2017

Investigating and Modeling the Impacts of Illegal U-Turn Violations at Medials Located on Florida's Limited Access Highways

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INVESTIGATING AND MODELING THE IMPACTS OF ILLEGAL U-TURN VIOLATIONS AT MEDIANS LOCATED ON FLORIDA'S LIMITED ACCESS HIGHWAYS

by

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B.S.C.E An-Najah National University, 2014

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Civil and Environmental Engineering
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Summer Term
2017

ABSTRACT

Illegal U-turn violations are considered part of the Wrong-Way Driving (WWD) maneuvers that could result in head-on crashes and severe injuries. Even without crashes, these illegal movements still cause disturbance for approaching traffic. Crashes that result from this type of violation on limited access facilities are often severe because of the high speed of the approaching traffic and the unexpected angle of entrance of the illegally turning vehicle into the through traffic stream. Therefore, reviewing this type of violation and understanding the contributing factors that may lead drivers to commit such illegal maneuver would help officials foresee and consequently minimize the potential risks that could lead to WWD crashes. This will improve safety and operations for the network users.

The purpose of this thesis is to review illegal U-turn maneuvers on limited access facilities and find the significant contributing factors that encourage or discourage drivers to commit this type of violation. Limited literature was found on this topic. In addition, a limited number of incidents (crashes and citations) was found on the limited access facility network studied in the state of Florida. The study analyzed the recorded incidents found on the locations with the highest frequency of WWD incidents. The study area included the Orlando metropolitan area (Orlando–Kissimmee–Sanford), referred to as Central Florida (CF), and the Miami metropolitan area (Miami-Fort Lauderdale-West Palm Beach), referred to as South Florida (SF) in this thesis. The CF area includes Seminole, Lake, Orange, Osceola, and Polk counties, and the SF area includes Broward, Miami-Dade, and Palm Beach counties. After reviewing the crash and citation data at both the median facilities and median openings from year 2011 to 2016, it was found that about 6

crossover crashes occurred in the CF area and none was found in SF. Moreover, about 620 citations occurred on median facilities in the two study areas defined.

It was found from analyzing the collected dataset, that most of the illegal U-turn incidents occurred during mid-day, and the majority of citations were cited during the months of January, February, and May. In addition, it was found that the age group with the highest percentage of illegal U-turn citations were from 26-36 years, followed by 36-45 years. The percentage of drivers from 16-25 years was slightly lower than the other groups mentioned. This could be explained that drivers from older age groups are over confident with their driving skills and have the propensity to commit such dangerous maneuvers intentionally. Moreover, it was found that the drivers from the white race had the highest exposure rate among the drivers included in the study.

The modeling methodology for this thesis had three goals: predicting the number of illegal U-turn violations across the traversable grass median sections per year, selecting the most effective variables in predicting the illegal U-turn violations, and estimating the probability of an illegal U-turn violation per year occurrence at paved median openings that are dedicated for official use only.

To achieve the first goal, a Poisson regression model was used to predict the number of illegal U-turn citations occurring at traversable medians each year. Poisson regression was selected because of its regression capability to model rare events over a certain time period. To achieve the second goal, the least absolute shrinkage and selection operator (LASSO) variable selection method was performed on the significant variables found from the Poisson model. The LASSO regression method is an effective variable selection method that produces models with

continuous outcome variables. LASSO regression selects from the included exploratory variables by shrinking the ineffective coefficients to the value of zero so they can be excluded from the model. Furthermore, to achieve the third goal, a logistic regression model was used to predict the probability of the illegal U-turn citation occurrence at the median openings. The logistic regression was selected due to the limited number of median openings with multiple citations, and the considerable number of median openings with no recorded citations (zero values).

To determine the variables that influence the illegal U-turn violations at limited access facilities, 11 exploratory variables that were expected to affect the occurrence of illegal U-turn violations were analyzed in the models mentioned earlier. The exploratory variables included 9 geometric design features and 2 traffic conditions that the operating agencies can measure and modify on their network.

