicle Defects	16 Vital defect	0	0
	17 Non-Vital Defect	0	0
Roadway Condition	18 Slick road	14	9
	19 Road geometry	1	0
	20 Work zone	2	1
	21 Rough road	1	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	0	0
	25 Wind gust	0	0
	26 Glare	0	0
	27 NA	40	37
Report Count		140	74

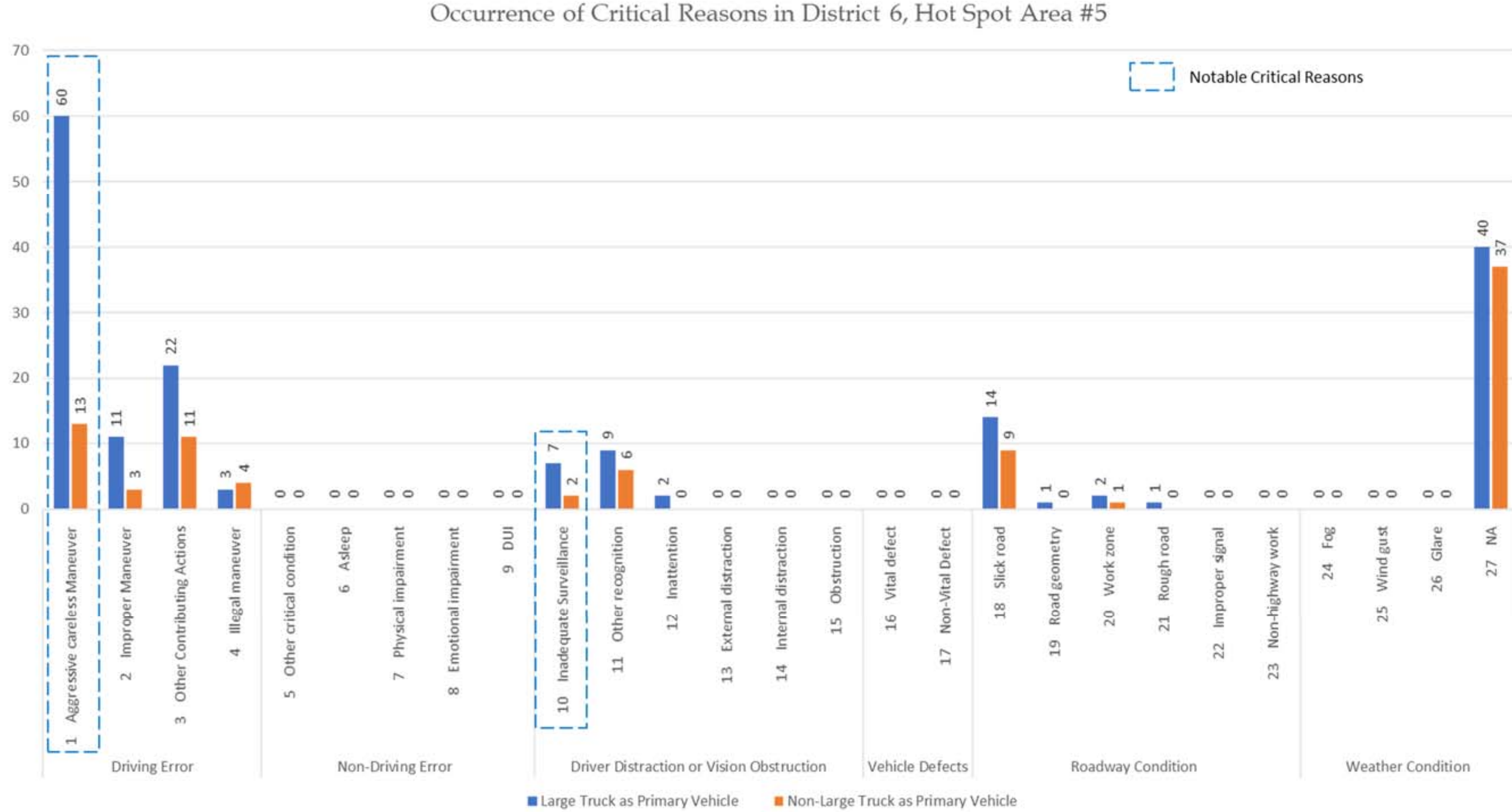


Figure 155 Occurrence of critical reasons in District 6, hotspot area #5

8.3.3.2. District 4 – three locations

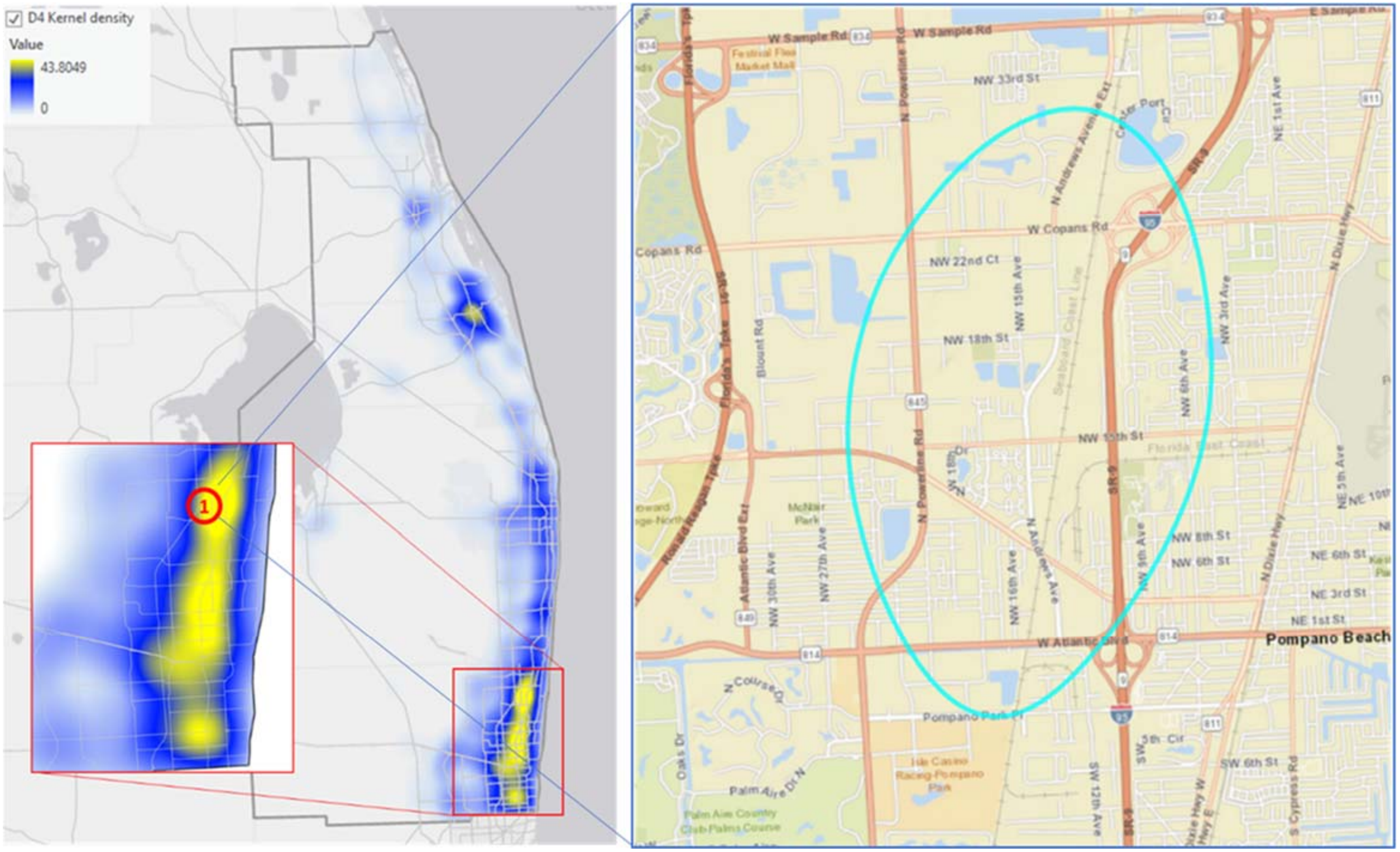
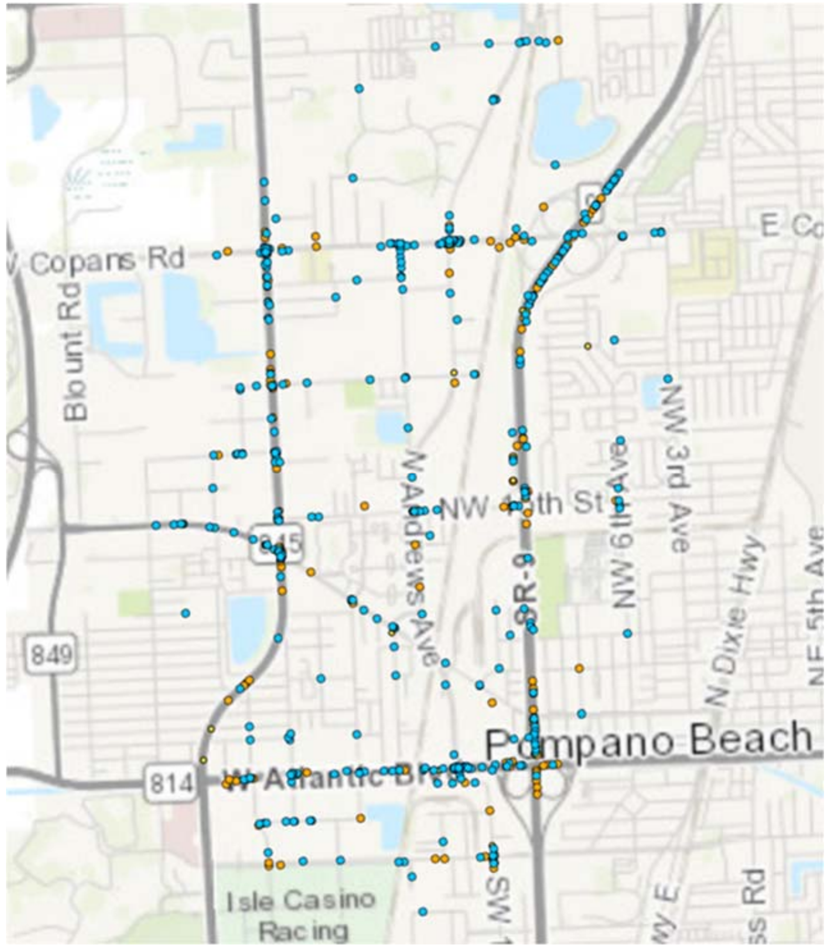


Figure 156 Hotspot area # 1 location and roads in District 4



Large Truck as Primary Vehicle: 503 crashes

Non – Large Truck as Primary Vehicle: 323 crashes

Figure 157 Crash locations by primary vehicle type in hotspot area # 1 in District 4

Table 75 Occurrence of Critical Reasons in District 4, Hotspot Area #1

D4, Hot Spot Area #1	Critical Reasons		Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	112	81
	2	Improper Maneuver	148	67
	3	Other Contributing Actions	60	63
	4	Illegal maneuver	38	40
Non-Driving Error	5	Other critical condition	2	2
	6	Asleep	2	1
	7	Physical impairment	1	3
	8	Emotional impairment	0	0
	9	DUI	1	2
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	27	8
	11	Other recognition	28	4
	12	Inattention	17	10
	13	External distraction	5	2
	14	Internal distraction	4	4
	15	Obstruction	3	0
Vehicle Defects	16	Vital defect	12	9
	17	Non-Vital Defect	4	9
Roadway Condition	18	Slick road	57	46
	19	Road geometry	16	12
	20	Work zone	7	4
	21	Rough road	4	0
	22	Improper signal	1	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	0
	25	Wind gust	0	0
	26	Glare	0	0
	27	NA	106	54
Report Count			503	323

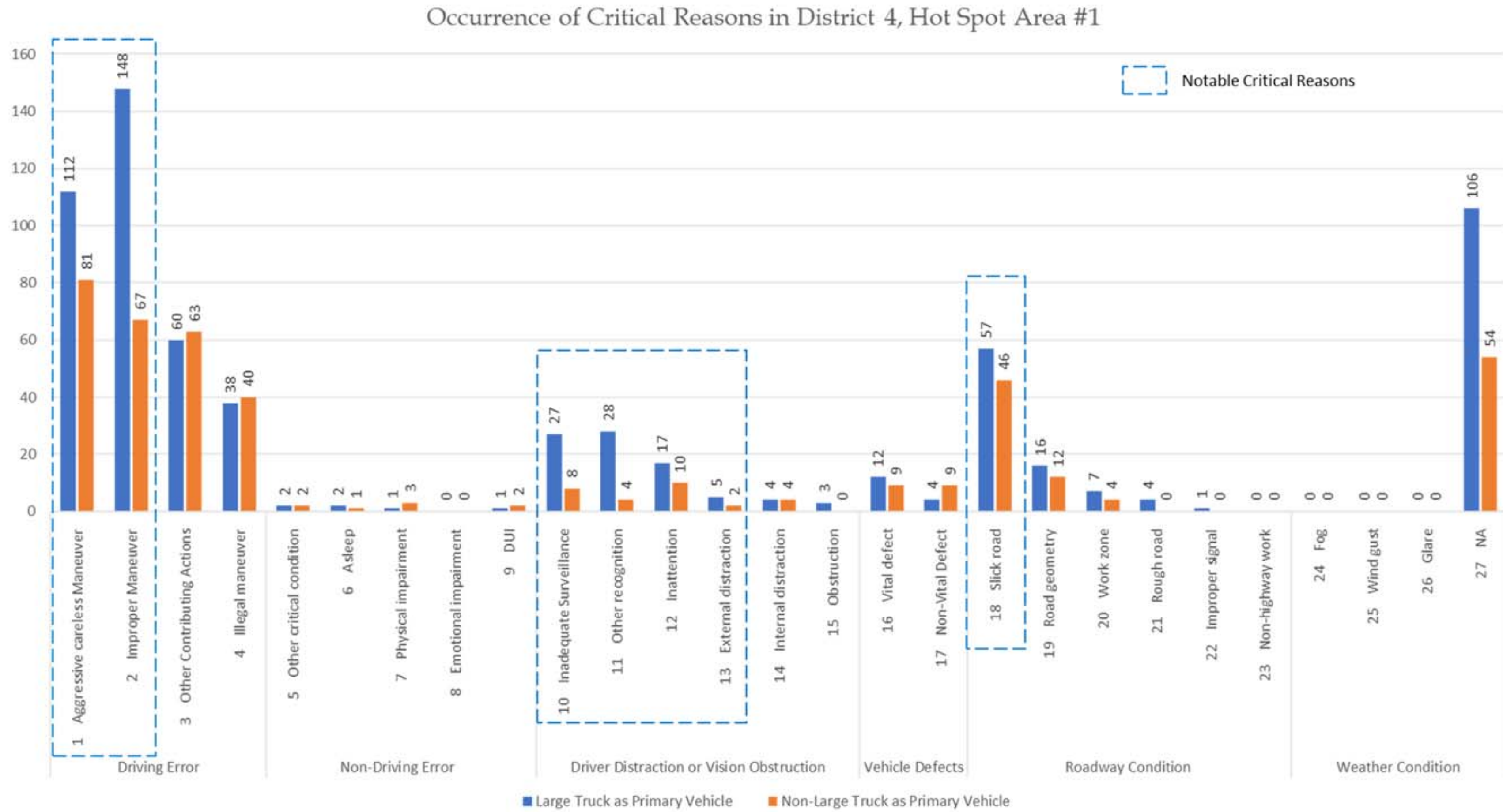


Figure 158 Occurrence of critical reasons in District 4, hotspot area #1

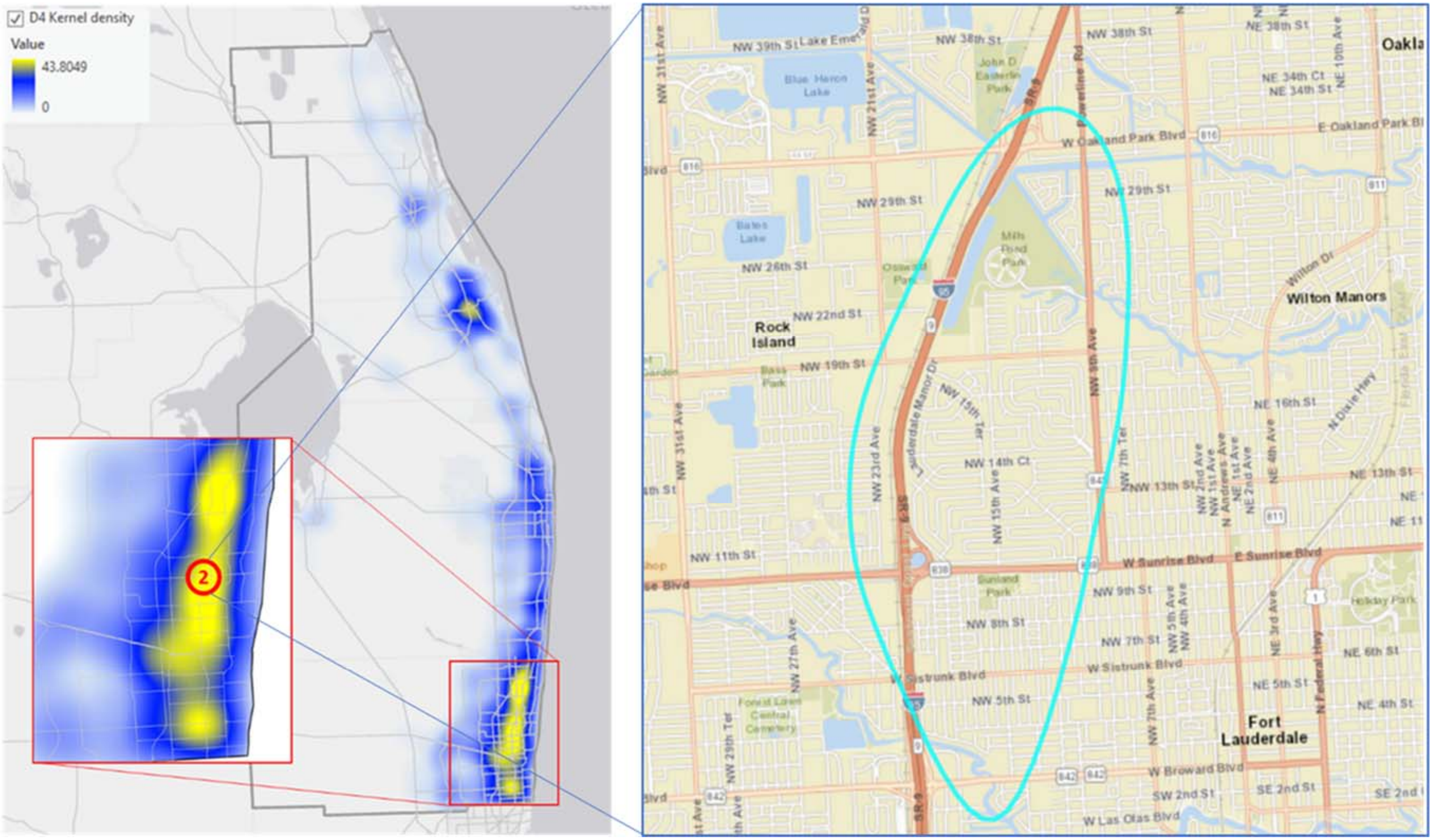
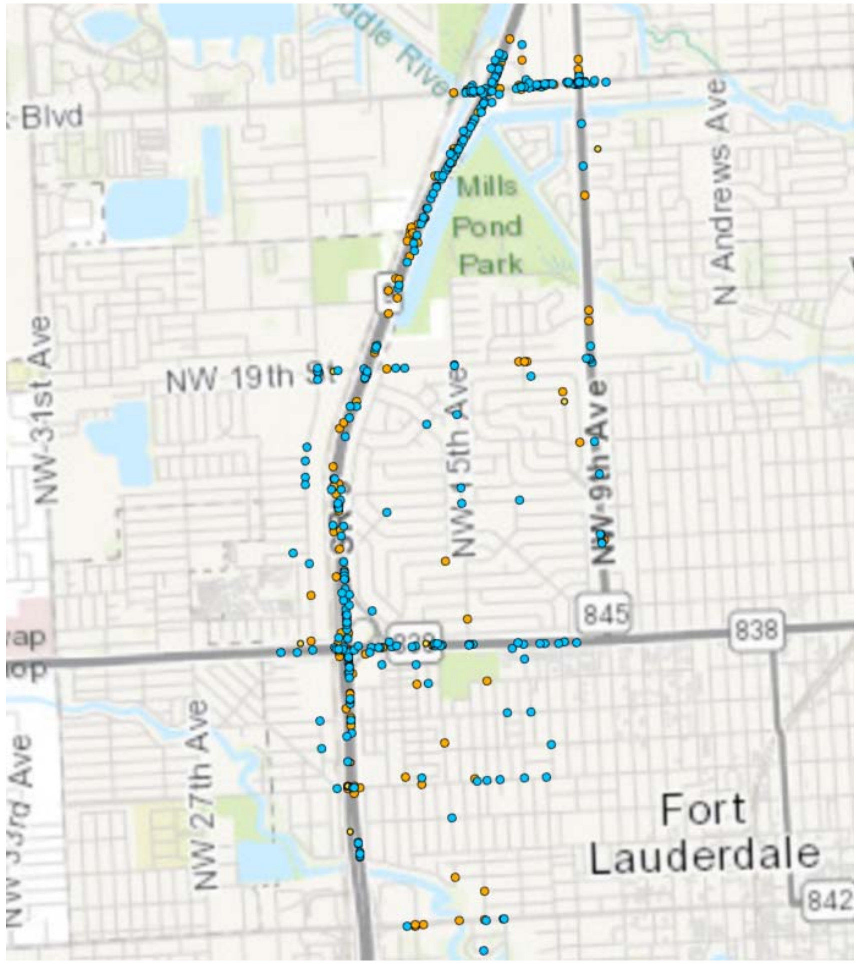


Figure 159 Hotspot area # 2 location and roads in District 4



Large Truck as Primary Vehicle: 404 crashes

Non – Large Truck as Primary Vehicle: 272 crashes

Figure 160 Crash locations by primary vehicle type in hotspot area # 2 in District 4

Table 76 Occurrence of Critical Reasons in District 4, Hotspot Area #2

D4, Hot Spot Area #2	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	75	49
	2 Improper Maneuver	75	46
	3 Other Contributing Actions	100	70
	4 Illegal maneuver	13	17
Non-Driving Error	5 Other critical condition	0	1
	6 Asleep	0	1
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	1
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	4	2
	11 Other recognition	11	7
	12 Inattention	10	8
	13 External distraction	1	2
	14 Internal distraction	3	4
	15 Obstruction	1	2
Vehicle Defects	16 Vital defect	20	8
	17 Non-Vital Defect	12	5
Roadway Condition	18 Slick road	53	38
	19 Road geometry	31	11
	20 Work zone	5	1
	21 Rough road	1	1
	22 Improper signal	1	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	0	0
	25 Wind gust	0	0
	26 Glare	0	0
	27 NA	102	75
Report Count		404	272

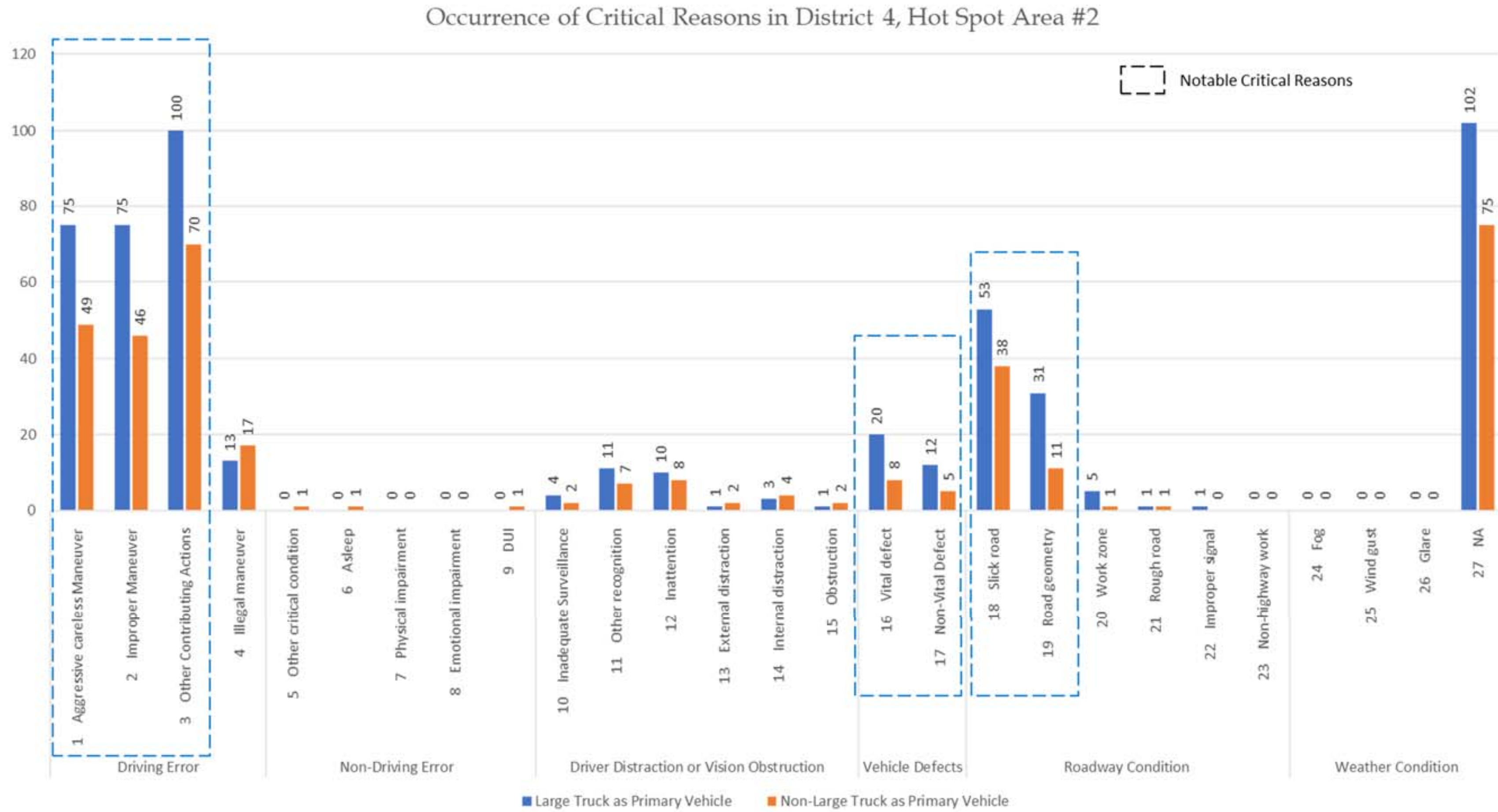


Figure 161 Occurrence of critical reasons in District 4, hotspot area #2

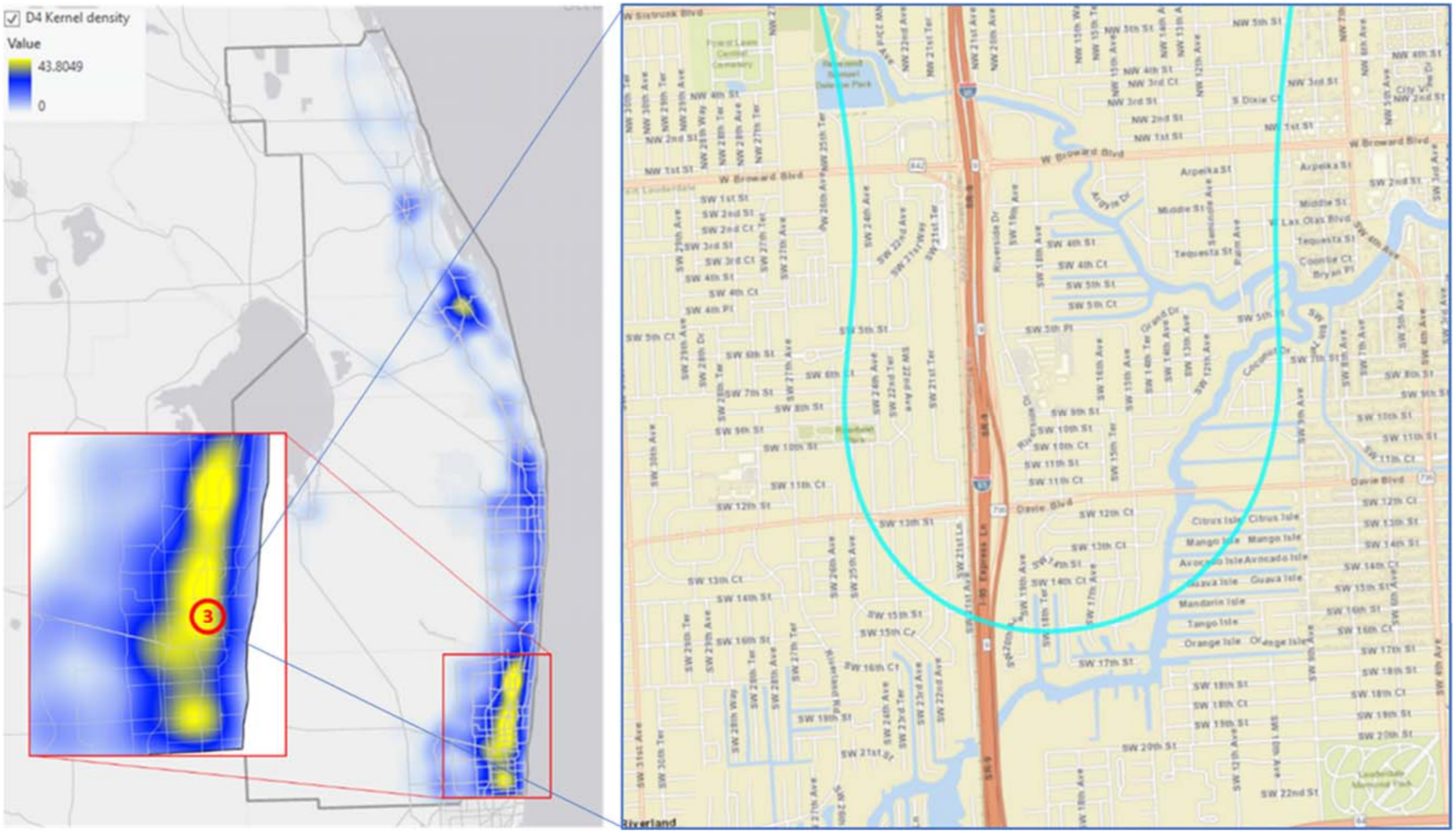
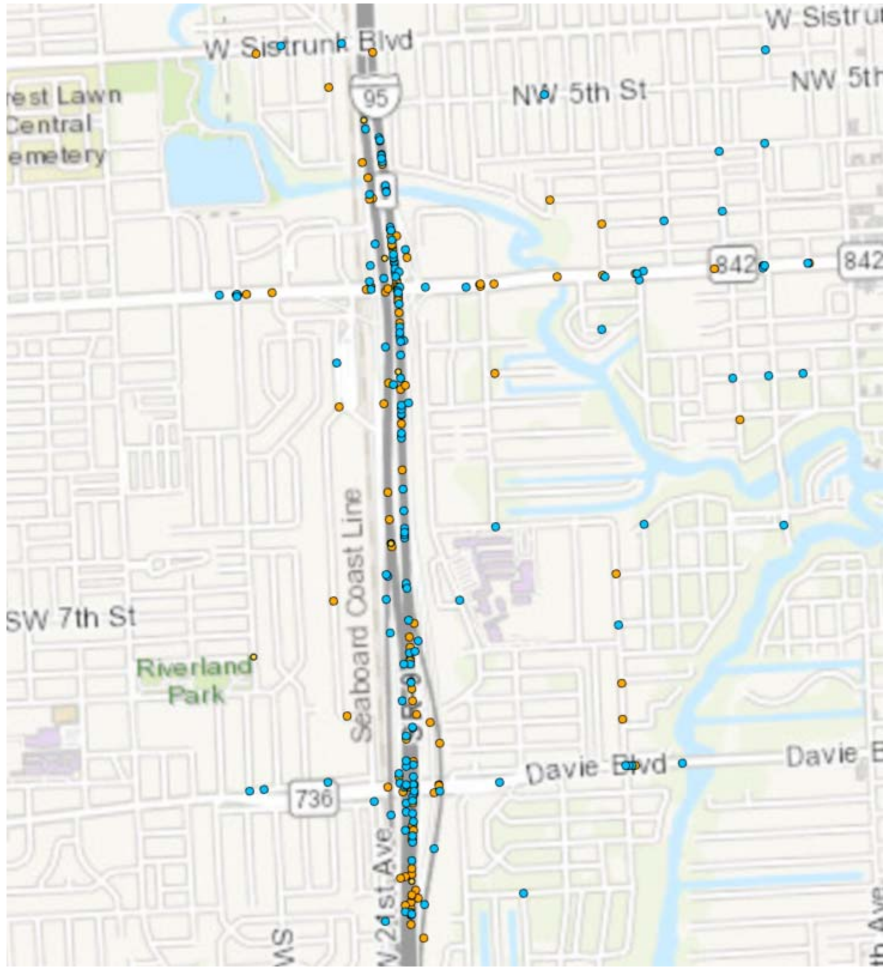


Figure 162 Hotspot area # 3 location and roads in District 4



Large Truck as Primary Vehicle: 197 crashes

Non – Large Truck as Primary Vehicle: 175 crashes

Figure 163 Crash locations by primary vehicle type in hotspot area # 3 in District 4

Table 77 Occurrence of Critical Reasons in District 4, Hotspot Area #3

D4, Hot Spot Area #3		Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	31	40
	2	Improper Maneuver	41	34
	3	Other Contributing Actions	39	26
	4	Illegal maneuver	4	9
Non-Driving Error	5	Other critical condition	0	1
	6	Asleep	0	1
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	1
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	3	5
	11	Other recognition	3	1
	12	Inattention	6	11
	13	External distraction	1	4
	14	Internal distraction	1	3
	15	Obstruction	3	1
Vehicle Defects	16	Vital defect	7	4
	17	Non-Vital Defect	9	4
Roadway Condition	18	Slick road	27	23
	19	Road geometry	8	10
	20	Work zone	6	0
	21	Rough road	1	1
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	0
	25	Wind gust	0	0
	26	Glare	0	0
	27	NA	65	54
Report Count			197	175

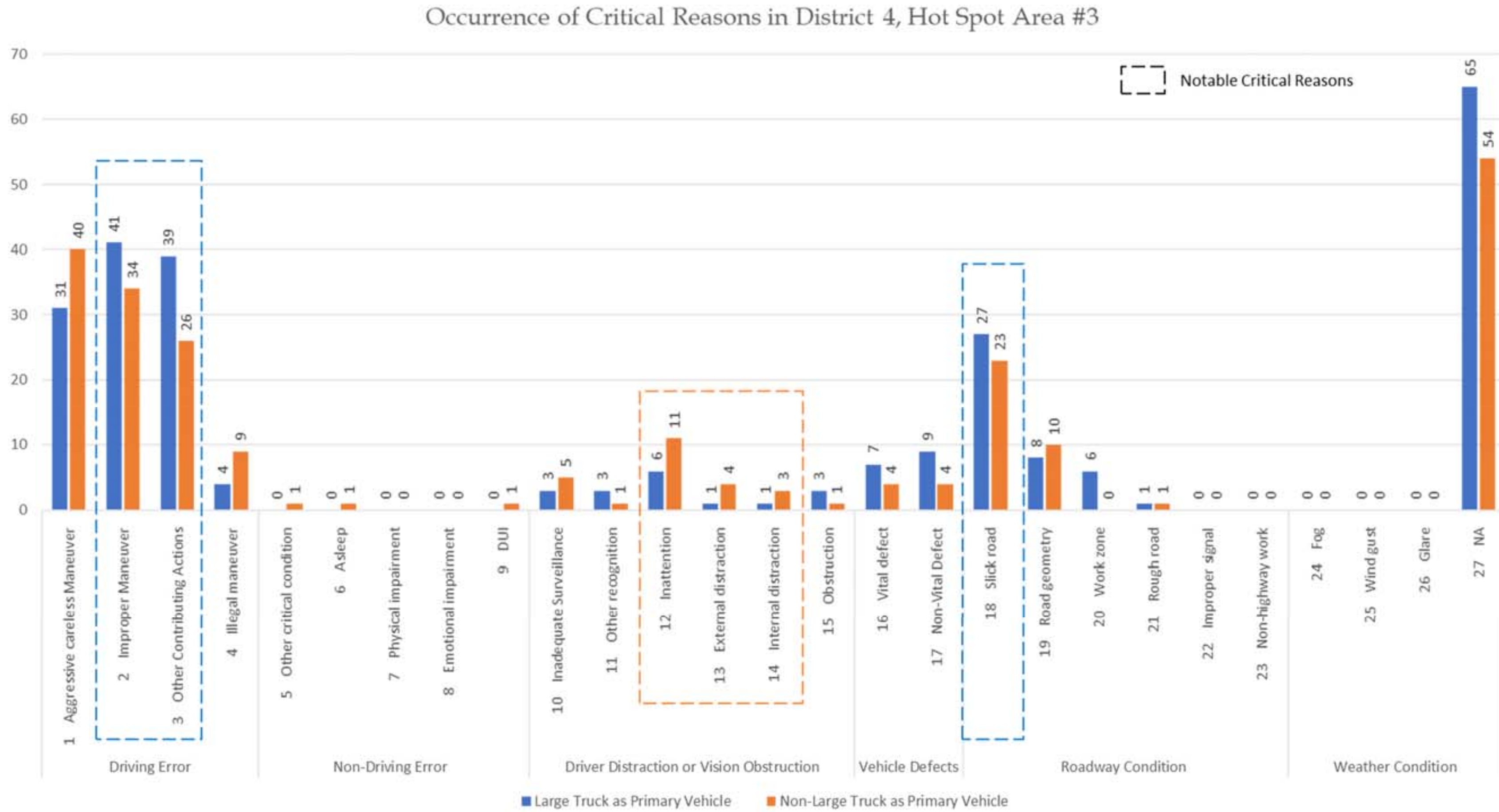


Figure 164 **Occurrence of critical reasons in District 4, hotspot area #3**

8.3.3.3. District 7 – three locations

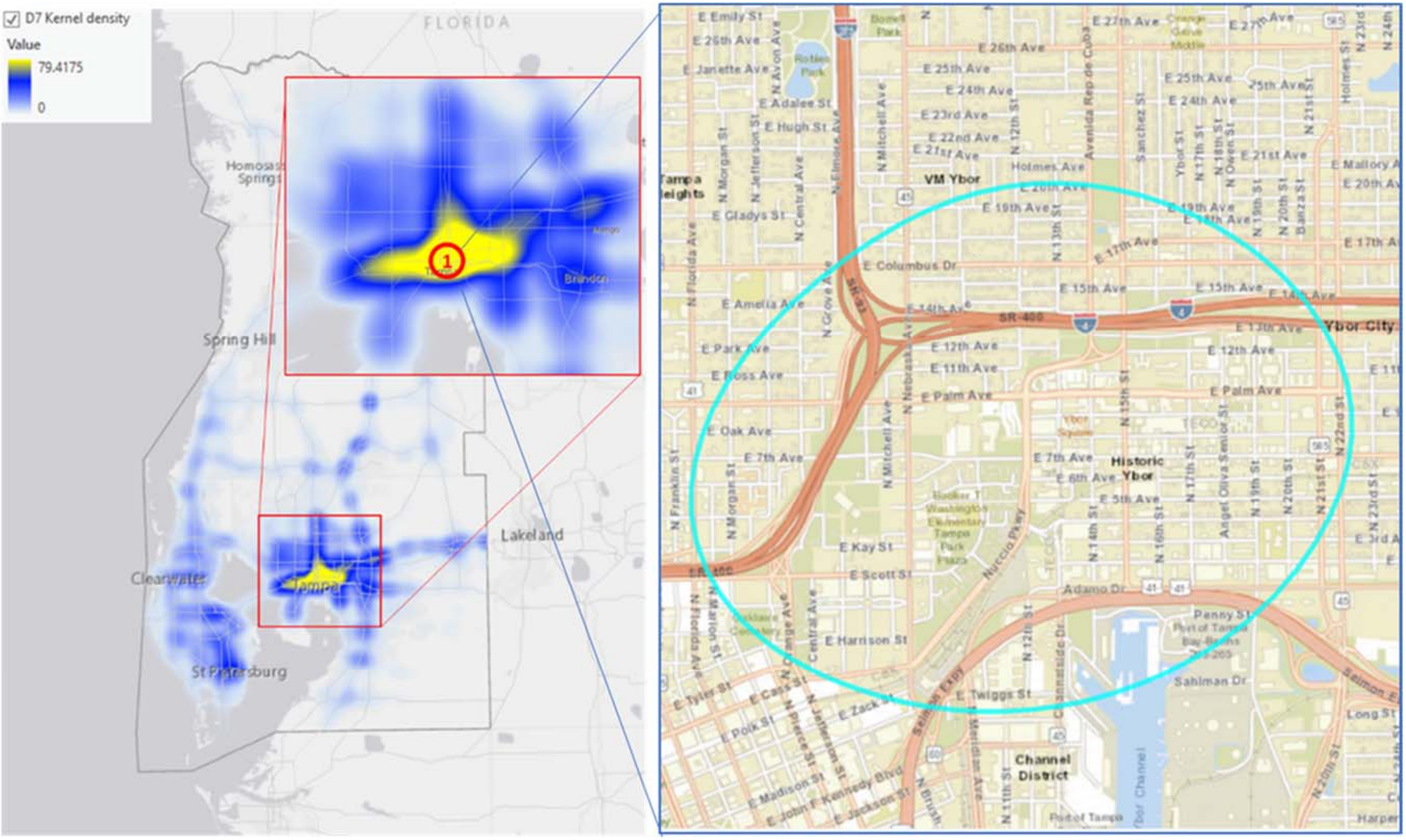
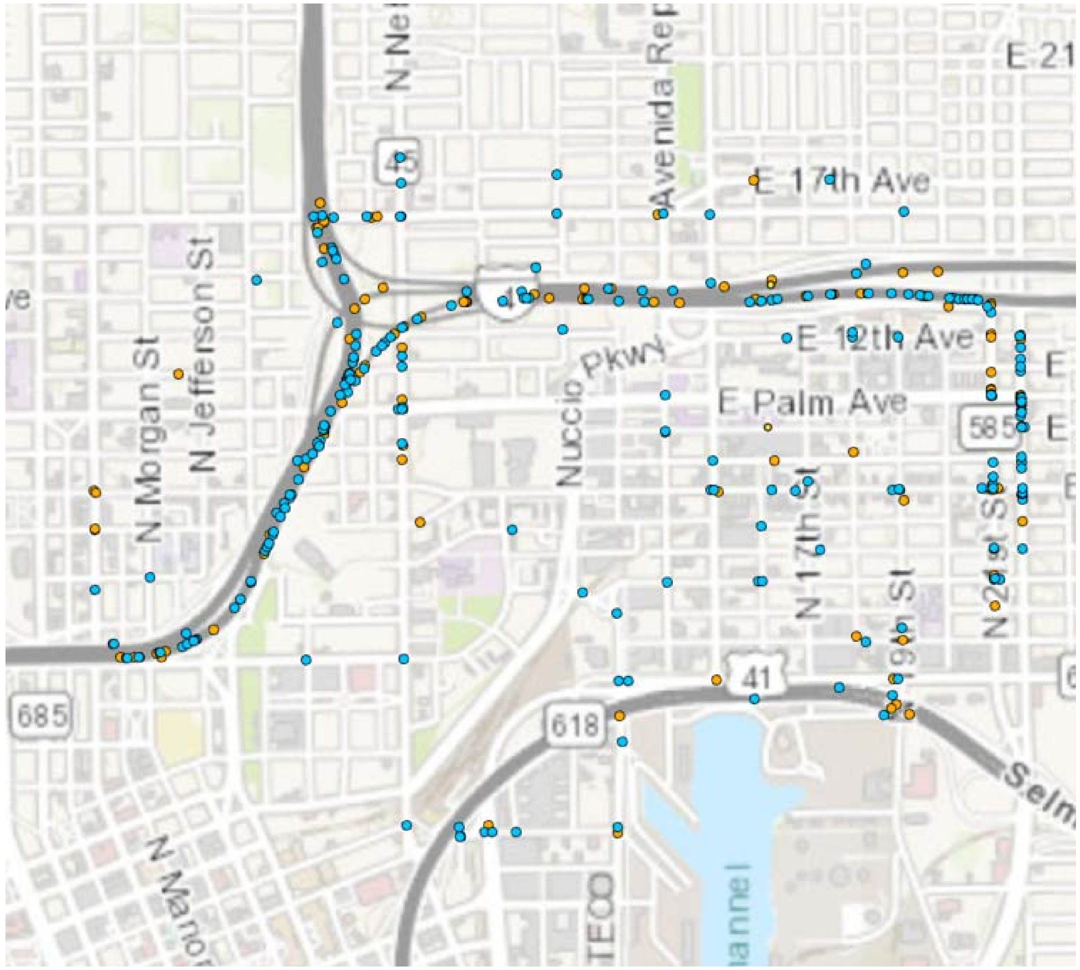


Figure 165 Hotspot area # 1 location and roads in District 7



Large Truck as Primary Vehicle: 279 crashes

Non – Large Truck as Primary Vehicle: 191 crashes

Figure 166 Crash locations by primary vehicle type in hotspot area # 1 in District 7

Table 78 Occurrence of Critical Reasons in District 7, Hotspot Area #1

D7, Hot Spot Area #1	Critical Reasons		Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	69	49
	2	Improper Maneuver	63	42
	3	Other Contributing Actions	39	25
	4	Illegal maneuver	18	26
Non-Driving Error	5	Other critical condition	0	1
	6	Asleep	0	2
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	4
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	7	3
	11	Other recognition	11	3
	12	Inattention	7	4
	13	External distraction	2	3
	14	Internal distraction	2	4
	15	Obstruction	2	0
Vehicle Defects	16	Vital defect	9	3
	17	Non-Vital Defect	5	1
Roadway Condition	18	Slick road	36	19
	19	Road geometry	16	20
	20	Work zone	5	3
	21	Rough road	3	0
	22	Improper signal	1	1
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	1
	25	Wind gust	0	0
	26	Glare	0	1
	27	NA	67	36
Report Count			279	191