The variables that were found significant from the Poisson model were the number of lanes, the distance to the nearest interchange, the length of the median segment, the number of access points in the segment, the median type, the average distance between the access points, and the speed limit. Afterwards, the previously mentioned variables were evaluated using the LASSO variable selection method to conclude that the most effective variables were the median design type and the distance of the section to the nearest interchange.

The variables found significant from the logistic regression model in CF area were the speed limit and the AADT. However, the significant variables in the SF area were distance to the nearest access point and the spacing between the median openings. This variation in results indicate the significant difference between the two study areas, this difference could be explained

with the different median design characteristics, traffic patterns, and demographic and driving behavior differences. For example, more than 95% of the SF roadway network (excluding SR-75) have median barriers installed, which makes the median openings the only access points for potential violators to commit an illegal U-turn. This variation should be accounted for in each area by analyzing and allocating the proper and effective countermeasures for that area separately.

The significant variables found in the mentioned modeling approach provide a first attempt to understand characteristics of illegal U-turn violations on limited access highways, and shed some light on how each variable influences drivers' behavior in performing such illegal maneuver.

Along with required design guidelines, the models found in this thesis could be used as effective planning tools to select the appropriate locations for installing new median openings and reevaluating the existing median openings to select (or keep) locations with the lowest probability of illegal U-turns (these are locations with the lowest potential risk).

Other modeling techniques that include additional factors could be tested in future research so that appropriate countermeasures can be installed to reduce or eliminate these illegal U-turns. Some suggested variables to be examined would be the type of land use where the median facilities are located, the driver characteristics, the weather effects on drivers' attitudes, the presence of police enforcements in the area, and finding the direction of movement for the illegal U-turn driver going EB to WB or vice versa, to locate the origin and destination of drivers that conducted such violation. Furthermore, the methodology could be extended to arterials (or roads with partially controlled access).

ACKNOWLEDGMENTS

First of all, I would like to state my sincere gratitude and appreciation to Professor Haitham Al-Deek, my advisor, for his continuous support, motivation, patience, and advice throughout my thesis and research. In addition, I would like to express my gratitude for the rest of the members of my committee; Dr. Alexander Mantzaris and Dr. Samiul Hasan for their participation and input.

Second, I would like to thank Mr. Adrian Sandt, Mr. Omar Faruk, Ms. Sara Wertanen, Mr. Antony Shamma, Ms. Abigail Vanluven, and Mr. Corin Staves for their assistance with my research and their accompany and friendship. I also would like to thank Dr. John Rogers for his help and valuable advice and recommendations.

Moreover, I would like to express my gratitude for the Engineers with the CFX for their input and assistance; Mr. Bryan Homayouni and Mr. Corey Quinn. I would like to also express my gratitude for Mr. Eric Gordin with the Florida Turnpike Enterprise (FTE) as well. Last, I would like to express appreciation for the assistance provided by Dr. Grady Carrick with Enforcement Engineering, Inc.

Last but not least, I would to give my appreciation to my parents, family, and friends for providing me with the support thought-out my master's degree.

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LIST OF ABBREVIATIONS

1. AASHTO: American Association of State Highway and Transportation Officials
2. CF: Central Florida
3. CFX: Central Florida Expressway Authority
4. CMF: Crash Modification Factor
5. FDOT: Florida Department Of Transportation
6. FHP: The Florida Highway Patrol
7. FTE: Florida Turnpike Enterprise
8. GIS: Geographic Information Systems
9. HEFT: Homestead Extension of Florida's Turnpike
10. PPM: Plans Preparation Manual
11. SF: South Florida
12. SHSP: Strategic Highway Safety Plan
13. THEA: Tampa Hillsborough Expressway Authority
14. TPPPH: Turnpike Plans Preparation and Practices Handbook
15. TXDOT: The Texas Department Of Transportation
16. WWD: Wrong-Way Driving

1. CHAPTER ONE: INTRODUCTION

1.1 Background

Recently, there have been several studies on Wrong-Way Driving (WWD) nationwide. The WWD studies commonly considered the illegal vehicular movement along a travel lane of the opposing direction of the legal flow of traffic (*1*). However, there is a lack of focus on the other WWD maneuver of illegal U-turns on divided and limited access highways.

Illegal U-turn movements are defined by the act of illegally driving over or across the dividing space between divided highways (median section), or at an emergency crossover for official use only (*2*). The term "crossover" is used for the openings on the medians separating two opposing directions of traffic on limited access facilities, and the openings should be used by officials only. This type of WWD may cause less damage than the commonly known WWD because WWD crashes are usually a direct head-on collision. However, illegal U-turns occur more often and cause considerable disturbance to the traffic network, numerous near-crashes (a near-crash is a sudden maneuver by vehicle to avoid crash), and some angle or head-on crashes resulting from vehicles crossing the median to the opposing direction of traffic. This was confirmed by analyzing the F.S. 316.090 citation statue in Orange, Seminole, Osceola, and Brevard Counties from year 2010 to 2012. It was found that 93% of the citations had the statue number 316.090 (2), (cited to drivers illegally crossing the median section on divided roadways) compared to the 316.090 (1) citation (cited to drivers travelling in the wrong direction of traffic). Although crashes resulting from illegal U-turns are less common than driving on the wrong side head-on crashes, illegal U-turns continue to pose a high risk for a potential head-on (or other types of) crashes. Therefore, it should not be taken lightly.

The definition of access management is the management of vehicular access points to the areas adjacent to all facilities of roadways, and has been one of the fundamental issues considered in highway design since the 1960s (3). For example, the first Plans Preparation Manual (PPM), published by the state of Florida Department of Transportation (FDOT) in 1967, included access management as one of its main chapters (*3*). Access management considers the median treatments and openings on the roadways; however, the regulations for median openings for official use only as access points on limited access facilities were only included in the mid-nineties (*4*).

For the past decade, a specialized section for crossovers on limited access facilities has been included in the FDOT PPM (*5*) after the submission of a roadway design bulletin in the year 2006 (*6*).

The criteria and guidelines for designing crossovers at limited access facilities are considered relatively new. They are still being evaluated and updated continuously to achieve optimal safety conditions while taking into consideration providing convenient access for emergency, law-enforcement, and maintenance vehicles.

1.2 Research Goals and Objectives

The research has three main goals to accomplish, the goals are listed below:

1. Determine and understand the contributing factors encouraging or discouraging drivers to commit illegal U-turn maneuvers on limited access facilities.
2. Develop significant statistical models that could explain the illegal U-turn maneuvers and highlight the locations with the high risk of WWD acts resulting from the predicted illegal U-turn maneuvers.
3. Discuss and suggest the appropriate countermeasures to combat such dangerous WWD acts.

To accomplish these goals, the following objectives must be achieved first:

1. Collect the illegal U-turn citations and crash data on the limited access facilities in the state of Florida from 2011 until 2016. The reason why the data collected was from 2011, was because after the year 2010 a new recording system for citations was adopted in the state of Florida. Therefore, to have a homogeneous sample, only citations after the year 2010 were included in the analysis
2. Determine the locations of the illegal U-turn citations that have occurred in the state of Florida, and the type of median facility where the citations occurred. The two types considered were the traversable median sections and the official median openings (crossovers) on the roadway. The official median openings include two types: grass sections with median openings, and sections that have concrete or cable barriers with paved median openings.
3. Examine the properties of the collected citations to find the potential contributing factors associated with such type of illegal U-turn maneuver.
4. Develop a violation prediction models using the citation dataset in order to predict the location of the illegal U-turn violations and WWD risks, and determine the significant factors associated with the illegal U-turn violations.

2. CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviews previous studies considering WWD at medians. These include studies on median access management, design guidelines and requirements, impacts of median facilities on safety and operational conditions, causes and potential locations of illegal U-turn maneuvers at median facilities and crossovers, WWD from off ramp entries influenced by the separating median facilities, and the potential countermeasures for illegal U-turn maneuvers and WWD at off ramp exits. The results and recommendations of these studies are beneficial to determine the most appropriate types and locations for median WWD countermeasures to effectively reduce median WWD events on limited access highway networks.