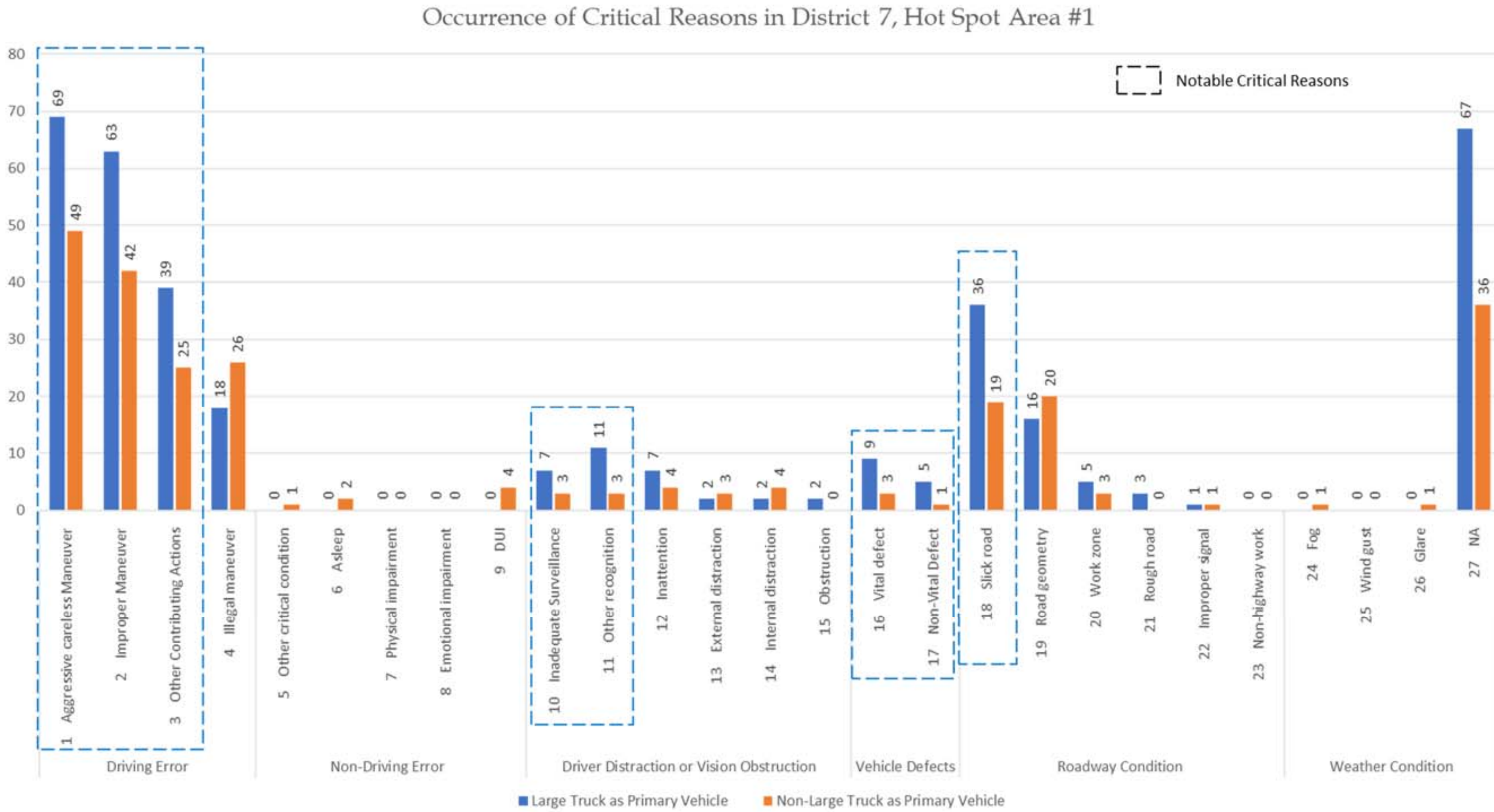


Figure 167 Occurrence of critical reasons in District 7, hotspot area #1

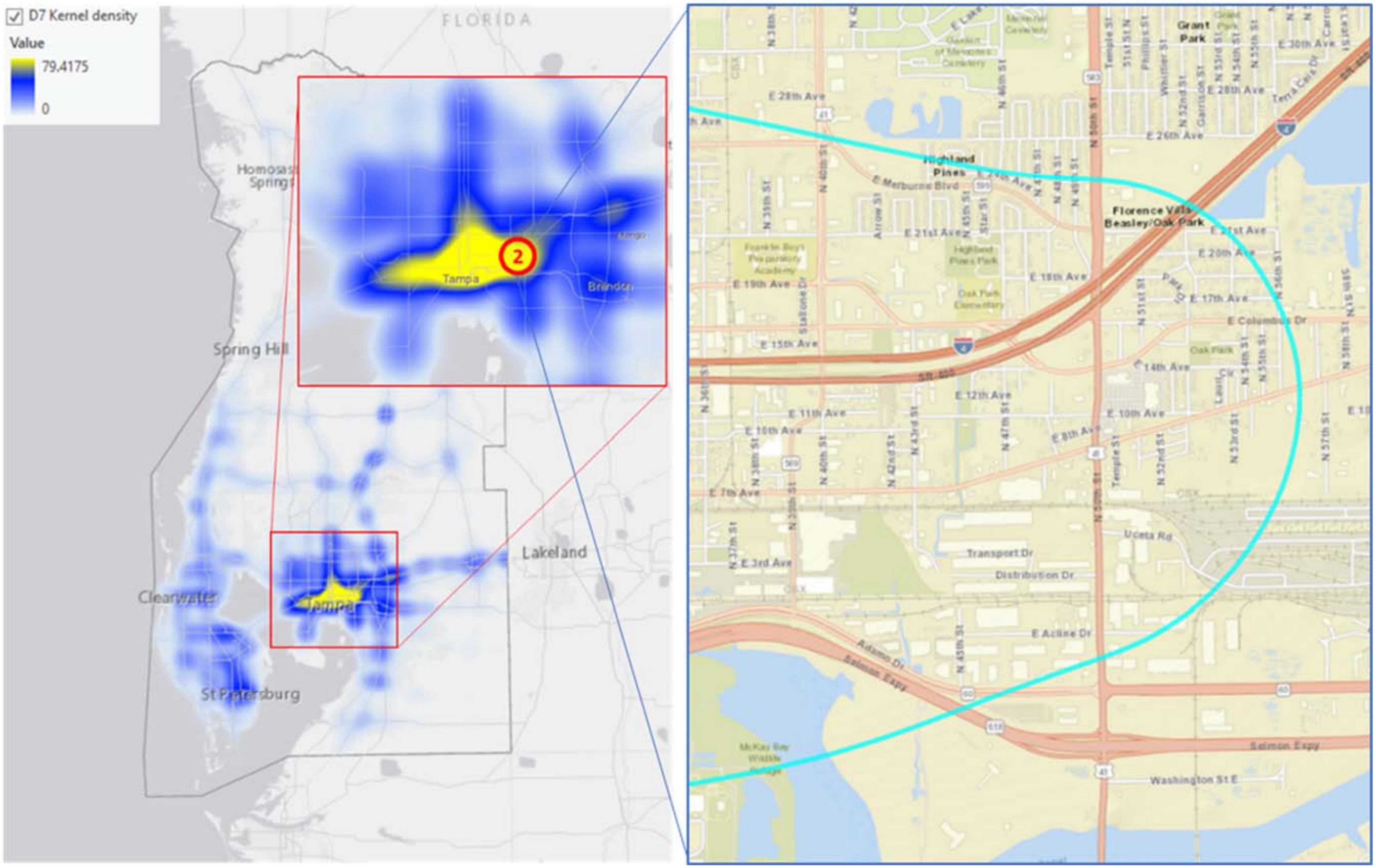
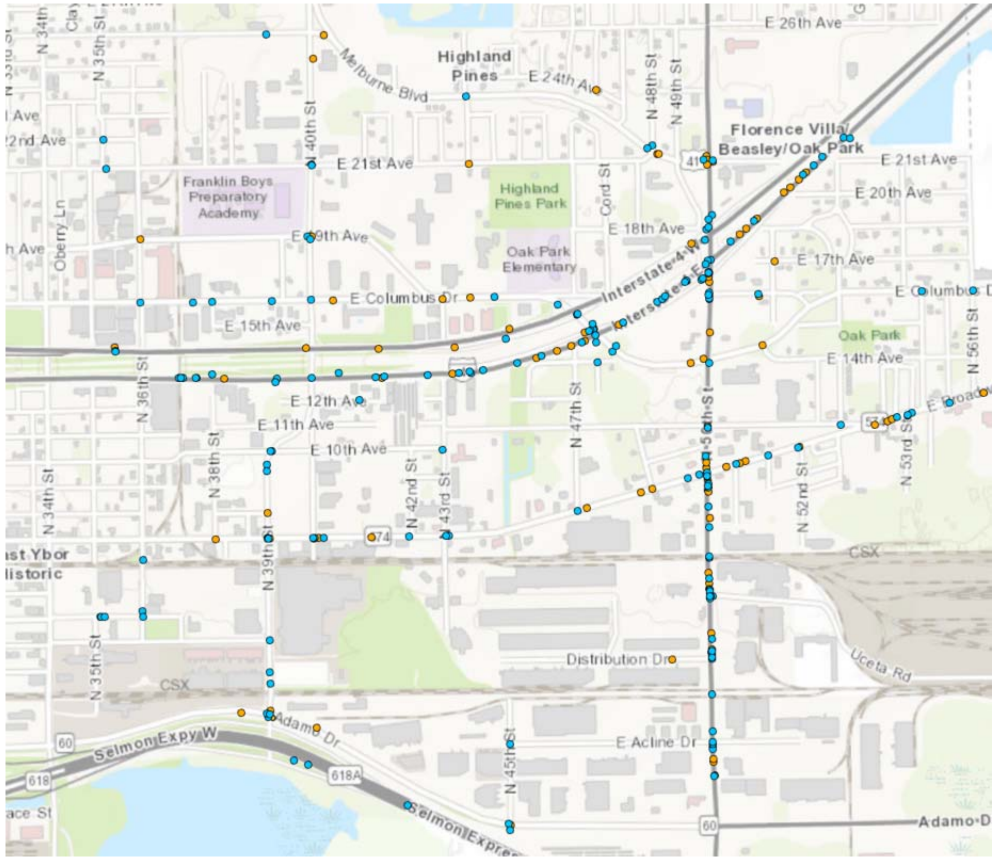


Figure 168 Hotspot area # 2 location and roads in District 7



Large Truck as Primary Vehicle: 238 crashes

Non – Large Truck as Primary Vehicle: 167 crashes

Figure 169 Crash locations by primary vehicle type in hotspot area # 2 in District 7

Table 79 Occurrence of Critical Reasons in District 7, Hotspot Area #2

D7, Hot Spot Area #2	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	64	38
	2 Improper Maneuver	61	35
	3 Other Contributing Actions	35	22
	4 Illegal maneuver	32	35
Non-Driving Error	5 Other critical condition	0	2
	6 Asleep	0	2
	7 Physical impairment	0	1
	8 Emotional impairment	0	0
	9 DUI	1	2
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	4	5
	11 Other recognition	13	9
	12 Inattention	1	8
	13 External distraction	1	2
	14 Internal distraction	0	4
	15 Obstruction	2	1
Vehicle Defects	16 Vital defect	6	4
	17 Non-Vital Defect	5	5
Roadway Condition	18 Slick road	19	14
	19 Road geometry	16	11
	20 Work zone	4	4
	21 Rough road	0	0
	22 Improper signal	1	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	1	1
	25 Wind gust	0	0
	26 Glare	0	1
	27 NA	34	30
Report Count		238	167

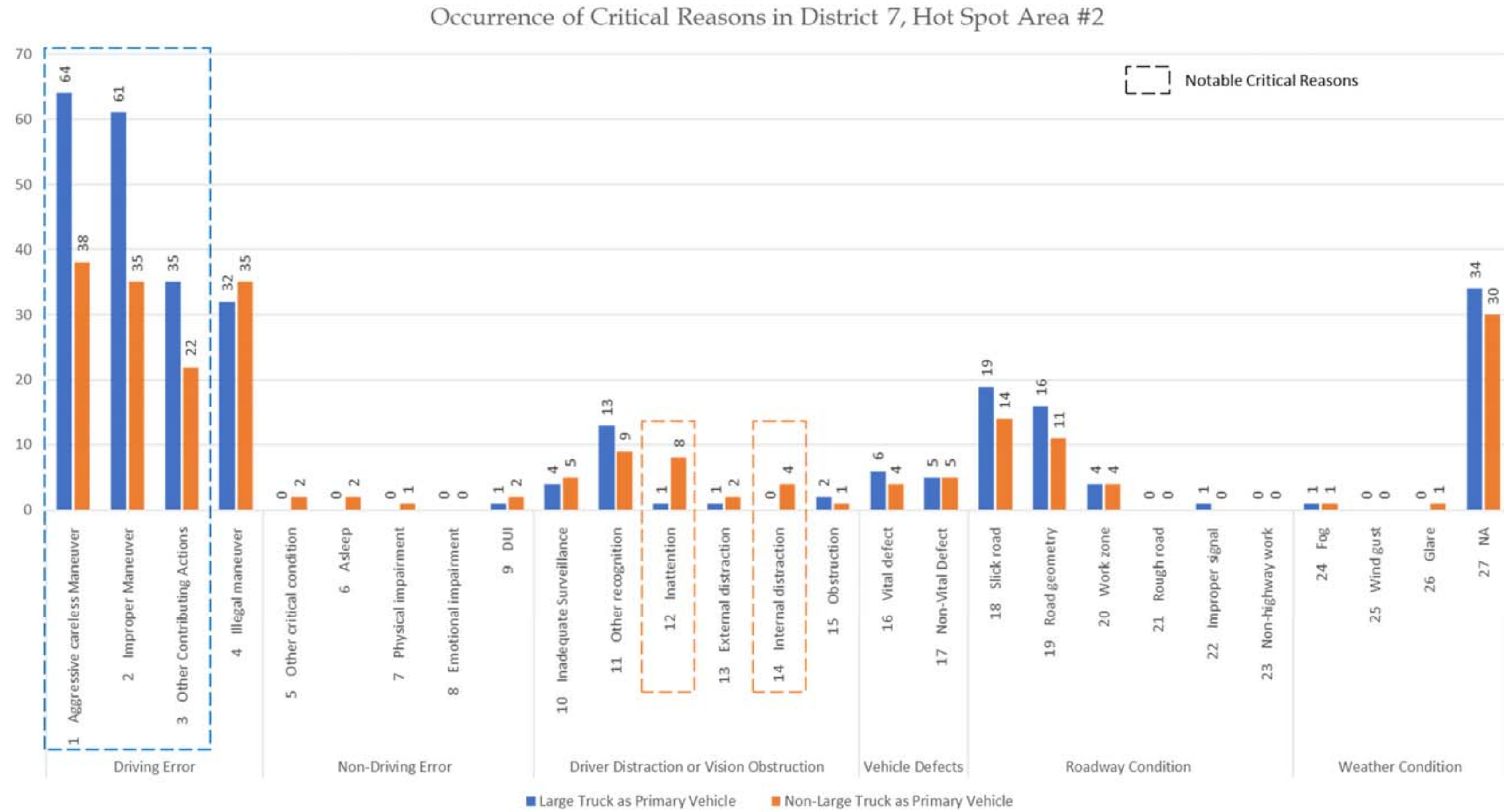


Figure 170 Occurrence of critical reasons in District 7, hotspot area #2

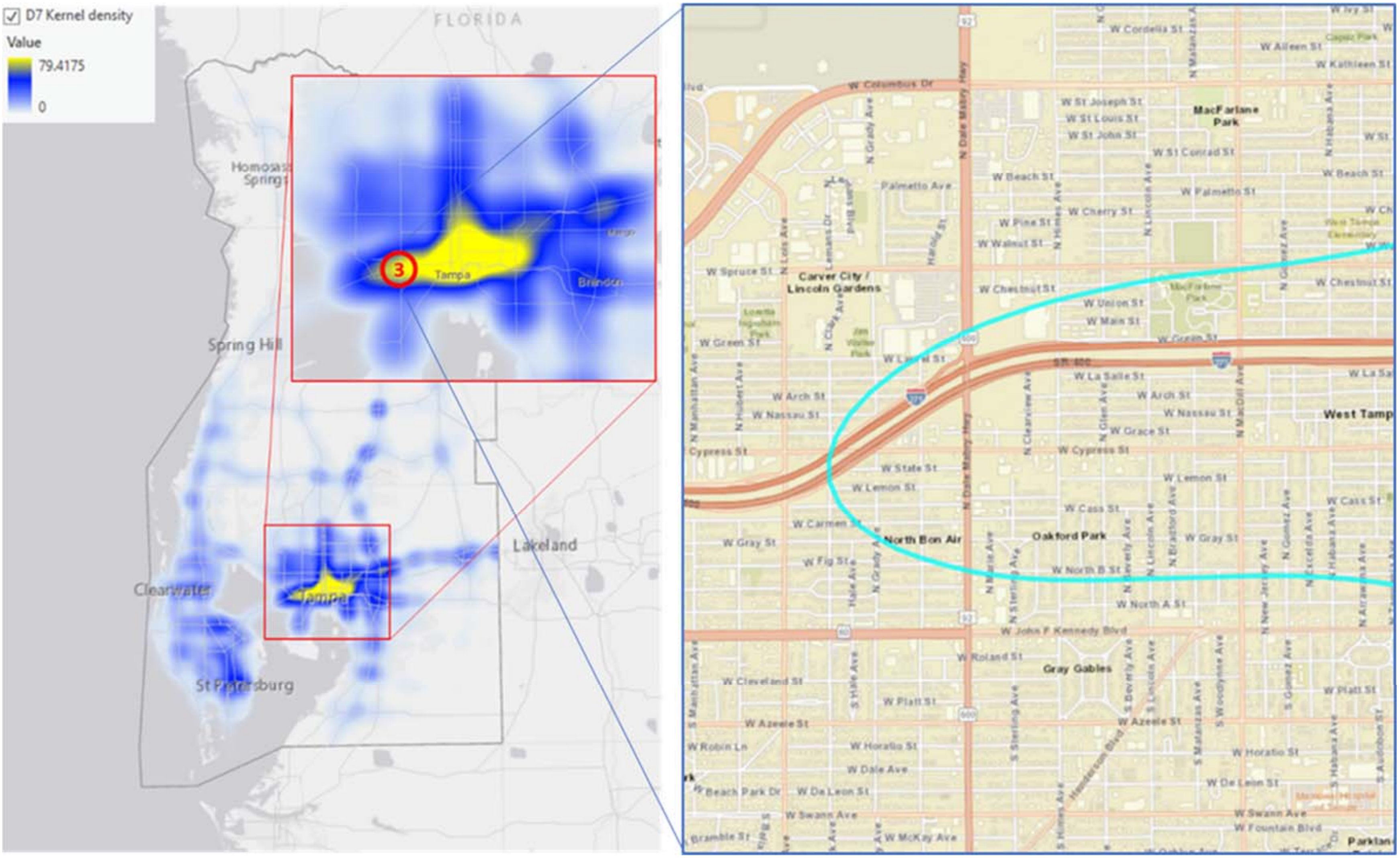
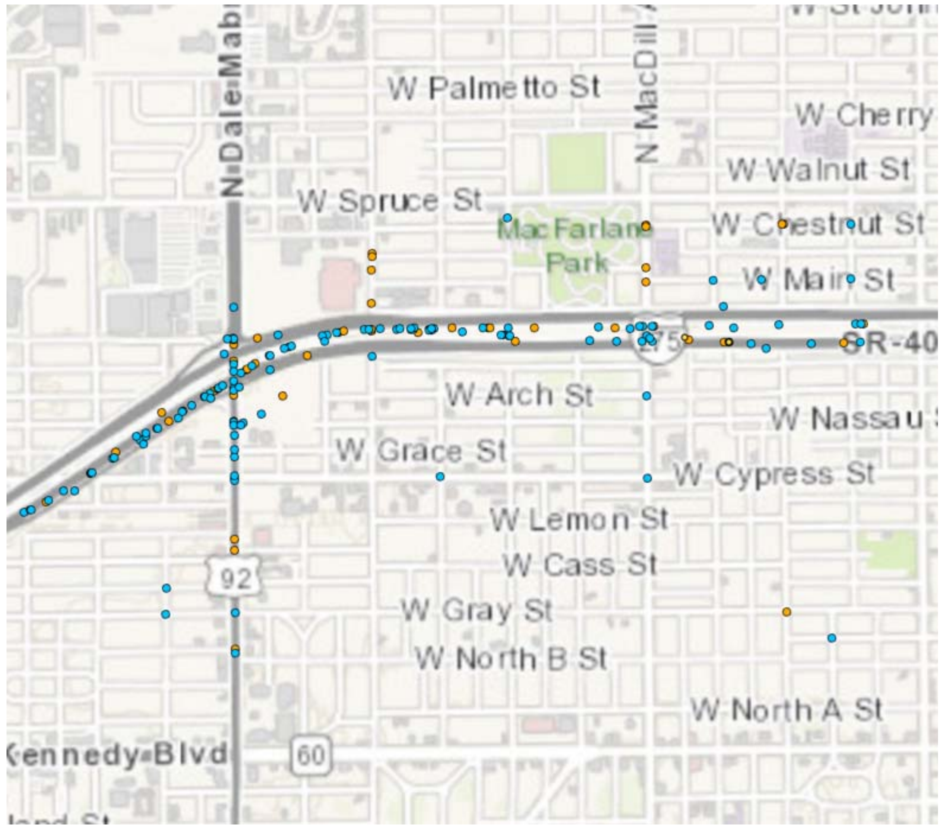


Figure 171 Hotspot area # 3 location and roads in District 7



Large Truck as Primary Vehicle: 156 crashes

Non – Large Truck as Primary Vehicle: 167 crashes

Figure 172 Crash locations by primary vehicle type in hotspot area # 3 in District 7

Table 80 Occurrence of Critical Reasons in District 7, Hotspot Area #3

D7, Hot Spot Area #3		Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	57	29
	2	Improper Maneuver	27	11
	3	Other Contributing Actions	19	12
	4	Illegal maneuver	11	13
Non-Driving Error	5	Other critical condition	0	1
	6	Asleep	0	0
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	1
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	3	3
	11	Other recognition	2	0
	12	Inattention	4	1
	13	External distraction	1	0
	14	Internal distraction	1	0
	15	Obstruction	2	1
Vehicle Defects	16	Vital defect	6	0
	17	Non-Vital Defect	1	0
Roadway Condition	18	Slick road	13	12
	19	Road geometry	13	14
	20	Work zone	2	2
	21	Rough road	0	0
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	0
	25	Wind gust	0	0
	26	Glare	1	0
	27	NA	31	15
Report Count			156	167

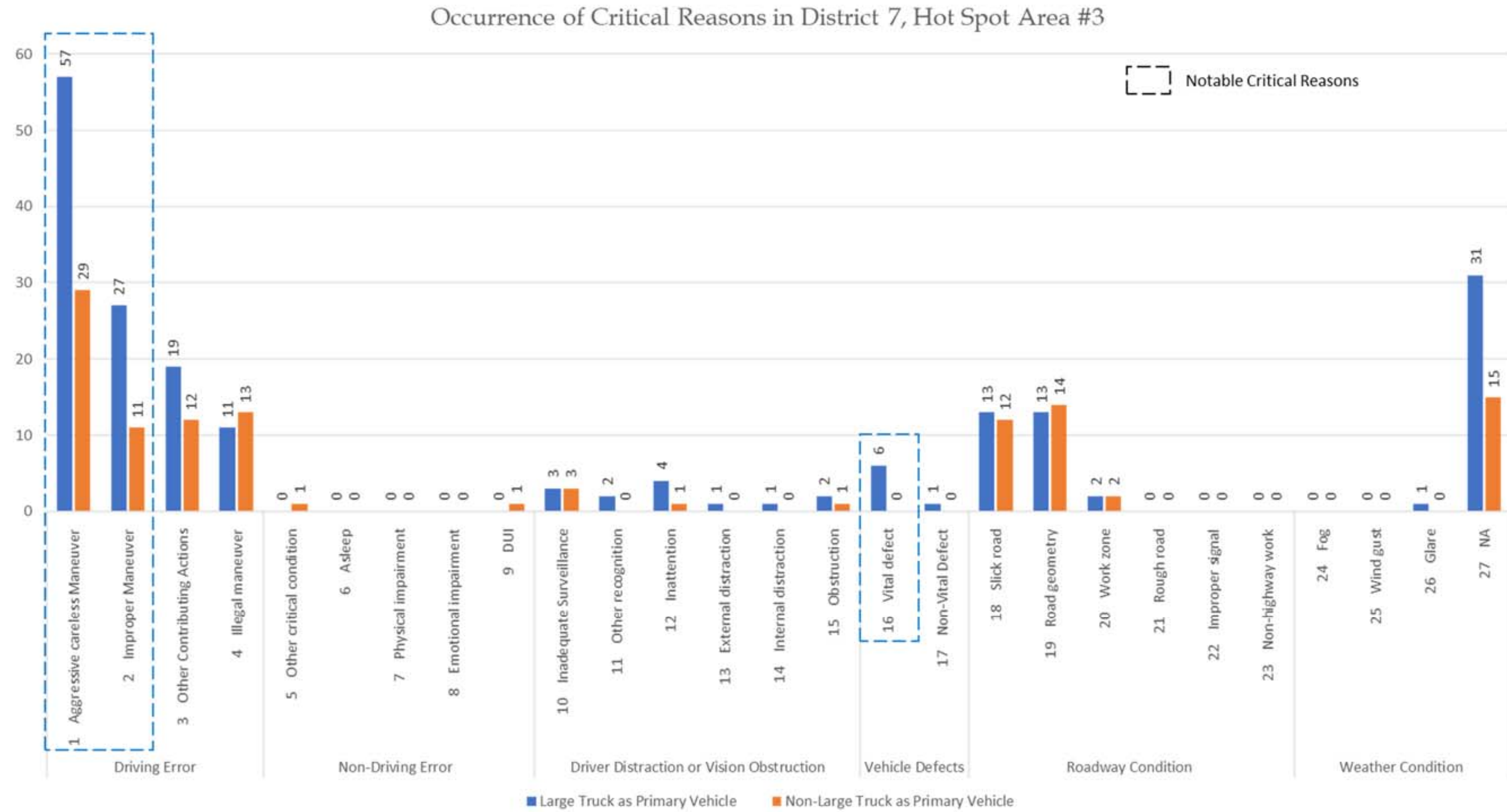


Figure 173 Occurrence of critical reasons in District 7, hotspot area #3

8.3.3.4. District 2 – two locations

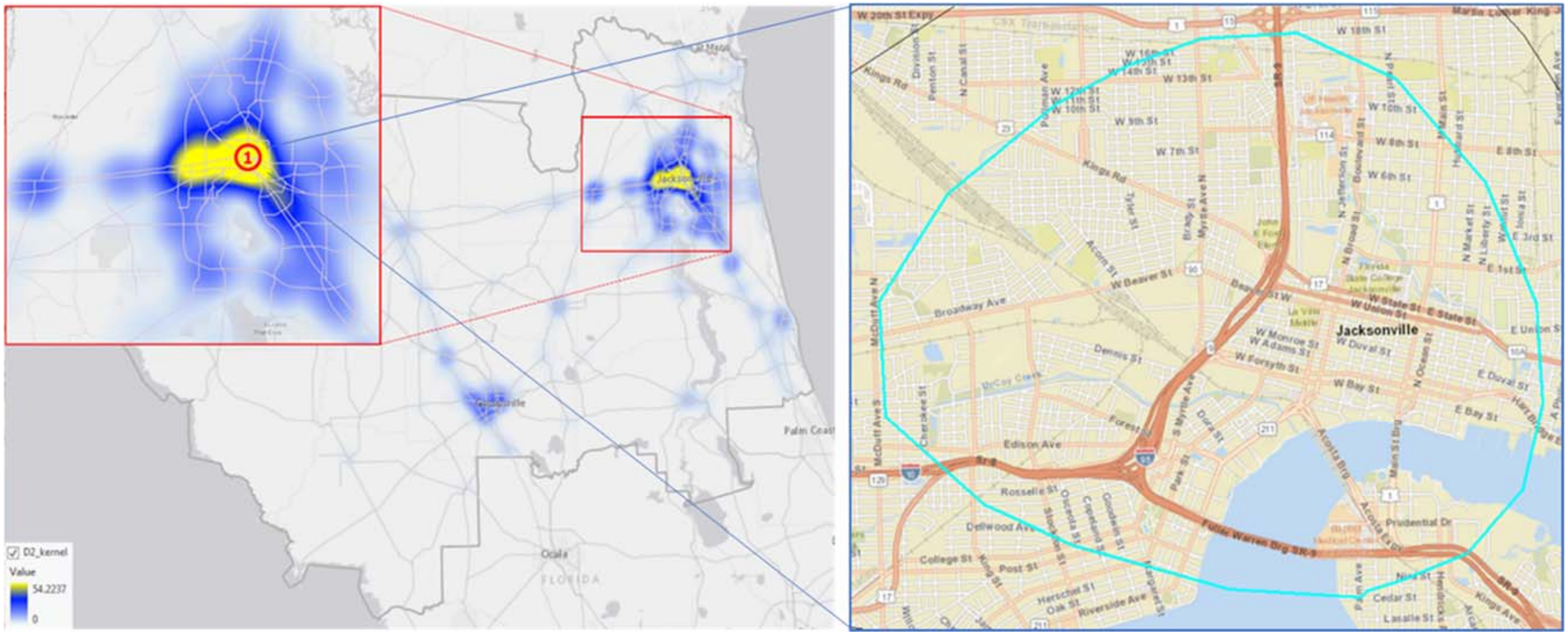
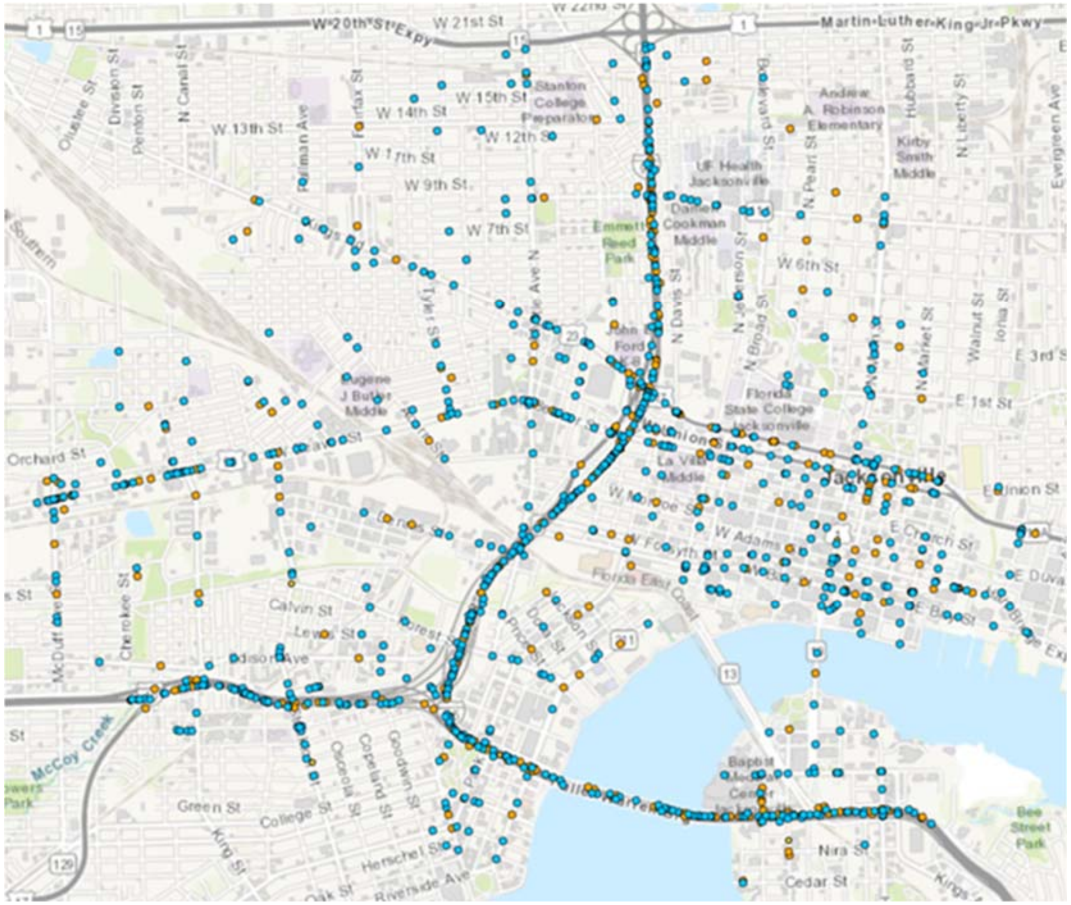


Figure 174 Hotspot area # 1 location and roads in District 2



Large Truck as Primary Vehicle: 1016 crashes

Non – Large Truck as Primary Vehicle: 584 crashes

Figure 175 Crash locations by primary vehicle type in hotspot area # 1 in District 2

Table 81 Occurrence of Critical Reasons in District 2, Hotspot Area #1

D2, Hot Spot Area #1	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	282	148
	2 Improper Maneuver	231	104
	3 Other Contributing Actions	140	96
	4 Illegal maneuver	48	85
Non-Driving Error	5 Other critical condition	1	1
	6 Asleep	0	3
	7 Physical impairment	0	1
	8 Emotional impairment	0	0
	9 DUI	2	4
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	38	15
	11 Other recognition	23	3
	12 Inattention	29	21
	13 External distraction	2	3
	14 Internal distraction	9	2
	15 Obstruction	4	5
Vehicle Defects	16 Vital defect	28	7
	17 Non-Vital Defect	29	22
Roadway Condition	18 Slick road	128	93
	19 Road geometry	96	63
	20 Work zone	52	35
	21 Rough road	9	4
	22 Improper signal	1	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	5	1
	25 Wind gust	0	0
	26 Glare	0	0
	27 NA	193	105
Report Count		1016	584

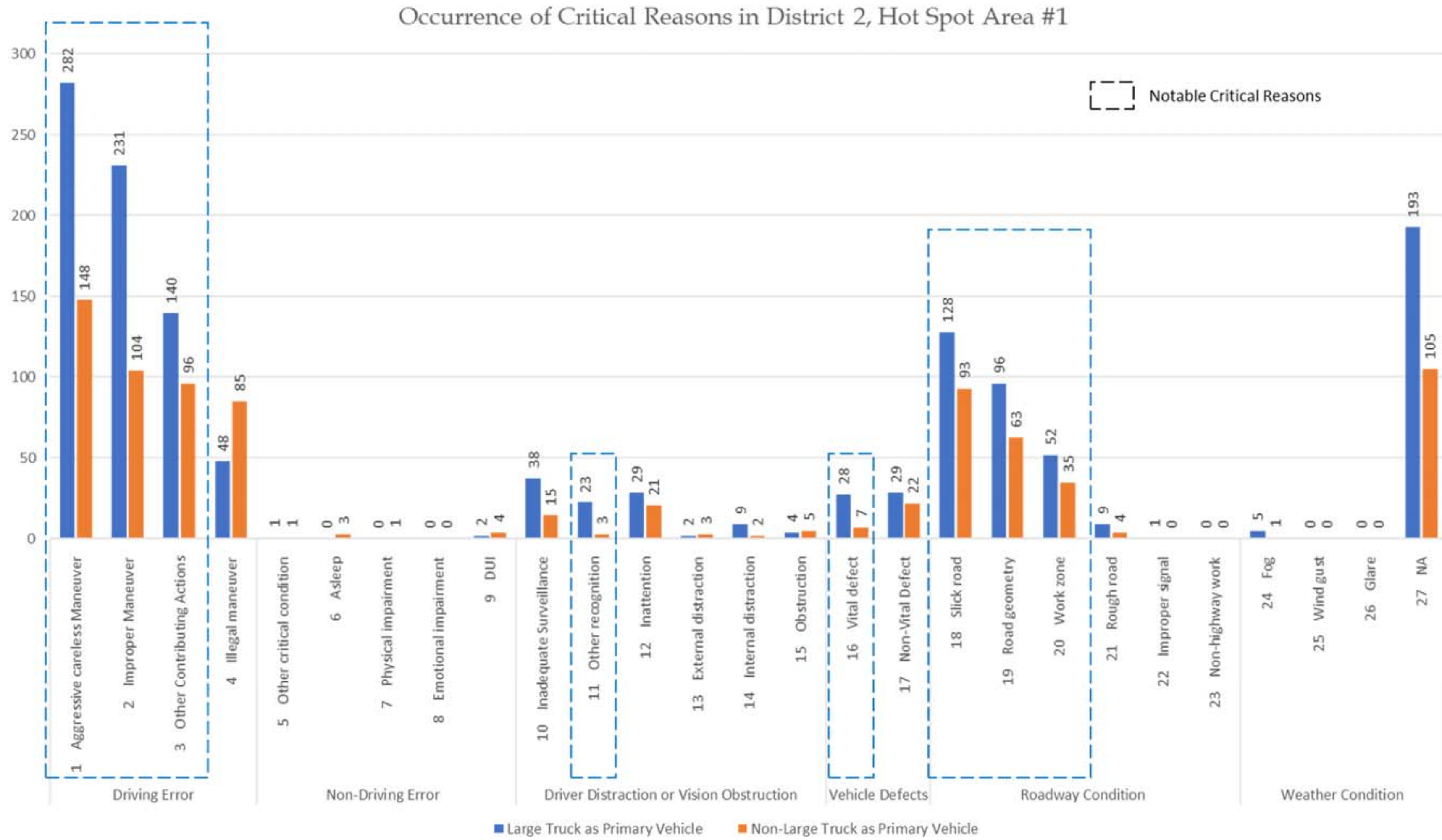


Figure 176 Occurrence of critical reasons in District 2, hotspot area #1

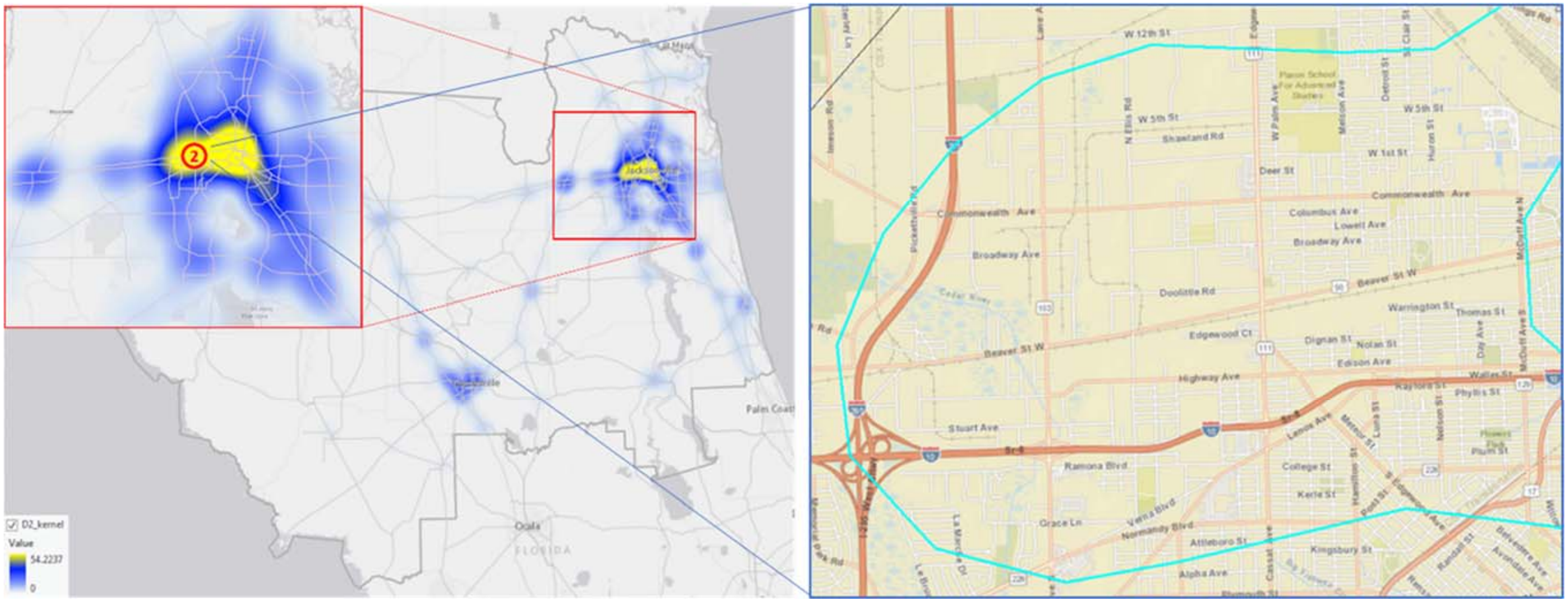
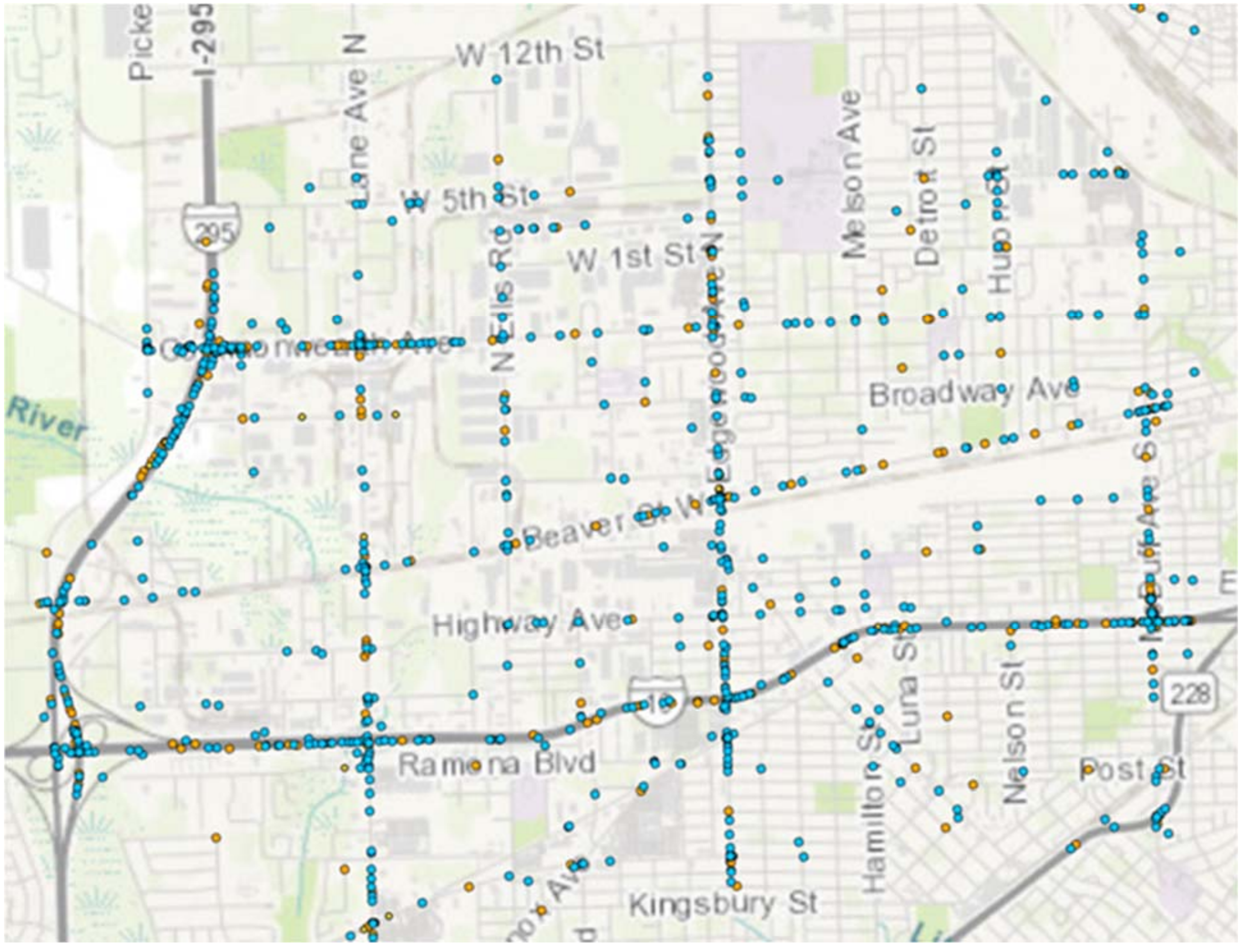


Figure 177 Hotspot area # 2 location and roads in District 2



Large Truck as Primary Vehicle: 921 crashes

Non – Large Truck as Primary Vehicle: 452 crashes

Figure 178 Crash locations by primary vehicle type in hotspot area # 2 in District 2

Table 82 Occurrence of Critical Reasons in District 2, Hotspot Area #2

D2, Hot Spot Area #2	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	270	151
	2 Improper Maneuver	218	65
	3 Other Contributing Actions	127	61
	4 Illegal maneuver	63	58
Non-Driving Error	5 Other critical condition	0	3
	6 Asleep	1	3
	7 Physical impairment	0	0
	8 Emotional impairment	0	1
	9 DUI	1	9
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	43	17
	11 Other recognition	26	5
	12 Inattention	29	20
	13 External distraction	7	0
	14 Internal distraction	4	12
	15 Obstruction	3	1
Vehicle Defects	16 Vital defect	28	9
	17 Non-Vital Defect	16	14
Roadway Condition	18 Slick road	128	71
	19 Road geometry	61	30
	20 Work zone	26	9
	21 Rough road	7	0
	22 Improper signal	2	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	9	1
	25 Wind gust	0	0
	26 Glare	1	0
	27 NA	172	94
Report Count		921	453