2.2 Access Management through Median Facilities

Access management has been researched thoroughly in the past years, but evaluating access management in relation to safety conditions with respect to median-related crashes is one of the research areas that has not been investigated as much (*7*). One of the possible reasons for the limited research in this type of crashes might be their small frequency of occurrence although they might result in head-on crashes due to loss of control after performing a U-turn maneuver at high speed especially over a grass section.

Two types of median related access management were reviewed, the first was the access provided through traversable medians (concreate or grass medians) separating the two directions of traffic, and the second was the access provided for emergency vehicles though the median crossovers as defined previously in the introduction section 1.1. Emergency crossovers may be

paved in the middle of a grass median or in the middle of a median with concrete or cable barriers. Crossovers are designated for official use only prohibiting the public from making U-turns there as these should be only used by emergency vehicles or authorized state department of transportation personnel. An example of a traversable median section and a crossover are found in Figure 1.

	
Traversable Grass Median Section – SR408	Median Crossover for Official Use – SR528

Figure 1: Street view pictures of a Traversable Grass Median Segment and a Median Crossover for Official Use in Florida (Google maps, 2017)

2.3 Impacts of Installing Median Barriers on Highways

To minimize the number of fatalities resulting from head-on collisions, agencies usually consider installing physical median barriers on their networks. Although installing median barriers might have negative effects in increasing the crash frequency of side sweep crashes, but its effectiveness in reducing severe crashes and fatalities has been proven nationwide. Several studies confirmed that installing median barriers, regardless of the type or material used, significantly reduces median crossover crashes. For example, Sicking et al. (*8*) found that the average cost of a cross median crash was about 1,022,700$ in the year 2008, and after considering that cost in the benefit-cost (b/c) ratio for installing median barriers, the ratio ranged from 2.0 to 4.0 depending on the traffic volume. The b/c ratio was estimated by dividing the difference

between the accident costs without and with barriers over the cost of installing and maintaning a median barrier. Moreover, Villwock et. al (*9*) indicated that the installation of cable barriers resulted in a decrease of 90% in the number of crashes for vehicles moving in opposing directions. In addition, Russo et. al (*10*) in Michigan estimated the Crash Modification Factor (CMF) for installing high-tension cable median barrier and found that the barriers significantly reduced the frequency of severe cross median crashes. Other studies performed by Burns and Bell (*11*), Alluri et. al (*12*), and Marzougui et. al (*13*) all agreed with the pervious findings on the effectiveness of median barriers in reducing cross median crashes.

2.3.1 Impact of Median Barriers on Response Time of Emergency Vehicles

The pervious section discusses the effectiveness of installing a median barrier on the safety conditions and crash related damages, but another aspect that should be also considered is the access limitations for emergency vehicles resulting from installing median barriers and importance of installing median crossovers in the presence of median barriers.

Because of the sensitivity and complexity of the operation of emergency responders, estimating the impact of median barriers on the response time and the total emergency operational cost is not simple. Barriers typically hinder the movement of emergency vehicles and increase the travel time for emergency vehicles to reach incidents on the opposite direction of traffic. On the other hand, barriers reduce the number of severe crashes and accordingly reduce the number of emergency calls received (*14*).

The exact response time for the emergency vehicle in the year 2003 was rarely recorded by agencies according to Srinivasan et. al (*14*). Therefore, this thesis would consider the additional delay in response times for officials resulting from the installation of median barriers on the roadways. As described before, the barriers hinder the movement of law enforcement

officers to cite drivers aggressively driving on the opposite direction of traffic and possibly resulting in severe crashes and injuries. The barriers would also delay emergency vehicles (such as ambulances and fire trucks) that are rushing to save lives and treat serve injuries resulting from crashes on the roadway. The cost of delay for such vehicles could be considered one of the highest delay costs for vehicles travelling on the roadway network. As FHWA mentioned in their Traffic Signal Preemption for Emergency Vehicles report, each minute of delay reduces the chances of survival from cardiac arrest by 7-10% up to 8 minutes, after that the chances of survival become very minimal (*15*). Therefore, each second of delay for an emergency vehicle would highly reduce the possibilities of survival or losses resulting from a fire or an emergency. As a result, the cost of delay of an emergency vehicle could be very high, and in the case of severe injuries losing a victim might have higher rates of reduction in survival chances for each minute of delay.