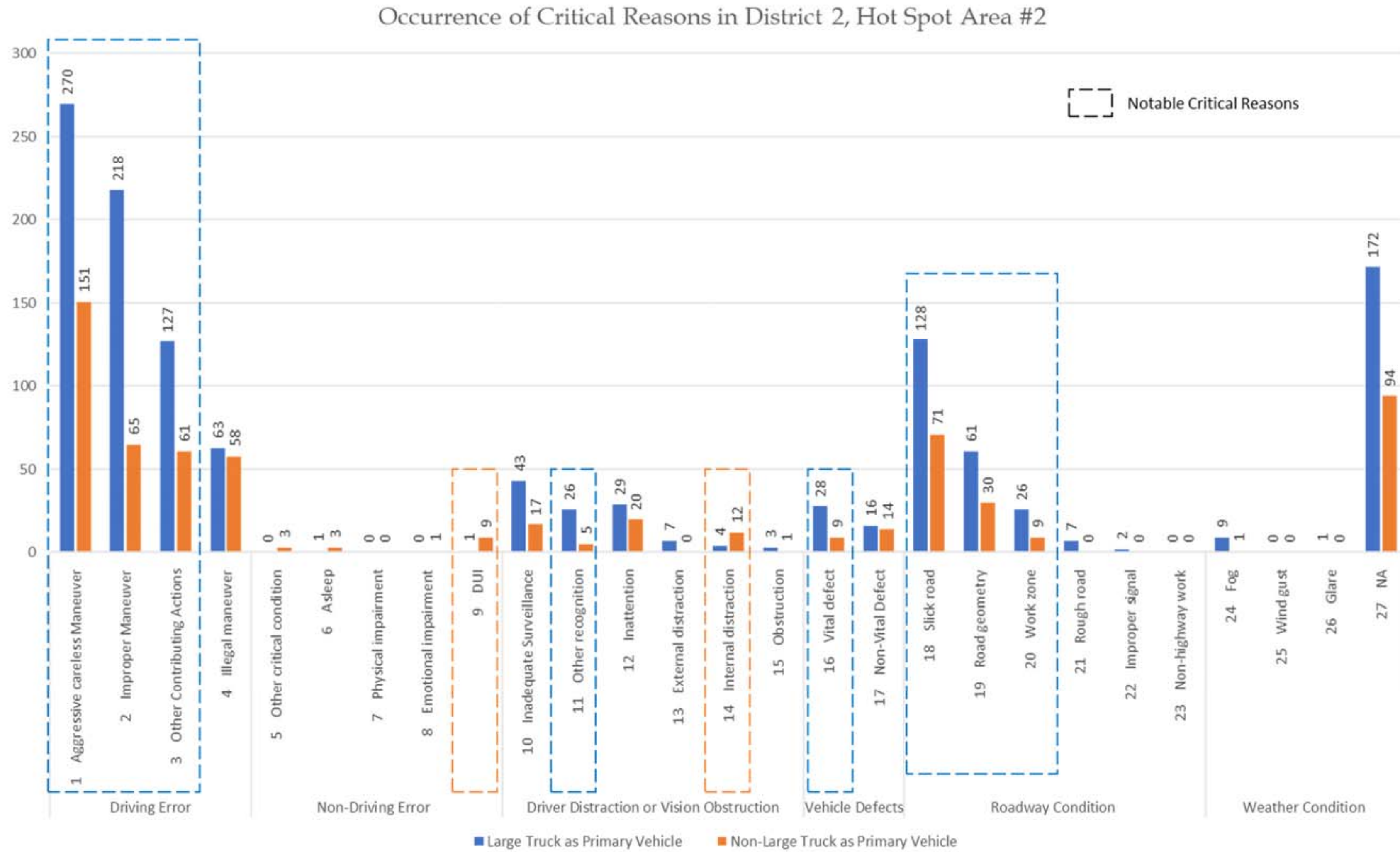


Figure 179 Occurrence of critical reasons in District 2, hotspot area #2

8.3.3.5. District 5 – two locations

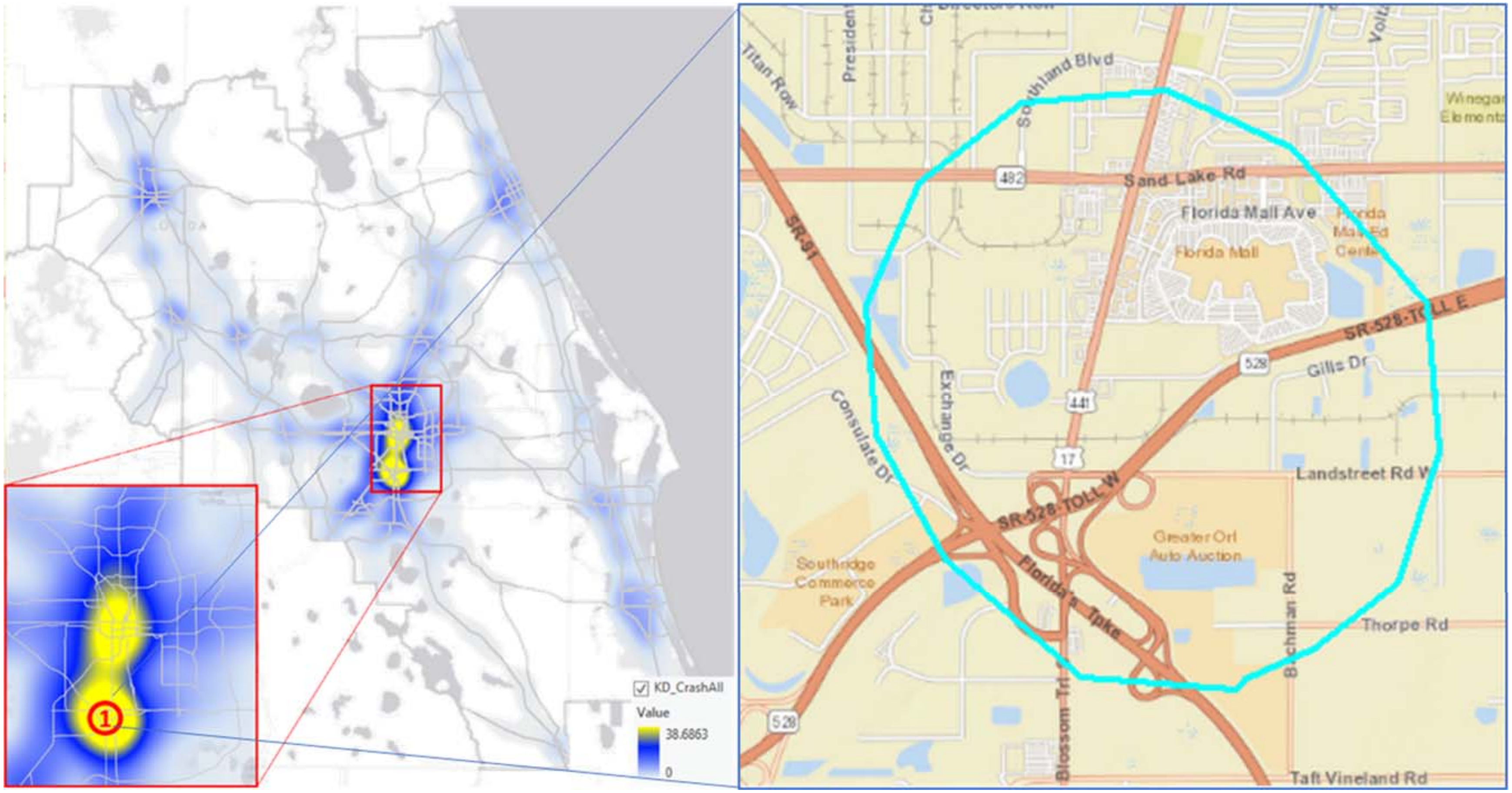
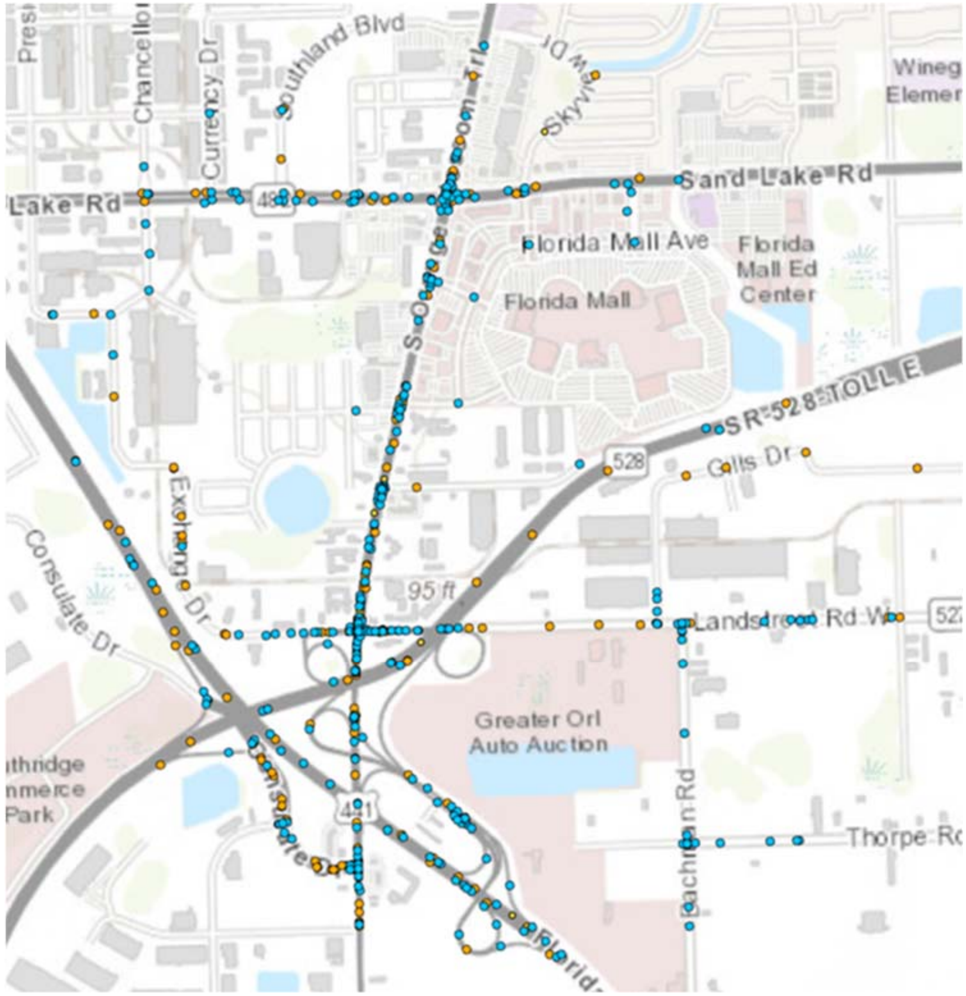


Figure 180 Hotspot area # 1 location and roads in District 5



● Large Truck as Primary Vehicle: 449 crashes

● Non – Large Truck as Primary Vehicle: 358 crashes

Figure 181 Crash locations by primary vehicle type in hotspot area # 1 in District 5

Table 83 Occurrence of Critical Reasons in District 5, Hotspot Area #1

D5, Hot Spot Area #1	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	112	81
	2 Improper Maneuver	148	67
	3 Other Contributing Actions	60	63
	4 Illegal maneuver	38	40
Non-Driving Error	5 Other critical condition	2	2
	6 Asleep	2	1
	7 Physical impairment	1	3
	8 Emotional impairment	0	0
	9 DUI	1	2
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	27	8
	11 Other recognition	28	4
	12 Inattention	17	10
	13 External distraction	5	2
	14 Internal distraction	4	4
	15 Obstruction	3	0
Vehicle Defects	16 Vital defect	12	9
	17 Non-Vital Defect	4	9
Roadway Condition	18 Slick road	57	46
	19 Road geometry	16	12
	20 Work zone	7	4
	21 Rough road	4	0
	22 Improper signal	1	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	0	0
	25 Wind gust	0	0
	26 Glare	0	0
	27 NA	106	54
Report Count		449	358

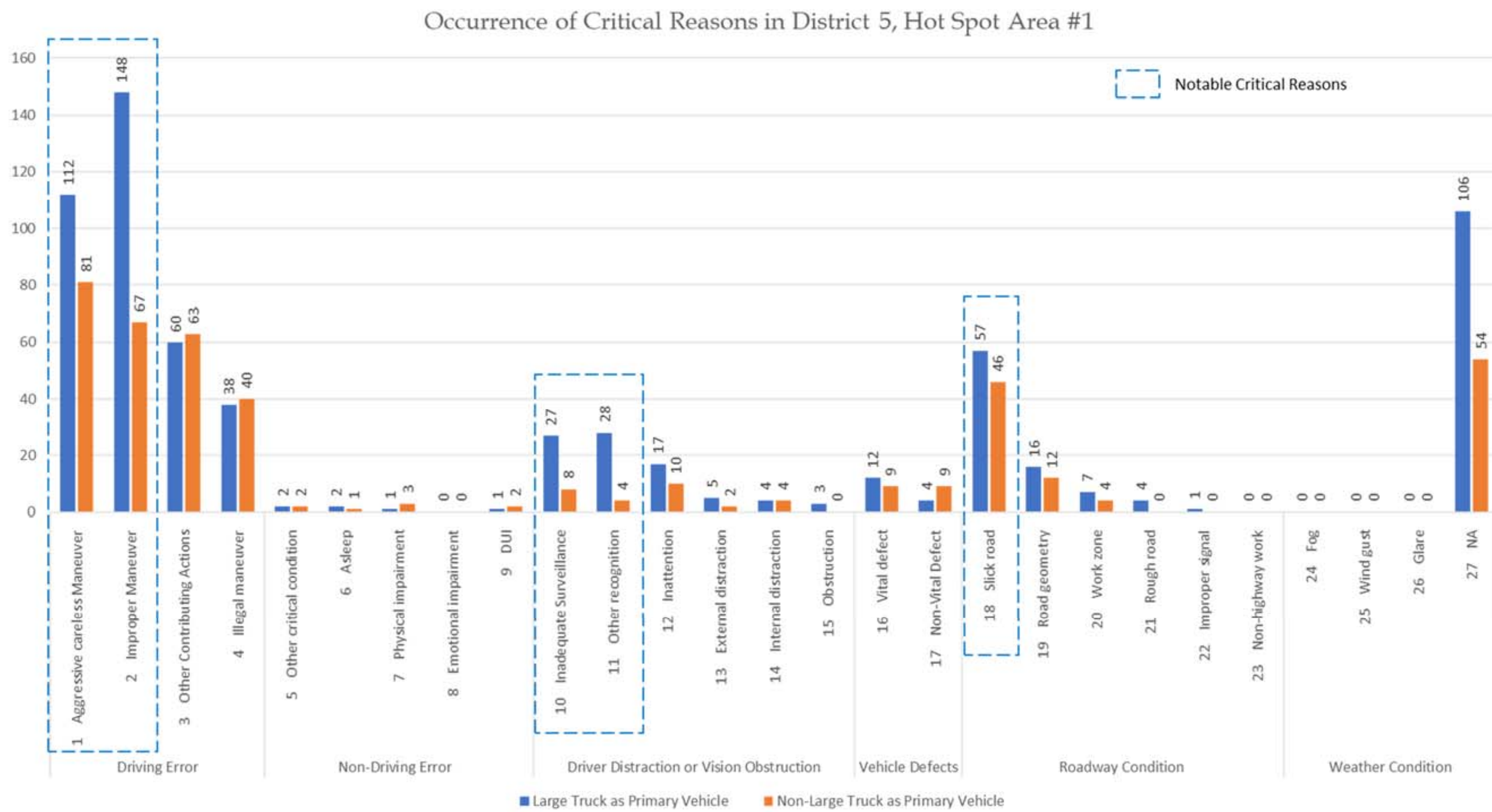


Figure 182 Occurrence of critical reasons in District 5, hotspot area #1

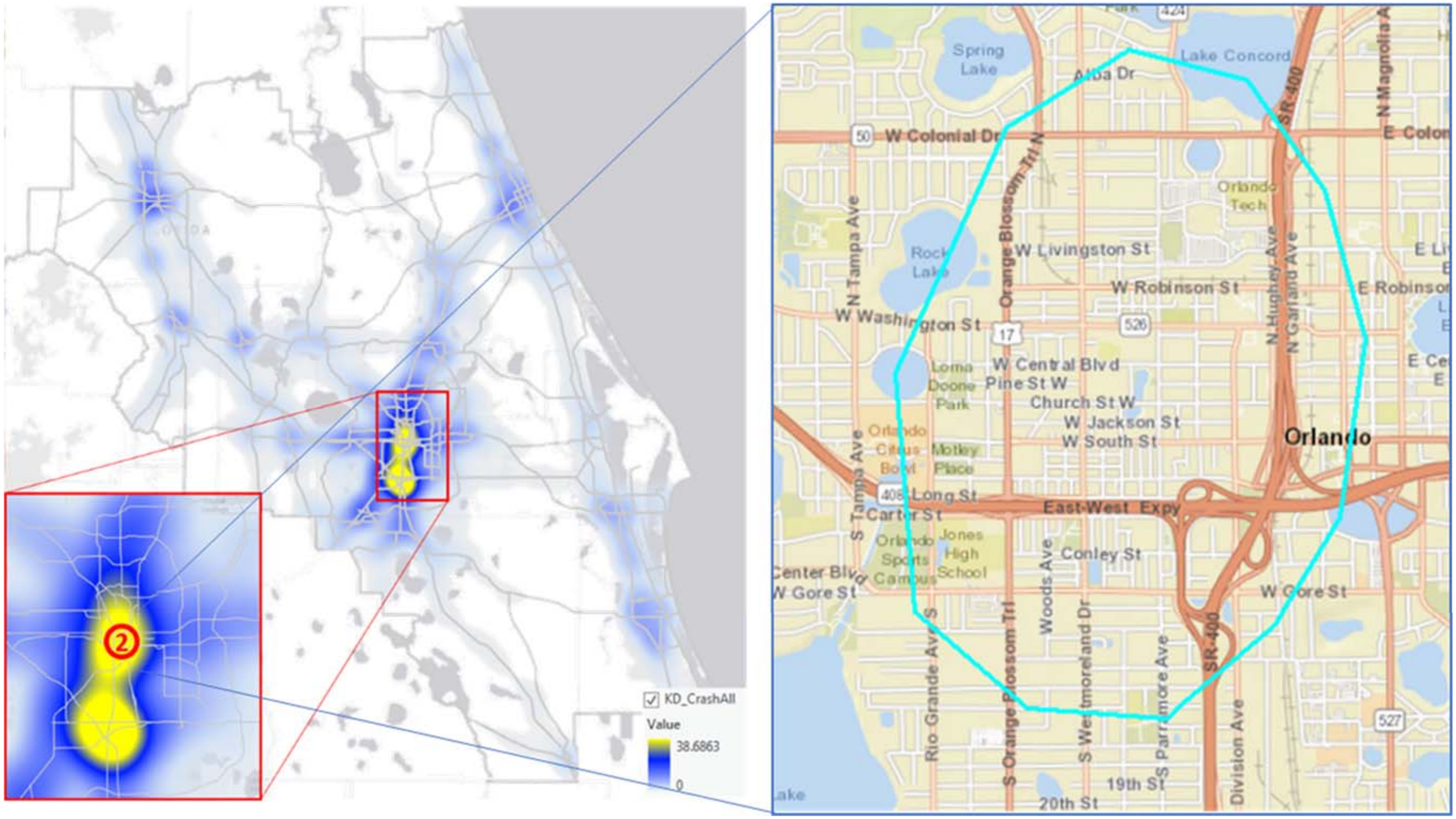
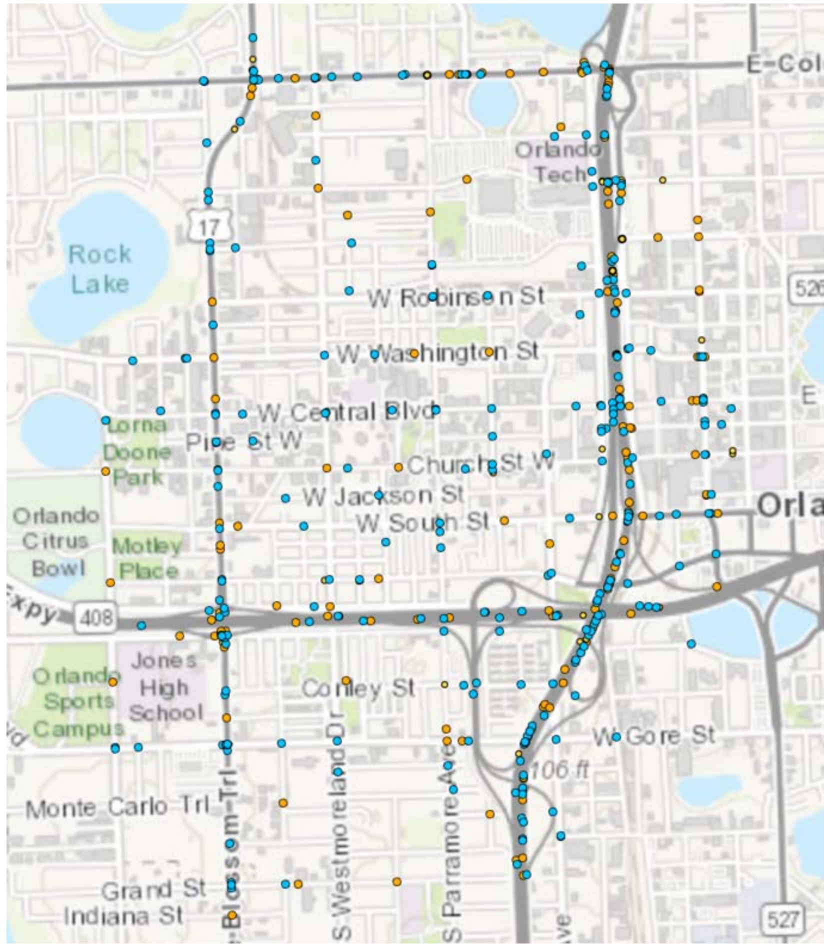


Figure 183 Hotspot area # 2 location and roads in District 5



Large Truck as Primary Vehicle: 306 crashes

Non – Large Truck as Primary Vehicle: 218 crashes

Figure 184 Crash locations by primary vehicle type in hotspot area # 2 in District 5

Table 84 Occurrence of Critical Reasons in District 5, Hotspot Area #2

D5, Hot Spot Area #2	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	98	56
	2 Improper Maneuver	64	46
	3 Other Contributing Actions	63	52
	4 Illegal maneuver	13	28
Non-Driving Error	5 Other critical condition	2	4
	6 Asleep	2	2
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	4
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	7	9
	11 Other recognition	15	9
	12 Inattention	9	5
	13 External distraction	3	0
	14 Internal distraction	3	3
	15 Obstruction	2	2
Vehicle Defects	16 Vital defect	10	2
	17 Non-Vital Defect	6	8
Roadway Condition	18 Slick road	50	21
	19 Road geometry	15	10
	20 Work zone	9	5
	21 Rough road	2	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	1	0
	25 Wind gust	0	0
	26 Glare	0	1
	27 NA	51	29
Report Count		306	218

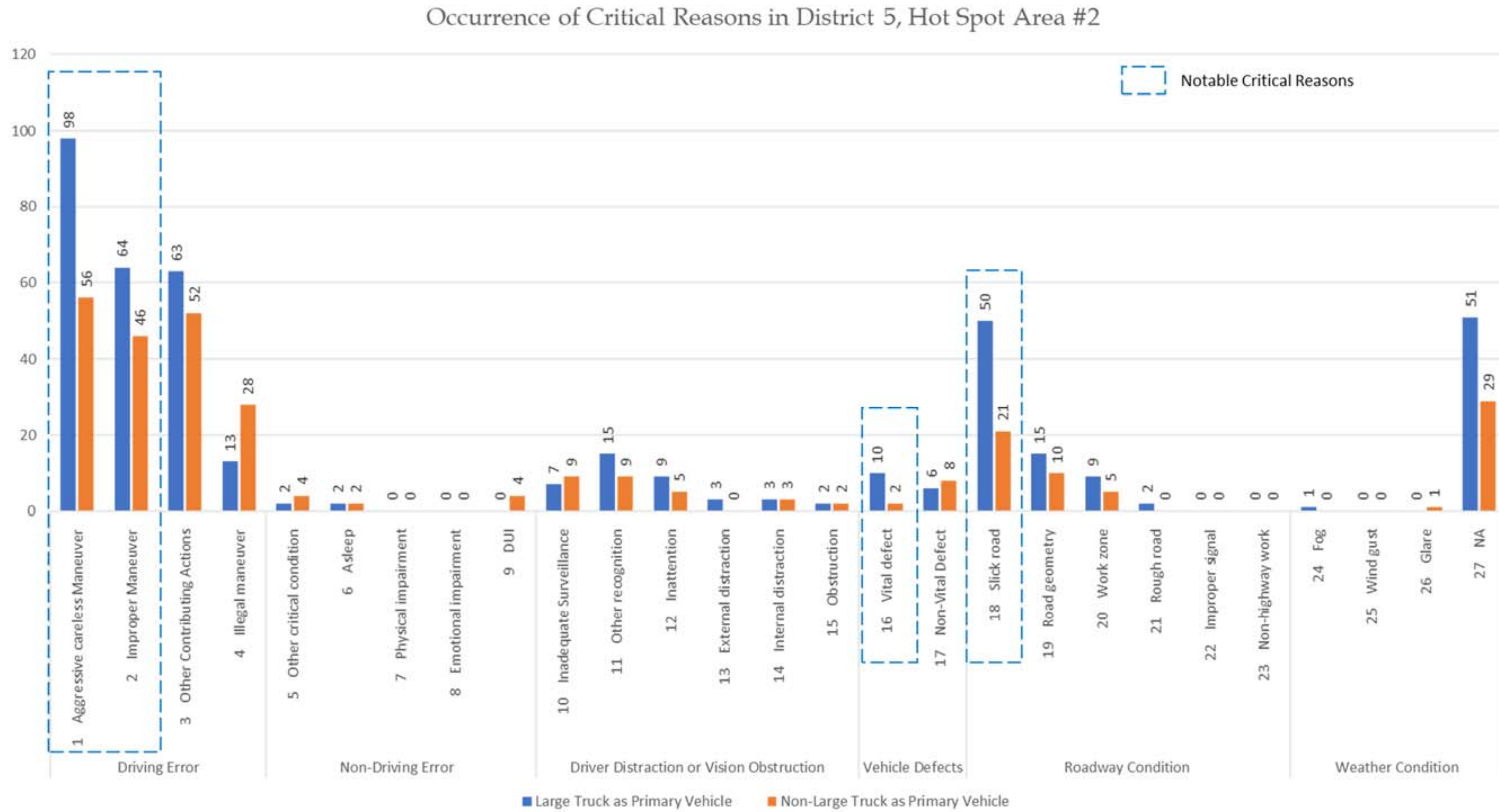


Figure 185 Occurrence of critical reasons in District 5, hotspot area #2

8.3.4. Problematic Intersection Locations for Large Trucks

Problematic intersections for large trucks in the state of Florida are identified based on high crash count, high crash severity, high crash rate, and relative high crash rate considering crash severity. Intersection crashes were extracted from the entire crash dataset using the following criteria:

- Crashes marked as at any type of intersection in the report except '1 – Not at Intersection' or '-'
- Crashes that are within 5 feet of marked intersection crashes in the report.
- Crashes that have a valid intersection ID in the dataset and its offset distance from the intersection is less than or equal to 250 feet and greater than or equal to 0.
- Crashes that are spatially within 35 feet of an intersection.

The criteria above returned 135,480 crashes (69%) from the total number of 197,397 crashes available for spatial analysis. The intersection crash data are processed and cleaned to make sure they are associated with an intersection.

ArcGIS and Python programing were used to calculate crash counts, crash severity, crash rate, and intersection AADTs for all intersections statewide. The top 5 intersections were identified respectively for each measure:

1. high crash counts,
2. high crash severity,
3. high crash rate, and
4. high crash rate considering severity

Crash severity index is measured as the sums of equivalent property damage only (EPDO) divided by crash count at an intersection. The EPDO is 12, 4 and 1 for fatality, injury, and PDO crashes respectively. Since some intersections with a very small number of fatal crashes will skew the injury severity of an intersection we selected intersections with more than 5 crashes and with an injury severity index greater than 4.

Crash rate is calculated based on formula:

$$R = \frac{1{,}000{,}000 \times C}{365 \times N \times V}$$

R = Crash rate for the intersection (crashes per million entering vehicles)
C = Total number of intersection crashes in the study period
N = Number of years of data
V = Traffic volumes entering the intersection daily

Since extreme low AADT will result in a very high crash rate, we only selected intersections with an intersection AADT larger than 2000.

Crash rate considering severity is similar to calculating the crash rate. The difference is that a crash involves fatality will be counted as 12 PDO (property damaged only) crashes. If a crash involved injury, it will be counted as 4 PDO crashes in the crash rate formula.

The top 5 intersections for each of the four measures are shown in Figure 184. Detailed analyses are presented in the following pages.

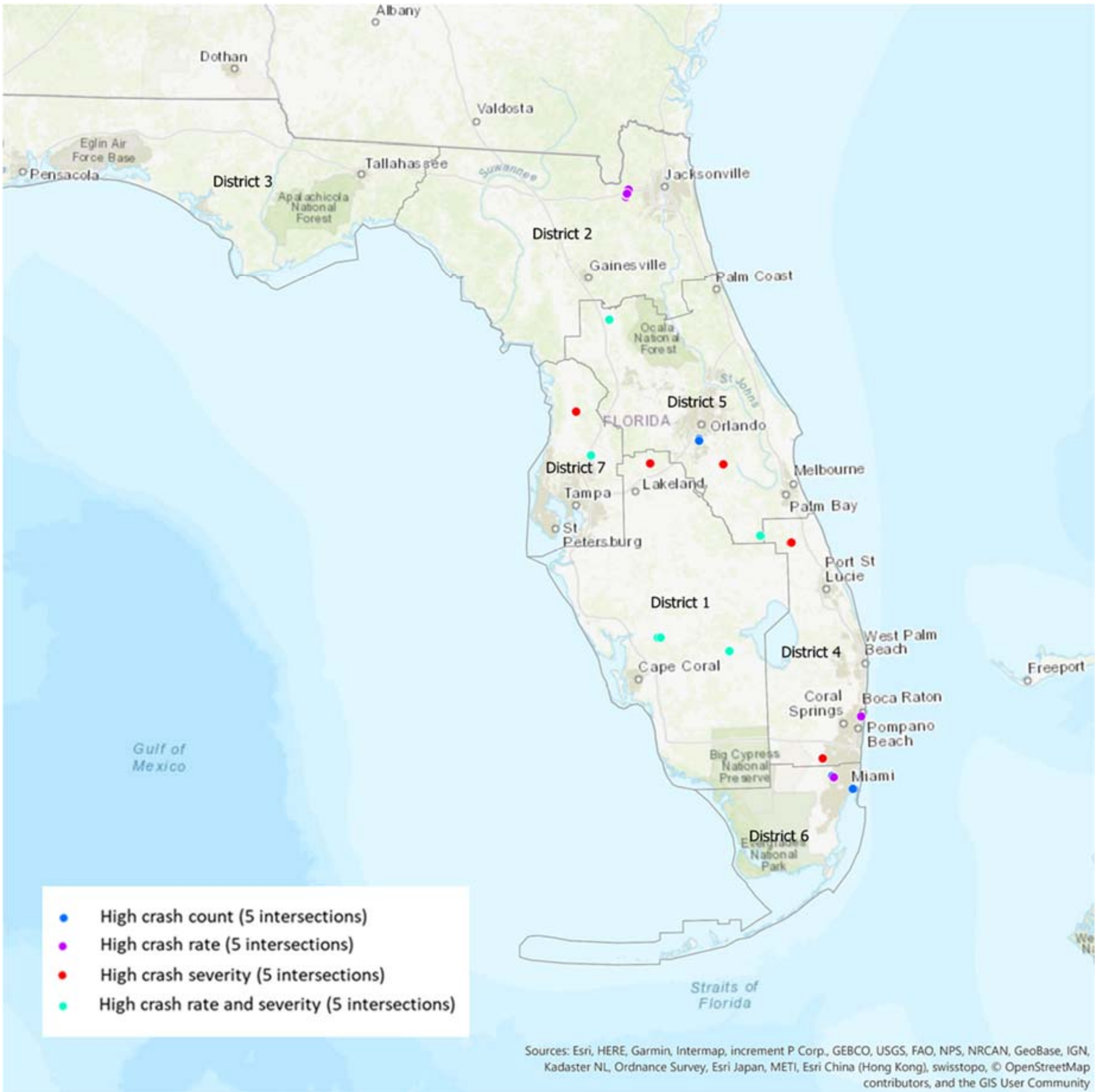


Figure 186 Statewide problematic intersections

Due to limited crash counts at some intersections, we did not find notable critical reasons for them. For such intersections, a more detailed study is needed to review the individual crash reports in order to investigate potential reasons in the police crash diagrams and narratives.

High crash count intersection #1

Intersection ID: 68886
City: Orlando
County: Orange
Street names: ORANGE BLOSSOM TRL S and LANDSTREET RD W
Intersection AADT: 74,900
Crash count: 147

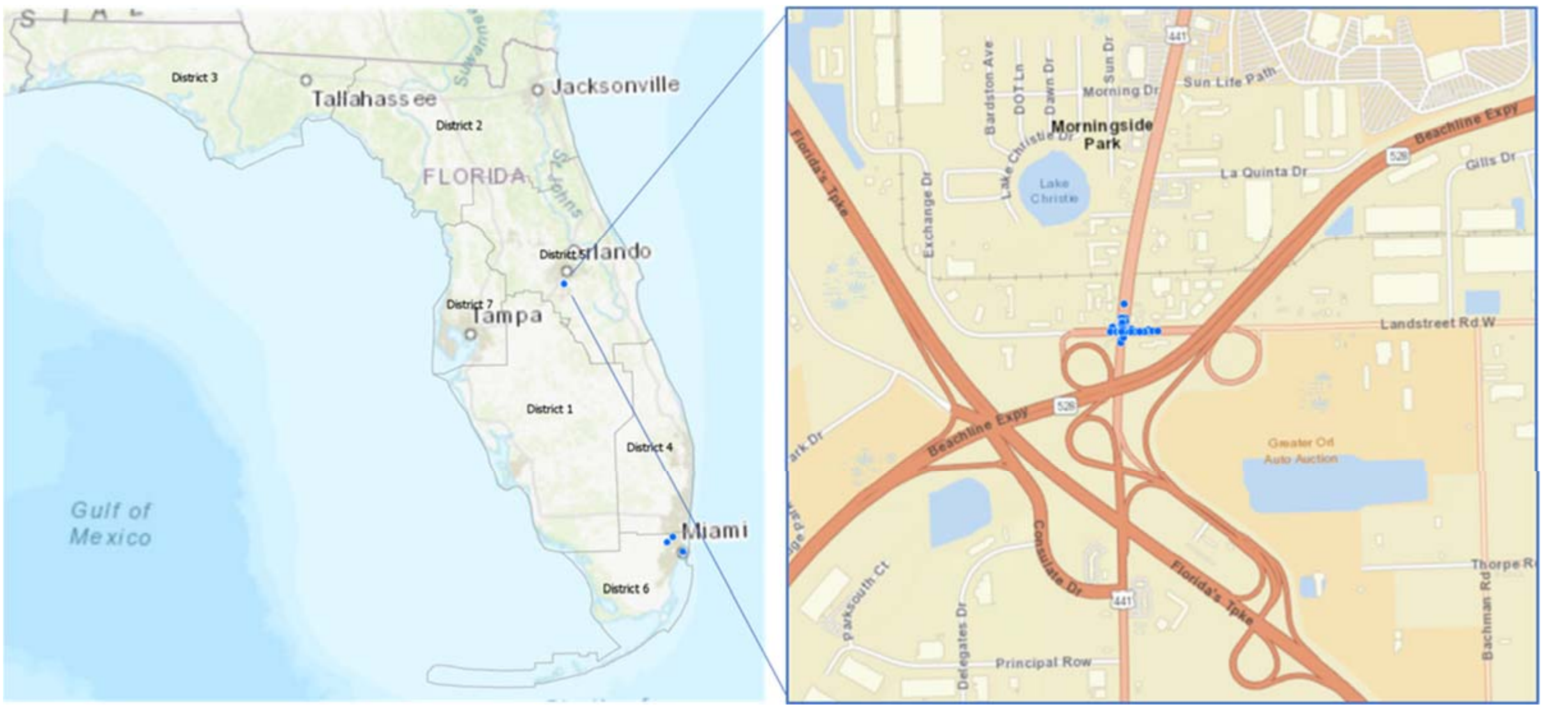


Figure 187 High crash count intersection #1

Figure 188 Crash locations by primary vehicle type at high crash count intersection # 1

Table 85 Occurrence of Critical Reasons at High Crash Count Intersection # 1

Intersection with high Crash count, #1	Critical Reasons		Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	32	9
	2	Improper Maneuver	19	19
	3	Other Contributing Actions	10	11
	4	Illegal maneuver	4	16
Non-Driving Error	5	Other critical condition	0	0
	6	Asleep	0	0
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	1
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	1	0
	11	Other recognition	0	0
	12	Inattention	21	14
	13	External distraction	0	0
	14	Internal distraction	0	0
	15	Obstruction	0	0
Vehicle Defects	16	Vital defect	1	0
	17	Non-Vital Defect	0	0
Roadway Condition	18	Slick road	5	5
	19	Road geometry	0	0
	20	Work zone	0	0
	21	Rough road	1	0
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	0
	25	Wind gust	0	0
	26	Glare	0	0
NA	27	NA	17	6
Report Count			84	63

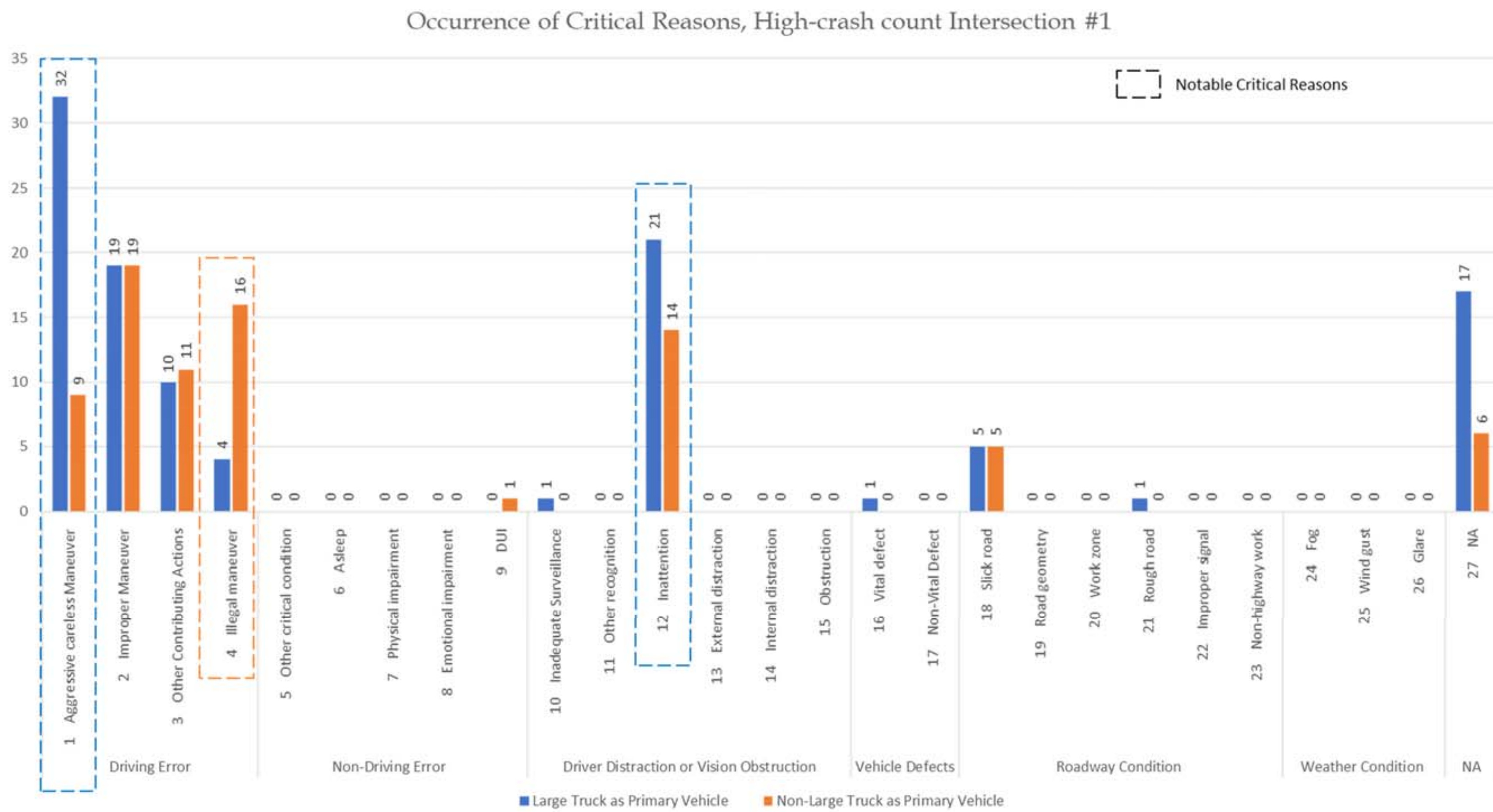


Figure 189 Occurrence of critical reasons at high crash count intersection #1

High Crash Count Intersection #2

Intersection ID: 542592
City: Hialeah Gardens
County: Miami-Dade
Street names: W OKEECHOBEE RD and NW 116TH WAY
Intersection AADT: 67,451
Report count: 142

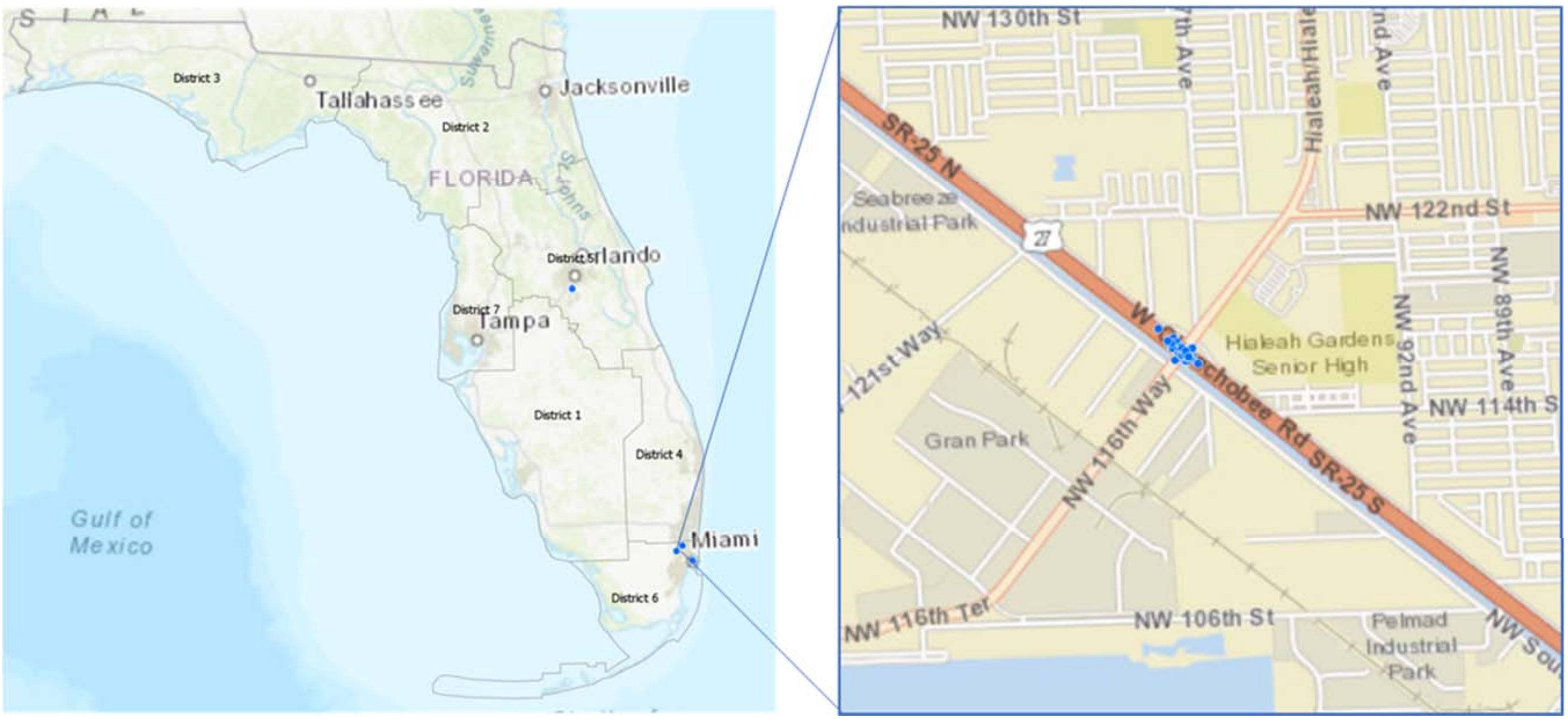


Figure 190 High crash count intersection #2

Large Truck as Primary Vehicle: 92 crashes

Non – Large Truck as Primary Vehicle: 50 crashes

Figure 191 Crash locations by primary vehicle type at high crash count intersection #2

Table 86 Occurrence of Critical Reasons at High Crash Count Intersection #2

Intersection with high Crash count, #2		Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	32	9
	2	Improper Maneuver	18	11
	3	Other Contributing Actions	8	4
	4	Illegal maneuver	9	10
Non-Driving Error	5	Other critical condition	0	0
	6	Asleep	0	0
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	0
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	0	0
	11	Other recognition	0	0
	12	Inattention	1	2
	13	External distraction	1	0
	14	Internal distraction	1	1
	15	Obstruction	0	1
Vehicle Defects	16	Vital defect	0	1
	17	Non-Vital Defect	0	0
Roadway Condition	18	Slick road	12	7
	19	Road geometry	1	0
	20	Work zone	1	0
	21	Rough road	0	0
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	0
	25	Wind gust	0	0
	26	Glare	0	0
NA	27	NA	23	14
Report Count			92	50

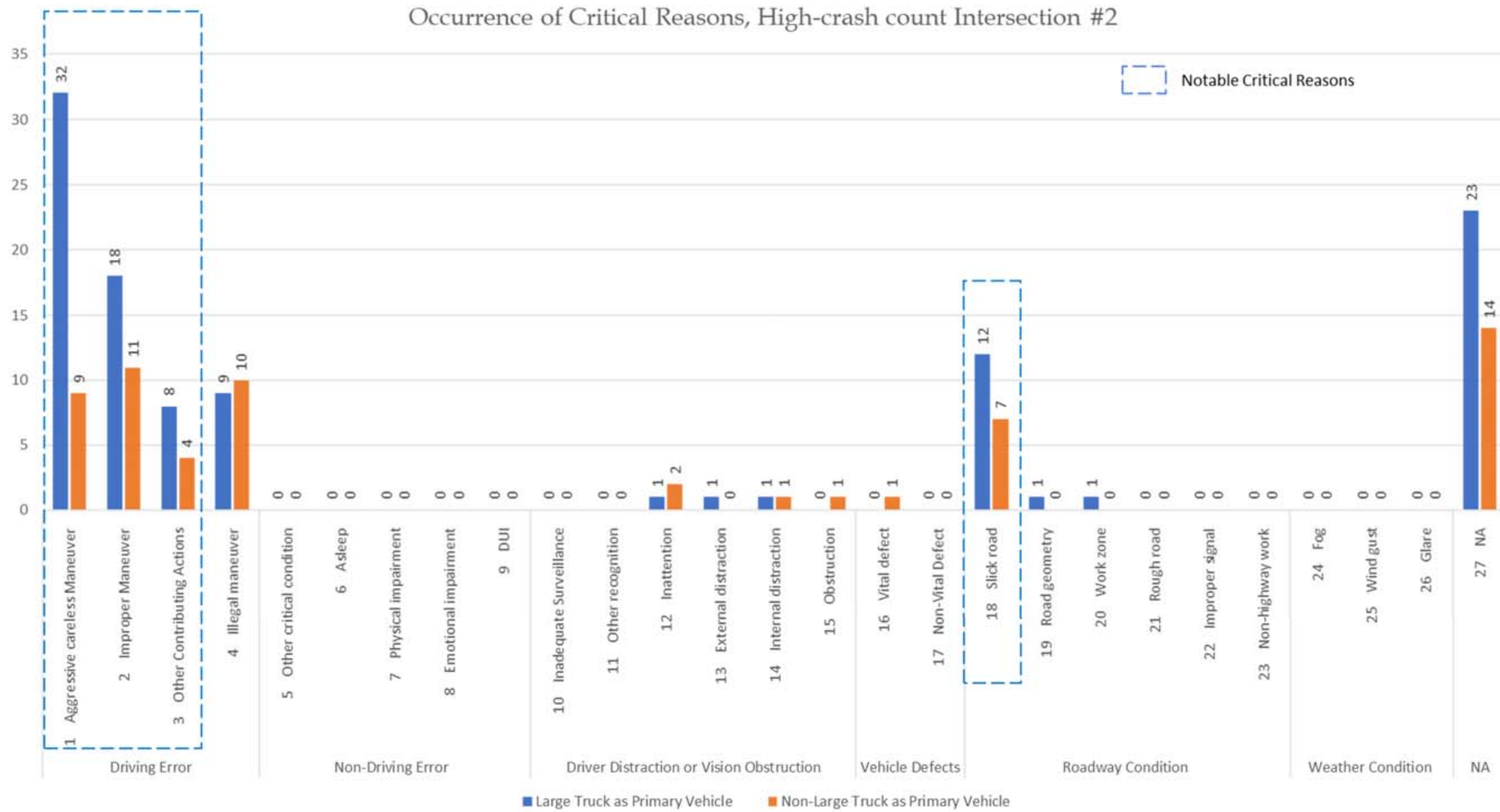


Figure 192 Occurrence of critical reasons at high crash count intersection #2

High crash count Intersection #3

Intersection ID: 220191
City: Orlando
County: Orange
Street names: TAFT VINELAND RD and ORANGE BLOSSOM TRL S
Intersection AADT: 60,750
Report count: 122

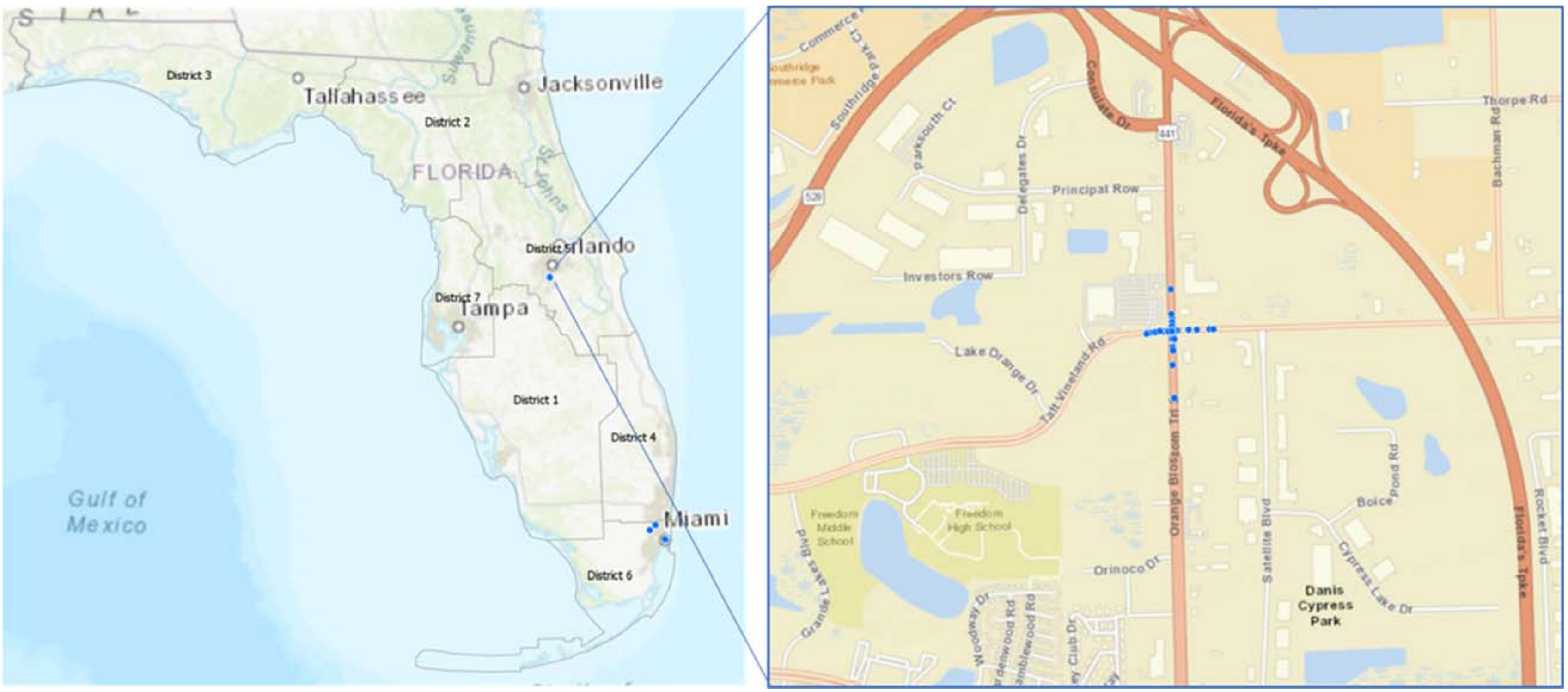


Figure 193 High crash count intersection #3

Figure 194 Crash locations by primary vehicle type at high crash count intersection #3

Table 87 Occurrence of Critical Reasons at High Crash Count Intersection #3

Intersection with high Crash count, #3	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	27	10
	2 Improper Maneuver	14	10
	3 Other Contributing Actions	6	8
	4 Illegal maneuver	10	16
Non-Driving Error	5 Other critical condition	0	0
	6 Asleep	0	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	1
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	3	1
	11 Other recognition	0	0
	12 Inattention	11	8
	13 External distraction	0	0
	14 Internal distraction	2	0
	15 Obstruction	1	0
Vehicle Defects	16 Vital defect	0	0
	17 Non-Vital Defect	1	2
Roadway Condition	18 Slick road	8	7
	19 Road geometry	0	1
	20 Work zone	0	0
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	0	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	12	7
Report Count		71	51

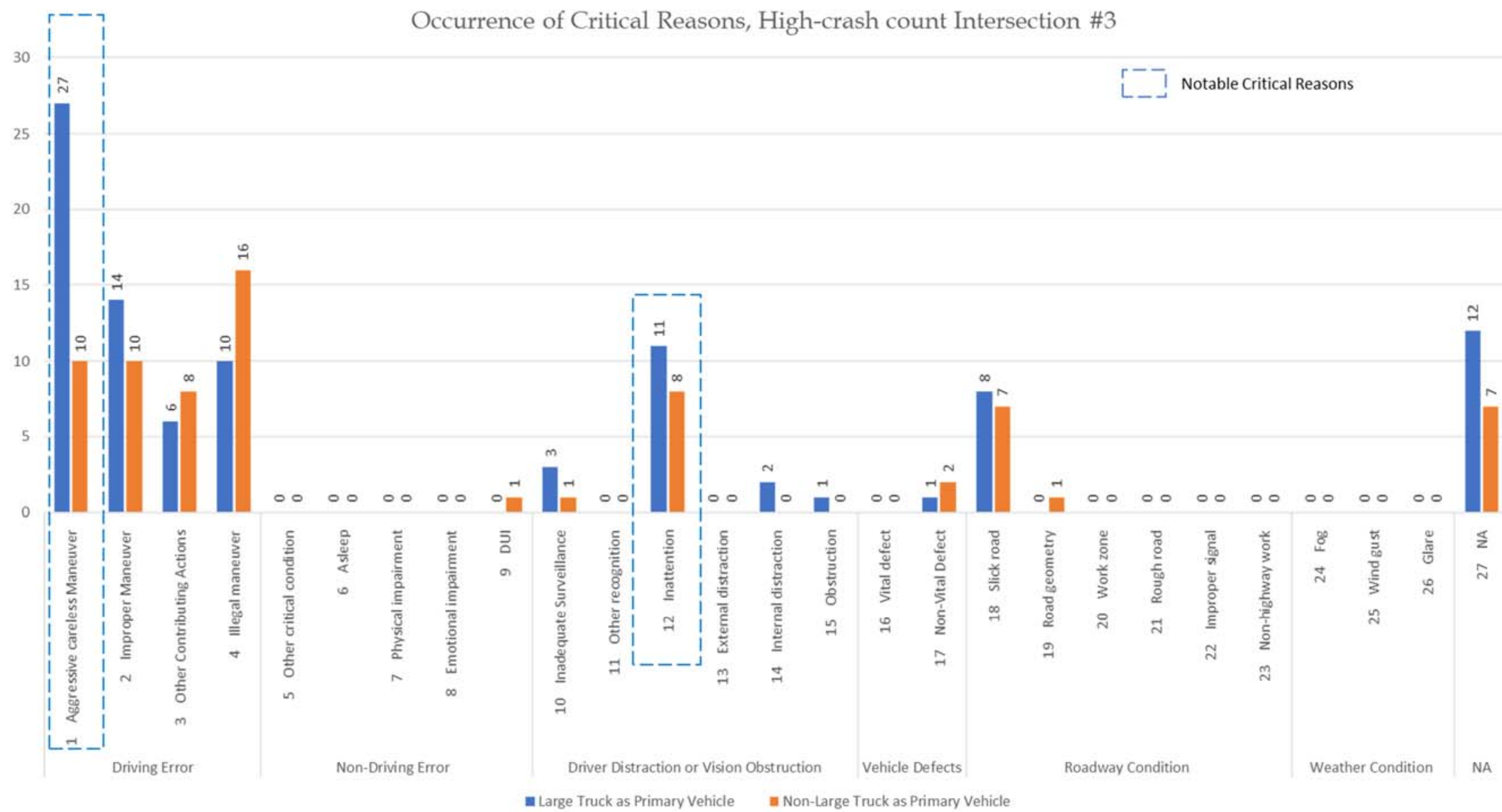


Figure 195 Occurrence of critical reasons at high crash count intersection #3

High crash count Intersection #4

Intersection ID: 567497
City: Miami Gardens
County: Miami-Dade
Street names: NW 57TH AVE and NW 167TH ST
Intersection AADT: 51,500
Report count: 106

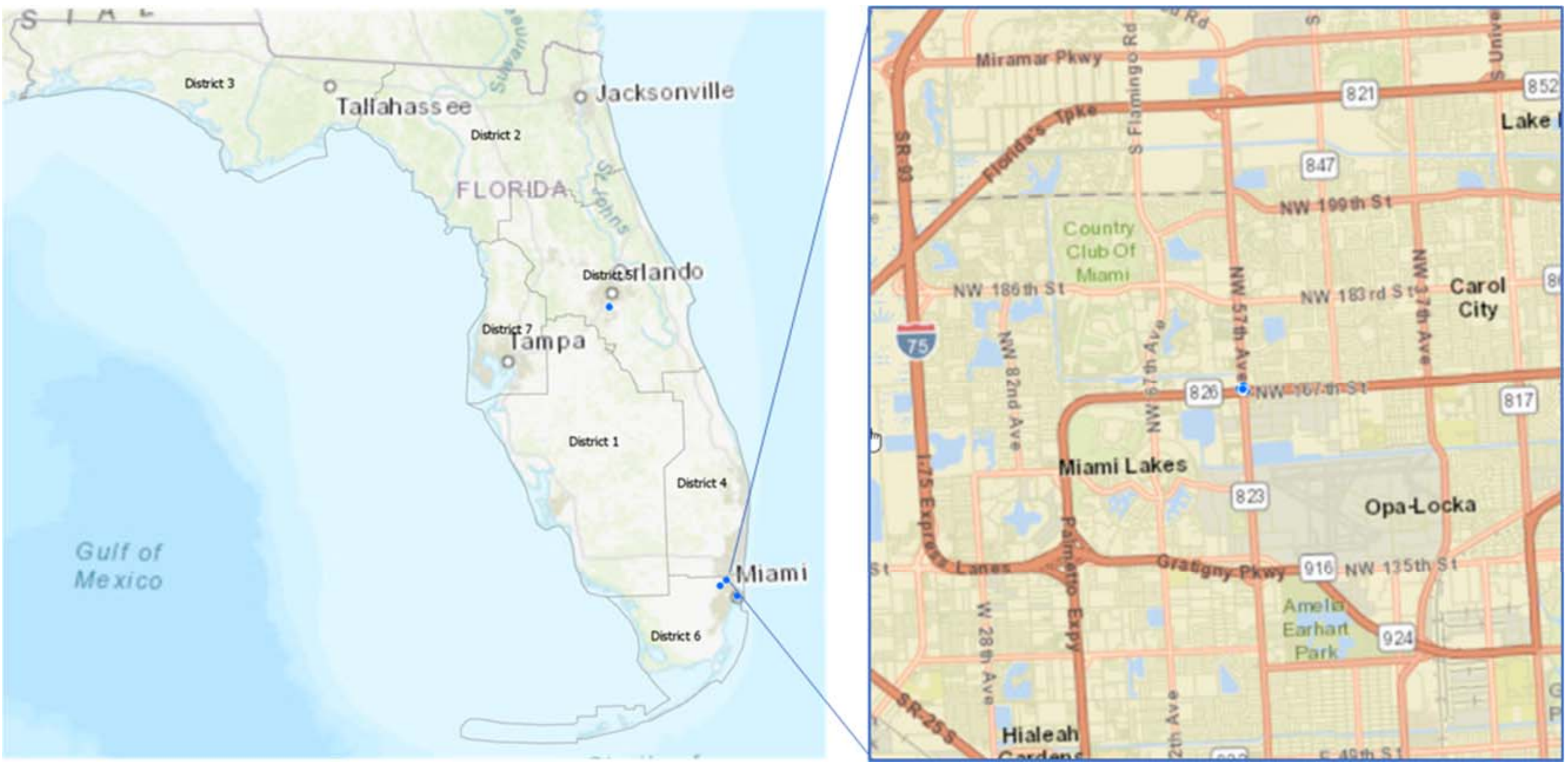
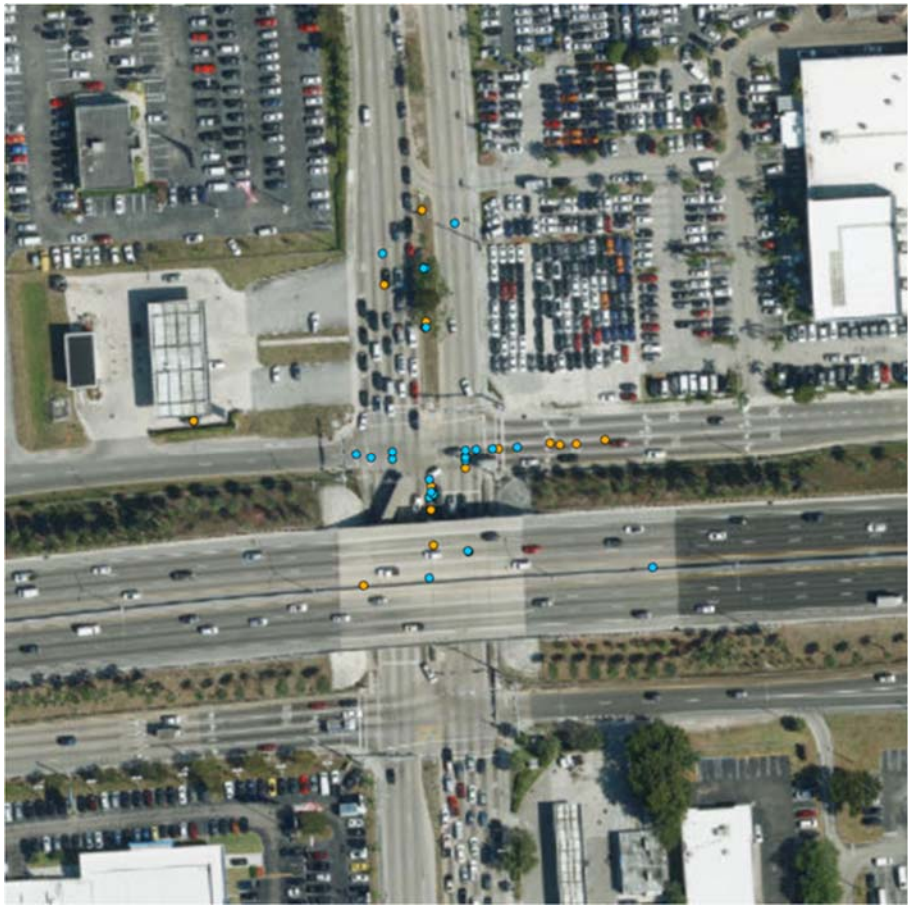


Figure 196 High crash count intersection #



Large Truck as Primary Vehicle: 54 crashes

Non – Large Truck as Primary Vehicle: 52 crashes

Figure 197 Crash locations by primary vehicle type at high crash count intersection #4

Table 88 Occurrence of Critical Reasons at High Crash Count Intersection #4

Intersection with high Crash count, #4	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	16	9
	2 Improper Maneuver	18	13
	3 Other Contributing Actions	8	6
	4 Illegal maneuver	3	11
Non-Driving Error	5 Other critical condition	0	0
	6 Asleep	1	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	2	0
	11 Other recognition	1	0
	12 Inattention	3	2
	13 External distraction	1	0
	14 Internal distraction	1	3
	15 Obstruction	0	1
Vehicle Defects	16 Vital defect	0	2
	17 Non-Vital Defect	1	1
Roadway Condition	18 Slick road	2	8
	19 Road geometry	0	2
	20 Work zone	1	0
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	0	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	9	8
Report Count		54	52

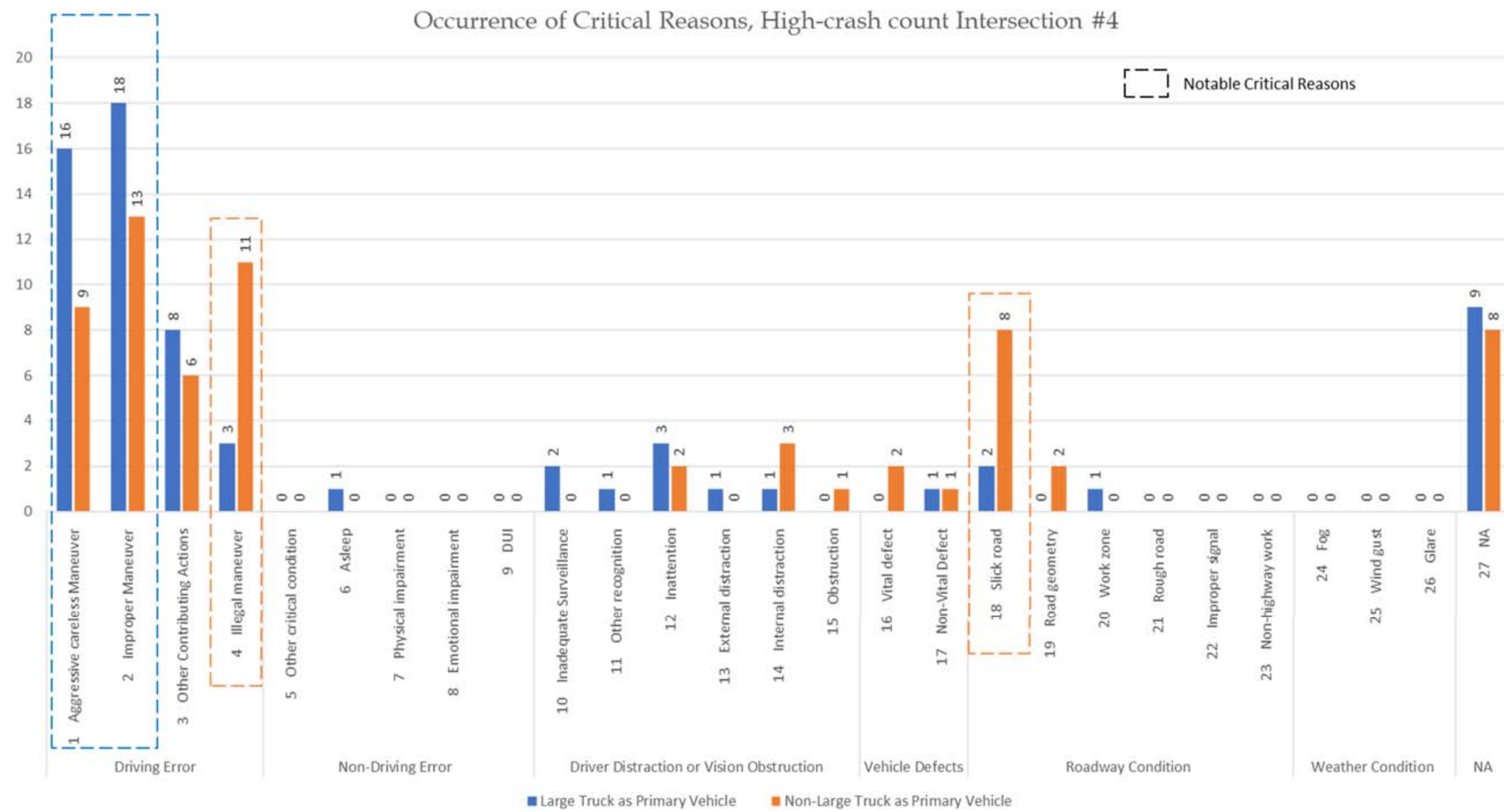


Figure 198 Occurrence of critical reasons at high crash count intersection #4

High crash count Intersection #5

Intersection ID: 542623
City: Miami
County: Miami-Dade County
Street names: BISCAYNE BLVD and PORT BLVD and NE 5TH ST and NE 6TH ST
Intersection AADT: 40,000
Report count: 101

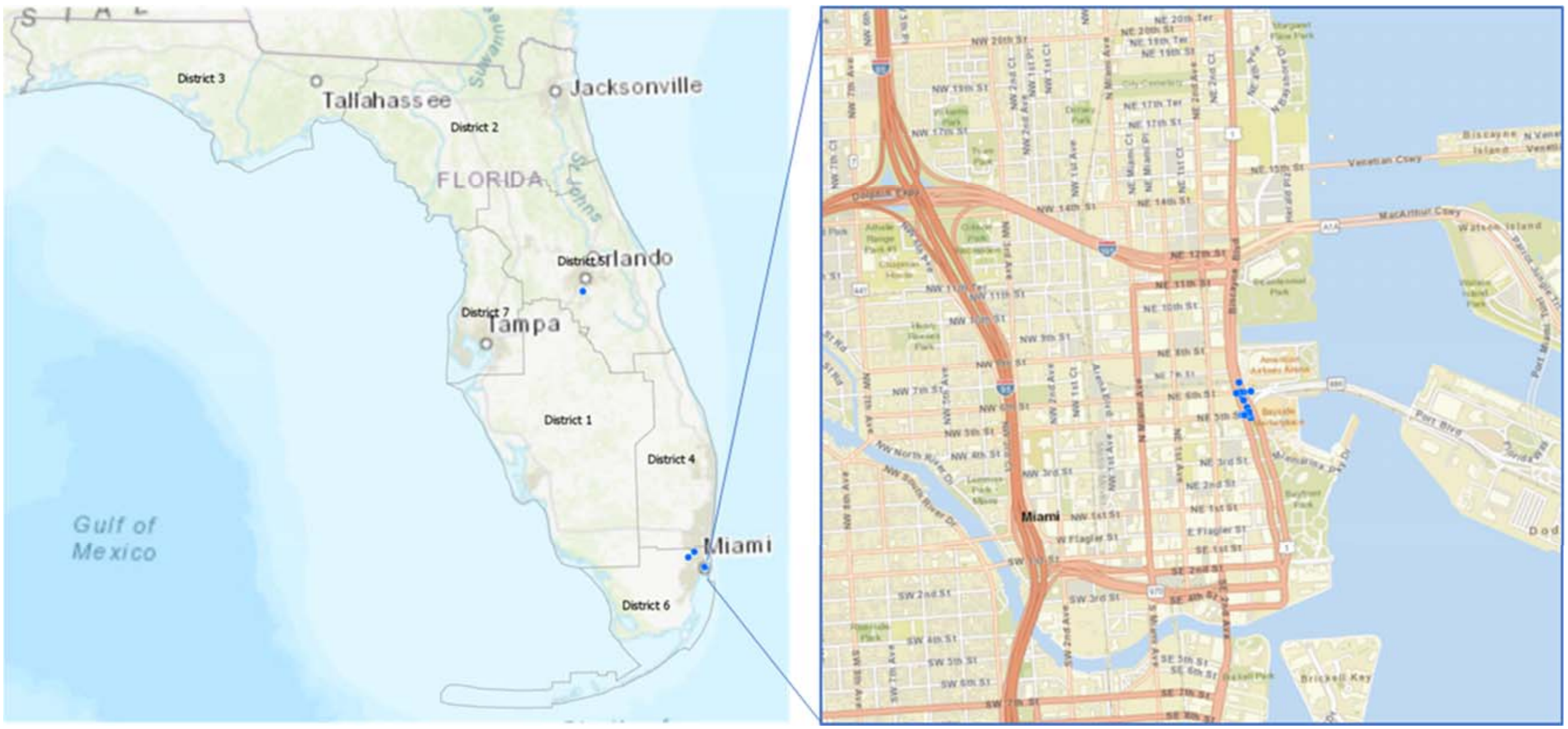
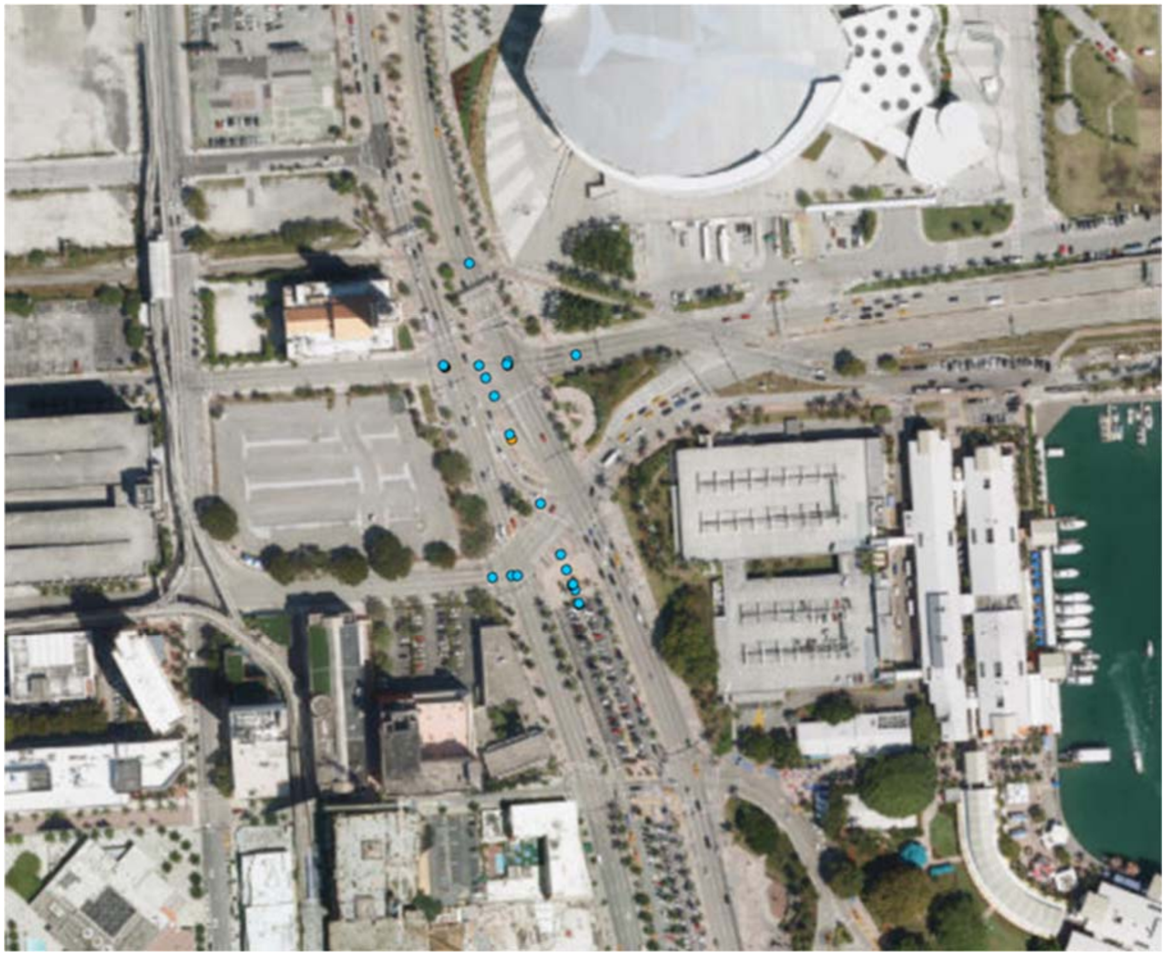


Figure 199 High crash count intersection #5



Large Truck as Primary Vehicle: 55 crashes

Non – Large Truck as Primary Vehicle: 46 crashes

Figure 200 Crash locations by primary vehicle type at high crash count intersection #5

Table 89 Occurrence of Critical Reasons at High Crash Count Intersection #5

Intersection with high Crash count, #5	Critical Reasons		Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	12	3
	2	Improper Maneuver	12	11
	3	Other Contributing Actions	11	8
	4	Illegal maneuver	1	4
Non-Driving Error	5	Other critical condition	0	0
	6	Asleep	0	0
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	0
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	0	0
	11	Other recognition	5	1
	12	Inattention	0	0
	13	External distraction	1	0
	14	Internal distraction	0	0
	15	Obstruction	2	0
Vehicle Defects	16	Vital defect	1	0
	17	Non-Vital Defect	1	0
Roadway Condition	18	Slick road	1	3
	19	Road geometry	4	1
	20	Work zone	0	0
	21	Rough road	0	0
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	0
	25	Wind gust	0	0
	26	Glare	0	0
NA	27	NA	17	17
Report Count			55	46

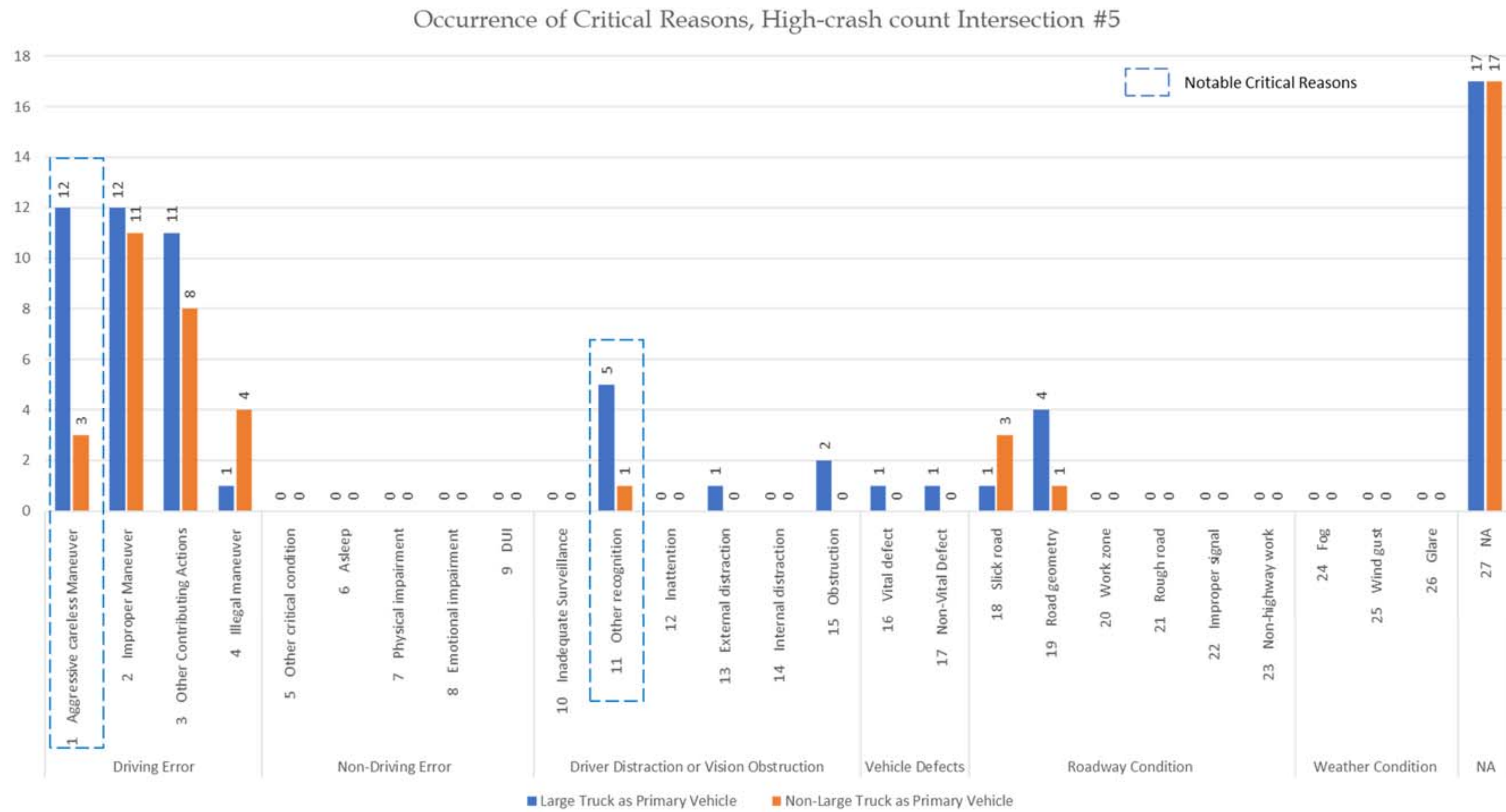


Figure 201 Occurrence of critical reasons at high crash count intersection #5

High Crash Injury Severity Intersection #1

Intersection ID: 560249
City: St Cloud
County: Osceola
Street names: E IRLO BRONSON MEMORIAL HWY and PINE GROVE RD
Intersection AADT: 21,550
Severity Index: 5.857

Figure 202 High crash injury severity intersection #1

Large Truck as Primary Vehicle: 3 crashes

Non – Large Truck as Primary Vehicle: 4 crashes

Figure 203 Crash locations by primary vehicle type at high crash injury severity intersection #1

Table 90 Occurrence of Critical Reasons at High Crash Injury Severity Intersection #1

Intersection with high Severity, #1	Critical Reasons		Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	1	0
	2	Improper Maneuver	1	1
	3	Other Contributing Actions	0	1
	4	Illegal maneuver	0	2
Non-Driving Error	5	Other critical condition	0	0
	6	Asleep	0	0
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	0
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	0	0
	11	Other recognition	0	1
	12	Inattention	0	1
	13	External distraction	0	0
	14	Internal distraction	0	0
	15	Obstruction	0	0
Vehicle Defects	16	Vital defect	0	0
	17	Non-Vital Defect	0	1
Roadway Condition	18	Slick road	1	0
	19	Road geometry	0	1
	20	Work zone	1	0
	21	Rough road	0	0
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	0
	25	Wind gust	0	0
	26	Glare	0	0
NA	27	NA	0	0
Report Count			3	4

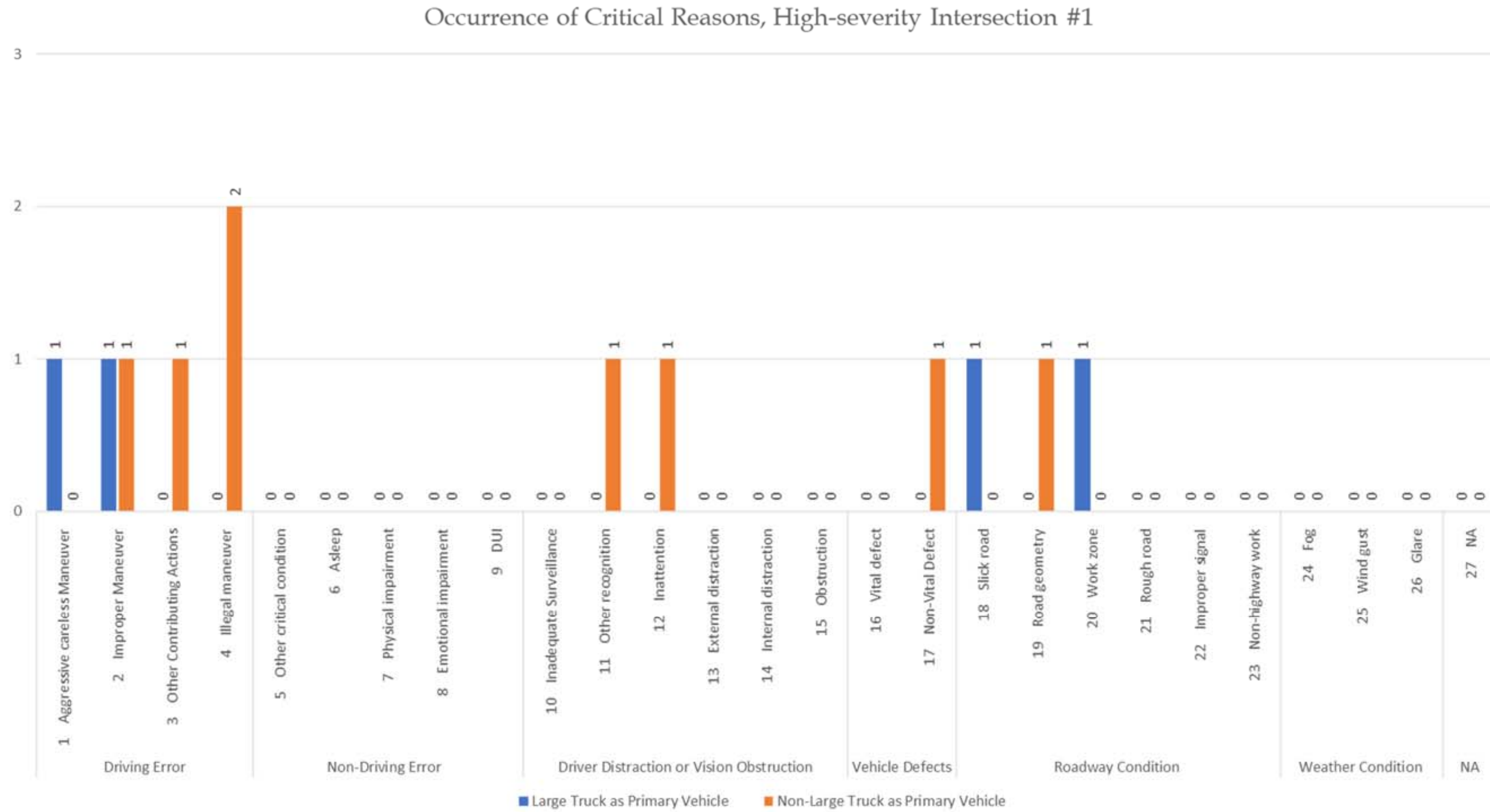


Figure 204 **Occurrence of critical reasons at high crash injury severity intersection #1**

High Crash Injury Severity Intersection #2

Intersection ID: 566970
City: Vero Beach
County: Indian River
Street names: SR-60 and CR-512 and ARMORY DR
Intersection AADT: 6,974
Severity Index: 5.333

Figure 205 High crash injury severity intersection #2

Figure 206 Crash locations by primary vehicle type at high crash injury severity intersection #2

Table 91 Occurrence of Critical Reasons at High Crash Injury Severity Intersection #2

Intersection with high Severity, #2		Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	2	0
	2	Improper Maneuver	2	1
	3	Other Contributing Actions	0	0
	4	Illegal maneuver	0	1
Non-Driving Error	5	Other critical condition	0	0
	6	Asleep	0	0
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	0
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	0	0
	11	Other recognition	0	0
	12	Inattention	1	0
	13	External distraction	0	0
	14	Internal distraction	1	0
	15	Obstruction	0	0
Vehicle Defects	16	Vital defect	0	0
	17	Non-Vital Defect	0	0
Roadway Condition	18	Slick road	1	0
	19	Road geometry	0	0
	20	Work zone	0	0
	21	Rough road	0	0
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	0
	25	Wind gust	0	0
	26	Glare	0	0
NA	27	NA	0	0
Report Count			4	2

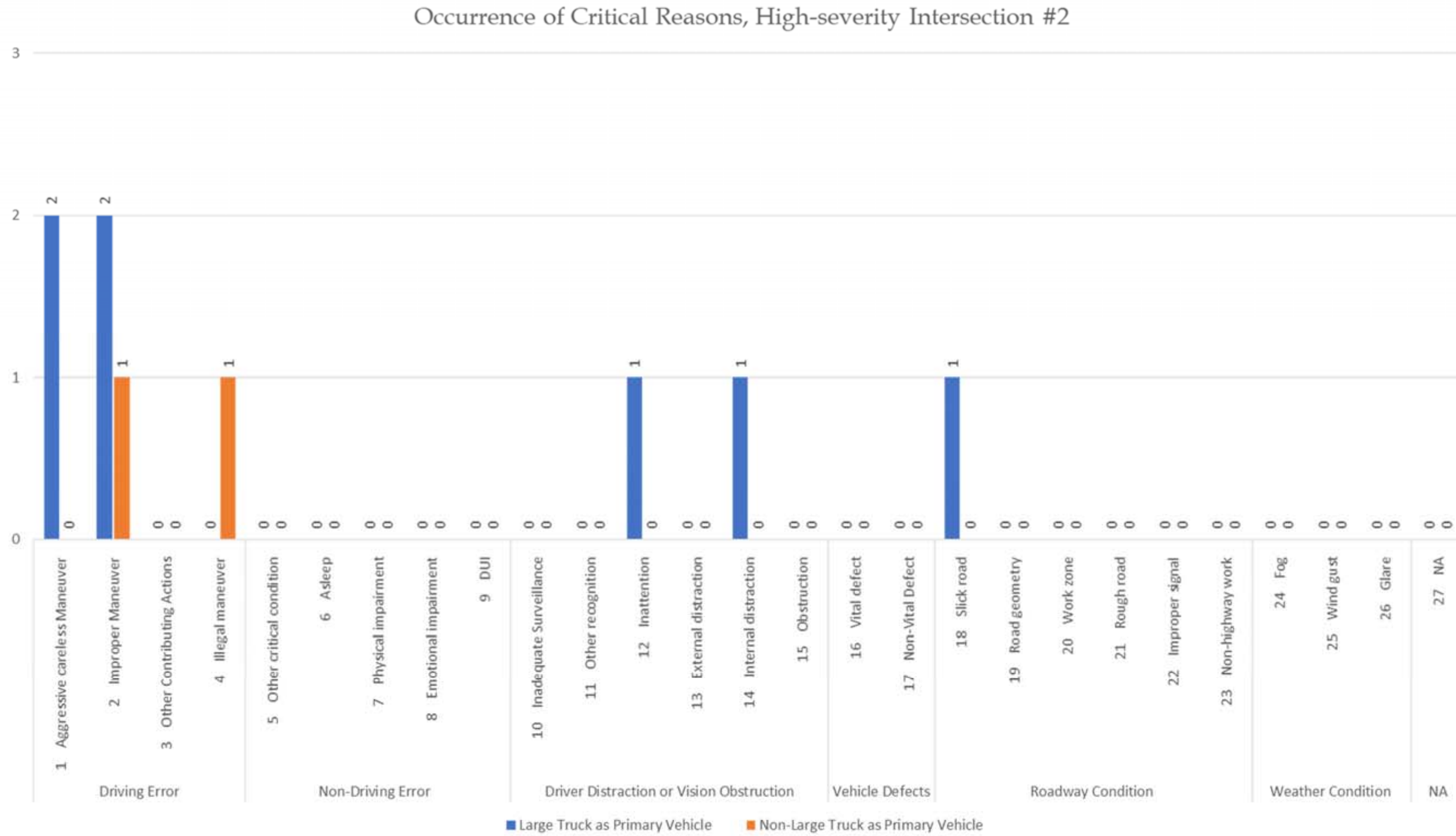


Figure 207 Occurrence of critical reasons at high crash injury severity intersection #2

High Crash Injury Severity Intersection #3

Intersection ID: 438582
City: Brooksville
County: Hernando
Street names: PONCE DE LEON BLVD and CITRUS WAY
Intersection AADT: 7,300
Severity Index: 4.75

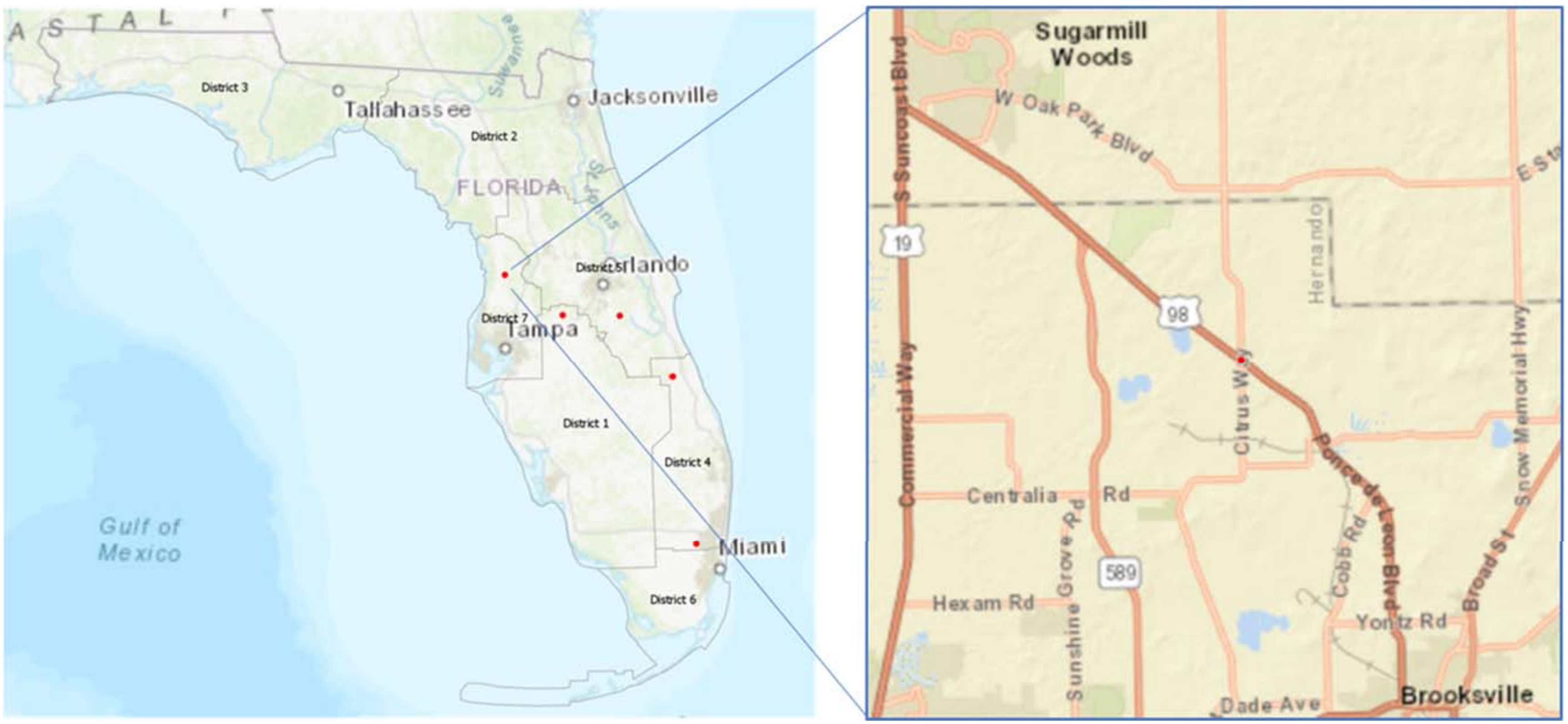
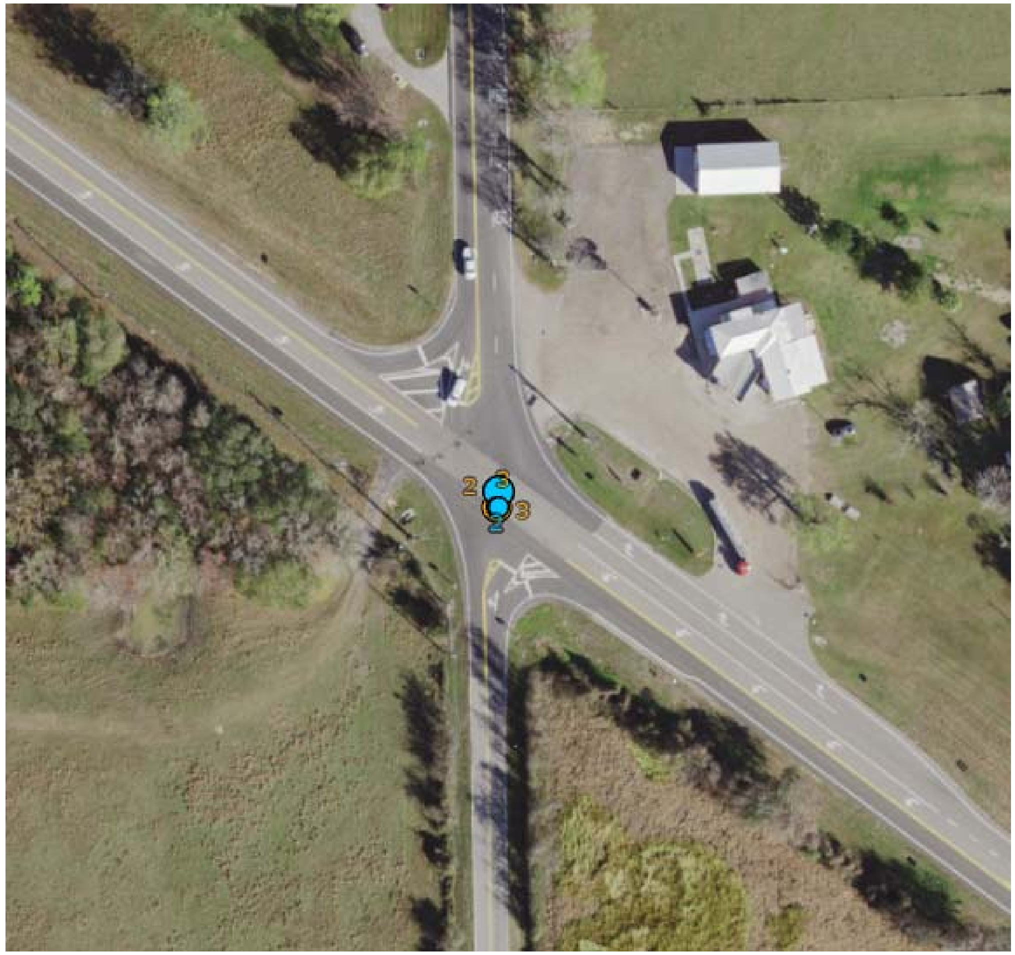


Figure 208 High crash injury severity intersection #3



Large Truck as Primary Vehicle: 4 crashes

Non – Large Truck as Primary Vehicle: 8 crashes

Figure 209 **Crash locations by primary vehicle type at high crash injury severity intersection #3**

Table 92 Occurrence of Critical Reasons at High Crash Injury Severity Intersection #3

Intersection with high Severity, #3	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	0	1
	2 Improper Maneuver	0	0
	3 Other Contributing Actions	0	0
	4 Illegal maneuver	2	7
Non-Driving Error	5 Other critical condition	0	0
	6 Asleep	0	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	0	0
	11 Other recognition	0	0
	12 Inattention	0	0
	13 External distraction	0	0
	14 Internal distraction	0	0
	15 Obstruction	0	0
Vehicle Defects	16 Vital defect	0	0
	17 Non-Vital Defect	0	0
Roadway Condition	18 Slick road	0	1
	19 Road geometry	1	0
	20 Work zone	0	0
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	1	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	1	0
Report Count		4	8

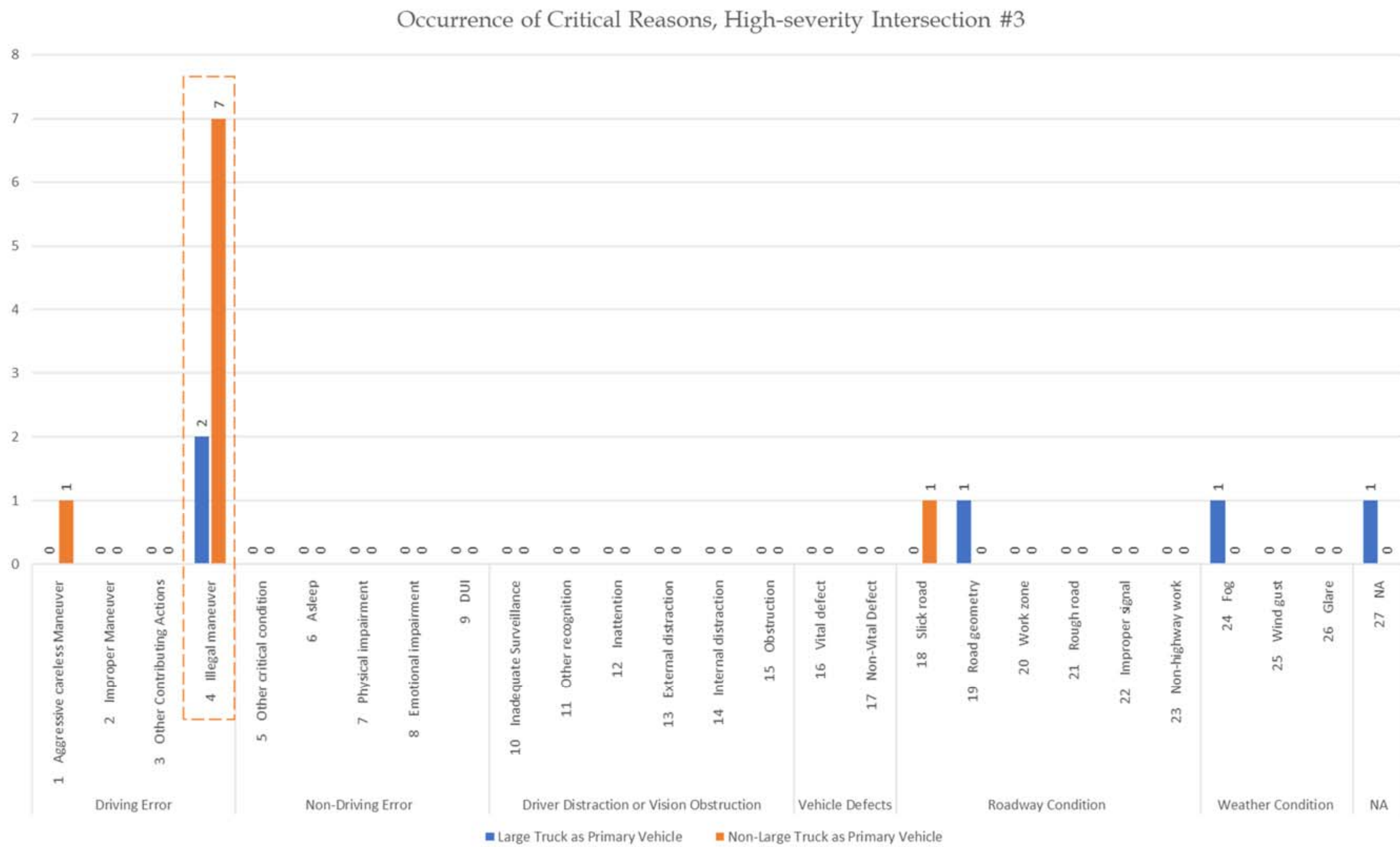


Figure 210 Occurrence of critical reasons at high crash injury severity intersection #3