The exact cost for one fatality might not be agreed on since several factors are included in calculating the cost of a fatality such as the average income, age, and other factors. However, a memorandum from USDOT stated that the value of a life saved was estimated to be $9.1 million (*16*). Using the estimated value for one fatality from the USDOT memo and the percentage of survival reduction found from the FHWA report (*15*), if each minute of delay would reduce the survival changes by 7-10% then multiplying the total life cost by the reduction in survival chances would result in a delay cost of $640,000-$910,000 (about $10,600 - $15,150/sec.), and this cost does not include the operational cost of emergency vehicle and the personnel operating the vehicle. However, the other costs are considerably small compared to fatality costs and could be neglected for this purpose. For example, the ambulance maintenance cost is estimated to be up to 1.03$ per mile (*17*). Assuming the average speed of an ambulance to be 70 mph, this would require an ambulance a duration of 0.85 minutes to cross 1 mile, which is equivalent to crossing 1.2 miles in

one minute. As a result, the cost of maintenance for 1 minute operation would be up to 1.24$ per minute, which could be neglected compared to the fatality cost.

This gives an indicator of the high cost of delay and the tragic consequences resulting from not providing adequate access for the emergency vehicles and the medical crew.

Other costs associated with median barriers include the construction and maintenance costs. According to the Minnesota Department of Transportation (MnDOT) (*18*), $400,000 to $500,000 per mile was estimated for the installation of concrete median barriers and $140,000 to $150,000 per mile for the installation of cable median barriers, in addition to the annual maintenance cost of $6000 to $7000 per year for cable median barriers.

To compare the suggested costs with the local costs in the state of Florida, a presentation prepared by Florida Turnpike Enterprise (FTE) in the year 2006 estimated the cost of installing one foot of cable median barrier to be $19, making the cost of one mile of cable barrier as $100,320 (*19*). In addition, according to Census-American Community Survey, the average household income in Florida is $47,507 compared to $61,492 in Minnesota (*20*). Using this ratio (0.77) to find the cost of installation and maintenance for cable median barriers in the state of Florida, the installation cost for median barriers was estimated to be about $107,800-$115,000. This value is consistent with the numbers found by the FTE presentation with a slight increase resulting from inflation and the increase in cost of living. Moreover, the annual maintenance costs for the barrier would be estimated at $4,600-$5,400 per year (*19*).

2.4 Installation of Median Openings for Official Use Only

Median openings could be classified into two categories, median openings on highway facilities for left turn and U-turn movements and median openings at limited access facilities dedicated for official use only (crossovers).

2.4.1 Mid-block Median Openings

Median openings are classified into two types regarding their design, full and directional as shown in Figure 2 (*21*).

Figure 2: Directional and Open Medians (Google maps, 2017)

Median openings have been well-investigated by several research and design committees, and several guidelines and recommendations were legislated for these openings. The FDOT Median Handbook included a section of guidelines for installing median openings and the sight distance required for the different turning movements (intersection, left turn, U-turns) and the type of land use where the roadway is located (*21*).

Haleem & Abdel-Aty (*7*) found that 81.3% of the crossover crashes occurred at unrestricted median openings, which are similar to open medians, and the study also found that converting an open median to a directional opening reduced the number of hourly conflicts by 50%. Therefore, the recommended design to reduce the crossover crashes occurring at the median

openings would be installing a type of restriction to minimize the number of conflicts and the conflict area as much as possible.