High Crash Injury Severity Intersection #4

Intersection ID: 268676
City: Polk City
County: Polk
Street names: DEEN STILL RD and COMMONWEALTH AVE N
Intersection AADT: 6,587
Severity Index: 4.6

Figure 211 High crash injury severity intersection #4

Large Truck as Primary Vehicle: 7 crashes

Non – Large Truck as Primary Vehicle: 7 crashes

Figure 212 Crash locations by primary vehicle type at high crash injury severity intersection #4

Table 93 Occurrence of Critical Reasons at High Crash Injury Severity Intersection #4

Intersection with high Severity, #4		Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	2	2
	2	Improper Maneuver	1	1
	3	Other Contributing Actions	0	0
	4	Illegal maneuver	1	2
Non-Driving Error	5	Other critical condition	0	0
	6	Asleep	0	0
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	0
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	1	0
	11	Other recognition	0	1
	12	Inattention	0	0
	13	External distraction	0	0
	14	Internal distraction	0	1
	15	Obstruction	0	0
Vehicle Defects	16	Vital defect	1	1
	17	Non-Vital Defect	0	0
Roadway Condition	18	Slick road	1	0
	19	Road geometry	0	0
	20	Work zone	0	1
	21	Rough road	0	0
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	1	0
	25	Wind gust	0	0
	26	Glare	0	0
NA	27	NA	3	1
Report Count			7	7

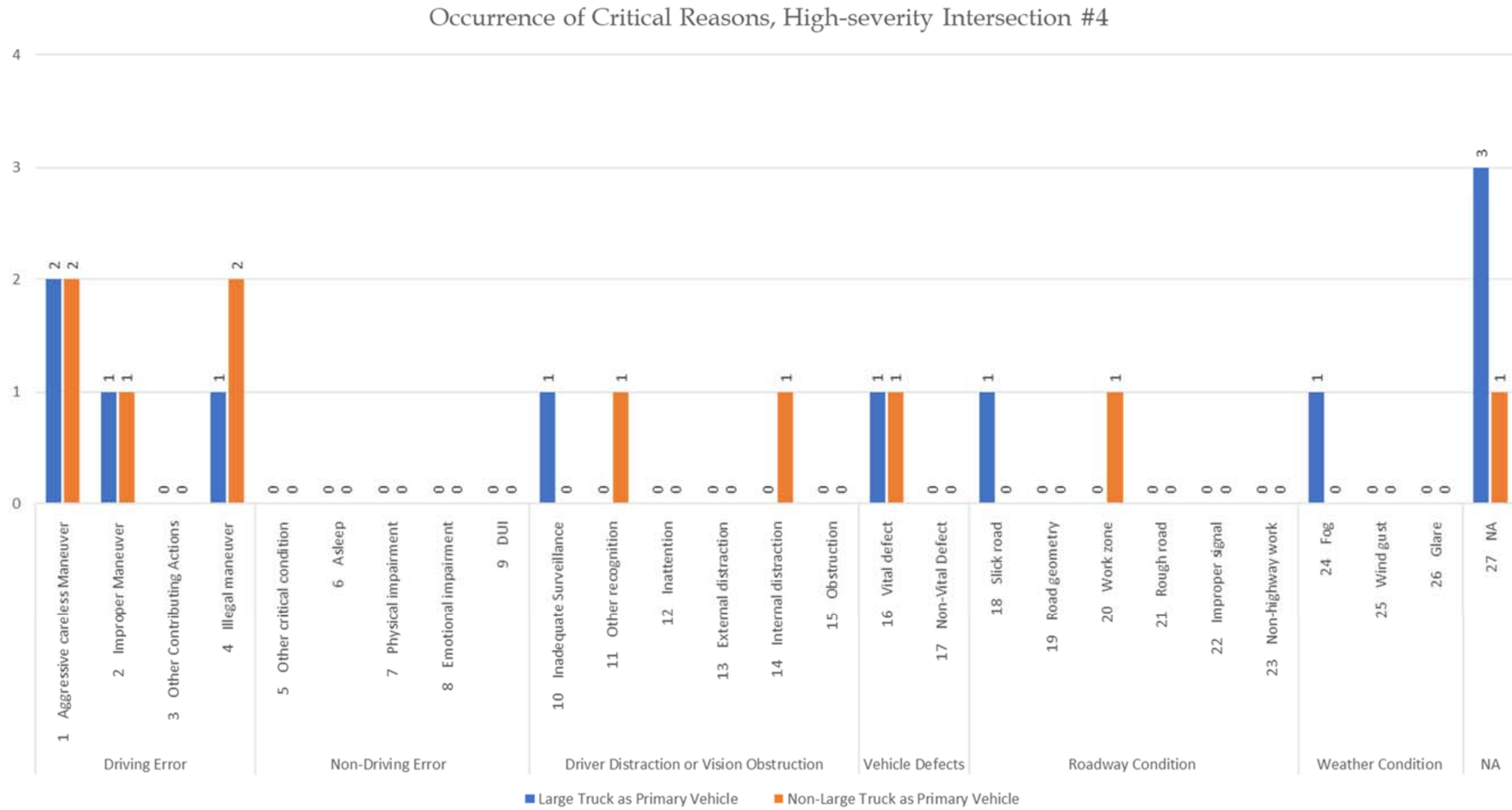


Figure 213 Occurrence of critical reasons at high crash injury severity intersection #4

High Crash Injury Severity Intersection #5

Intersection ID: 548481
City: Pembroke Pines
County: Broward
Street names: JOHNSON ST and OKEECHOBEE RD
Intersection AADT: 24,400
Severity Index: 4.5

Figure 214 High crash injury severity intersection #5

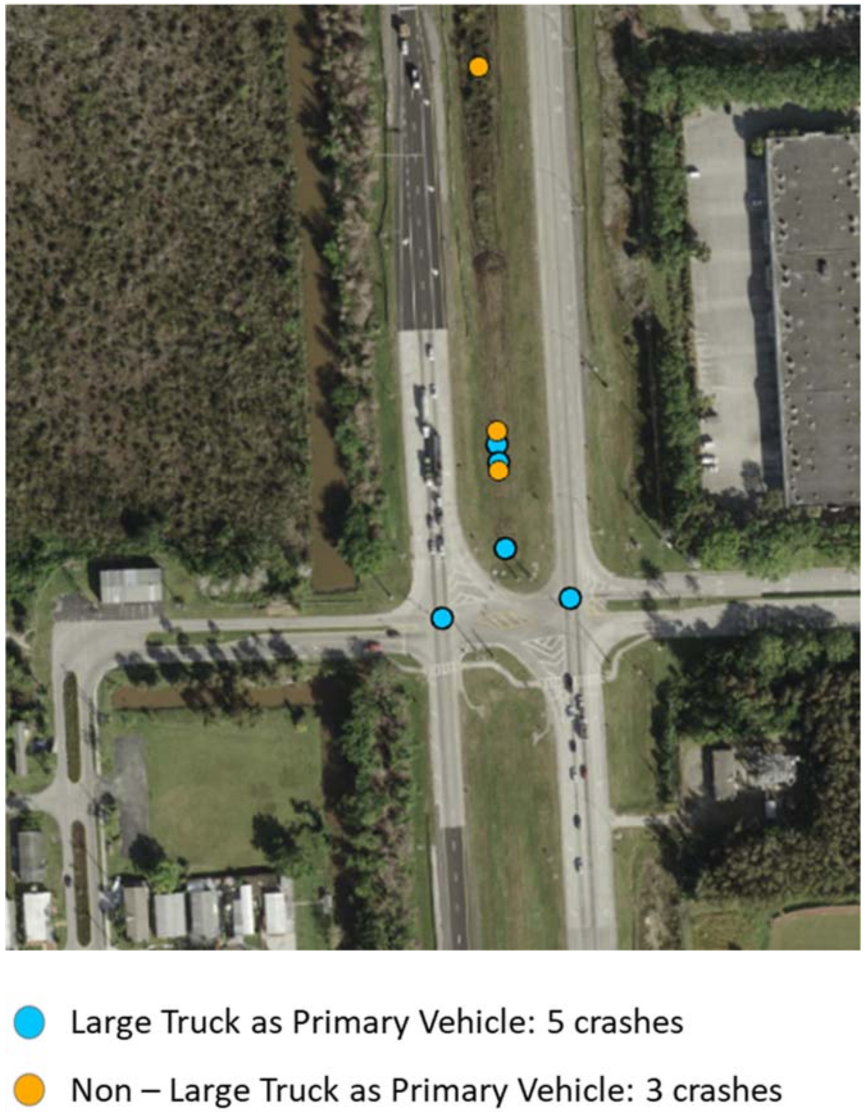


Figure 215 Crash locations by primary vehicle type at high crash injury severity intersection #5

Table 94 Occurrence of Critical Reasons at High Crash Injury Severity Intersection #5

Intersection with high Severity, #5	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	5	1
	2 Improper Maneuver	0	0
	3 Other Contributing Actions	0	1
	4 Illegal maneuver	0	1
Non-Driving Error	5 Other critical condition	0	0
	6 Asleep	0	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	1	0
	11 Other recognition	0	0
	12 Inattention	0	0
	13 External distraction	0	0
	14 Internal distraction	0	0
	15 Obstruction	0	0
Vehicle Defects	16 Vital defect	0	0
	17 Non-Vital Defect	0	0
Roadway Condition	18 Slick road	0	1
	19 Road geometry	0	0
	20 Work zone	0	0
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	0	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	0	0
Report Count		5	3

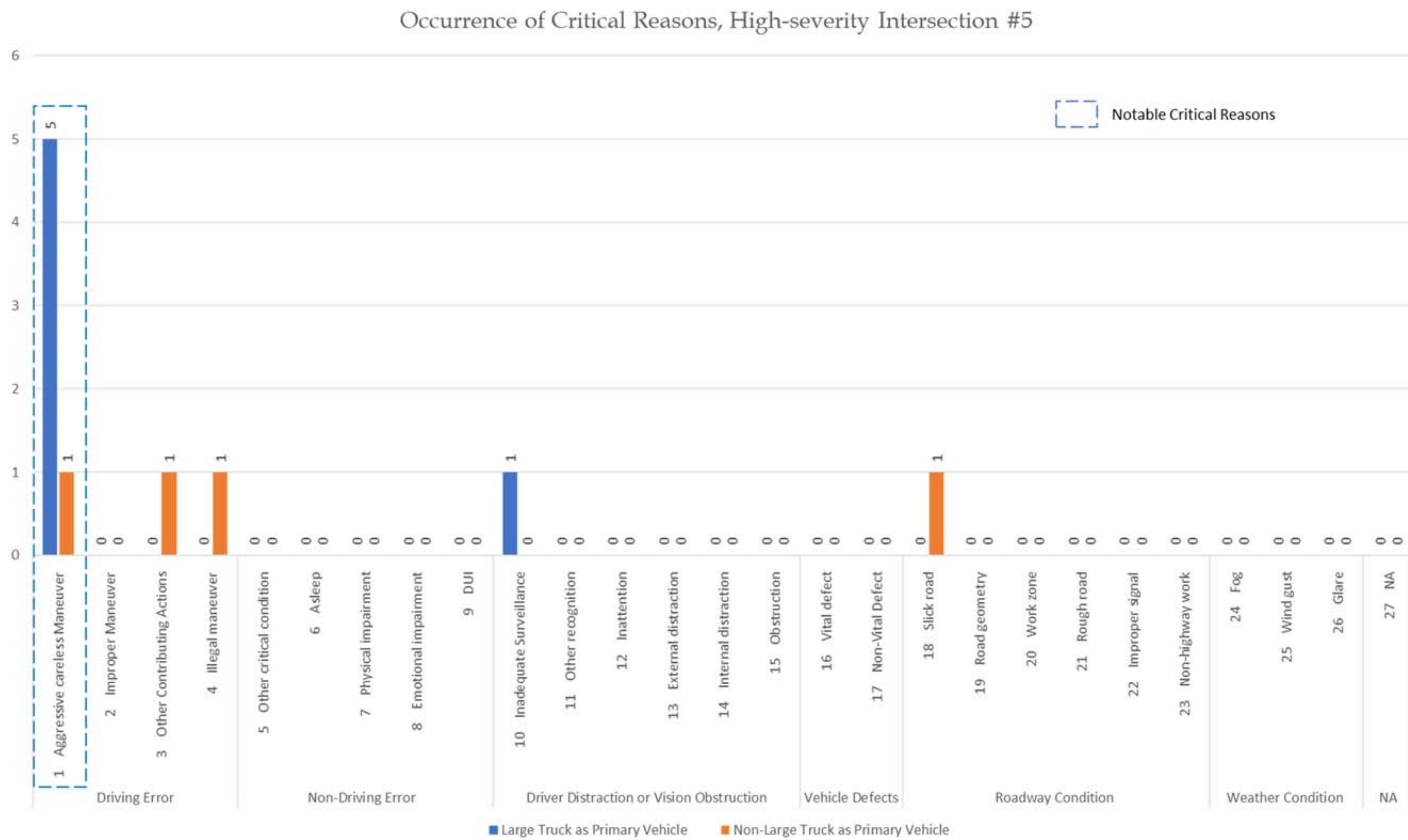


Figure 216 Occurrence of critical reasons at high crash injury severity intersection #5

High Crash Rate Intersection #1

Intersection ID: 117065
City: Jacksonville
County: Duval
Street names: US-301 N and HAP WAY
Intersection AADT: 4,387
Crash rate: 4.996

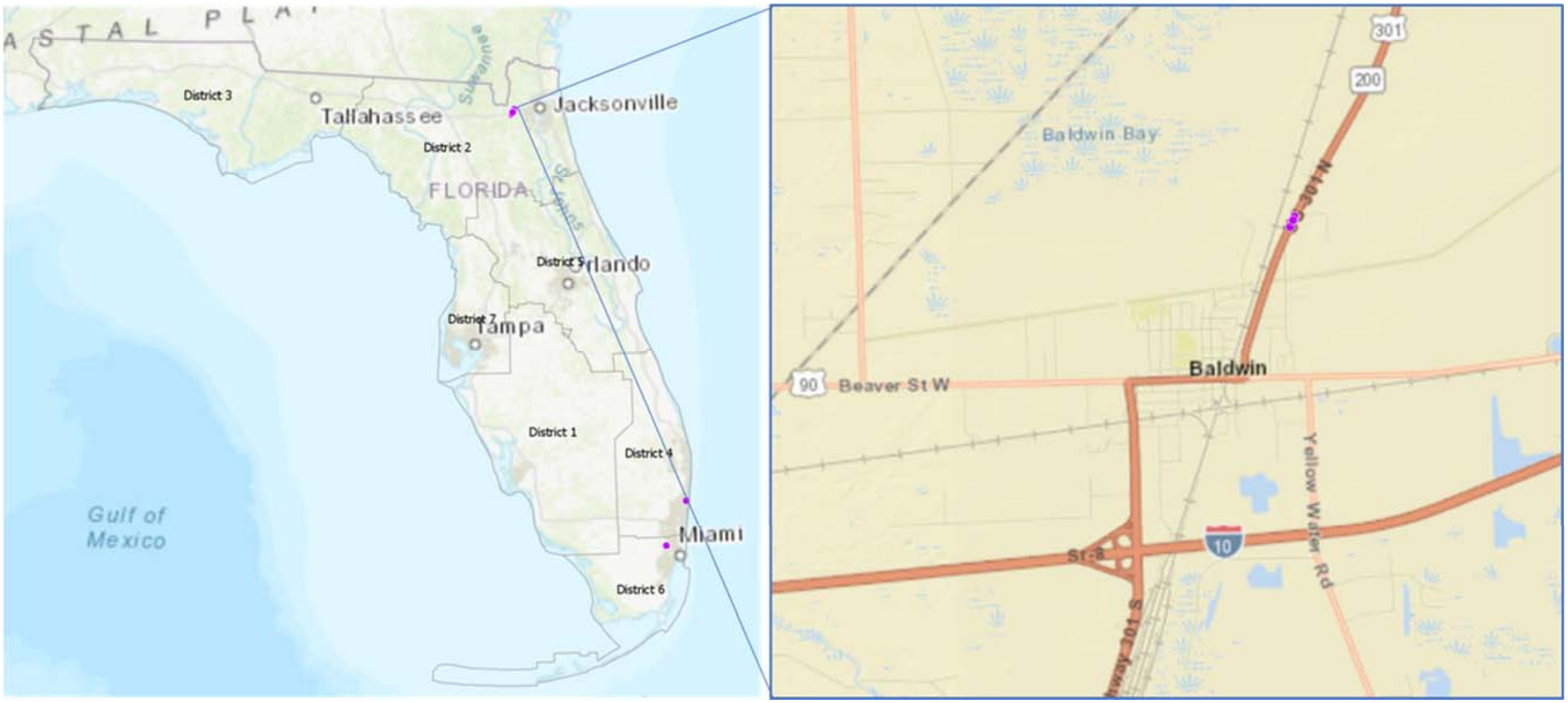


Figure 217 High crash rate intersection #1

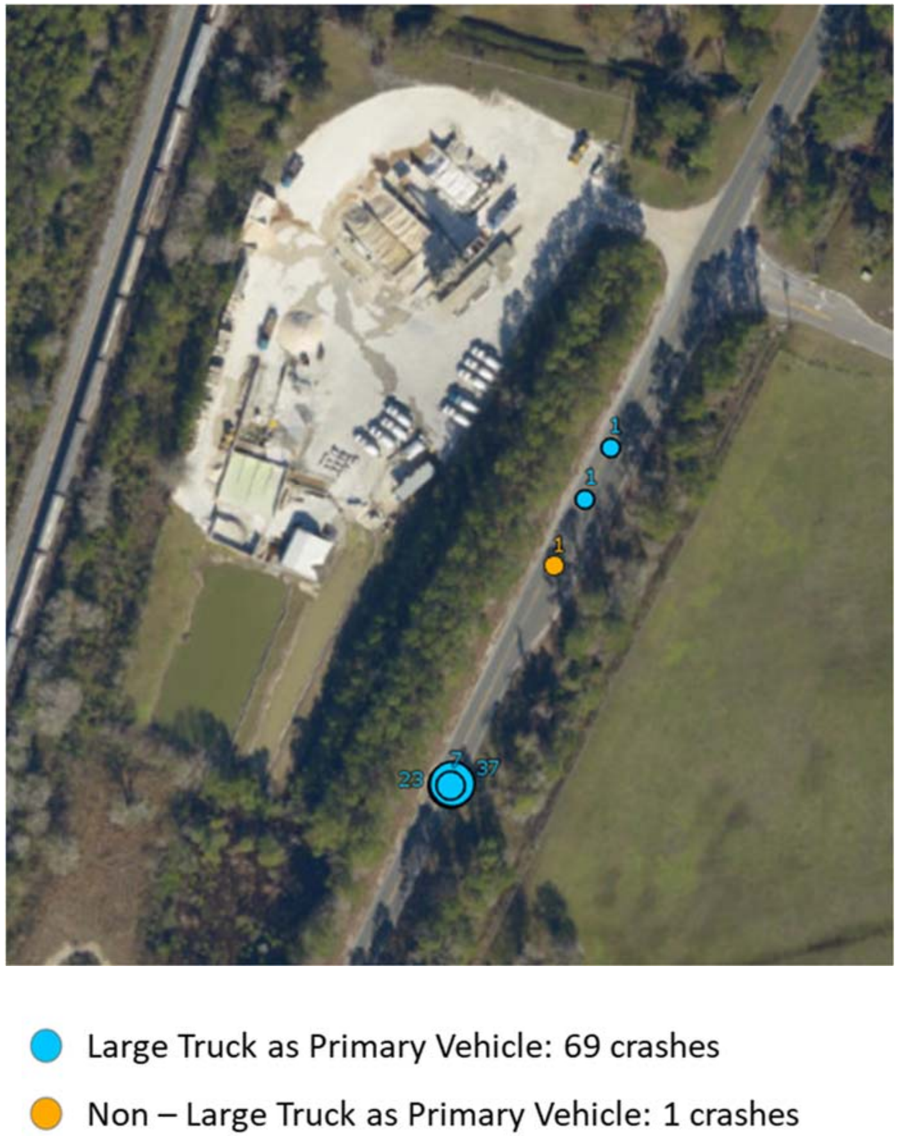


Figure 218 Crash locations by primary vehicle type at high crash rate intersection #1

Table 95 Occurrence of Critical Reasons at High Crash Rate Intersection #1

Intersection with high Crash Rate, #1	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	30	0
	2 Improper Maneuver	19	0
	3 Other Contributing Actions	5	0
	4 Illegal maneuver	1	0
Non-Driving Error	5 Other critical condition	1	0
	6 Asleep	0	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	4	1
	11 Other recognition	1	0
	12 Inattention	3	0
	13 External distraction	1	0
	14 Internal distraction	1	0
	15 Obstruction	1	0
Vehicle Defects	16 Vital defect	2	0
	17 Non-Vital Defect	1	0
Roadway Condition	18 Slick road	8	0
	19 Road geometry	2	0
	20 Work zone	0	0
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	0	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	8	0
Report Count		69	1

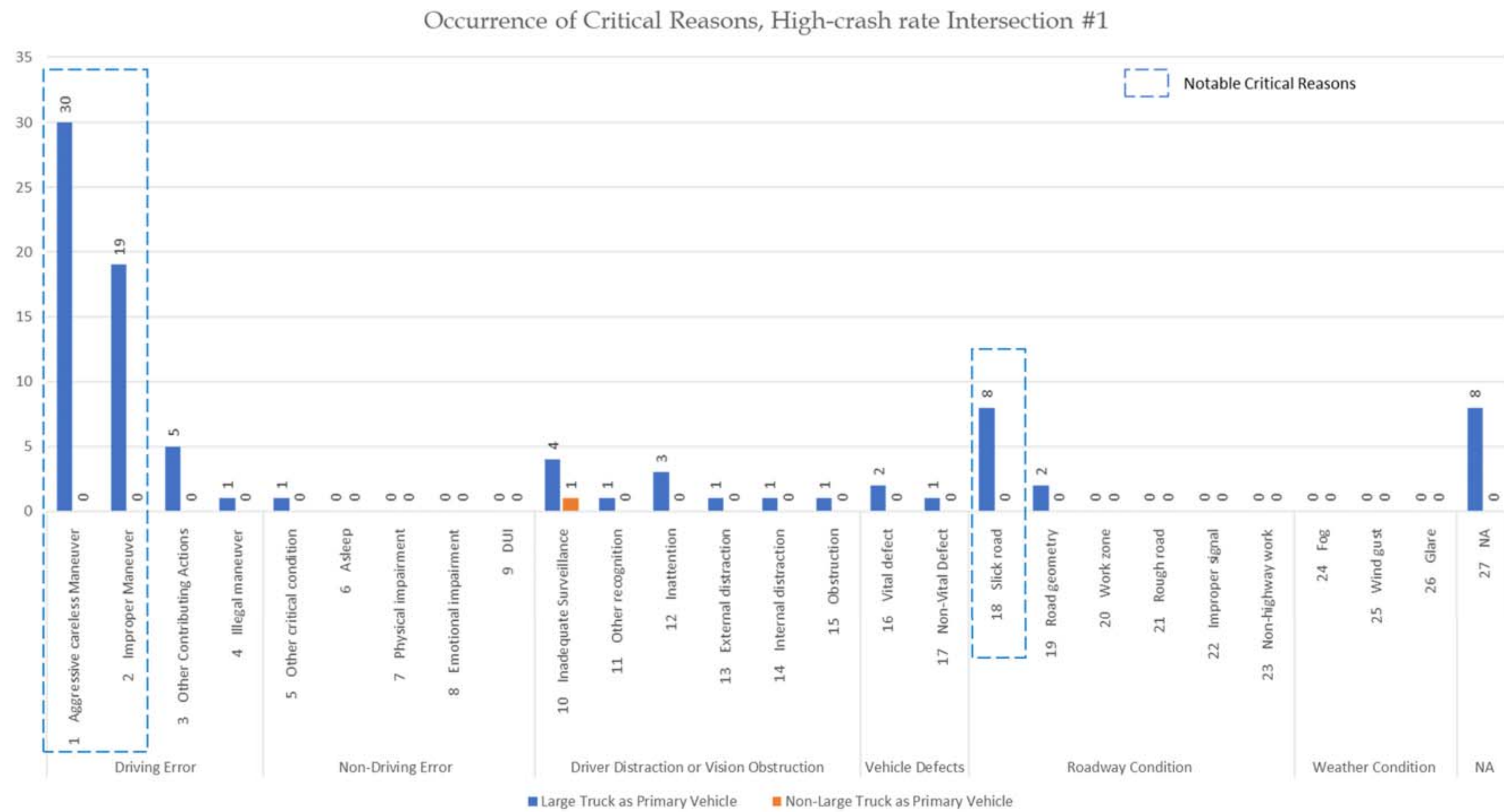


Figure 219 Occurrence of critical reasons at high crash rate intersection #1

High Crash Rate Intersection #2

Intersection ID: 276435
City: Town of Baldwin
County: Duval
Street names: MARTIN LUTHER KING JR DR and US-301
Intersection AADT: 4,387
Crash rate: 1.374

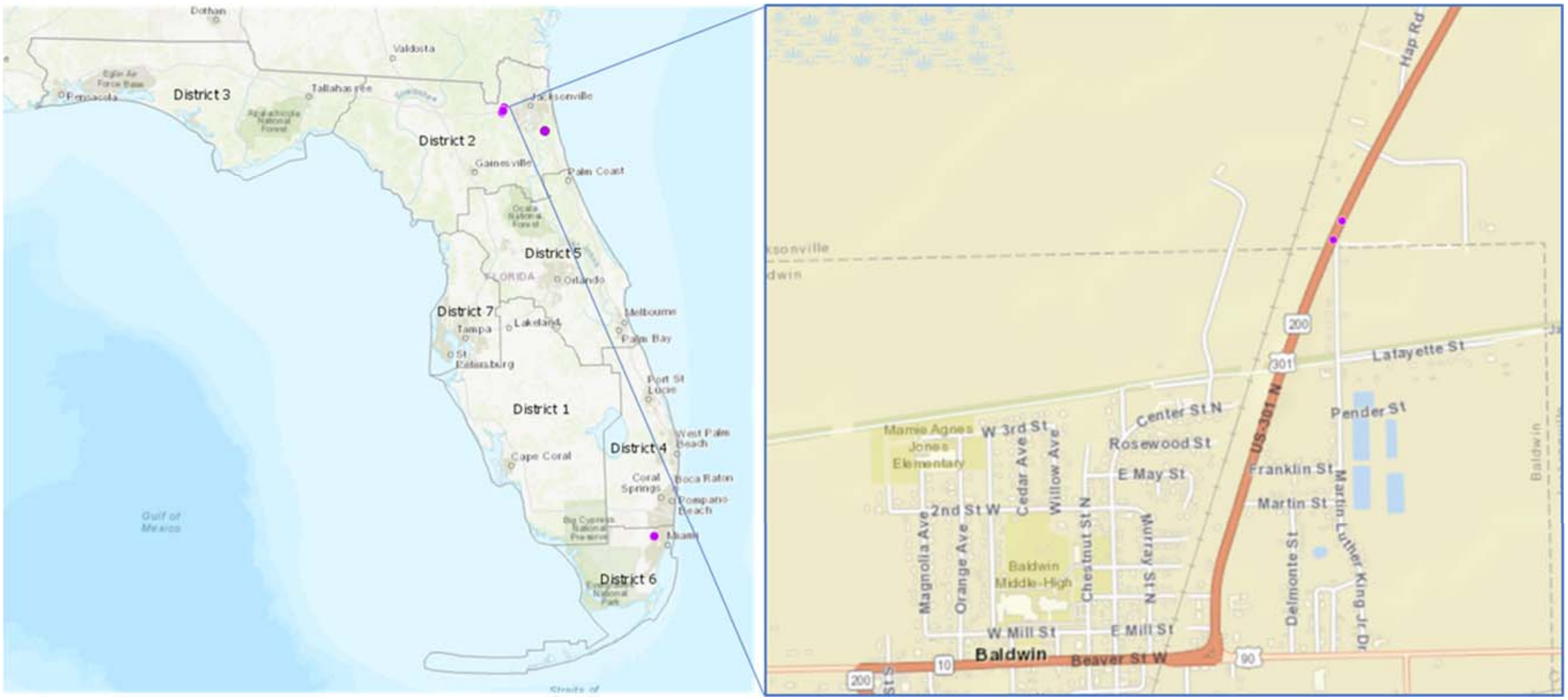


Figure 220 **High crash rate intersection #2**

Large Truck as Primary Vehicle: 18 crashes

Non – Large Truck as Primary Vehicle: 1 crashes

Figure 221 Crash locations by primary vehicle type at high crash rate intersection #2

Table 96 Occurrence of Critical Reasons at High Crash Rate Intersection #2

Intersection with high Crash Rate, #2	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	3	0
	2 Improper Maneuver	3	1
	3 Other Contributing Actions	2	0
	4 Illegal maneuver	1	0
Non-Driving Error	5 Other critical condition	0	0
	6 Asleep	1	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	1	0
	11 Other recognition	1	0
	12 Inattention	1	0
	13 External distraction	1	0
	14 Internal distraction	0	0
	15 Obstruction	0	0
Vehicle Defects	16 Vital defect	1	0
	17 Non-Vital Defect	0	0
Roadway Condition	18 Slick road	4	0
	19 Road geometry	1	0
	20 Work zone	0	0
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	0	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	5	0
Report Count		18	1

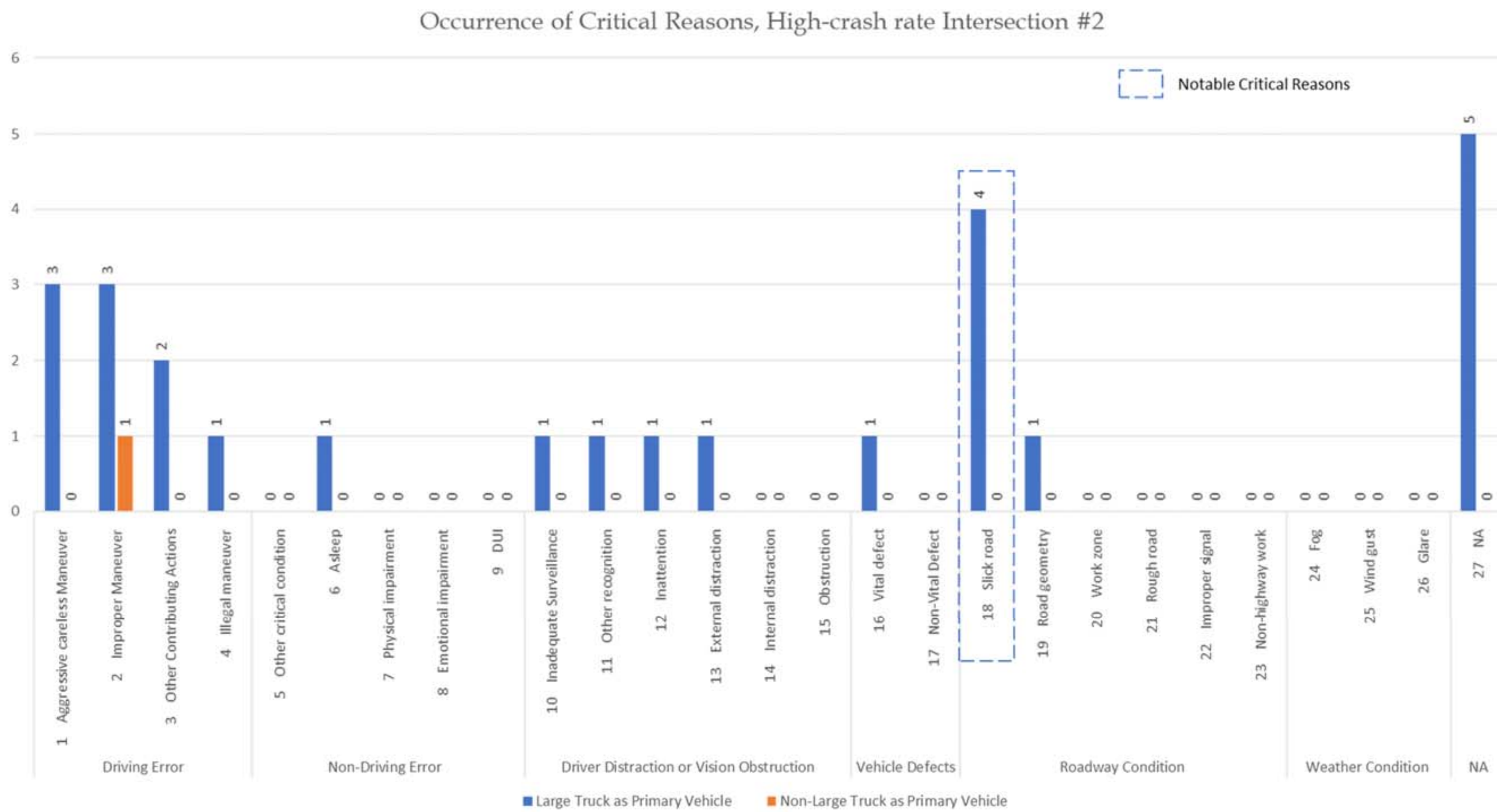


Figure 222 Occurrence of critical reasons at high crash rate intersection #2

High Crash Rate Intersection #3

Intersection ID: 527489
City: Town of Medley
County: Miami-Dade
Street names: NW SOUTH RIVER DR and NW 105TH WAY
Intersection AADT: 5,800
Crash rate: 1.275

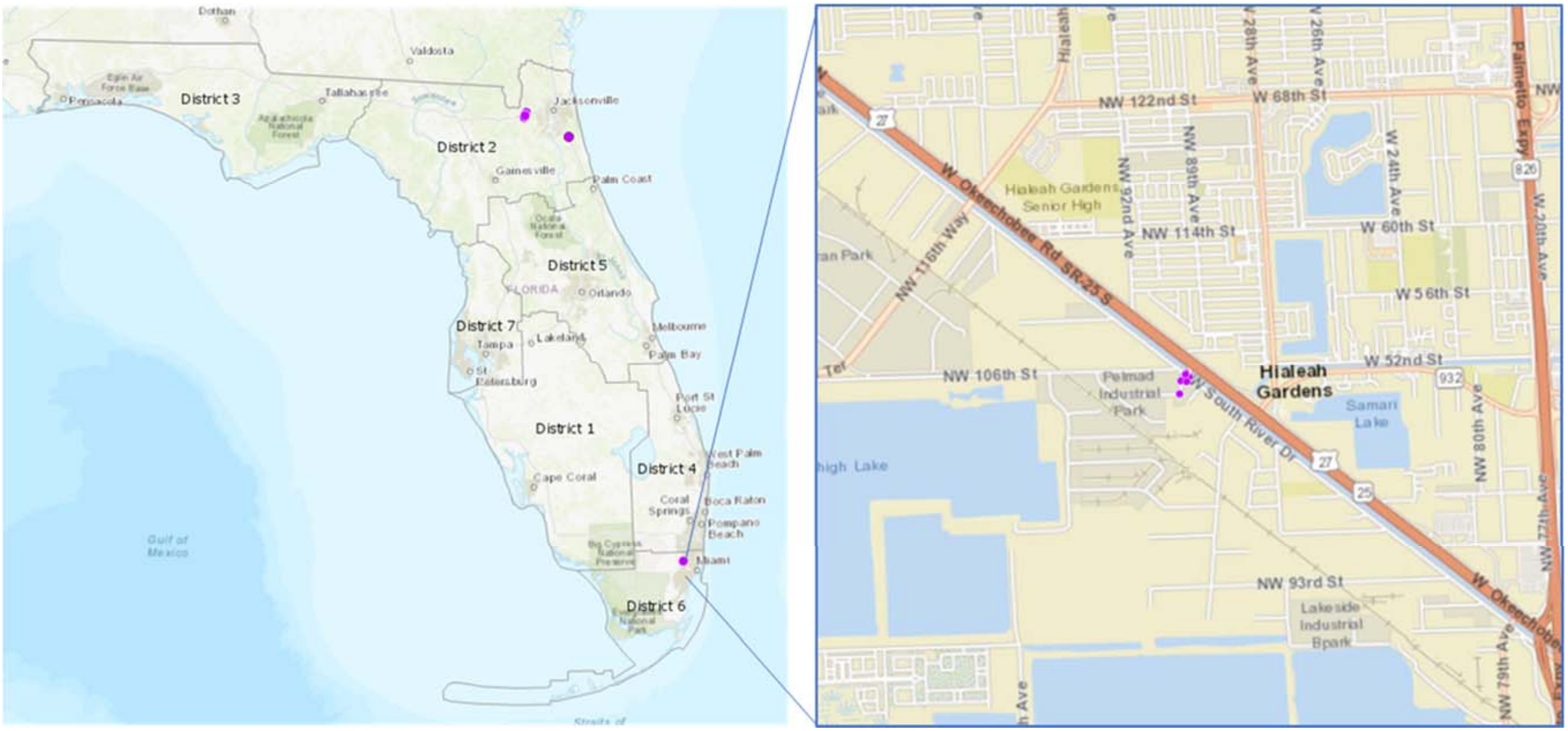


Figure 223 High crash rate intersection #3

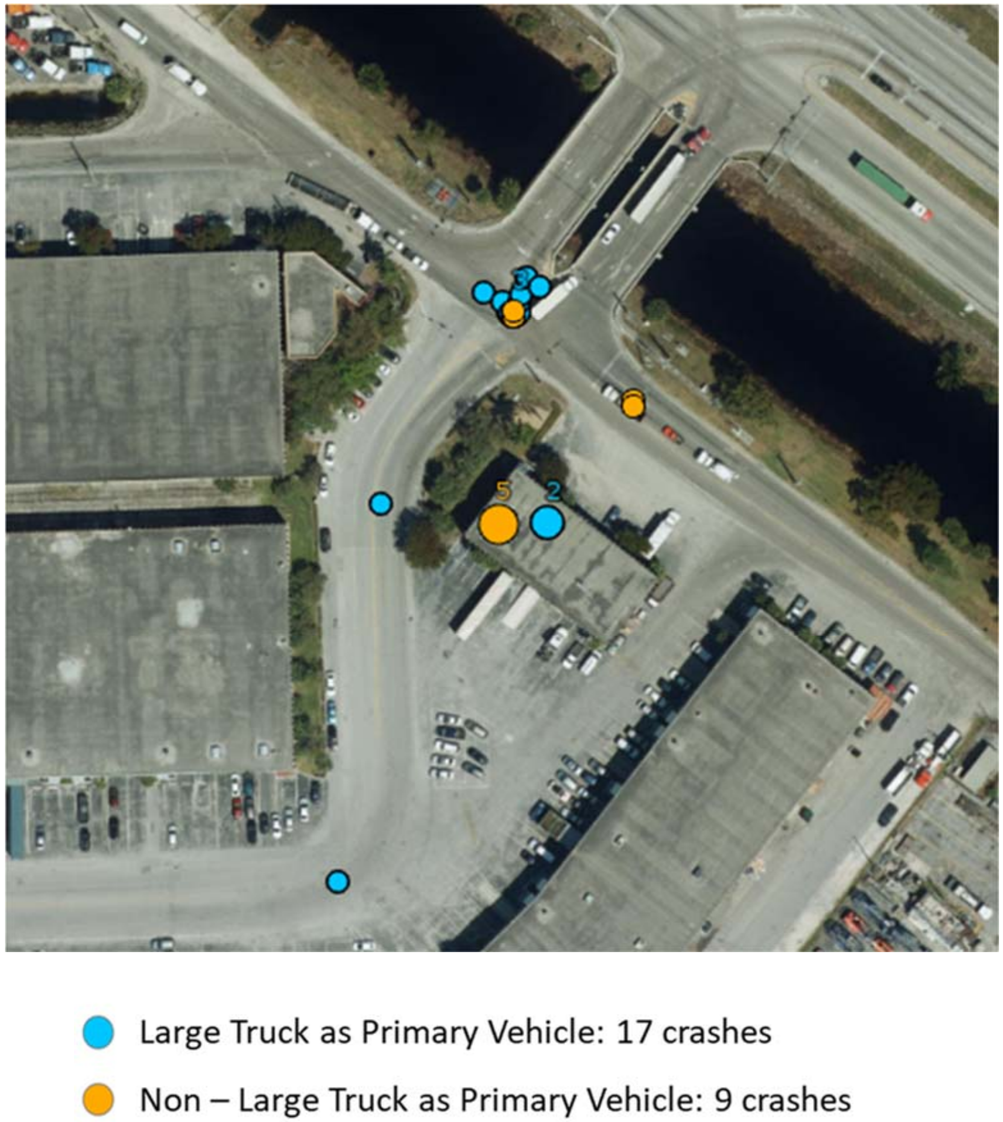


Figure 224 Crash locations by primary vehicle type at high crash rate intersection #3

Table 97 Occurrence of Critical Reasons at High Crash Rate Intersection #3

Intersection with high Crash Rate, #3	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	4	1
	2 Improper Maneuver	5	3
	3 Other Contributing Actions	0	1
	4 Illegal maneuver	0	2
Non-Driving Error	5 Other critical condition	0	1
	6 Asleep	0	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	1	0
	11 Other recognition	0	0
	12 Inattention	0	0
	13 External distraction	0	0
	14 Internal distraction	0	0
	15 Obstruction	0	0
Vehicle Defects	16 Vital defect	0	0
	17 Non-Vital Defect	1	0
Roadway Condition	18 Slick road	1	2
	19 Road geometry	3	1
	20 Work zone	0	0
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	0	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	4	2
Report Count		17	9

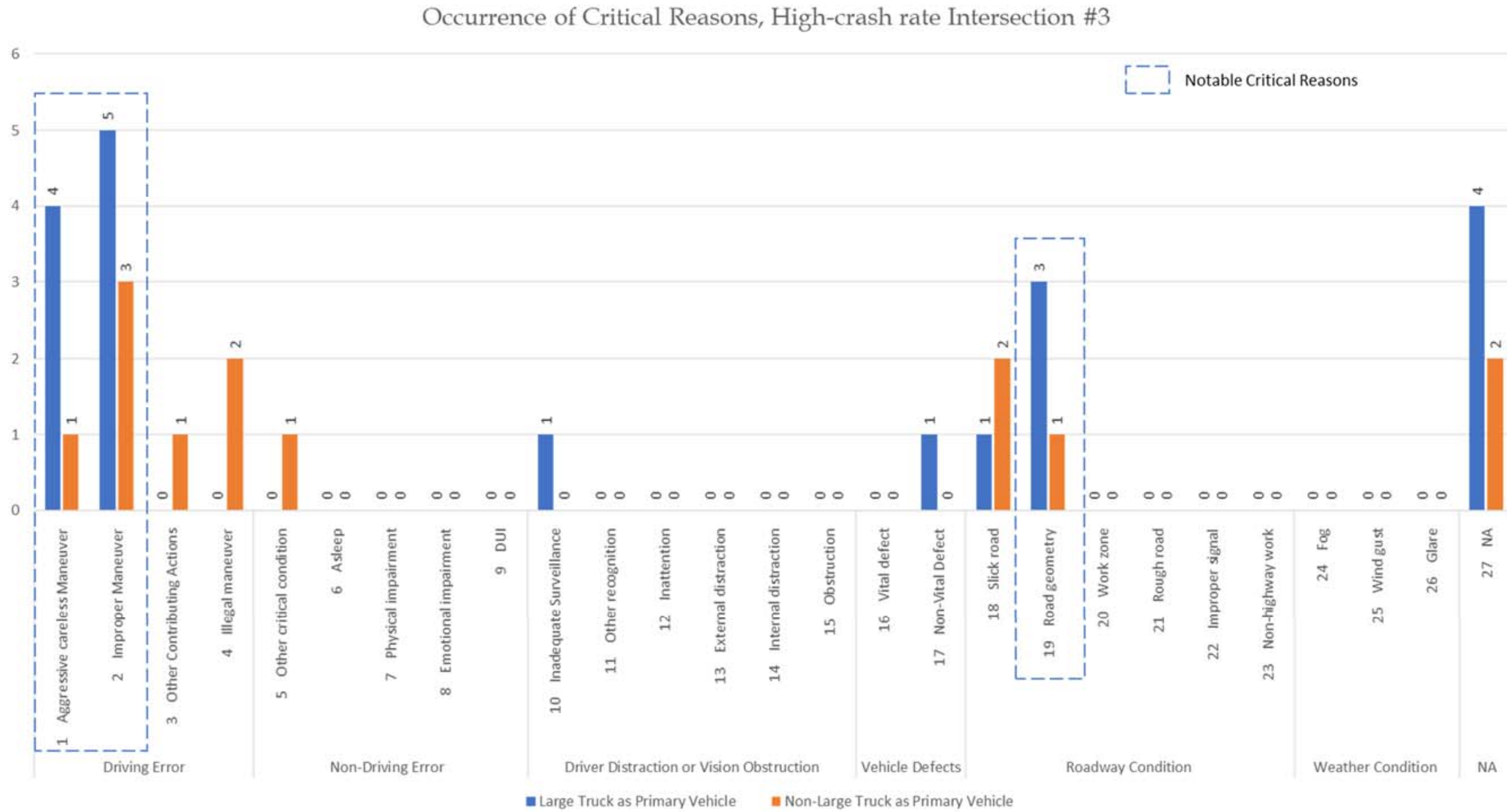


Figure 225 Occurrence of critical reasons at high crash rate intersection #3

High Crash Rate Intersection #4

Intersection ID: 562052
City: Jacksonville
County: Duval
Street names: US-301 and BOXCAR DR
Intersection AADT: 15,800
Crash rate: 1.231

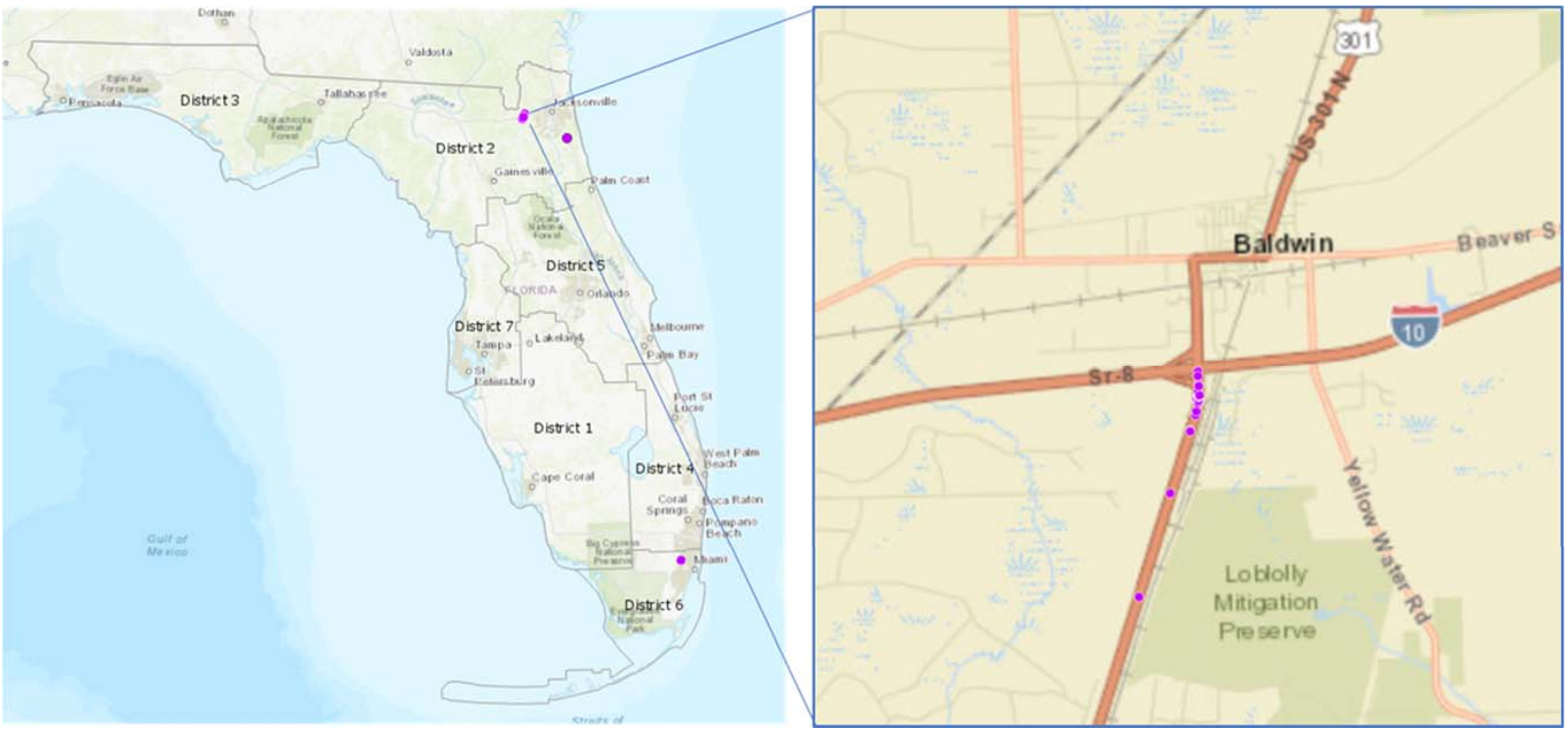


Figure 226 High crash rate intersection #4

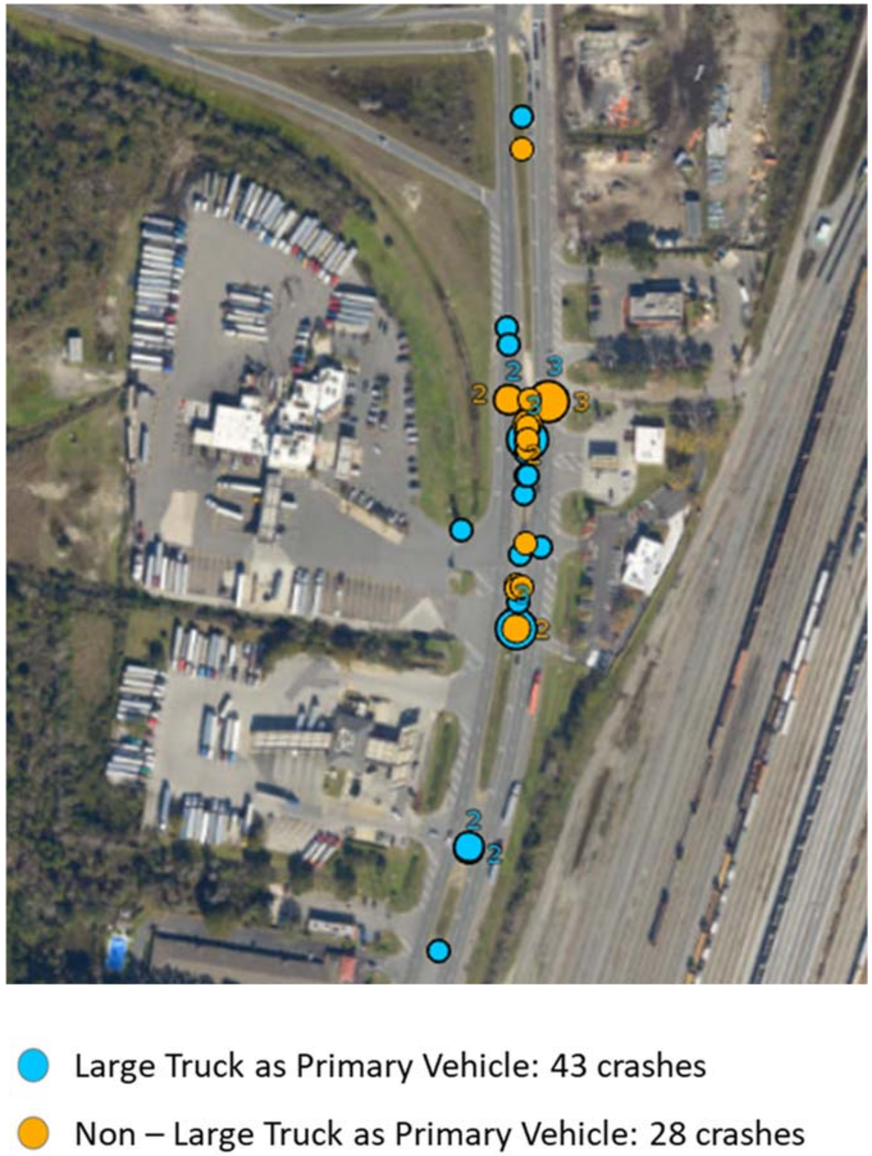


Figure 227 Crash locations by primary vehicle type at high crash rate intersection #4

Table 98 Occurrence of Critical Reasons at High Crash Rate Intersection #4

Intersection with high Crash Rate, #4	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	16	7
	2 Improper Maneuver	3	5
	3 Other Contributing Actions	5	3
	4 Illegal maneuver	10	10
Non-Driving Error	5 Other critical condition	0	0
	6 Asleep	0	1
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	0	4
	11 Other recognition	0	0
	12 Inattention	1	0
	13 External distraction	1	0
	14 Internal distraction	0	0
	15 Obstruction	0	0
Vehicle Defects	16 Vital defect	2	1
	17 Non-Vital Defect	0	1
Roadway Condition	18 Slick road	6	5
	19 Road geometry	0	1
	20 Work zone	0	0
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	1	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	7	1
Report Count		43	28

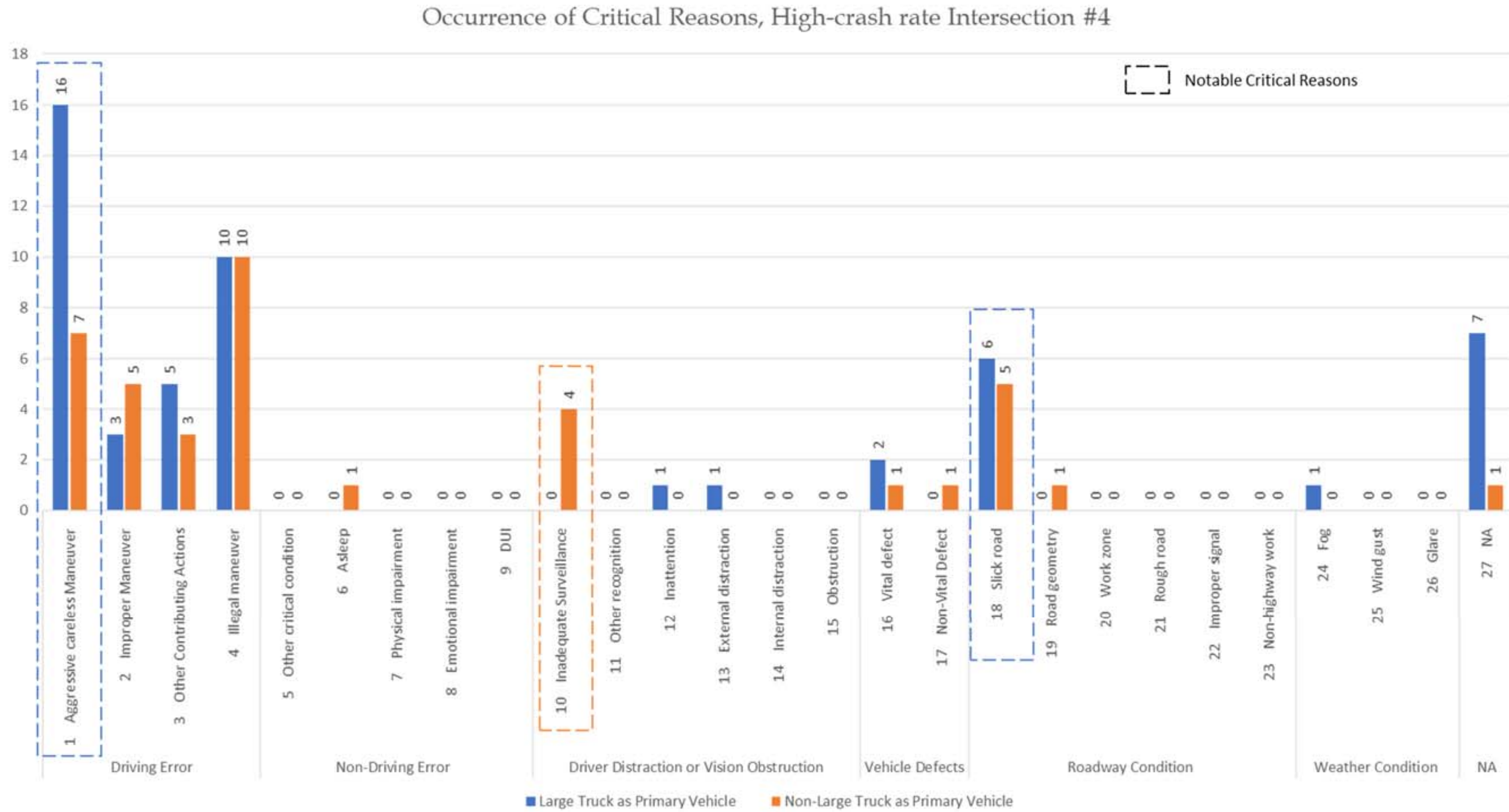


Figure 228 Occurrence of critical reasons at high crash rate intersection #4

High Crash Rate Intersection #5

Intersection ID: 364859
City: St Augustine
County: St Johns
Street names: SANDY CREEK PKWY and CR-210
Intersection AADT: 13,500
Crash rate: 1.218

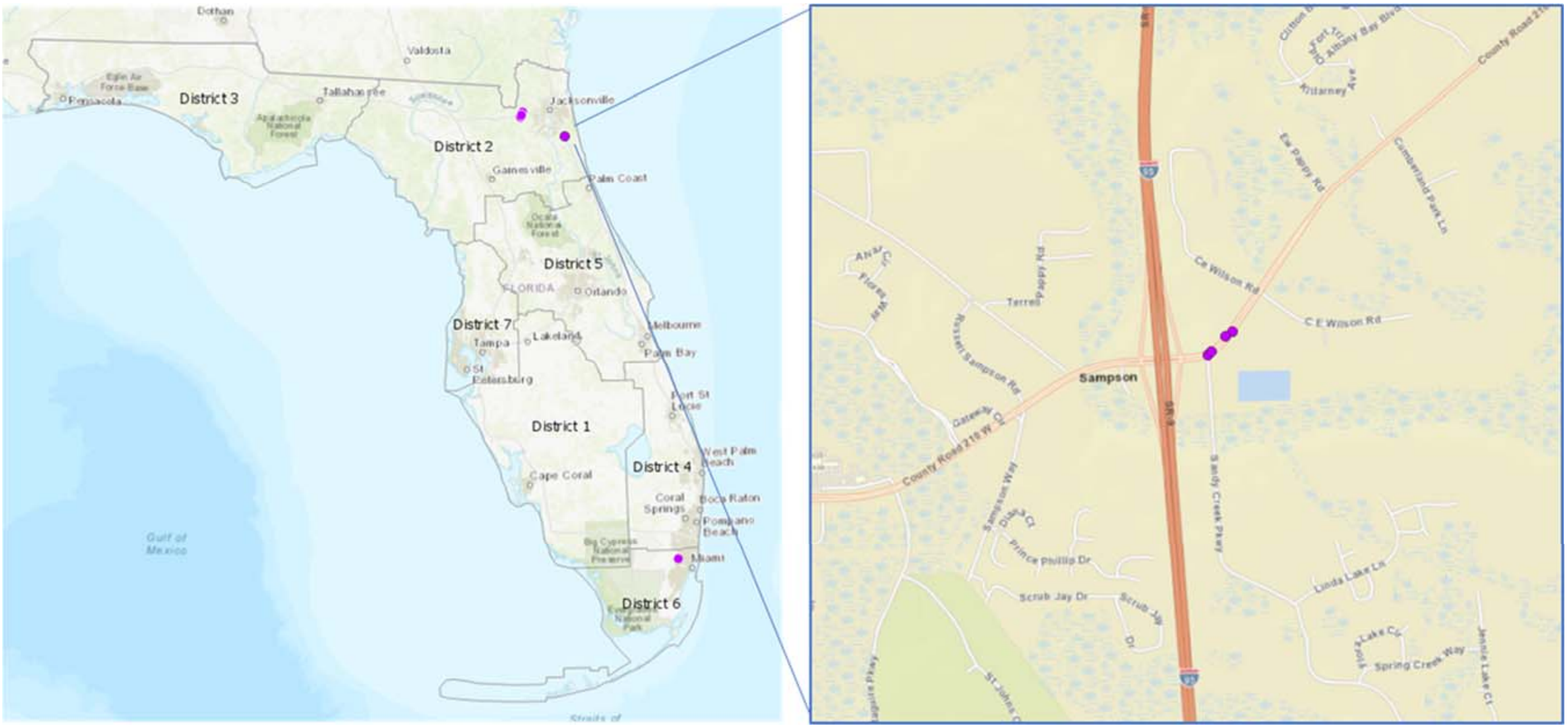


Figure 229 High crash rate intersection #5

Figure 230 Crash locations by primary vehicle type at high crash rate intersection #5

Table 99 Occurrence of Critical Reasons at High Crash Rate Intersection #5

Intersection with high Crash Rate, #5		Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	12	2
	2	Improper Maneuver	15	0
	3	Other Contributing Actions	6	0
	4	Illegal maneuver	1	0
Non-Driving Error	5	Other critical condition	0	0
	6	Asleep	0	0
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	0
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	8	0
	11	Other recognition	1	1
	12	Inattention	3	0
	13	External distraction	3	0
	14	Internal distraction	0	0
	15	Obstruction	1	0
Vehicle Defects	16	Vital defect	0	0
	17	Non-Vital Defect	2	1
Roadway Condition	18	Slick road	8	0
	19	Road geometry	1	0
	20	Work zone	1	0
	21	Rough road	1	0
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	0	0
	25	Wind gust	0	0
	26	Glare	1	0
NA	27	NA	14	1
Report Count			52	3

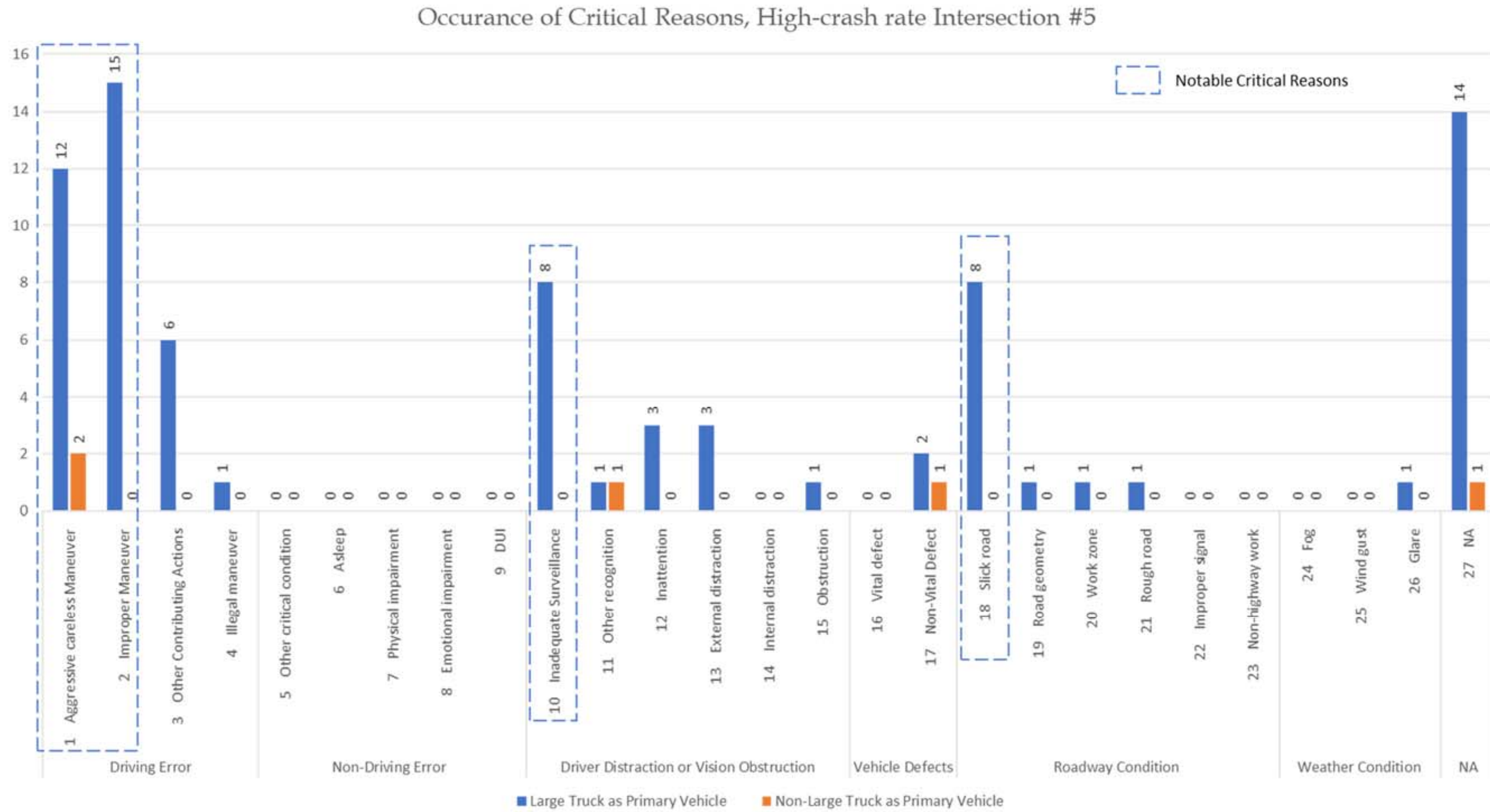
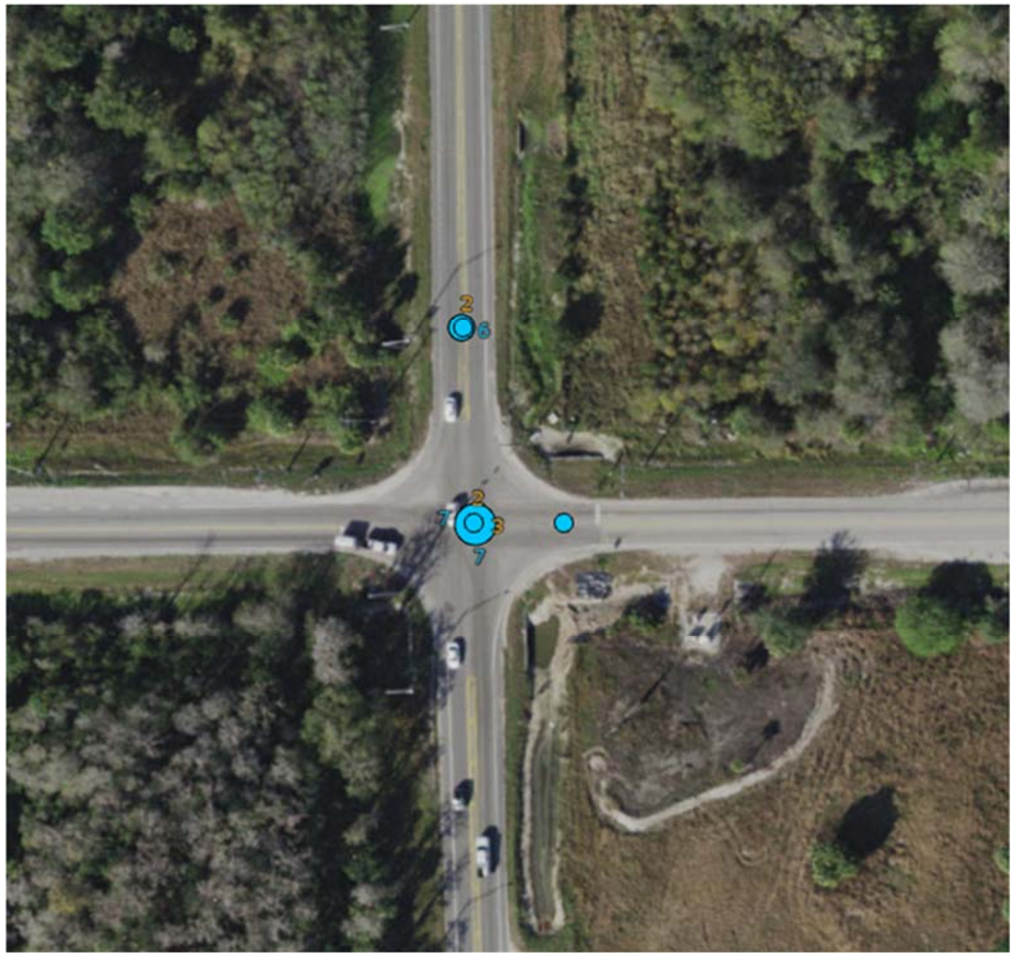


Figure 231 Occurrence of critical reasons at high crash rate intersection #5

Intersection of High Crash Rate Considering Severity #1

Intersection ID: 280979
City: Punta Gorda
County: Charlotte
Street names: BERMONT RD and SR-31
Intersection AADT: 8,550
Crash rate considering severity: 2.98

Figure 232 Intersection of high crash rate considering severity #1



Large Truck as Primary Vehicle: 24 crashes

Non – Large Truck as Primary Vehicle: 8 crashes

Figure 233 Crash locations by primary vehicle type at the intersection of high crash rate considering severity #1

Table 100 Occurrence of Critical Reasons at the Intersection of High Crash Rate Considering Severity #1

Intersections with relative High Severity and High Crash Rate, #1	Critical Reasons		Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1	Aggressive careless Maneuver	1	0
	2	Improper Maneuver	3	0
	3	Other Contributing Actions	4	2
	4	Illegal maneuver	10	4
Non-Driving Error	5	Other critical condition	1	0
	6	Asleep	0	0
	7	Physical impairment	0	0
	8	Emotional impairment	0	0
	9	DUI	0	0
Driver Distraction or Vision Obstruction	10	Inadequate Surveillance	0	0
	11	Other recognition	0	0
	12	Inattention	0	1
	13	External distraction	0	0
	14	Internal distraction	1	0
	15	Obstruction	0	0
Vehicle Defects	16	Vital defect	0	0
	17	Non-Vital Defect	2	0
Roadway Condition	18	Slick road	1	0
	19	Road geometry	0	0
	20	Work zone	0	0
	21	Rough road	0	0
	22	Improper signal	0	0
	23	Non-highway work	0	0
Weather Condition	24	Fog	1	1
	25	Wind gust	0	0
	26	Glare	0	0
NA	27	NA	6	2
Report Count			24	8

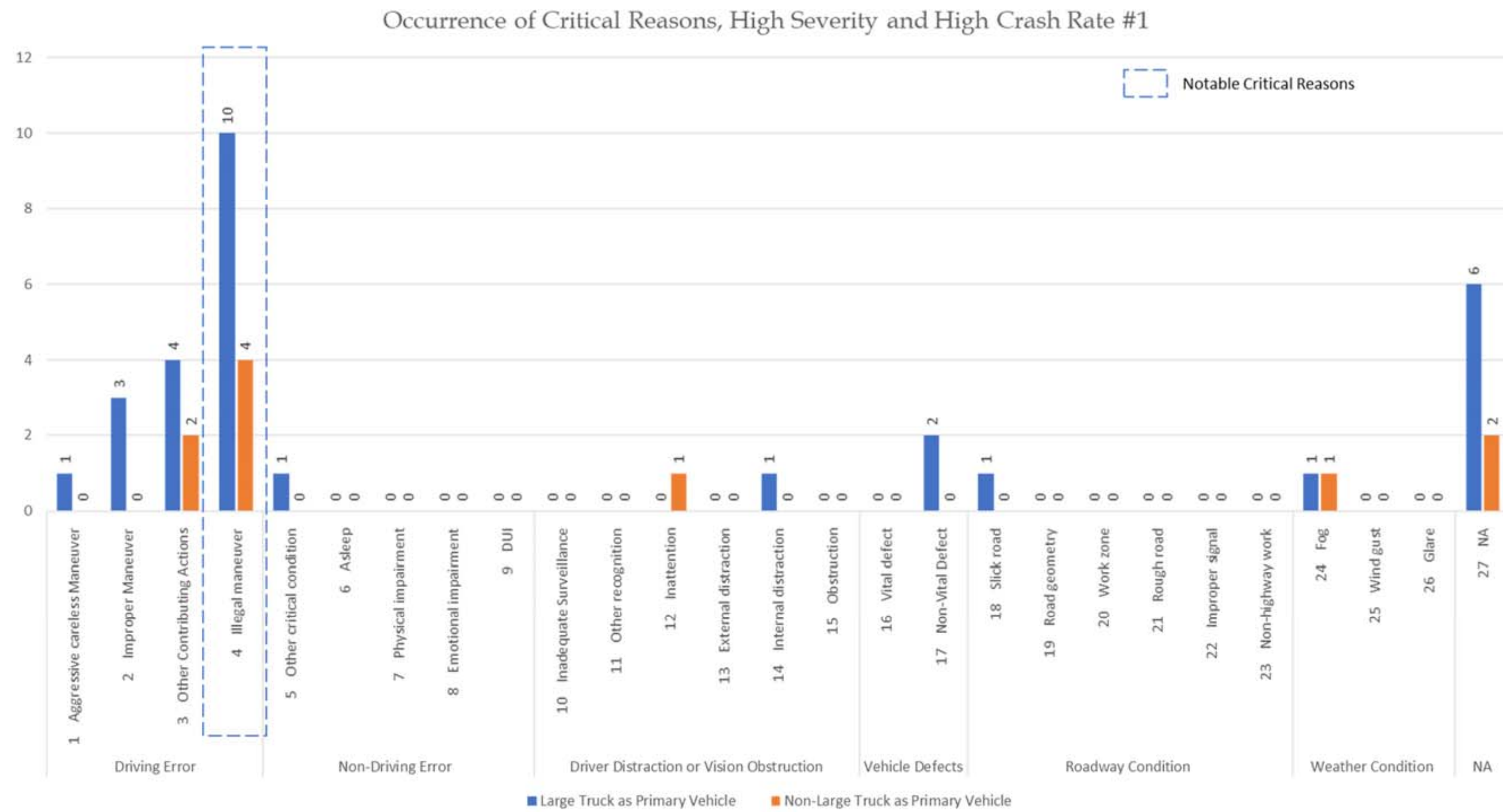


Figure 234 **Occurrence of critical reasons at intersection of high crash rate considering severity #1**

Intersection of High Crash Rate Considering Severity #2

Intersection ID: 150985
City: Okeechobee
County: Osceola
Street names: SR-60 and S KENANSVILLE RD
Intersection AADT: 11,250
Crash rate considering severity: 1.412

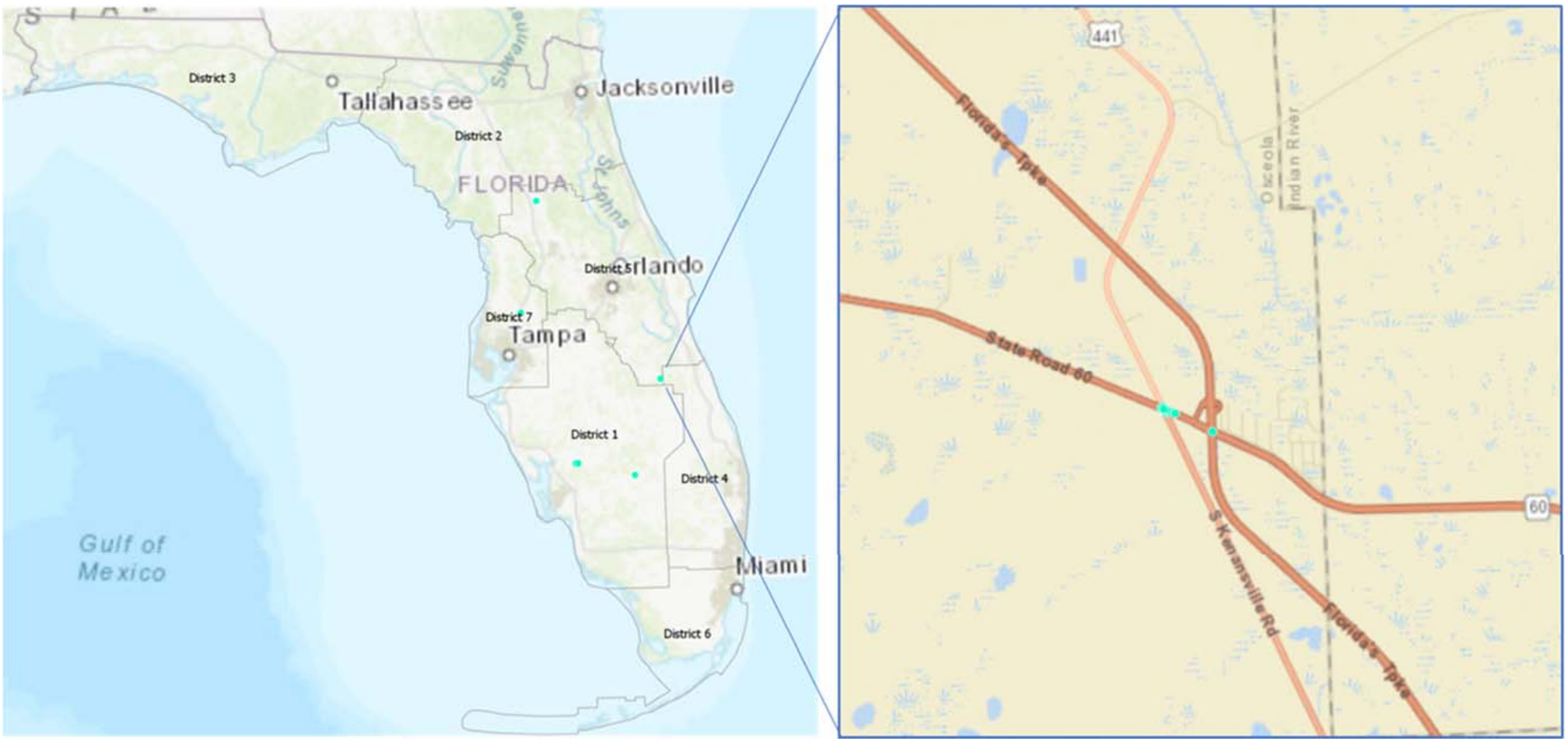


Figure 235 Intersection of high crash rate considering severity #2

Large Truck as Primary Vehicle: 18 crashes

Non – Large Truck as Primary Vehicle: 10 crashes

Figure 236 Crash locations by primary vehicle type at the intersection of high crash rate considering severity #2

Table 101 Occurrence of Critical Reasons at the Intersection of High Crash Rate Considering Severity #2

Intersections with relative High Severity and High Crash Rate, #2	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	2	4
	2 Improper Maneuver	1	0
	3 Other Contributing Actions	3	1
	4 Illegal maneuver	6	5
Non-Driving Error	5 Other critical condition	0	1
	6 Asleep	0	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	1
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	1	0
	11 Other recognition	0	0
	12 Inattention	5	3
	13 External distraction	0	0
	14 Internal distraction	0	0
	15 Obstruction	0	0
Vehicle Defects	16 Vital defect	1	0
	17 Non-Vital Defect	0	0
Roadway Condition	18 Slick road	3	3
	19 Road geometry	0	0
	20 Work zone	0	0
	21 Rough road	1	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	1	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	4	0
Report Count		18	10

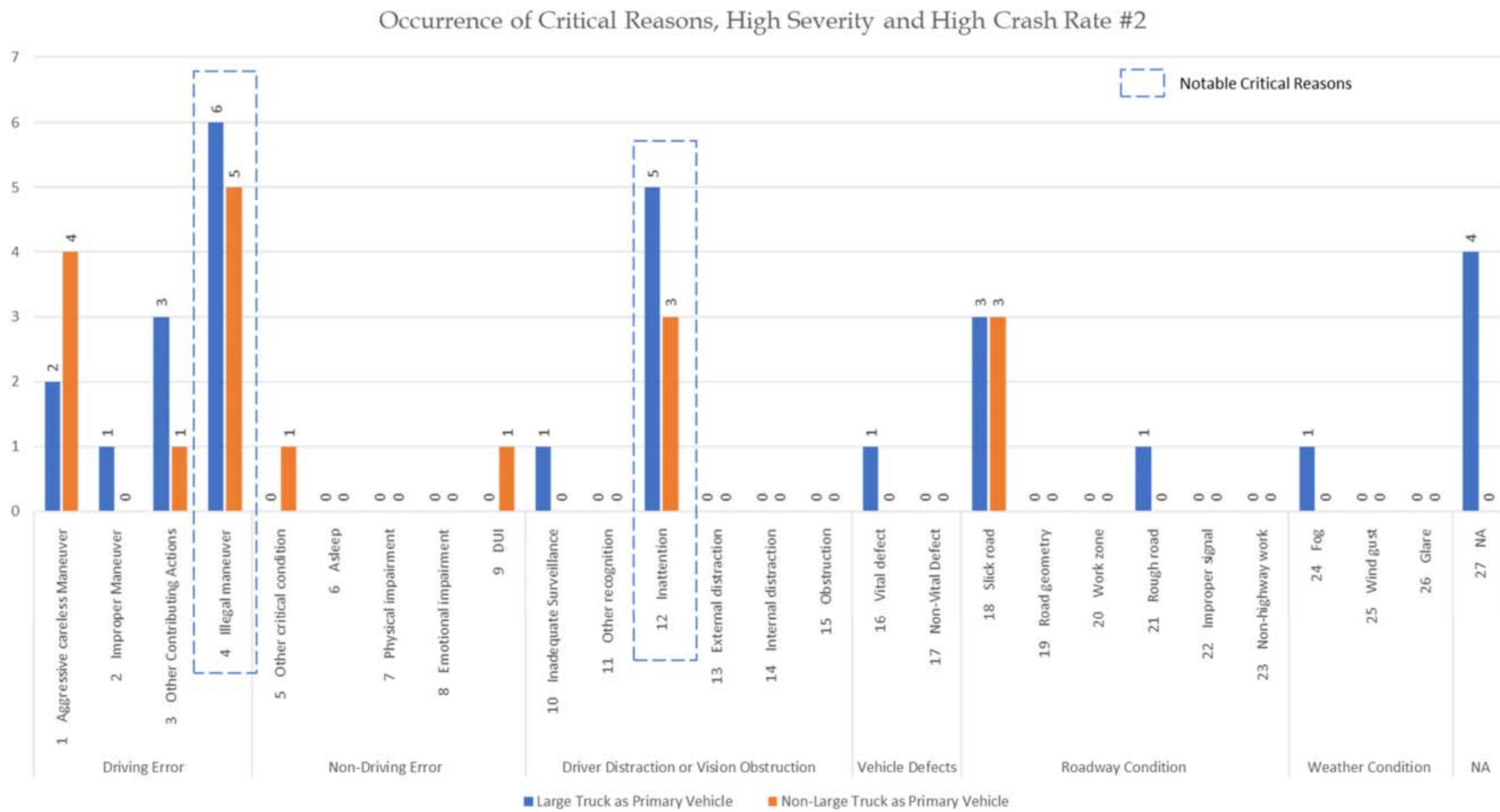


Figure 237 Occurrence of critical reasons at intersection of high crash rate considering severity #2

Intersection of High Crash Rate Considering Severity #3

Intersection ID: 542750
City: Moore Haven
County: Glades
Street names: US-27 and SR-78
Intersection AADT: 9,250
Crash rate considering severity: 1.185

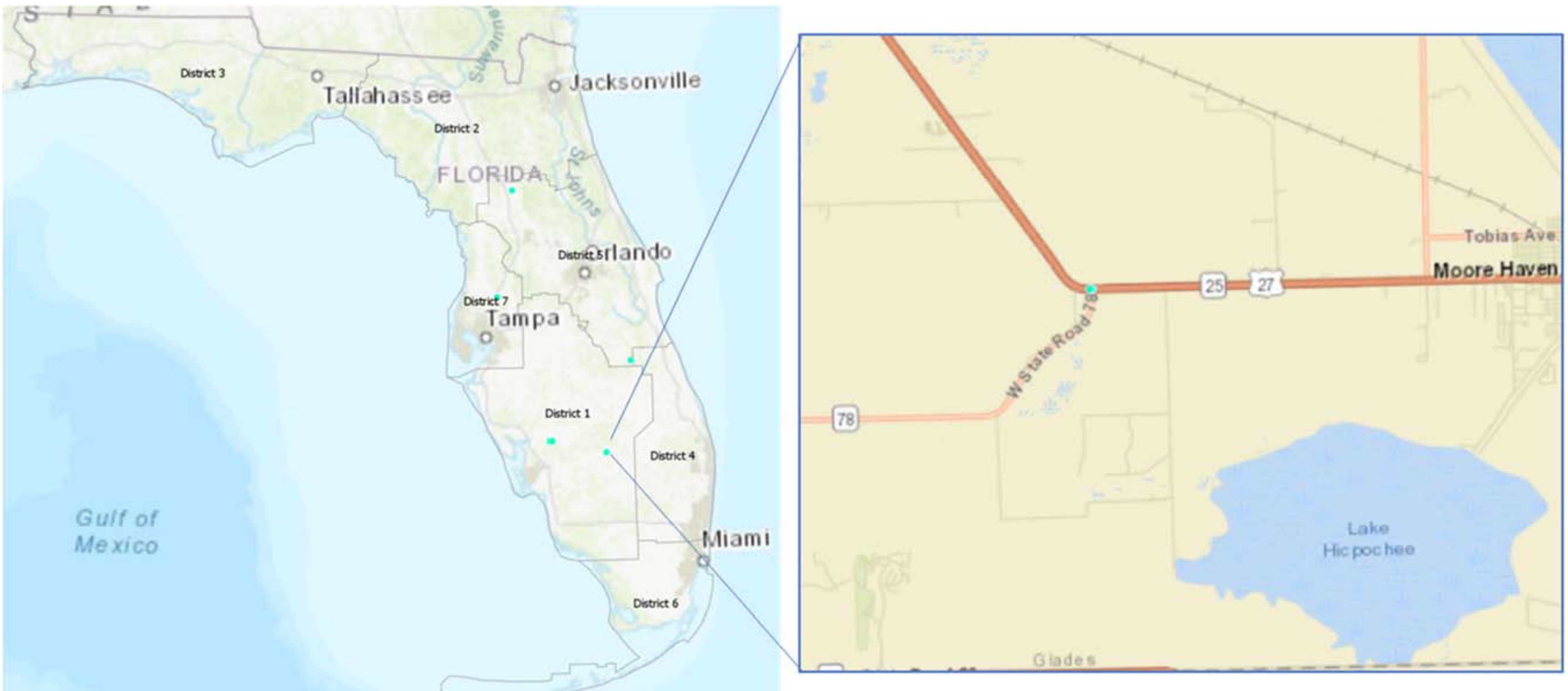


Figure 238 Intersection of high crash rate considering severity #3

Large Truck as Primary Vehicle: 15 crashes

Non – Large Truck as Primary Vehicle: 1 crashes

Figure 239 Crash locations by primary vehicle type at the intersection of high crash rate considering severity #3

Table 102 Occurrence of critical reasons at the intersection of high crash rate considering severity #3

Intersections with relative High Severity and High Crash Rate, #3	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	3	1
	2 Improper Maneuver	0	0
	3 Other Contributing Actions	2	0
	4 Illegal maneuver	4	0
Non-Driving Error	5 Other critical condition	0	0
	6 Asleep	0	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	2	0
	11 Other recognition	0	0
	12 Inattention	0	0
	13 External distraction	0	0
	14 Internal distraction	0	0
	15 Obstruction	0	0
Vehicle Defects	16 Vital defect	3	0
	17 Non-Vital Defect	2	0
Roadway Condition	18 Slick road	3	0
	19 Road geometry	0	0
	20 Work zone	0	0
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	4	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	2	0
Report Count		15	1

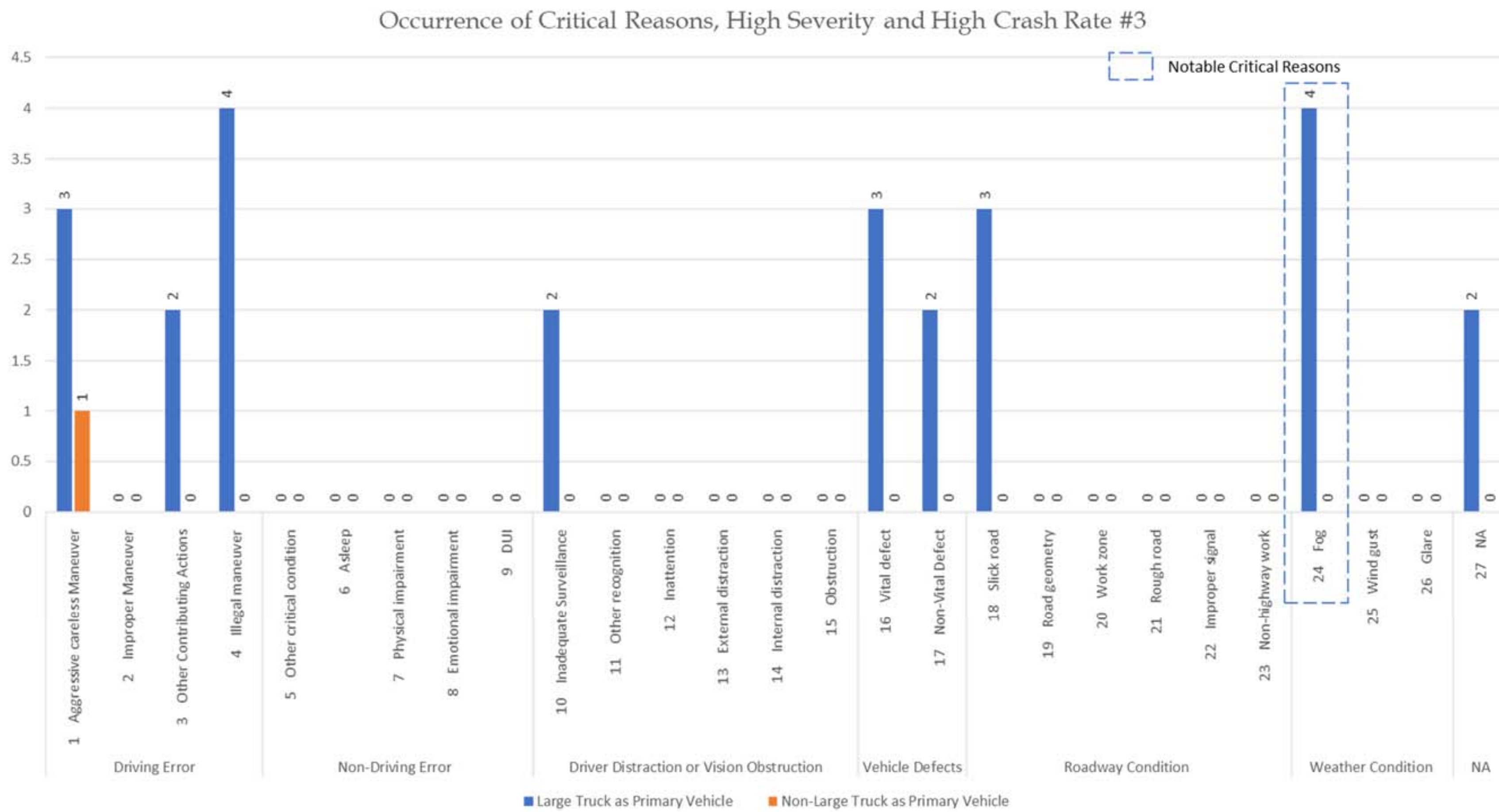


Figure 240 Occurrence of critical reasons at intersection of high crash rate considering severity #3

Intersection of High Crash Rate Considering Severity #4

Intersection ID: 542720
City: Citra (unincorporated)
County: Ocala
Street names: US-301 and CR-329
Intersection AADT: 20,100
Crash rate considering severity: 1.036

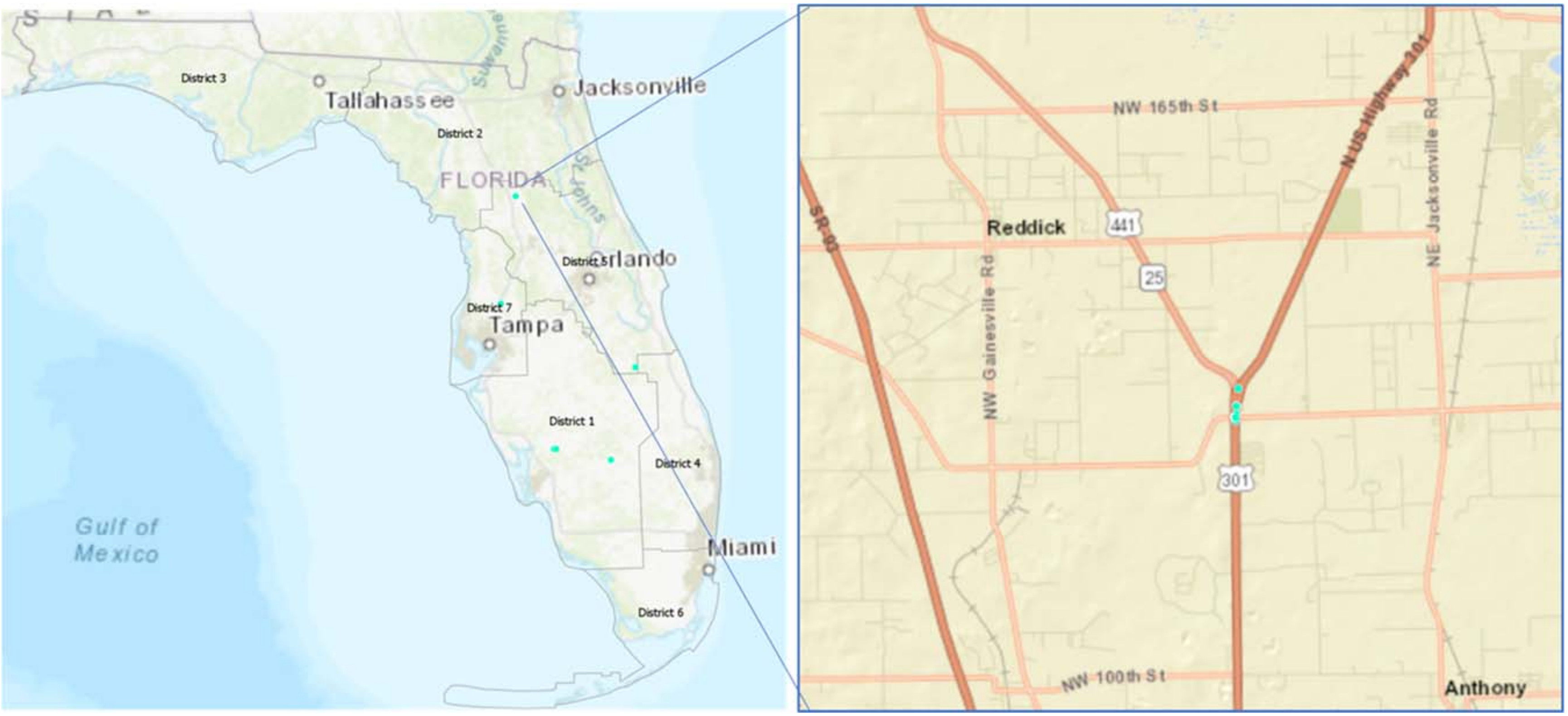
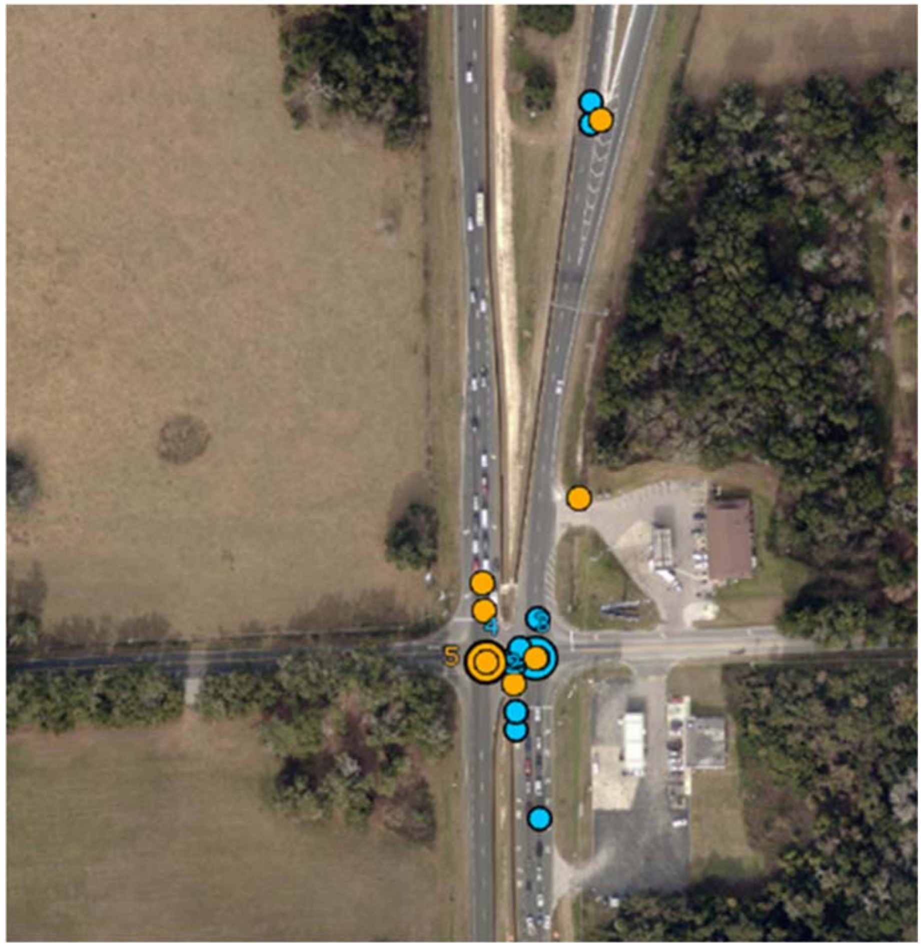