As a comparison between the states, a report prepared by CTC & Associates LLC. (*22*) for Wisconsin Department of Transportation, found that 76% of the states that were included in the study (22 states) followed the American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide to determine the location for installing median barriers (*23*). Florida, Indiana, and Maryland were found among the states that do not follow these guidelines, and follow their own guidelines that slightly modify the AASHTO guidelines to suit their state circumstances.

In the scope of this thesis, finding the Crash Modification Factors (CMF) for the installation of median barriers and median openings for official use only, and testing the transferability of the CMFs between states and roadways was not considered. However, this could be considered in future studies.

2.4.1.1 Advantages vs. Disadvantages for Installing Median Openings

The installation of median openings on limited access facilities is an essential issue to provide convenient access for emergency vehicles. However, installing median openings would add additional access points creating additional conflict points that usually would results in an increase in potential for crashes. There was a scarce in literature on the median openings limited access facilities. However, numerous researchers studied the effect of median openings on separated accessible highway. Therefore, the studies on accessible and partially controlled highways were reviewed as an attempt to understand the impact of median facilities on crashes occurring on limited access and fully controlled highways even though the two facilities vary in

several aspects and characteristics such as speed, sight distance, side clearance, etc. As an example of the numerous studies found on separated highways, Rodegerdts et. al (*24*) evaluated the CMF for creating directional median openings versus having full median openings that facilitate all movements, and found a reduction in crashes (CMF < 1), but the CMFs found had low level of quality, which indicated that more research should be considered in this area. In addition, a study performed by Xu found that replacing the direct left-turn with right/U-turn had CMF values varying from of 0.64 to 0.89 (*25*). Therefore, it could be concluded that installing median openings would reduce the number of crashes at the separated highways. The findings could be explained that the U-turn mid-block movement would reduce the left turn movement at an intersection that could be more exposed to traffic and have a higher risk of collision than the mid-block conflict point.

This section reviews the median opening related studies that consider the impact of the openings on safety and operational conditions for the roadway facilities. Although, the operating conditions on accessible partially controlled highways and fully controlled limited access facilities are different, this would provide a preliminary understanding of the impact of median openings on the operating conditions.

2.4.2 Official Use Median Openings

Studies related to safety conditions or CMF for crashes occurring at official use median openings are scarce in the literature. A study conducted by Srinivasan et. al (*14*) for the year 2003, considered the illegal use of median crossovers on the North Carolina highways. As a part of their research they observed 4 median crossovers for two hours each. They found that 3 illegal and 1 legal U-turn occurred at these crossovers. The study did not conduct any further analysis in such regard but focused on the difference between the states on following guidelines in regards to the

median crossovers. By then, each state had its own design criteria for emergency openings. In addition, the AASHTO Roadway design guideline released in 2001 did not focus on the emergency crossovers but included spacing guidelines for the emergency crossovers in the median section for rural freeways (*26*). However, after reviewing the most recent AASHTO geometric design guidelines for highways and streets released in year 2016, it was found that very limited modifications have been included as compared to the old AASHTO 2001 design manual.

There has been a growing interest in the design criteria and specifications of the official use median openings to define the design requirement for those emergency crossovers design requirements at the state level. Currently, several states such as Florida (*27*), California (*28*), and Texas (*29*), prepared their own design guidelines for median crossovers for their engineers to follow.

2.5 Median Countermeasures for WWD

This section discusses the median countermeasures that are suggested to prevent drivers from entering into the limited access facilities from the off-ramps to travel on the opposing direction of traffic and being susceptible to a WWD head-on crash, and also the countermeasures to reduce the potential of a median crossover crash resulting from an illegal U-turn maneuver.

Vaswani (*30*) performed a study on Virginia interstates that examined the extent of WWD and various engineering measures to reduce WWD, including using reflectorized pavement arrows on ramps, providing stop lines across exit ramps near junctions with crossroads, continuing the pavement edge line across exit ramps, and reducing crossover width across exit ramps. It was concluded that about 65% of the WWD events on Virginia interstates were either entries from

interchanges or were related to U-turns and median crossovers. Therefore, it is important to reduce WWD at medians, both on mainlines and at intersections with arterial streets and ramps.