Figure 241 Intersection of high crash rate considering severity #4



Large Truck as Primary Vehicle: 20 crashes

Non – Large Truck as Primary Vehicle: 13 crashes

Figure 242 Crash locations by primary vehicle type at the intersection of high crash rate considering severity #4

Table 103 Occurrence of Critical Reasons at the Intersection of High Crash Rate Considering Severity #4

Intersections with relative High Severity and High Crash Rate, #4	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	9	7
	2 Improper Maneuver	2	2
	3 Other Contributing Actions	2	1
	4 Illegal maneuver	3	1
Non-Driving Error	5 Other critical condition	0	0
	6 Asleep	0	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	2	0
	11 Other recognition	0	0
	12 Inattention	1	0
	13 External distraction	0	0
	14 Internal distraction	0	2
	15 Obstruction	0	0
Vehicle Defects	16 Vital defect	1	0
	17 Non-Vital Defect	0	0
Roadway Condition	18 Slick road	9	3
	19 Road geometry	2	3
	20 Work zone	0	0
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	1	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	1	0
Report Count		20	13

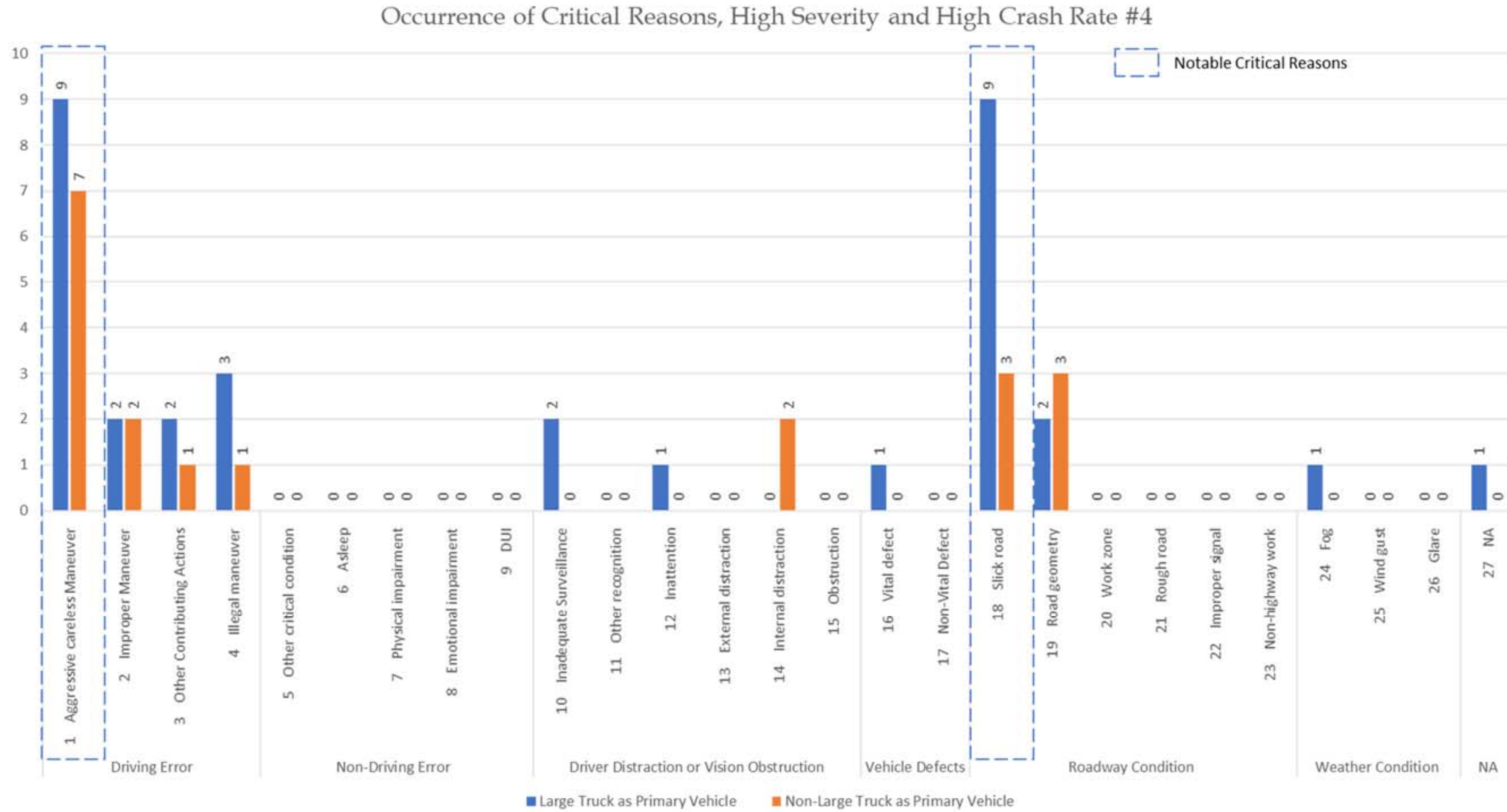


Figure 243 Occurrence of critical reasons at intersection of high crash rate considering severity #4

Intersection of High Crash Rate Considering Severity #5

Intersection ID: 588575
City: San Antonio
County: Pasco
Street names: RAMP SR-52/STATE ROAD 52 and S I-75/SR-93
Intersection AADT: 21,200
Crash rate considering severity: 0.969

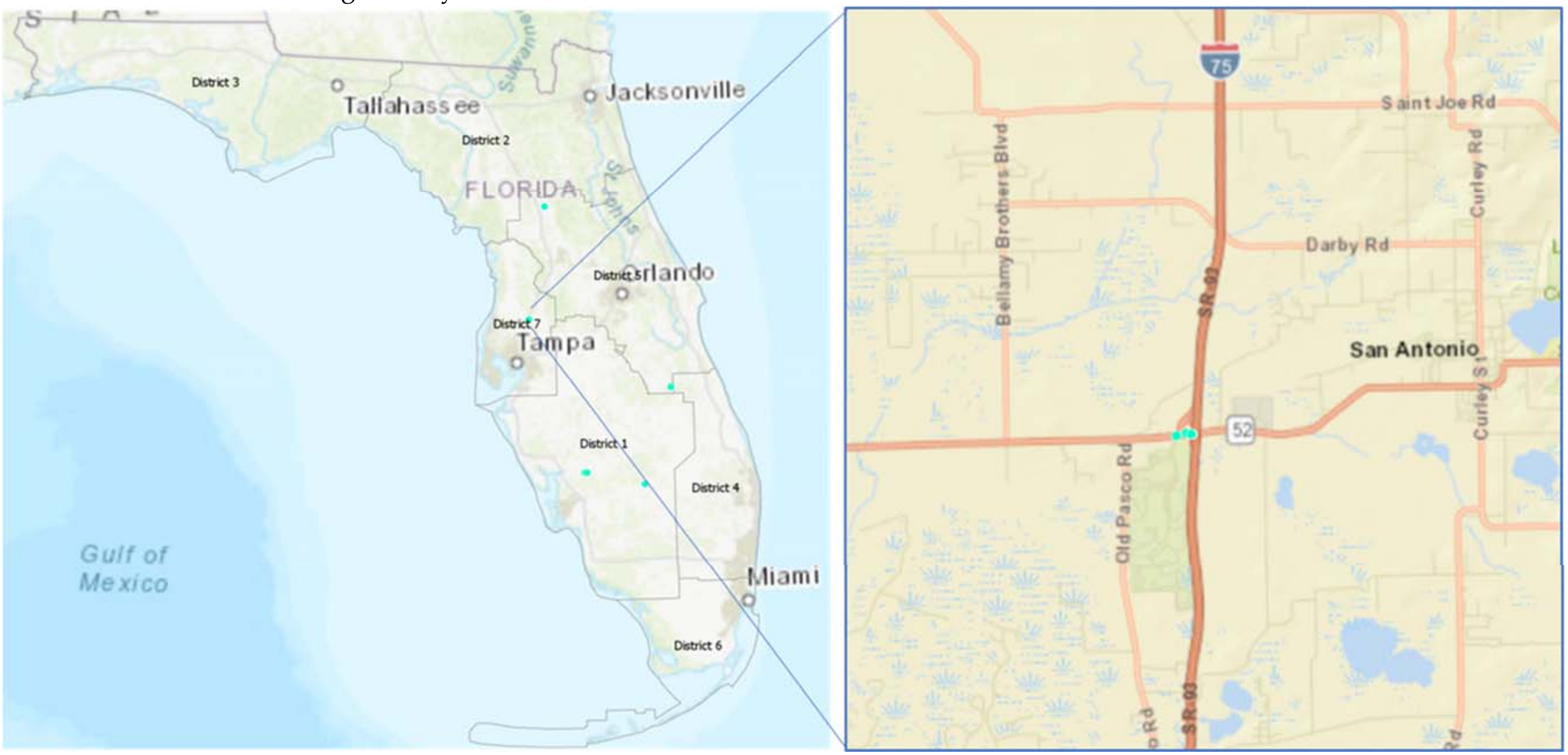


Figure 244 Intersection of high crash rate considering severity #5

Figure 245 Crash locations by primary vehicle type at the intersection of high crash rate considering severity #5

Table 104 Occurrence of Critical Reasons at the Intersection of High Crash Rate Considering Severity #5

Intersections with relative High Severity and High Crash Rate, #5	Critical Reasons	Large Truck as Primary Vehicle	Non-Large Truck as Primary Vehicle
Driving Error	1 Aggressive careless Maneuver	2	0
	2 Improper Maneuver	0	0
	3 Other Contributing Actions	1	0
	4 Illegal maneuver	0	1
Non-Driving Error	5 Other critical condition	0	0
	6 Asleep	0	0
	7 Physical impairment	0	0
	8 Emotional impairment	0	0
	9 DUI	0	0
Driver Distraction or Vision Obstruction	10 Inadequate Surveillance	0	1
	11 Other recognition	0	0
	12 Inattention	0	0
	13 External distraction	0	0
	14 Internal distraction	0	0
	15 Obstruction	0	0
Vehicle Defects	16 Vital defect	0	0
	17 Non-Vital Defect	0	0
Roadway Condition	18 Slick road	0	1
	19 Road geometry	1	0
	20 Work zone	0	0
	21 Rough road	0	0
	22 Improper signal	0	0
	23 Non-highway work	0	0
Weather Condition	24 Fog	0	0
	25 Wind gust	0	0
	26 Glare	0	0
NA	27 NA	2	0
Report Count		5	1

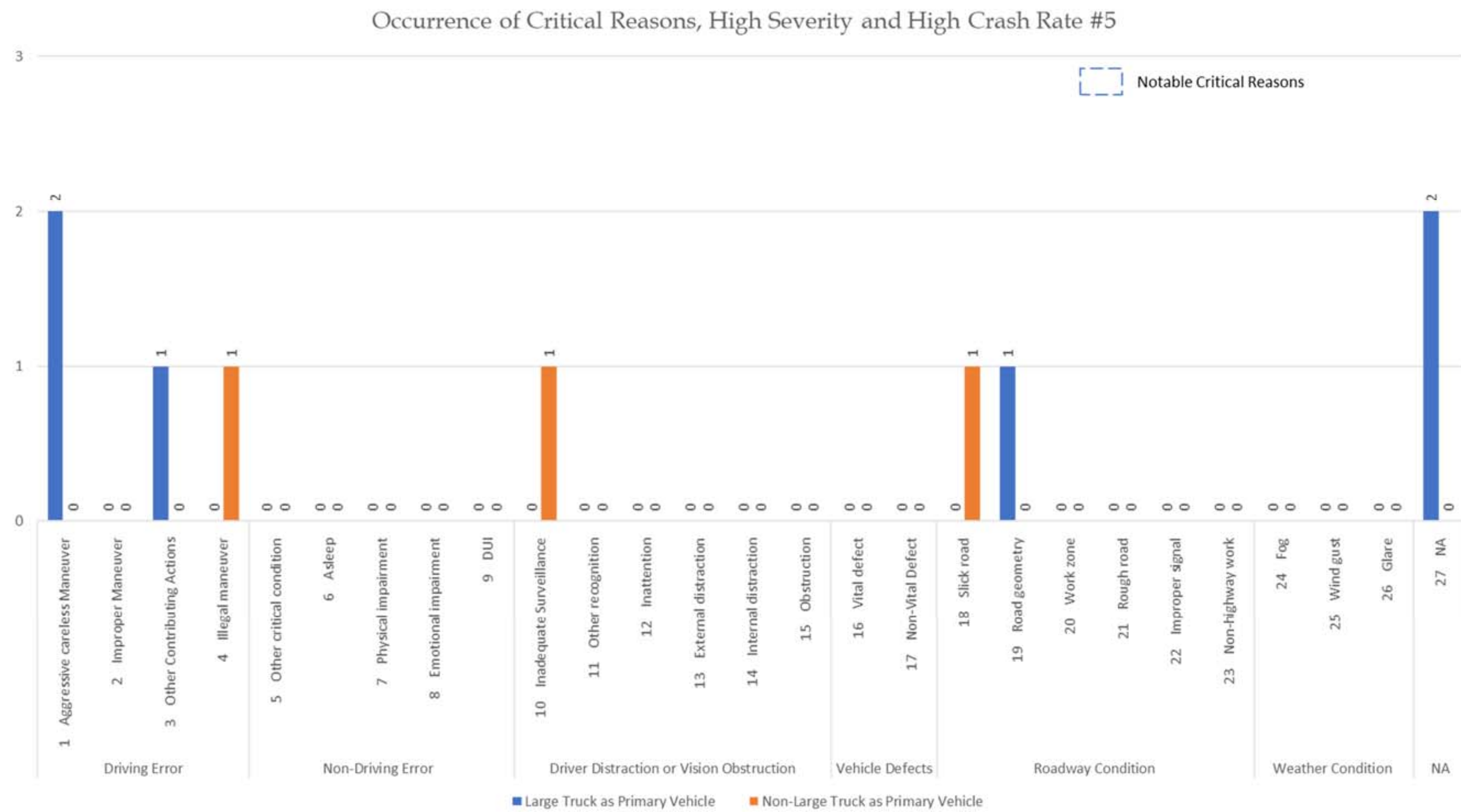


Figure 246 Occurrence of critical reasons at intersection of high crash rate considering severity #5

8.3.5. Recommended Countermeasures for Notable Critical Reasons

Based on the charts of occurrence of critical reasons, the most notable reasons for large truck crashes at the hotspot areas and some intersections are driving error, driver distraction or vision obstruction, and the roadway condition.

The final recommended countermeasures are selected from the summary tables (section 8.3.1) by most critical reasons, and they are ranked based on cost levels from high cost to low cost in the following sections. When considering countermeasures for a specific site, the decision makers can first look up the notable critical reasons, maps and charts in sections 8.3.3 and 8.3.4, consider the budget and expected effectiveness, and then apply suitable countermeasures for that site.

Table 105 Countermeasures for Driving Error

Notable Critical Reason	Recommended Countermeasure			CMF Value
Driving Error (Aggressive careless Maneuver, Improper Maneuver, Other Contributing Actions, Illegal maneuver)	Engineering Countermeasures	High Cost	Eng2 Back-up camera systems	
			Eng3 Side-object detection	
			Eng5 Forward collision avoidance systems	0.8
			Eng6 Adaptive cruise control	
			Eng9 Oversize/Overweight Corridors	
			Eng11 Flatten Curve	0.315 - 0.584
			Eng18 Climbing Lanes	0.58 - 0.75
			Eng19 Alternate Passing Lanes	0.58 - 0.75
			Eng20 Exclusive Truck Roadways	
			Eng21 Interchange Truck bypass	
			Eng29 Detection-Control Systems for Traffic Signals	
			Eng31 Work Zone and Incident Notification Systems	
		Moderate Cost	Eng7 Enhanced seat belt earning system	
			Eng10 Virtual Weigh Stations	
			Eng14 Cross-slope breaks	
			Eng23 Updating retroreflective traffic signs	
			Eng24 Updating signs to MUTCD standards	
			Eng25 Dynamic warning signs	0.1 - 0.46
			Eng26 Truck rollover warning system	0.1 - 0.46
			Eng27 Contrast marking	
			Eng34 Truck Parking Availability Systems (TPAS)	
		Low Cost	Eng1 Lane Departure Warning Systems (virtual rumble strips)	
			Eng8 Truck restricted lanes	0.73-1.12
			Eng12 Rumble Strips	0.34 - 1.021
			Eng22 Static Warning Signs	0.7-0.92
			Eng30 Wider Edge Lines	0.341 - 0.962
			Eng33 Traffic Incident Management (TIM)	

Table 105 Countermeasures for Driving Error (Continued)

Notable Critical Reason	Recommended Countermeasure			CMF Value
Driving Error (Aggressive careless Maneuver, Improper Maneuver, Other Contributing Actions, Illegal maneuver)	Enforcement Countermeasures	High Cost		
		Moderate Cost	Enf1 High Visibility Enforcement (HVE)	
			Enf2 Targeted Enforcement – Truck Lane Restrictions	
			Enf3 Targeted Enforcement - Oversize/Overweight	
			Enf5 Targeted Enforcement – Following Too Closely	
			Enf6 Targeted Enforcement – General Patrol	
			Enf7 Targeted Enforcement – CMV Electronic Device use	
			Enf8 Strengthen Commercial Driver's License (CDL) Program	
			Enf9 Targeted Enforcement - HAZMAT	
		Low Cost		
	Education Countermeasures	High Cost		
		Moderate Cost	Ed1 Increase Public Understanding of Driving with Trucks	
			Ed2 No Zone	
			Ed3 Safe Passing	
			Ed4 Slow Traffic in Left Lane	
			Ed5 Distracted Driving	
			Ed6 Driver Fatigue	
			Ed7 Bike/ped safety	
		Low Cost		

Table 106 Countermeasures for Distraction / Vison Obstruction

Notable Critical Reason	Recommended Countermeasure			CMF Value
Distraction / Vision Obstruction (Inadequate Surveillance, Other recognition, Inattention, External distraction, Internal distraction, Obstruction)	Engineering Countermeasures	High Cost	Eng2 Back-up camera systems	
			Eng3 Side-object detection	
			Eng18 Climbing Lanes	0.58 - 0.75
		Moderate Cost	Eng25 Dynamic warning signs	0.1 - 0.46
			Eng26 Truck rollover warning system	0.1 - 0.46
			Eng27 Contrast marking	
		Low Cost	Eng1 Lane Departure Warning Systems (virtual rumble strips)	
			Eng12 Rumble Strips	0.34 - 1.021
			Eng22 Static Warning Signs	0.7-0.92
			Eng30 Wider Edge Lines	0.341 - 0.962
	Enforcement Countermeasures	High Cost		
		Moderate Cost		
		Low Cost		
	Education Countermeasures	High Cost		
		Moderate Cost	Ed1 Increase Public Understanding of Driving with Trucks	
		Low Cost		

Table 107 Countermeasures for Road Condition

Notable Critical Reason	Recommended Countermeasure			CMF Value
Roadway Condition (Slick road, Road geometry, Work zone, Rough road, Improper signal, Non-highway work)	Engineering Countermeasures	High Cost	Eng11 Flatten Curve	0.315 - 0.584
			Eng17 Adding Escape Ramps	0.25
			Eng29 Detection-Control Systems for Traffic Signals	
		Moderate Cost	Eng13 High-Friction Surface Treatments (HFST)	0 - 0.36
			Eng14 Cross-slope Breaks	
			Eng15 Enhanced Drainage	
			Eng23 Updating retroreflective traffic signs	
			Eng24 Updating signs to MUTCD standards	
			Eng26 Truck rollover warning system	0.1 - 0.46
		Low Cost	Eng22 Static Warning Signs	0.7-0.92

9. ECONOMIC APPRAISAL APPROACH

This chapter describes the recommended economic appraisal approach that considers the economic impacts of enhanced freight safety and mobility in project evaluation process. The next section describes the cost values for truck crashes by crash type and severity level. The following sections summarizes the proposed economic appraisal approach, along with a spreadsheet tool to demonstrate the process.

9.1. Large Truck Crash Costs

Crashes involving large trucks impose a variety of costs on the owners of the vehicles, drivers and passengers involved, and the society as a whole. In addition to direct costs such as property damage and medical expenses for injuries and fatalities, indirect costs from productivity loss such as work lost by the injured drivers and damaged vehicles, company staff time and resources allocated for investigating crashes, recruiting and training replacements for disabled workers, and repairing damaged company vehicles all contribute significantly to the overall cost of large truck crashes. Comprehensive and reliable estimates on crash costs are required for the evaluation of cost effectiveness of various crash reduction measures and safety regulations.

Zaloshnja and Miller (2002) presents the most comprehensive effort in estimating the costs of highway crashes involving large trucks. Prepared for the Federal Motor Carrier Safety Administration (FMCSA) of the US Department of Transportation (US DOT), they analyzed large truck (i.e., trucks with a gross weight rating of more than 10,000 pounds) crash data dating from 1982 to 1999 and produced estimates of costs per crash by truck types and injury severity levels (Table 108). Crash costs are divided into five categories including:

- Medical costs,
- Emergency services,
- Property damage,
- Lost productivity (i.e., from delays and other sources), and
- Monetized Quality-Adjusted Life Years (QALYs) based on Value of Statistical Life (VSL) estimated by US DOT (2016).

Table 108 Cost per Crash by Type of Truck and Injury Severity Involved (in 2000 dollars)

Truck/Bus Type Involved in Crash	Injury Severity	Medical Costs	Emergency Services	Property Damage	Lost Productivity from Delays	Lost Productivity from Other Sources	Monetized QALYs Based on VSL $3	Total
Straight truck, no trailer	O – No injury	176	91	3,282	3,759	1,397	486	9,191
	C – Possible injury	5,883	279	5,888	7,467	9,821	13,556	42,894
	B – Non-incapacitating injury	6,816	406	7,419	7,993	9,679	10,814	43,128
	A – Incapacitating injury	15,847	744	9,974	8,837	33,563	37,990	106,955
	K – Killed	31,633	1,270	19,811	10,893	976,393	1,951,498	2,991,498
	U – Injury, severity unknown	3,746	261	5,712	6,303	6,745	7,543	30,310
	Unknown if injured	901	164	3,946	5,420	2,838	2,101	15,371
Straight truck with trailer	O – No injury	883	97	4,677	3,998	1,463	835	11,953
	C – Possible injury	9,312	323	10,109	7,748	11,361	22,786	61,640
	B – Non-incapacitating injury	10,370	429	11,126	7,567	14,103	27,085	70,680
	A – Incapacitating injury	35,434	961	19,580	11,935	58,114	99,483	225,507
	K – Killed	38,642	1,479	33,667	12,981	1,184,262	2,374,243	3,645,273
	U – Injury, severity unknown	1,547	260	12,509	7,981	5,444	3,944	31,685
	Unknown if injured	1,398	126	5,188	3,856	2,555	2,722	15,846
Straight truck, unknown if with trailer	O – No injury	883	81	3,104	3,362	1,290	813	9,533
	C – Possible injury	8,319	295	6,868	7,097	9,233	17,967	49,779
	B – Non-incapacitating injury	9,450	436	9,774	7,997	13,134	24,423	65,214
	A – Incapacitating injury	37,963	586	9,746	6,680	36,677	114,811	206,464
	Unknown if injured	4,684	265	8,389	6,662	5,877	10,991	36,867
Bobtail	O – No injury	717	96	4,618	5,026	1,974	1,354	13,785
	C – Possible injury	5,561	252	7,951	9,191	10,084	10,963	44,002
	B – Non-incapacitating injury	4,986	434	10,945	9,769	11,105	10,256	47,495
	A – Incapacitating injury	5,288	611	12,325	9,024	15,372	11,547	54,166
	K – Killed	35,721	1,483	33,081	12,047	1,362,133	2,741,658	4,186,122
	U – Injury, severity unknown	1,031	203	6,438	4,572	2,282	1,992	16,518
	Unknown if injured	1,101	110	5,193	4,104	2,420	2,474	15,401

Source: Adapted from Zaloshnja and Miller (2002)

Medically related costs include ambulance, emergency medical, physician, hospital, rehabilitation, prescription, and related treatment costs, as well as costs for crutches, and physical therapy. Medical costs were estimated based on police-reported KABCO severity scales (i.e., K=Killed, A=Incapacitating injury, B=Non-incapacitating injury, C=Possible injury, O=No injury). Emergency services includes cost for police and fire responder services, computed from assumed response patterns by crash severity and vehicle involvement.

Property damage is the cost to repair or replace damaged vehicles, cargo, and to compensate for other damaged properties. Property damage costs were estimated from insurance data detailing payments per insurance claim, aggregate payments for damage to the insured vehicle and to the damage it imposed on other vehicles in at-fault crashes.

Productivity loss includes loss from traffic delays due to crashes (i.e., additional travel time imposed on the vehicles in the queues behind the crashes) and loss from other sources directly involved in the crashes such as the carriers and the drivers and passengers injured in the crashes. Lost productivity from other sources includes wages, fringe benefits, and household work lost by the injured, as well as the costs of processing productivity loss compensation claims. It also includes productivity loss by company staff time and resources allocated for investigating crashes, recruiting and training replacements for disabled workers, and repairing damaged company vehicles.

In addition to costs related to medical care, emergency services, property damage and productivity loss, injury crashes also cost victims and families by reducing their quality of life. The good health lost when someone suffers a health problem or dies can be accounted for by estimating QALYs lost. A QALY is a health outcome measure that assigns a value of 1 to a year of perfect health and 0 to death (Weinstein et al., 1996). Based on the types of injuries and the health problems (e.g., disability) associated with the injuries, the QALY loss of a crash victim for each year of the victim's remaining life is estimated as a fraction of one QALY. The monetized value of one QALY is derived by dividing the value of USDOT's VSL at 3 million dollars in 2000 (US DOT, 2016) with the person's life span.

These itemized unit crash costs can be used for benefit cost analysis of various crash countermeasures. These figures can also be used to calculate and compare the cost-effectiveness of proposed safety regulations. It is noted that the FMCSA continues to use these unit costs adjusted to current dollars and the most recent VSL value to estimate annual cost of large truck crashes (FMCSA, 2018c).

9.2. Economic Appraisal for Large Truck Crash Reduction Measures

An economic appraisal of a transportation project deals with the identification and measurement of project costs and the size and distribution of the benefits created by the project (Adler, 1987). Benefit-Cost Analysis (BCA) is a type of economic appraisal commonly used in the US for evaluation of highway projects (FHWA, 2003). In the US, benefits associated with reduced crashes are considered a standard element in the BCA for highway projects.

9.2.1. Safety Benefit Estimation

The Benefit-Cost Analysis Guidance for Discretionary Grant Programs published by the US DOT (USDOT, 2018) recommends using the model in Equation 1 to estimate the benefits of crash reduction.

$$Safety\ Benefits = Baseline\ Risk \times Risk\ Reduction \times Expected\ Consequences \quad \text{[Eq. 1]}$$

- Baseline Risk refers to existing crash rate at the project site without improvement.
- Risk Reduction refers to the ratio of crash reduction that the improvement is expected to achieve.
- The Expected Consequences refer to the monetary values associated with the expected crash severity levels and/or property damages that can be prevented by the proposed improvement.

To apply the model in Equation 1 for estimation of benefits involving large truck crash reduction, baseline annual crash rate needs to be specified. The baseline crash rate of large trucks for a specific project can be identified by obtaining and analyzing large truck crash data where the project is located. For example, in the State of Florida, the Florida Highway Safety and Motor Vehicles department (FLHSMV) collects and maintains official crash reports and is responsible for statewide crash data dissemination. FLHSMV crash data are available by the KABCO scales. With the data, baseline crash rates involving large trucks and the fatalities and injuries resulting from the crashes at specific locations in Florida can be identified.

For highway projects involving construction of safety features, USDOT recommends the use of crash modification factors (CMFs), which relate different types of safety improvements to crash outcomes, to estimate potential risk reduction of the projects (FHWA, 2018). CMFs are estimated by relating crash types, injury severities, and property damages to different types of transportation project. FHWA sponsored extensive research on CMFs for various types of transportation projects and the results are available from the online database CMF Clearinghouse (FHWA, 2018). Each type of project has a corresponding CMF that identifies the potential for the project to reduce crashes involving injuries of specific severity levels. For example, the CMF of installing an additional lane on a highway is 0.76. That is, if a particular stretch of a highway has an average of 100 crashes per year, the number of crashes with installation of an additional lane can be reduced to 76, which means that the improvement is expected to prevent 24 crashes. The crash reduction ratio of the improvement is thus 0.24 (i.e., 1 –CMF).

With large truck crash unit costs from Table 108, expected crash consequences (i.e., monetary costs of crashes) specific to large trucks can be calculated by multiplying the expected number of fatalities and injuries with the corresponding unit costs. To demonstrate how expected consequence is calculated, assume that on average a crash with a large truck at a particular section of a highway causes 1 fatality, 2 incapacitating injury and 1 incapacitating injury. The expected consequence of a large truck crash at this location is calculated with Equation 2.

Expected Consequences = 2 × unit cost per fatality + 2 × unit cost per incapacitating injury + 1 ×unit cost per capacitating injury [Eq.2]

To estimate crash reduction benefits from the projects with CMFs, the model in Equation 3, adapted from Equation 1, can be used.

Annual benefits of Reduced Crashes = Baseline Annual Crash Rate ×(1-CMF) ×Expected Consequences [Eq. 3]

9.2.2. Case Study Example

An example is provided here to illustrate how benefits from reduced large truck crashes can be estimated with Equation 3 and the unit costs in Table 108. US Highway 1 (US-1) in Islamorada, Florida has seen vehicle crashes throughout the years. After a tragic crash involving a large truck in March, 2018, there was a proposal from the locals calling for the speed limit on US-1 where the crash occurred to be lowered from 55 mph to 45 mph (Miami Herald, 2018). To estimate the potential crash reduction benefits of lowering posted speed limit on US-1, data on crashes involving large trucks that occurred along US-1 in Islamorada were identified from historic FLHSMV crash data. A total of 62 crashes involving at least one large truck were identified along the 18-mile stretch (i.e., milepost 73 to 91) of US-1 in Islamorada from year 2012 to 2016 (i.e., 2017 and 2018 data were not available for this analysis). These 62 crashes resulted in 2 fatalities, 11 incapacitating injuries, 11 non-incapacitating injuries and 16 possible injuries. The baseline annual crash rate is thus 12.4 crashes per year, resulting in 0.03 fatalities, 0.18 non-incapacitating injuries, 0.18 incapacitating injuries, and 0.26 possible injuries per crash. These baseline crash rates are categorized by truck types and KABCO injury severity levels and summarized in Table 109.

After obtaining the baseline crash rates, CMFs associated with lowering posted speed limit were identified by searching the CMF Clearinghouse (FHWA, 2018). It was found that Parker (1997) conducted the only US study on the effects of raising and lowering speed limits on crash rates. Lowering speed limit by 10 mph was found to have a CMF of 0.96. The applicability of this CMF is to all crash types, severity levels, roadway types and area types. Baseline crash rate of 12.4 crashes per year and the crash reduction ratio of 0.04 (i.e., 1-CMF = 1 -0.96 = 0.04) were then applied to Equation 3 with corresponding unit costs in Table 108. Table 110 summarizes the cost estimation for this example. The unit costs per crash in Table 110 have been adjusted from 2000 dollar to 2018 dollar with an average inflation rate of 2.12% per year during this period (Bureau of Labor Statistics, 2019). The monetized QALYs per case is also updated with the most recent VSL value of $9.6 million dollars (USDOT, 2016).

Table 109 Number of Injuries on US-1 (MP 73-91) from 2012 to 2016 by Truck Types and Injury Severity Levels

Truck Type	Injury Level	5-Year Total	Annual Total	Number of Injuries or Fatalities per Crash
Straight truck, no trailer	O – No injury	32	6.4	0.52
	C – Possible injury	10	2	0.16
	B – Non-incapacitating injury	10	2	0.16
	A – Incapacitating injury	9	1.8	0.15
	K – Killed	2	0.4	0.03
	U – Injury, severity unknown	0	0	0.00
	Unknown if injured	0	0	0.00
Straight truck with trailer	O – No injury	4	0.8	0.06
	C – Possible injury	1	0.2	0.02
	B – Non-incapacitating injury	1	0.2	0.02
	A – Incapacitating injury	0	0	0.00
	K – Killed	0	0	0.00
	U – Injury, severity unknown	0	0	0.00
	Unknown if injured	0	0	0.00
Truck-Tractor, 1 trailer	O – No injury	11	2.2	0.18
	C – Possible injury	5	1	0.08
	B – Non-incapacitating injury	0	0	0.00
	A – Incapacitating injury	2	0.4	0.03
	K – Killed	0	0	0.00
	U – Injury, severity unknown	0	0	0.00
	Unknown if injured	0	0	0.00
All Large Trucks (> 10,000 lbs)	**O – No injury**	**47**	**9.4**	**0.76**
	C – Possible injury	**16**	**3.2**	**0.26**
	B – Non-incapacitating injury	**11**	**2.2**	**0.18**
	A – Incapacitating injury	**11**	**2.2**	**0.18**
	K – Killed	**2**	**0.4**	**0.03**
	U – Injury, severity unknown	**0**	**0**	**0.00**
	Unknown if injured	**0**	**0**	**0.00**
Number of Crashes		**62**	**12.4**	**1**

Table 110 Estimation of Annual Crash Reduction Benefits of Lowering Posted Speed Limit by 10 mph on US-1 (MP 73-91)

			Unit Costs per Crash (in 2018 Dollars)						
Truck Type	**Injury Level**	**Injuries or Fatalities Per Crash**	**Medical Costs**	**Emergency Services**	**Property Damage**	**Lost Productivity from Delays**	**Lost Productivity from Other Sources**	**Monetized QALYs Based on VSL $9.6 Million**	**Total**
Straight truck, no trailer	O – No injury	0.52	$257	$133	$4,792	$5,488	$2,040	$2,271	$14,980
	C – Possible injury	0.16	$8,589	$407	$8,596	$10,902	$14,339	$63,334	$106,167
	B – Non-incapacitating injury	0.16	$9,951	$593	$10,832	$11,670	$14,131	$50,523	$97,700
	A – Incapacitating injury	0.15	$23,137	$1,086	$14,562	$12,902	$49,002	$177,489	$278,178
	K – Killed	0.03	$46,184	$1,854	$28,924	$15,904	$1,425,534	$9,117,399	$10,635,799
	U – Injury, severity unknown	0.00	$5,469	$381	$8,340	$9,202	$9,848	$35,241	$68,481
	Unknown if injured	0.00	$1,315	$239	$5,761	$7,913	$4,143	$9,816	$29,189
	Expected Consequences per Crash*		**$7,971**	**$447**	**$8,654**	**$8,859**	**$58,743**	**$339,410**	**$424,084**
	Annual Crash Reduction Benefits = 12.4* (1-0.96) * Expected Consequence		**$3,954**	**$222**	**$4,292**	**$4,394**	**$29,136**	**$168,347**	**$210,346**
Straight truck with trailer	O – No injury	0.06	$1,289	$142	$6,828	$5,837	$2,136	$3,901	$20,133
	C – Possible injury	0.02	$13,596	$472	$14,759	$11,312	$16,587	$106,456	$163,182
	B – Non-incapacitating injury	0.02	$15,140	$626	$16,244	$11,048	$20,590	$126,541	$190,190
	A – Incapacitating injury	0.00	$51,734	$1,403	$28,587	$17,425	$84,846	$464,785	$648,780
	K – Killed	0.00	$56,417	$2,159	$49,154	$18,952	$1,729,023	$11,092,463	$12,948,169
	U – Injury, severity unknown	0.00	$2,259	$380	$18,263	$11,652	$7,948	$18,426	$58,928
	Unknown if injured	0.00	$2,041	$184	$7,574	$5,630	$3,730	$12,717	$31,877
	Expected Consequences per Crash		**$547**	**$27**	**$941**	**$737**	**$737**	**$4,010**	**$6,998**
	Annual Crash Reduction Benefits = 12.4* (1-0.96) * Expected Consequence		**$271**	**$13**	**$467**	**$366**	**$366**	**$1,989**	**$3,471**

*Expected Consequence per Crash= Sum of (number of injuries by severity level *categorical unit cost by severity level)

Table 110 Estimation of Annual Crash Reduction Benefits of Lowering Posted Speed Limit by 10 mph on US-1 (MP 73-91) (Continued)

			Unit Costs per Crash (in 2018 Dollars)						
Truck Type	**Injury Level**	**Injuries or Fatalities Per Crash**	**Medical Costs**	**Emergency Services**	**Property Damage**	**Lost Productivity from Delays**	**Lost Productivity from Other Sources**	**Monetized QALYs Based on VSL $9.6 Million**	**Total**
Truck-Tractor, 1 trailer	O – No injury	0.18	$1,191	$128	$6,913	$5,349	$1,962	$3,565	$19,109
	C – Possible injury	0.08	$13,179	$466	$15,612	$10,643	$16,294	$108,788	$164,981
	B – Non-incapacitating injury	0.00	$15,469	$632	$17,866	$10,973	$21,407	$133,820	$200,167
	A – Incapacitating injury	0.03	$28,690	$981	$21,259	$11,566	$51,547	$245,434	$359,478
	K – Killed	0.00	$55,157	$2,002	$49,405	$16,457	$1,598,161	$10,246,873	$11,968,056
	U – Injury, severity unknown	0.00	$5,777	$207	$10,998	$7,499	$6,341	$13,782	$44,604
	Unknown if injured	0.00	$2,159	$199	$9,115	$6,158	$3,653	$12,044	$33,328
	Expected Consequences per Crash		**$2,200**	**$92**	**$3,171**	**$2,181**	**$3,325**	**$17,323**	**$28,291**
	Annual Crash Reduction Benefits = 12.4* (1-0.96) * Expected Consequence		**$1,091**	**$46**	**$1,573**	**$1,082**	**$1,649**	**$8,592**	**$14,033**
TOTAL ANNUAL LARGE TRUCK CRASH REDUCTION BENEFITS			**$5,316**	**$281**	**$6,332**	**$5,841**	**$31,151**	**$178,928**	**$227,850**

9.3. Large Truck Crash Cost Estimator

A Microsoft Excel spreadsheet (*Large Truck Crash Reduction Benefits Calculation.xls*) is created to calculate crash reduction benefits in the way illustrated by the above example. Table 111 shows the worksheet for entering input variables. Users need to specify three types of information:

- Unit cost inflation adjustment
  - Analysis year
  - Annual inflation rate
  - Value of statistical life (VSL)
- Crash Rate
  - Baseline annual crash rate
  - CMF (expected risk reduction from the project)
- Number of Injuries per crash
  - By truck type, or
  - For all large trucks

The analysis year and an annual inflation rate as well as the latest US DOT VSL value are used to adjust the unit costs to the desired analysis year from year 2000 dollars, as shown in Table 111. To calculate crash reduction benefits, users need to identify a CMF and obtain crash data to estimate baseline annual crash rate and the expected numbers of injuries and fatalities per crash. If truck types cannot be distinguished from the data, users enter the aggregate injury and fatality numbers for all large trucks (shown in Table 112). If the expected injuries and fatalities are available by truck types, users can calculate the benefits specific to truck types by entering numbers corresponding to the truck types and injury severities (shown in Table 113).

Table 111 Input Data – Unit Cost Inflation Adjustment and Crash Rate Information

Intruction:
Enter numbers in yellow cells only

Unit Costs Inflation Adjustment

	Value	Unit	Note
Analysis Year	2018		Enter the target year to adjust for inflation (e.g., 2018, 2019)
Annual Inflation Rate	2.12	%	Enter an inflation rate to adjust for inflation from year 2000
Value of Statistical Life (VSL)	9.60	Millions	Enter the latest USDOT VSL value in millions

Baseline Crash Rate

	Value	Unit	Note
Baseline Annual Crash Rate	12.40	crashes per year	Enter the number of large trucks crashes per year
CMF	0.96		Enter Crash Modification Factor

Table 112 Input Data – Number of Injuries per Crash for All Large Trucks

Number of injuries per crash for all large trucks
(Enter here if injuries per crash are for all large trucks)
Results in "Benefits for All Large Trucks" worksheet

Truck Type	Injury Level	# per Crash
All large trucks	O – No injury	0.76
	C – Possible injury	0.26
	B – Non-incapacitating injury	0.18
	A – Incapacitating injury	0.18
	K – Killed	0.03
	U – Injury, severity unknown	0.00
	Unknown if injured	0.00

Table 113 Input Data – Number of Injuries per Crash by Large Truck Type

Expected Number of Injuries per Crash		
Number of injuries per crash by truck types		
(Enter here if expected numbers of injuries per crash are available by truck types)		
Results in "Benefits by Truck Types" worksheet		
Truck Type	**Injury Level**	**# per Crash**
Straight truck, no trailer	O – No injury	0.52
	C – Possible injury	0.16
	B – Non-incapacitating injury	0.16
	A – Incapacitating injury	0.15
	K – Killed	0.03
	U – Injury, severity unknown	0.00
	Unknown if injured	0.00
Straight truck with trailer	O – No injury	0.06
	C – Possible injury	0.02
	B – Non-incapacitating injury	0.02
	A – Incapacitating injury	0.00
	K – Killed	0.00
	U – Injury, severity unknown	0.00
	Unknown if injured	0.00
Straight truck, unknown if with trailer	O – No injury	0.00
	C – Possible injury	0.00
	B – Non-incapacitating injury	0.00
	A – Incapacitating injury	0.00
	Unknown if injured	0.00
Bobtail	O – No injury	0.00
	C – Possible injury	0.00
	B – Non-incapacitating injury	0.00
	A – Incapacitating injury	0.00
	K – Killed	0.00
	U – Injury, severity unknown	0.00
	Unknown if injured	0.00
Truck-Tractor, 1 trailer	O – No injury	0.18
	C – Possible injury	0.08
	B – Non-incapacitating injury	0.00
	A – Incapacitating injury	0.03
	K – Killed	0.00
	U – Injury, severity unknown	0.00
	Unknown if injured	0.00
Truck-Tractor, 2 or 3 trailers	O – No injury	0.00
	C – Possible injury	0.00
	B – Non-incapacitating injury	0.00
	A – Incapacitating injury	0.00
	K – Killed	0.00
	U – Injury, severity unknown	0.00
	Unknown if injured	0.00
Truck-Tractor, unknown # of trailers	O – No injury	0.00
	C – Possible injury	0.00
	B – Non-incapacitating injury	0.00
	A – Incapacitating injury	0.00
	K – Killed	0.00
	Unknown if injured	0.00
Medium/heavy truck, unknown if with trailer	O – No injury	0.00
	C – Possible injury	0.00
	B – Non-incapacitating injury	0.00
	A – Incapacitating injury	0.00
	K – Killed	0.00
	U – Injury, severity unknown	0.00
	Unknown injured	0.00

Table 114 shows part of the worksheet containing the results when users enter expected injuries and fatalities by truck types. The worksheet is formatted in the same way as Table 110.

Table 114 Crash Reduction Benefits Calculation by Truck Type

			Unit costs in year 2018 dollars						
Truck Type	Injury Level	Injuries or Fatalities Per Crash	Medical Costs	Emergency Services	Property Damage	Lost Productivity from Delays	Lost Productivity from Other Sources	Monetized QALYs based on VSL of 9.6 millions	Total
Straight truck, no trailer	O – No injury	0.52	$257	$133	$4,788	$5,484	$2,038	$2,269	
	C – Possible injury	0.16	$8,582	$407	$8,589	$10,893	$14,327	$63,281	
	B – Non-incapacitating	0.16	$9,943	$592	$10,823	$11,660	$14,120	$50,481	
	A – Incapacitating injury	0.15	$23,118	$1,085	$14,550	$12,891	$48,962	$177,343	
	K – Killed	0.03	$46,146	$1,853	$28,900	$15,891	$1,424,358	$9,109,879	
	U – Injury, severity	0.00	$5,465	$381	$8,333	$9,195	$9,840	$35,212	
	Unknown if injured	0.00	$1,314	$239	$5,756	$7,907	$4,140	$9,808	
	Expected Consequences per Crash*		$7,965	$447	$8,646	$8,852	$58,694	$339,130	$423,735
	Annual Crash Reduction Benefits = Baseline Annual Crash Rate * (1-CMF) * Expected Consequence		$3,951	$222	$4,289	$4,390	$29,112	$168,209	$210,172
Straight truck with trailer	O – No injury	0.06	$1,288	$142	$6,823	$5,832	$2,134	$3,898	
	C – Possible injury	0.02	$13,584	$471	$14,747	$11,303	$16,573	$106,368	
	B – Non-incapacitating	0.02	$15,128	$626	$16,231	$11,039	$20,573	$126,437	
	A – Incapacitating injury	0.00	$51,691	$1,402	$28,563	$17,411	$84,776	$464,401	
	K – Killed	0.00	$56,371	$2,158	$49,113	$18,937	$1,727,596	$11,083,314	
	U – Injury, severity	0.00	$2,257	$379	$18,248	$11,643	$7,942	$18,411	
	Unknown if injured	0.00	$2,039	$184	$7,568	$5,625	$3,727	$12,707	
	Expected Consequences per Crash		$546	$27	$940	$737	$737	$4,006	$6,993
	Annual Crash Reduction Benefits = Baseline Annual Crash Rate * (1-CMF) * Expected Consequence		$271	$13	$466	$365	$365	$1,987	$3,468
Straight truck, unknown if with trailer	O – No injury	0.00	$1,288	$118	$4,528	$4,904	$1,882	$3,795	
	C – Possible injury	0.00	$12,136	$430	$10,019	$10,353	$13,469	$83,873	
	B – Non-incapacitating	0.00	$13,786	$636	$14,258	$11,666	$19,160	$114,010	
	A – Incapacitating injury	0.00	$55,380	$855	$14,217	$9,745	$53,504	$535,955	
	Unknown if injured	0.00	$6,833	$387	$12,238	$9,718	$8,573	$51,308	
	Expected Consequences per Crash*		$0	$0	$0	$0	$0	$0	$0
	Annual Crash Reduction Benefits = Baseline Annual Crash Rate * (1-CMF) * Expected Consequence		$0	$0	$0	$0	$0	$0	$0

The spreadsheet tool contains five spreadsheets:

- Inputs – collects inputs from the user as indicated previously
- Year 2000 Unit Costs – presents the unit costs in year 2000 dollar as described in section 2
- Analysis Year Unit Costs – shows the adjusted unit costs
- Benefits by Truck Types – presents the benefit results by truck type if the expected injuries and fatalities per crash are provided by truck type
- Benefits for All Large Trucks – presents the benefit results for all large trucks if the expected injuries and fatalities per crash cannot be distinguished by truck type

Crashes involving large trucks impose a variety of costs on the parties directly involved and the society as a whole. We identified a study conducted for FMCSA by Zaloshnja and Miller (2002) that breaks down the overall costs of large truck crashes into five categories including medical costs, emergency services, property damage, lost productivity (i.e., from delays and other sources), and monetized Quality-Adjusted Life Years. For each of these five categories, this study produced estimates of unit costs by truck types and injury severity levels.

For economic appraisal of crashes involving large trucks, we recommend using the crash reduction benefit model of USDOT (2018). We demonstrated how this model can be used with large truck crash unit costs produced by Zaloshnja and Miller with an example. Depending on availability of reliable crash reduction factors, the US DOT model can also be used to estimate the benefits/costs of safety regulation and interventions.

10. CONCLUSIONS

In the aims to improve transportation safety and economic viability in Florida, this study conducted a comprehensive statewide crash analysis focusing on large truck crashes in the past ten years. Over 243,000 crashes involving large trucks in the ten-year period between 2007 and 2016 were retrieved and analyzed.

Three different approaches were undertaken to analyze the crash data. A framework was developed to identify the critical reason for individual crashes, which provides insights on the potential causes or factors that lead to the increasing risk of a crash. Disaggregate crash severity analysis was conducted to investigate the impacts of contributing factors on crash severity outcomes through random parameter ordered logit (RPOL) models. Spatial analysis was also conducted to illustrate the spatial pattern of large truck crashes and identity concentration or problematics areas, using ArcGIS Spatial Analyst extension - Kernel Density tool.

Incorporating findings from the three major crash analysis efforts, a data-driven and evidence-based set of countermeasures were developed that target the behavioral factors and critical locations identified from those efforts. A group of selected systemic countermeasures were presented and discussed with some examples representing the common applications. Targeted countermeasures were then recommended for 35 priority locations identified in the state of Florida based on spatial analysis, including 15 hotspot areas by kernel density ranking, and 20 high priority intersections by high crash severity or high crash rate. An economic appraisal approach was recommended that considers the economic impacts of enhanced freight safety and mobility in project evaluation process. The Large Truck Crash Cost Estimator, a spreadsheet-based tool, was developed to facilitate the economic appraisal process.

These analyses represented the first comprehensive attempt to analyze large truck crashes in the state and paved the pathway to further analysis that would help develop more effective strategies in enhancing freight safety and mobility. Future work could focus on some of the following areas:

- Risk analysis that identifies and evaluates all co-existing conditions that contribute to a crash, and see how the risk factors might be different for trucks and non-trucks;
- Aggregate (segment-level) analysis that investigates the occurrence (i.e. crash frequency or crash rate) as well as severity of large truck crashes, which will allow predictive analysis of expected safety performance on freight-related crashes;
- Heterogeneity analysis that examines the potential sources of heterogeneity in crash severity which shows how the impacts of the same contributing factor may vary by driver characteristics or roadway conditions.

These works are expected to provide further understanding of the causes and contributing risk factors for large truck crashes, and provide the means to develop more effective and freight-specific countermeasures to enhance freight safety and mobility.

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APPENDIX A – Crash Data Tables and Attributes

Table A- 1 Crash Event Attributes

Attributes	Description
HSMV_RPT_NBR	HSMV report number
CONTRIB_CIRCUM_ENV (1,2,3)	Contributing circumstances: environment
CONTRIB_CIRCUM_RD (1,2,3)	Contributing circumstances: road
CRASH_DT	Crash date
CRASH_TM	Crash time
CRASH_SEV	Crash severity
CRASH_SEV_DTL	Crash severity detail
CRASH_TYPE	Crash type
CRASH_TYPE_DIR	Crash type direction
BIKE_PED_CRASH_GROUP	Bike/ped crash group
BIKE_PED_CRASH_TYPE	Bike/ped crash type
FIRST_HARMFUL_EVT	First harmful event
FIRST_HARMFUL_EVT_LOC	First harmful event location
FIRST_HARMFUL_EVT_REL_TO_JCT	First harmful event relation to junction
CNTY_CD	County code
CNTY_NM	County name
CITY_CD	City code
CITY_NM	City name
LIGHT_COND	Light condition
LOC_IN_WORK_ZONE	Location in work zone
MANNER_OF_COLLISION	Manner of collision
NOTIFIED_BY	Notified by
RPTG_AGNCY	Reporting agency
RPTG_UNIT	Reporting unit
ROAD_SYS_ID	Road system identifier
ROAD_SURFACE_COND	Road surface condition
TYPE_OF_INTRSECT	Type of intersect
TYPE_OF_SHOULDER	Type of shoulder
TYPE_OF_WORK_ZONE	Type of work zone
WEATHER_COND	Weather condition
INTRSECT_ST_NM	Intersecting street name
ALCOHOL_RELATED	Alcohol related
DISTRACTED	Distracted
DRUG_RELATED	Drug related

Table A- 1 Crash Event Attributes (Continued)

Attributes	Description
FIRST_HE_WITHIN_INTRCHG	First harmful event within interchange
LAW_ENFORCEMENT_IN_WORK_ZONE	Law enforcement in work zone
PICTURES_TAKEN	PICTURES_TAKEN
SCHOOL_BUS_RELATED	School bus related
WITHIN_CITY_LIMITS	Within city limits
WORKERS_IN_WORK_ZONE	Workers in work zone
OFFSET_DIR	Offset direction
OFFSET_FT	Offset feet
REPORTING_OFFICER_RANK	Reporting officer rank
HOUSE_NBR	Street number
STREET_NAME	Street name
VEHICLE_CNT	Vehicle count
MOPED_CNT	Moped count
MOTORCYCLE_CNT	Motorcycle count
NON_MOTORIST_CNT	Non-motorist count
PASSENGER_CNT	Passenger count
TRAILER_CNT	Trailer count
BIKE_CNT	Bike count
PEDESTRIAN_CNT	Pedestrian count
FATALITY_CNT	Fatality count
FATALITY_UNRESTRAINED_CNT	Unrestrained fatality count
INJURY_CNT	Injury count
INJURY_UNRESTRAINED_CNT	Unrestrained injury count
CITATION_CNT	Citation count
CITATION_AMT	Citation amount
PROP_DMG_CNT	Property damage count
PROP_DMG_AMT	Property damage amount
VEH_DMG_CNT	Vehicle damage count
TOT_DMG_AMT	Total damage amount
TRANSPORTED_BY_EMS_CNT	Transport by EMS count
TRANSPORTED_BY_LE_CNT	Transport by low enforcement count
TRANSPORTED_BY_OTHER_CNT	Transport by other count
FORM_TYPE	Form type (short or long)
AGNCY_RPT_NBR	Agency reporting number
INJ_NONE_CNT	None injury count
INJ_POSSIBLE_CNT	Possible injury count
INJ_NON_INCAPACITATING_CNT	Non-incapacitating injury count

Table A- 1 Crash Event Attributes (Continued)

Attributes	Description
INJ_INCAPACITATING_CNT	incapacitating injury count
INJ_FATAL_30_CNT	Fatality in 30 days count
INJ_FATAL_NON_TRAFFIC_CNT	Non-traffic fatality count
DATA_SOURCE	Data source
COMPLETE	Investigation completed
AGGRESSIVE	Aggressive driving
REPORT_DT	Date reported
NOTIFIED_TM	Time notified
DISPATCHED_TM	Dispatched time
ARRIVED_TM	Arrived time
CLEARED_TM	Cleared time
COADABLE	

Table A- 2 Drivers Table Attributes

Attributes	Description
HSMV_RPT_NBR	HSMV report number
VEH_NBR	Code of vehicle involved in each crash
PERSON_NBR	Code of drivers involved in each crash
DRIVER_ACTION (1,2,3,4)	Driver action
DRIVER_AGE	Driver age
AIRBAG_DEPLOYED	Airbag deployed
ALC_USE_SUSPECTED	Alcohol suspected
ALC_TESTED	Alcohol tested
ALC_TEST_TYPE	Alcohol test type
ALC_TEST_RESULT	Alcohol test result
BLOOD_ALC_CONTENT	Blood alcohol content
DRIVER_COND_AT_TIME_OF_CRASH	Driver condition at time of the crash
CRASH_DT	Crash date
DISTRACTED_BY	Distracted by
DL_ENDORSEMENTS	Driver license required endorsements
DL_TYPE	Driver license type
DRUG_USE_SUSPECTED	Drug suspected
DRUG_TESTED	Drug tested
DRUG_TEST_TYPE	Drug test type

Table A- 2 Drivers Table Attributes (Continue)

Attributes	Description
DRUG_TEST_RESULT	Drug test result
EJECTION	ejection
GENDER	Gender
HELMET_USE	Helmet use
INJURY_SEVERITY	Injury severity
RESTRAINT_SYSTEM	Restraint system
SOURCE_OF_TRANSPORT	Source of transport
VEH_BODY_TYPE	Vehicle body type
VISION_OBSTRUCTION	Vision obstruction
ADDR_CITY	Driver's city address
ADDR_STATE	Driver's state address
ADDR_ZIP	Driver's zip code address
DL_STATE	Driver license state
INSURANCE_CO	Insurance company
IS_DISTRACTED	Driver distracted
EYE_PROTECTION	Eye protection
RE_EXAM_RECOMMENDED	Re exam recommended
FATALITY_CNT	Fatality count
FATALITY_UNRESTRAINED_CNT	Fatality unrestrained count
INJURY_CNT	Injury count
INJURY_UNRESTRAINED_CNT	Injury unrestrained count
CITATION_CNT	Citation count
CITATION_AMT	Citation amount
PROP_DMG_CNT	Property damage count
PROP_DMG_AMT	Property damage amount

Table A- 3 Vehicles Table Attributes

Attributes	Description
HSMV_RPT_NBR	HSMV report number
VEH_NBR	Code of vehicle involved in each crash
AREA_OF_INITIAL_IMPACT	Area of initial impact
BODY_TYPE	Body type
CRASH_DT	Crash date
DAMAGE_EXTENT	Extent of damage
DIR_BEFORE_CRASH	Direction before a crash
HARMFUL_EVT (1,2,3,4)	Harmful event

Table A- 3 Vehicles Table Attributes (Continued)

Attributes	Description
VEH_MANEUVER_ACTION	Vehicle maneuver action
MOST_DAMAGED_AREA	Most damaged area
MOST_HARMFUL_EVT	Most harmful event
ROADWAY_ALIGNMENT	Roadway alignment of where a crash occurred
ROADWAY_GRADE	Roadway grade of where a crash occurred
SPECIAL_FUNCTION	Special function of motor vehicle
TRAFFIC_CONTROL_DEVICE	Traffic control device for a vehicle
TRAFFICWAY	Road type of where a crash occurred
VEH_DEFECT (1,2)	Vehicle defects
VEH_TYPE	Vehicle type
WRECKER_SELECTION_METHOD	Vehicle removed by
ESTIMATED_SPEED	Estimated speed
POSTED_SPEED	Posted speed
COMMERCIAL	Commercial vehicle
EMERGENCY_VEH	Emergency vehicle
HIT_AND_RUN	Hit and run crash
VEH_OWNER_IS_BUSINESS	Vehicle owner is business
PERMANENT_REGISTRATION	Vehicle permanent registration
TOWED_DUE_TO_DAMAGE	Damaged vehicle towed
REGISTRATION_STATE	Registration state
TOTAL_LANES	Total lanes of where a crash occurred
TRAVELING_ON_STREET	Street name
VEH_COLOR	Vehicle color
VEH_MAKE	Vehicle make
VEH_MODEL	Vehicle model
VEH_OWNER_CITY	Vehicle owner city address
VEH_OWNER_STATE	Vehicle owner state address
VEH_OWNER_ZIP	Vehicle owner zip code address
VEH_STYLE	Vehicle style
VEH_YEAR	Vehicle model year
MOPED_CNT	Moped count
MOTORCYCLE_CNT	Motorcycle count
PASSENGER_CNT	Passenger count
TRAILER_CNT	Trailer count
FATALITY_CNT	Fatality count
FATALITY_UNRESTRAINED_CNT	Unrestrained fatality count

Table A- 3 Vehicles Table Attributes (Continued)

Attributes	Description
INJURY_CNT	Injury count
INJURY_UNRESTRAINED_CNT	Unrestrained injury count
INJ_NONE_CNT	None injury count
INJ_POSSIBLE_CNT	Possible injury count
INJ_NON_INCAPACITATING_CNT	Non-incapacitating injury count
INJ_INCAPACITATING_CNT	incapacitating injury count
INJ_FATAL_30_CNT	Fatality in 30 days count
INJ_FATAL_NON_TRAFFIC_CNT	Non-traffic fatality count
INJ_POSSIBLE_CNT	Possible injury count
INJ_NON_INCAPACITATING_CNT	Non-incapacitating injury count
CITATION_CNT	Citation count
CITATION_AMT	Citation amount
PROP_DMG_CNT	Property damage count
PROP_DMG_AMT	Property damage amount
VEH_DMG_CNT	Vehicle damage count
VEH_DMG_AMT	Vehicle damage amount
TOT_DMG_AMT	Total damage amount
CARGO_BODY_TYPE	Cargo body type
CMV_CONFIGURATION	CMV configuration
COMMERCIAL_NON_COMM	Comm/Non-Commercial
GVWR_GCWR	Gross Vehicle/Combination Weight Rating
HAZ_MAT_RELEASED	Hazmat released
PLACARD_HAZMAT_CLASS	Placard hazmat class
MOTOR_CARRIER_CITY	Motor carrier city
MOTOR_CARRIER_STATE	Motor carrier state
MOTOR_CARRIER_ZIP	Motor carrier zip

Table A- 4 Non-motorists Table Attributes

Attributes	Description
HSMV_RPT_NBR	HSMV report number
PERSON_NBR	Code of non-motorist involved in each crash
ACTION_PRIOR	Action prior to crash
ACTION_CIRCUM (1,2)	Action circumstances
NM_AGE	Non-motorist age
ALC_USE_SUSPECTED	Alcohol suspected
ALC_TESTED	Alcohol tested

Table A- 4 Non-motorists Table Attributes (Continued)

Attributes	Description
ALC_TEST_TYPE	Alcohol test type
ALC_TEST_RESULT	Alcohol test result
BLOOD_ALC_CONTENT	Blood alcohol content
CRASH_DT	Crash date
NM_DESCRIPTION	Non-motorist description
DRUG_USE_SUSPECTED	Drug suspected
DRUG_TESTED	Drug tested
DRUG_TEST_TYPE	Drug test type
DRUG_TEST_RESULT	Drug test result
GENDER	gender
CNTY_CD	County code
CNTY_NM	County name
CITY_CD	City code
CITY_NM	City name
LOC_AT_TIME_OF_CRASH	Location at the time of crash
RPTG_AGNCY	Reporting unit
RPTG_UNIT	Reporting unit
SAFETY_EQUIP (1,2)	Safety equipment (1,2)
SOURCE_OF_TRANSPORT	Source of transport
ADDR_CITY	Driver's city address
ADDR_STATE	Driver's state address
ADDR_ZIP	Driver's zip code address
DL_STATE	Driver license state
BIKE_CNT	Bike count
PED_CNT	Pedestrian count
FATALITY_CNT	Fatality count
INJURY_CNT	Injury count
CITATION_CNT	Citation count
CITATION_AMT	Citation amount
PROP_DMG_CNT	Property damage count
PROP_DMG_AMT	Property damage amount

Table A- 5 Violation Table Attributes

Attributes	Description
HSMV_RPT_NBR	HSMV report number
PERSON_NBR	Code of person involved in each crash
CITATION_NBR	Citation number
CRASH_DT	Crash date
CNTY_CD	County code
CNTY_NM	County name
CITY_CD	City code
CITY_NM	City name
RPTG_AGNCY	Reporting agency
RPTG_UNIT	Reporting unit
FL_STATUTE_NBR	
CHARGE	Type of charge

APPENDIX B – Details of Unmapped Crashes

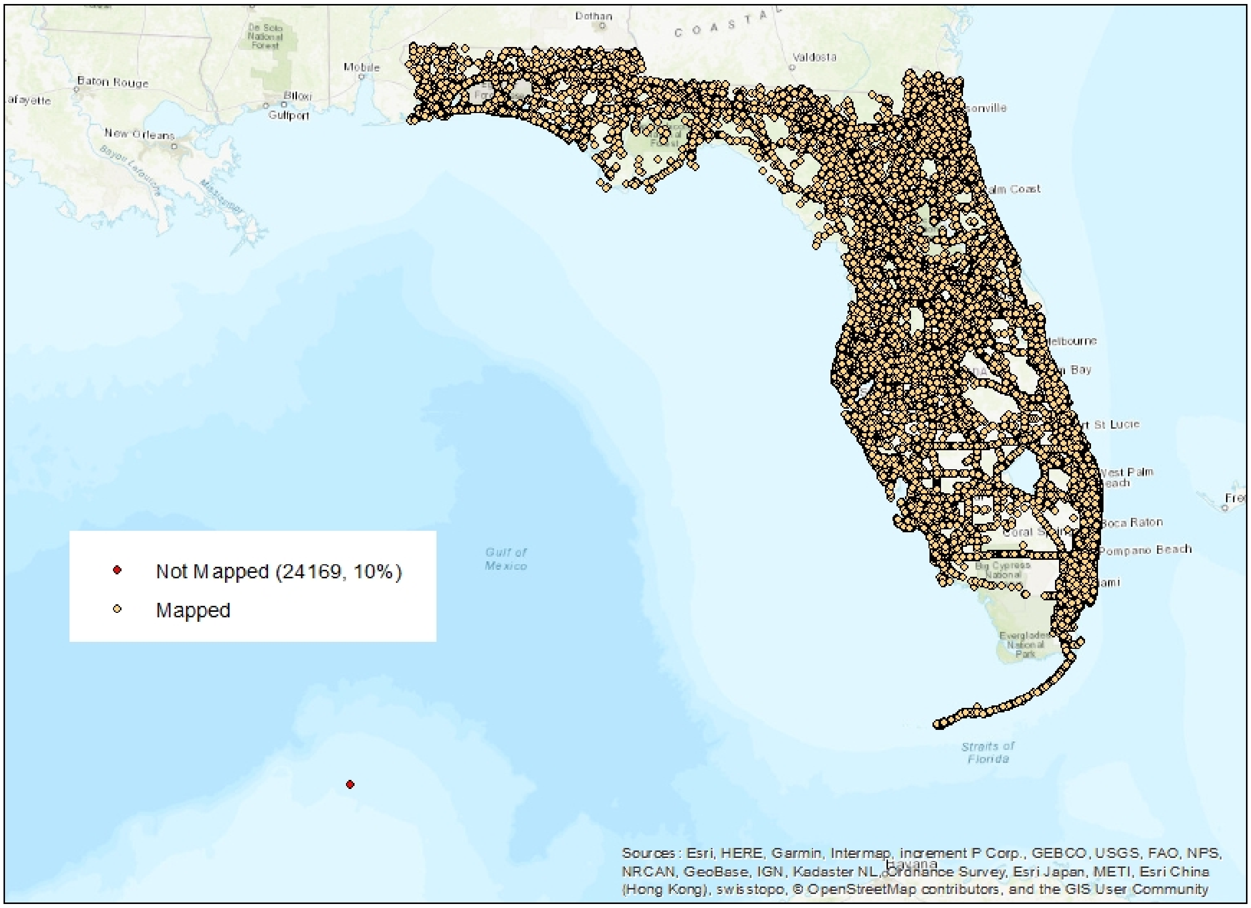

Figure B- 1 Locations of mapped vs. unmapped crashes

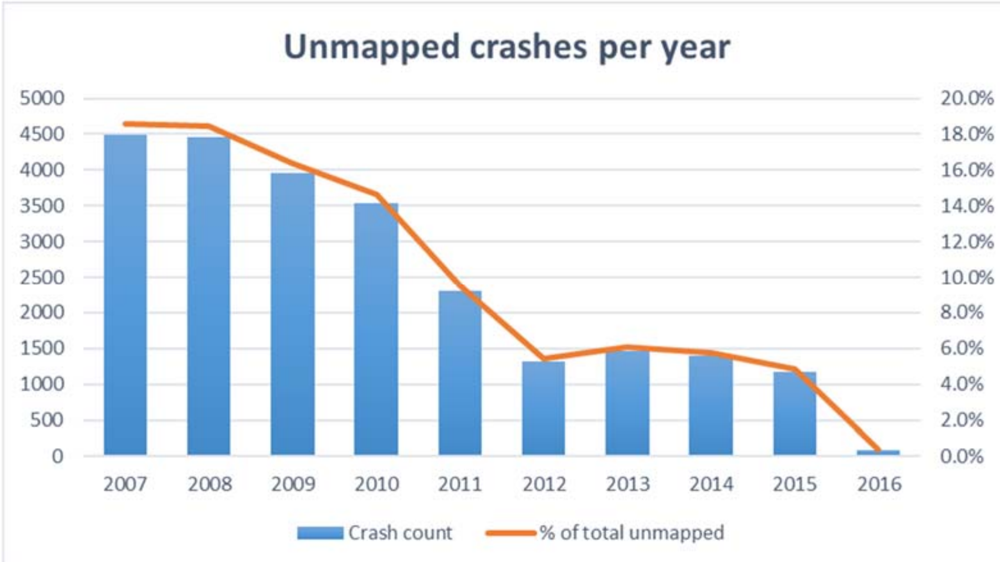

Figure B- 2 Unmapped crashes per year

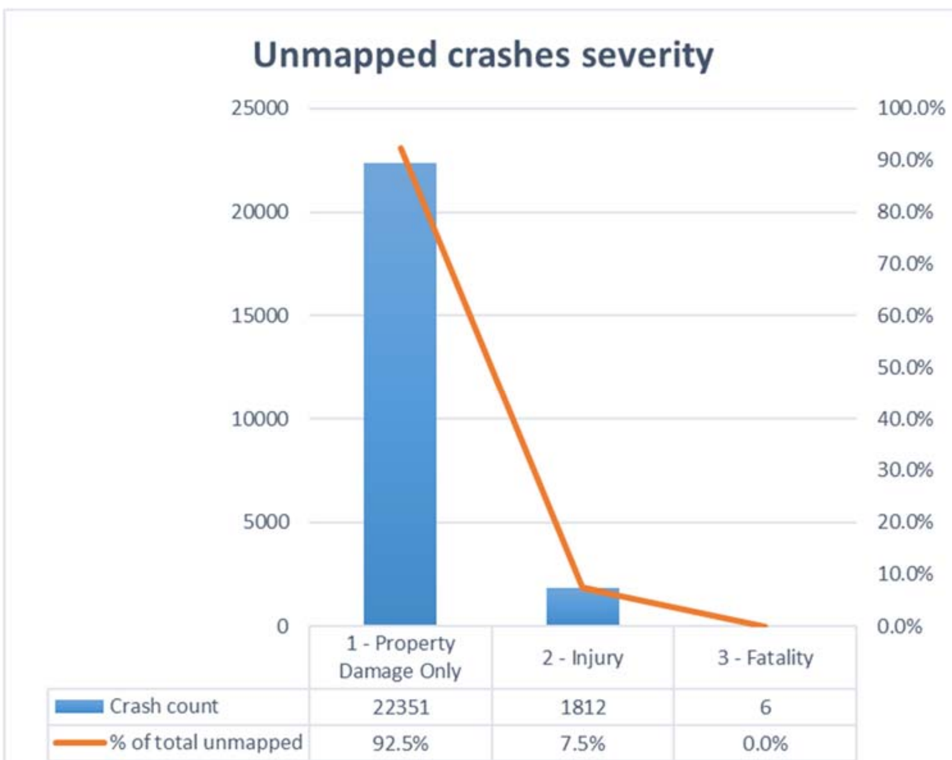

Figure B- 3 Unmapped crashes severity

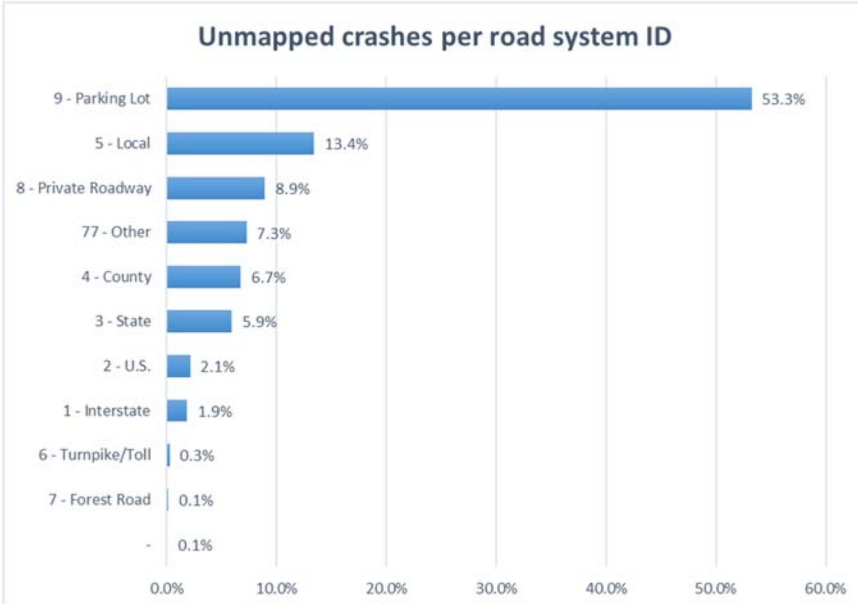

Figure B- 4 Unmapped crashes per road system ID

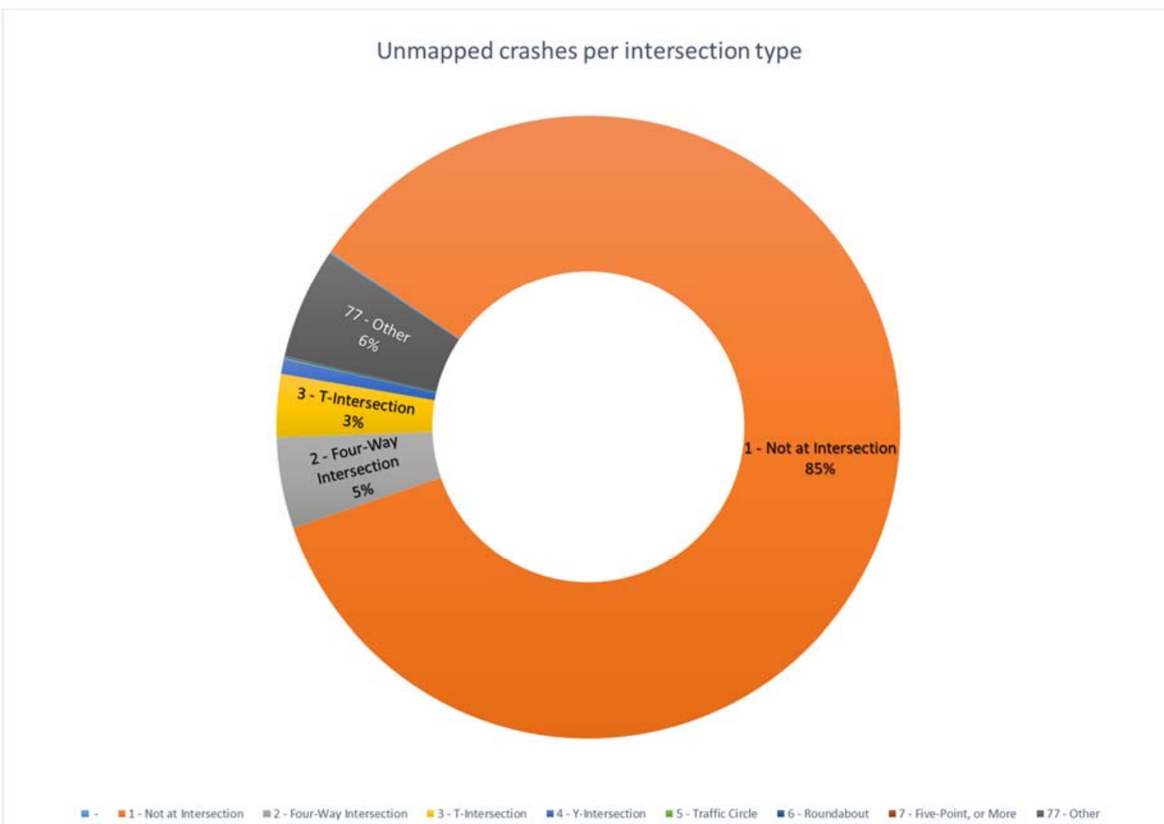

Figure B- 5 Unmapped crashes per intersection type

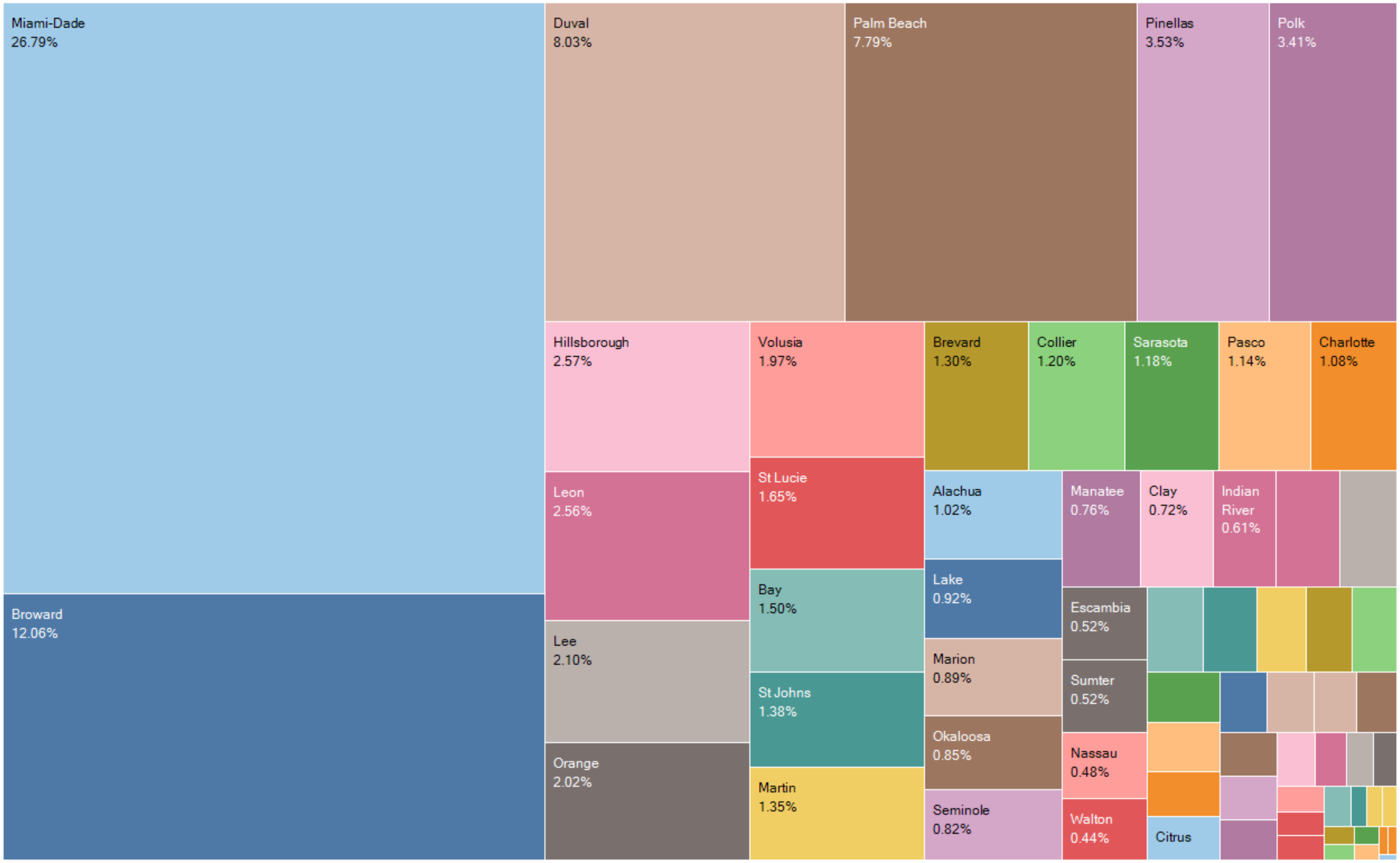

Figure B- 6 Unmapped crashes aggregated by Counties

Table B- 1 Unmapped Crashes by Counties (road length in meters)

Crash unmapped	Percent	Rank_unmapped	Road length	Percent	Rand_road_length
Miami-Dade	26.79%	1	15415645	4.98%	1
Hillsborough	2.57%	7	12659095	4.09%	2
Palm Beach	7.79%	4	12548682	4.05%	3
Broward	12.06%	2	12017705	3.88%	4
Orange	2.02%	10	11390302	3.68%	5
Lee	2.10%	9	10881481	3.51%	6
Marion	0.89%	23	10724493	3.46%	7
Polk	3.41%	6	9866827	3.19%	8
Duval	8.03%	3	9760288	3.15%	9
Pinellas	3.53%	5	7784472	2.51%	10
Brevard	1.30%	16	7717205	2.49%	11
Volusia	1.97%	11	7364034	2.38%	12
Pasco	1.14%	19	6256391	2.02%	13
Lake	0.92%	22	6240905	2.02%	14
Sarasota	1.18%	18	5846847	1.89%	15
Alachua	1.02%	21	5201707	1.68%	16
Collier	1.20%	17	5187556	1.68%	17
Levy	0.17%	51	5160524	1.67%	18
Putnam	0.35%	37	5124028	1.65%	19
Citrus	0.26%	43	5030787	1.62%	20
Taylor	0.24%	45	4995263	1.61%	21
Okaloosa	0.85%	24	4890997	1.58%	22
Santa Rosa	0.20%	49	4769140	1.54%	23
Bay	1.50%	13	4559414	1.47%	24
Charlotte	1.08%	20	4464727	1.44%	25
Manatee	0.76%	26	4441757	1.43%	26
Escambia	0.52%	31	4337572	1.40%	27
Seminole	0.82%	25	4238245	1.37%	28
Highlands	0.19%	50	4057507	1.31%	29
Jackson	0.39%	35	4047872	1.31%	30
Leon	2.56%	8	4047859	1.31%	31
St Lucie	1.65%	12	3991105	1.29%	32
Osceola	0.61%	29	3964327	1.28%	33
Walton	0.44%	34	3904796	1.26%	34

Table B- 1 Unmapped Crashes by Counties (road length in meters) (Continued)

Crash unmapped	Percent	Rank_unmapped	Road length	Percent	Rand_road_length
Hernando	0.30%	41	3860074	1.25%	35
Columbia	0.32%	39	3742617	1.21%	36
St Johns	1.38%	14	3339919	1.08%	37
Clay	0.72%	27	3276042	1.06%	38
Dixie	0.05%	59	3175811	1.03%	39
Suwannee	0.27%	42	3015707	0.97%	40
Washington	0.05%	62	2902646	0.94%	41
Nassau	0.48%	33	2860218	0.92%	42
Madison	0.22%	46	2768830	0.89%	43
Sumter	0.52%	32	2747042	0.89%	44
Indian River	0.61%	28	2665455	0.86%	45
Lafayette	0.03%	65	2531481	0.82%	46
Baker	0.21%	47	2479019	0.80%	47
Franklin	0.02%	66	2453283	0.79%	48
Gulf	0.02%	67	2410199	0.78%	49
Calhoun	0.04%	63	2315774	0.75%	50
Hendry	0.24%	44	2224913	0.72%	51
Martin	1.35%	15	2189197	0.71%	52
Hamilton	0.12%	53	2111619	0.68%	53
Wakulla	0.10%	57	2105065	0.68%	54
Gadsden	0.38%	36	2020630	0.65%	55
Flagler	0.32%	38	1972680	0.64%	56
Liberty	0.04%	64	1963600	0.63%	57
Okeechobee	0.31%	40	1740828	0.56%	58
Holmes	0.05%	60	1729874	0.56%	59
Bradford	0.21%	48	1728148	0.56%	60
Jefferson	0.11%	54	1659029	0.54%	61
DeSoto	0.09%	58	1549686	0.50%	62
Glades	0.14%	52	1530694	0.49%	63
Gilchrist	0.01%	68	1503976	0.49%	64
Hardee	0.10%	55	1299318	0.42%	65
Monroe	0.56%	30	1289261	0.42%	66
Union	0.05%	61	1222439	0.39%	67
Unknown	0.10%	56	346582	0.11%	68

APPENDIX C – Crash Data Issues and Attribute Statistics

Table C- 1 Null vs Unknown Light Conditions

Light Condition	Frequency	Percent	Cumulative Percent
Null	82	0.0	0.0
1 - Daylight	192,172	79.1	79.1
2 - Dusk	4,365	1.8	80.9
3 - Dawn	4,304	1.8	82.7
4 - Dark - Lighted	26,875	11.1	93.7
5 - Dark - Not Lighted	13,793	5.7	99.4
6 - Dark - Unknown Lighting	196	0.1	99.5
77 - Other	78	0.0	99.5
88 - Unknown	1,152	05	100.0
Grand Total	243,017	100.0	

Table C- 2 Illegal Driving Age

Driver Age	Frequency	Percent
0	40	0.0
1	8	0.0
2	4	0.0
3	6	0.0
4	4	0.0
5	8	0.0
6	12	0.0
7	7	0.0
8	6	0.0
9	14	0.0
10	21	0.0
11	15	0.0
12	15	0.0
13	30	0.0
14	55	0.0
15	161	0.0
16-126	417,687	91.7
Total	418,093	91.7
System	37,606	8.3
Total	455,699	100.0

Table C- 3 Total Lanes =0

Total Lanes	Frequency	Percent	Cumulative Percent
Null	222,131	46.3	46.3
0	3,127	0.7	47.0
1	10,608	2.2	49.2
2	89,004	18.6	67.8
3	17,187	3.6	71.3
4	60,434	12.6	83.9
5	12,010	2.5	86.4
6	51,698	10.8	97.2
7	2,312	0.5	97.7
8	7,883	1.6	99.4
9	546	0.1	99.5
10	1,492	0.3	99.8
11	43	0.0	99.8
12	767	0.2	100.0
13	32	0.0	100.0
14	97	0.0	100.0
15	38	0.0	100.0
16	25	0.0	100.0
17	5	0.0	100.0
18	4	0.0	100.0
19	3	0.0	100.0
20	26	0.0	100.0
Grand Total	479472	100.0	

Table C- 4 Distracted Drivers

Distracted	Frequency	Percent	Cumulative Percent
Null	214,963	47.2	47.2
N	225,654	49.5	96.7
Y	15,082	3.3	100.0
Total	455,699	100.0	

Table C- 5 Airbag Deployment

Airbag Deployed	Frequency	Percent	Cumulative Percent
Null	122,481	26.9	26.9
1 - Not Applicable	55,817	12.2	39.1
2 - Not Deployed	251,779	55.3	94.4
3 - Deployed - Front	18,662	4.1	98.5
4 - Deployed - Side	947	0.2	98.7
5 - Deployed - Other	27	0.0	98.7
6 - Deployed - Combination	2,085	0.5	99.1
7 - Deployed - Curtain	111	0.0	99.2
88 - Deployment Unknown	3,790	0.8	100.0
Grand Total	455,699	100.0	

Table C- 6 Non-Traffic Fatalities

Injury Severity	Frequency	Percent	Cumulative Percent
Null	32,768	7.2	7.2
1 - None	365,104	80.1	87.3
2 - Possible	30,655	6.7	94.0
3 - Non-Incapacitating	18,284	4.0	98.0
4 - Incapacitating	7,158	1.6	99.6
5 - Fatal (within 30 days)	1,628	0.4	100.0
6 - Non-Traffic Fatality	102	0.0	100.0
Grand Total	455,699	100.0	

Table C- 7 No Restraint System

Restraint System	Frequency	Percent	Cumulative Percent
Null	33,664	7.4	7.4
1 - Not Applicable (non-motorist)	5,995	1.3	8.7
10 - Child Restraint System - Type Unknown	146	0.0	8.7
2 - None Used - Motor Vehicle Occupant	18,277	4.0	12.7
3 - Shoulder and Lap Belt Used	388,006	85.1	97.9
4 - Shoulder Belt Only Used	2,429	0.5	98.4
5 - Lap Belt Only Used	1,412	0.3	98.7
6 - Restraint Used - Type Unknown	872	0.2	98.9
7 - Child Restraint System - Forward Facing	24	0.0	98.9
77 - Other	4,868	1.1	100.0
8 - Child Restraint System - Rear Facing	2	0.0	100.0
9 - Booster Seat	4	0.0	100.0
Grand Total	455,699	100.0	

Table C- 8 Suspicious Speed Information

Speed	Counts	Speed	Counts	Speed	Counts	Speed	Counts	Speed	Counts
0	51,813	27	14	54	21	81	3	115	3
1	3,146	28	24	55	19,124	82	4	120	12
2	6,042	29	12	56	30	83	2	125	3
3	5,518	30	19,214	57	51	84	4	130	1
4	803	31	8	58	96	85	200	135	1
5	55,927	32	21	59	23	86	4	137	1
6	193	33	21	60	12,625	87	1	140	3
7	487	34	24	61	37	88	3	145	7
8	568	35	18,207	62	260	89	1	150	3
9	42	36	14	63	160	90	145	151	1
10	38,524	37	28	64	116	91	2	152	2
11	17	38	51	65	21,117	92	2	153	2
12	150	39	14	66	37	93	1	154	2
13	37	40	15,945	67	106	95	17	155	1
14	28	41	13	68	293	96	2	156	1
15	23,726	42	44	69	50	99	1	157	1
16	12	43	26	70	20,292	100	75	158	1
17	21	44	26	71	25	101	3	165	1
18	49	45	23,626	72	68	102	3	185	4
19	11	46	11	73	42	103	9	190	1
20	18,665	47	27	74	28	104	1	199	4
21	4	48	43	75	1,293	105	7	993	1
22	19	49	11	76	14	106	3	999	39628
23	23	50	10,997	77	11	107	1		
24	27	51	21	78	24	108	1		
25	15,413	52	44	79	13	110	14	Null	52903
26	7	53	34	80	627	114	1	Total	479472

Table C- 9 Vision Obstruction

Vision Obstruction	Frequency	Percent	Cumulative Percent
Null	2,629	.6	.6
1 - Vision Not Obscured	42,7849	93.9	94.5
10 - Glare	1,318	.3	94.8
2 - Inclement Weather	5,928	1.3	96.1
3 - Parked/Stopped Vehicle	3,553	.8	96.8
4 - Trees/Crops/Bushes	697	.2	97.0
5 - Load on Vehicle	2,061	.5	97.4
6 - Building/Fixed Object	307	.1	97.5
7 - Signs/Billboards	132	.0	97.5
77 - All Other	10,326	2.3	99.8
8 - Fog	754	.2	100.0
9 - Smoke	145	.0	100.0
Grand Total	455,699	100.0	

Table C- 10 Road System

Road System ID	Frequency	Percent	Cumulative Percent
Null	108	.0	.0
1 - Interstate	39,570	16.3	16.3
2 - U.S.	20,439	8.4	24.7
3 - State	53,574	22.0	46.8
4 - County	30,894	12.7	59.5
5 - Local	56,323	23.2	82.7
6 - Turnpike/Toll	7,117	2.9	85.6
7 - Forest Road	54	.0	85.6
77 - Other	3,501	1.4	87.1
8 - Private Roadway	4,427	1.8	88.9
9 - Parking Lot	27,010	11.1	100.0
Grand Total	243,017	100.0	

Table C- 11 Intersection Type

Type of Intersection	Frequency	Percent	Cumulative Percent
Null	127	.1	.1
1 - Not at Intersection	167,805	69.1	69.1
2 - Four-Way Intersection	49,900	20.5	89.6
3 - T-Intersection	15,370	6.3	96.0
4 - Y-Intersection	3,200	1.3	97.3
5 - Traffic Circle	118	.0	97.3
6 - Roundabout	196	.1	97.4
7 - Five-Point, or More	124	.1	97.5
77 - Other	6,177	2.5	100.0
Grand Total	243,017	100.0	

Table C- 12 Shoulder Type

Type of Shoulder	Frequency	Percent	Cumulative Percent
Null	8,100	3.3	3.3
1 - Paved	104,993	43.2	46.5
2 - Unpaved	54,028	22.2	68.8
3 - Curb	75,896	31.2	100.0
Grand Total	243,017	100.0	

Table C- 13 Weather Condition

Weather Condition	Frequency	Percent	Cumulative Percent
Null	4,404	1.8	1.8
1 - Clear	175,499	72.2	74.0
2 - Cloudy	43,229	17.8	91.8
3 - Rain	17,330	7.1	98.9
4 - Fog, Smog, Smoke	1,335	.5	99.5
5 - Sleet/Hail/Freezing Rain	12	.0	99.5
6 - Blowing Sand, Soil, Dirt	5	.0	99.5
7 - Severe Crosswinds	30	.0	99.5
77 - Other	1,173	.5	100.0
Grand Total	243,017	100.0	

Table C- 14 Alcohol Related

Alcohol Related	Frequency	Percent	Cumulative Percent
N	238,525	98.2	98.2
Y	4,492	1.8	100.0
Grand Total	243,017	100.0	

Table C- 15 Distraction

Distracted	Frequency	Percent	Cumulative Percent
N	228,223	93.9	93.9
Y	14,794	6.1	100.0
Grand Total	243,017	100.0	

Table C- 16 Drug Related

Drug Related	Frequency	Percent	Cumulative Percent
N	241,993	99.6	99.6
Y	1,024	.4	100.0
Total	243,017	100.0	

Table C- 17 Gender

Gender	Frequency	Percent	Cumulative Percent
Null	27,432	6.0	6.0
1 - Male	335,346	73.6	79.6
2 - Female	90,096	19.8	99.4
88 - Unknown	2,825	.6	100.0
Grand Total	455,699	100.0	

Table C- 18 Area of Initial Impact

Area of Initial Impact	Frequency	Percent	Cumulative Percent
1 - Front Center Bumper	91,684	19.1	19.1
2 - Front Right Bumper	40,650	8.5	27.6
3 - Right Front Fender	24,384	5.1	32.7
4 - Right Front Door	14,814	3.1	35.8
5 - Right Rear Door	9,702	2.0	37.8
6 - Right Rear Fender	14,227	3.0	40.8
7 - Rear Right Bumper	18,145	3.8	44.6
8 - Rear Center Bumper	46,573	9.7	54.3
9 - Rear Left Bumper	21,028	4.4	58.6
10 - Left Rear Fender	18,962	4.0	62.6
11 - Left Rear Door	11,157	2.3	64.9
12 - Left Front Door	17,543	3.7	68.6
13 - Left Front Fender	21,074	4.4	73.0
14 - Front Left Bumper	33,230	6.9	79.9
15 - Hood	2,284	0.5	80.4
16 - Roof	3,426	0.7	81.1
17 - Trunk	894	0.2	81.3
18 - Undercarriage	4,195	0.9	82.2
19 - Overturn	2,996	0.6	82.8
20 - Windshield	1,864	0.4	83.2
21 - Trailer	37,603	7.8	91.0
Null	43,037	9.0	100.0
Grand Total	479,472	100.0	

Table C- 19 Roadway Alignment

Roadway Alignment	Frequency	Percent	Cumulative Percent
Null	207,228	43.2	43.2
1 - Straight	257,986	53.8	97.0
2 - Curve Right	7,379	1.5	98.6
3 - Curve Left	6,879	1.4	100.0
Grand Total	479,472	100.0	

Table C- 20 Roadway Grade

Roadway Grade	Frequency	Percent	Cumulative Percent
Null	200,207	41.8	41.8
1 - Level	261,170	54.5	96.2
2 - Hillcrest	1,823	.4	96.6
3 - Uphill	7,427	1.5	98.2
4 - Downhill	8,400	1.8	99.9
5 - Sag (bottom)	445	.1	100.0
Total	479,472	100.0	

Table C- 21 Vehicle Body Type

Vehicle Body Type	Frequency	Percent	Cumulative Percent
Null	8,033	1.7	1.7
1 - Passenger Car	135,596	28.3	30.0
11 - Motorcycle	1,569	.3	30.3
12 - Moped	148	.0	30.3
13 - All Terrain Vehicle (ATV)	106	.0	30.3
15 - Low Speed Vehicle	218	.0	30.4
16 - (Sport) Utility Vehicle	17,846	3.7	34.1
17 - Cargo Van (10,000 lbs (4,536 kg) or less)	2,785	.6	34.7
18 - Motor Coach	270	.1	34.7
19 - Other Light Trucks (10,000 lbs (4,536 kg) or less)	6,345	1.3	36.1
2 - Passenger Van	14,275	3.0	39.0
20 - Medium/Heavy Trucks (more than 10,000 lbs (4,536 kg))	247,342	51.6	90.6
21 - Farm Labor Vehicle	162	.0	90.7
3 - Pickup	33,650	7.0	97.7
7 - Motor Home	499	.1	97.8
77 - Other	4,653	1.0	98.8
8 - Bus	4,001	.8	99.6
88 - Unknown	1,974	.4	100.0
Total	479,472	100.0	