Numerous median WWD research studies had been performed by the Illinois Center for Transportation (ICT). Villwock et. al (*9*) acknowledged that one of the goals pursued by the Strategic Highway Safety Plan (SHSP) is to reduce the number of highway crash fatalities. Since cross-median crashes can result in head-on collisions, which are often severe, reducing the amount of these crashes can help reduce fatalities. According to their research, the majority of WWD crashes on freeways were initiated by entering medians and making U-turns on the freeway. Crash records in Illinois were reviewed over a five-year period (2004 – 2009). Based on the crash reports and narrative descriptions, it was determined that 70 out of the total 217 WWD crashes during that period had a recognizable entry point. Out of these 70 crashes, 22 crashes (31%) had recognized entry points that were associated with medians or U-turns on freeways. Figure 3 shows the crash frequency for each wrong-way entry point for the Illinois data. This figure indicates that medians could potentially be a more frequent source of WWD than ramps.

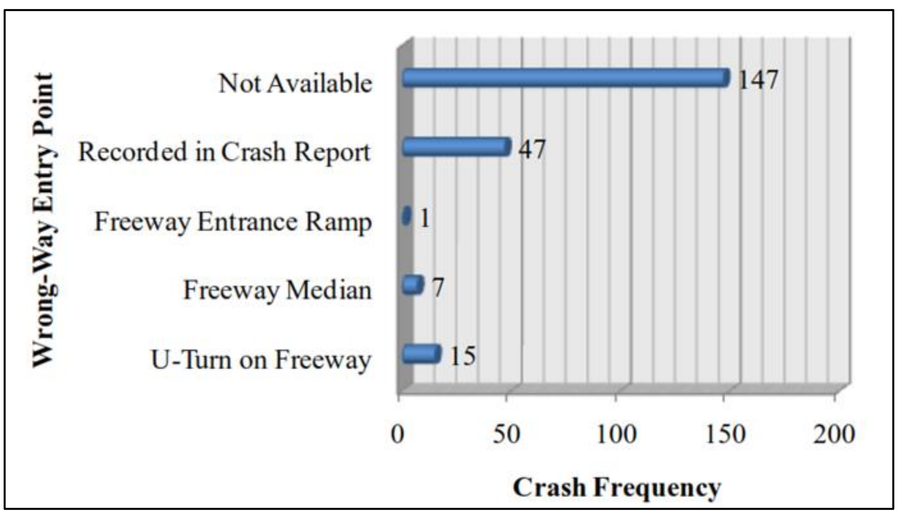

Figure 3: Entry Point Type for Wrong-Way Crashes (*31*).

Zhou et. al (*31*) also studied the effects of median barriers on crash severity for freeways. The percentages of fatal crashes were 14.7% and 19.0% for divided highways with and without a median barrier, respectively. Therefore, having a median barrier could reduce fatalities, as the barrier can reduce the chance of a vehicle crossing over the median and having a head-on collision with a vehicle going in the opposite direction.

While median barriers could reduce the risk of WWD, it is often not possible to have barriers along the entire roadway. One reason is that openings are needed so emergency vehicles can turn around if they need to quickly get to the scene of a traffic crash. These openings can take different forms. NCHRP (*32*) examined the median openings, also called midblock median openings that are designed to only accommodate U-turn traffic and categorized them into four types (1a, 2a, 2b, and 2c, as shown in Figure 4, Figure 5, Figure 6, and Figure 7 respectively).

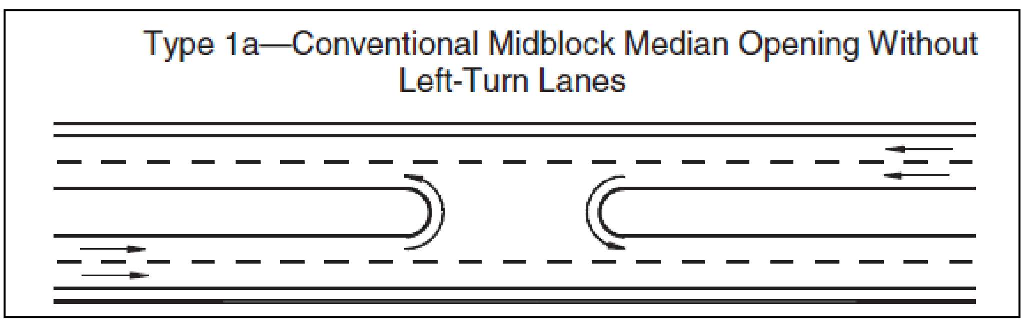

Figure 4: Midblock Median Opening Type 1a (*32*).

Type 1a (Figure 4) is a conventional midblock median opening without left-turn lanes. The advantage of using this type of midblock median openings is that turning vehicles would have less delay than other median openings that have deceleration lanes. A minimum gap of only 4 to 6 seconds is required to perform a U-turn maneuver. However, the absence of a deceleration lane increases the potential for a rear-end collision. Additionally, if the median width is not wide enough to completely store an emergency vehicle waiting for an adequate gap in the opposing

traffic to make a U-turn, the emergency vehicle could partially block the adjacent through lanes and potentially endanger vehicles travelling in these lanes. Since no directional island is constructed, it could cause improper merging maneuvers with the through traffic, resulting in delay and potential risk for WWD.

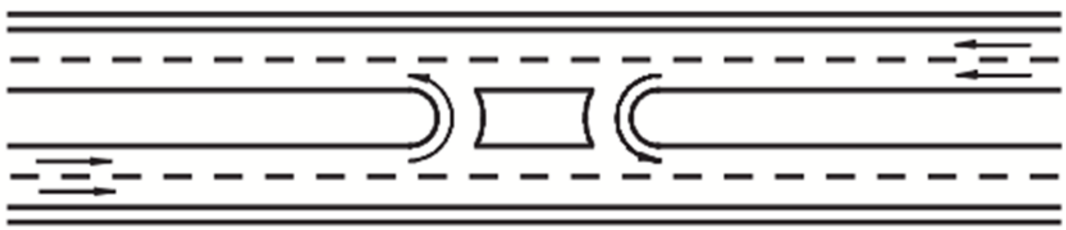

Figure 5: Directional Midblock Median Opening Type 2a (*32*).

The second design is Type 2a (Figure 5), the directional midblock median opening without left-turn lanes. This design is the same as type 1a, but with a directional island located in the median opening to help the turning traffic perform a more effective maneuver. However, if this directional island is installed on emergency openings, it could suggest to drivers of non-emergency vehicles that it is permissible for them to do a U-turn at this location. The island also reduces the space available for emergency vehicles to perform U-turns.

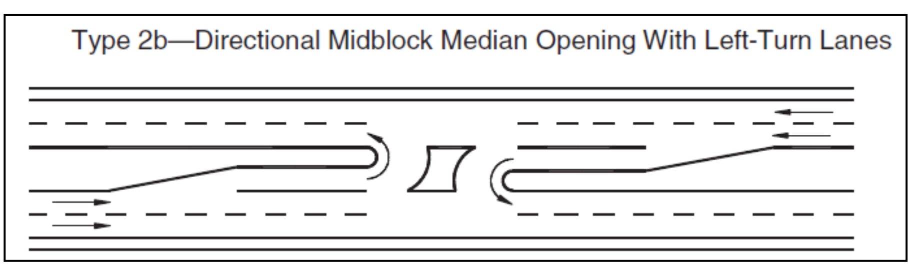

Figure 6: Midblock Median Opening Type 2b (*32*).

The other two types of median openings have left-turn lanes; these types are not present on limited access facilities in Florida. Type 2b (Figure 6), which is a directional midblock median

opening with left-turn lanes, can reduce the potential of rear-end crashes because the left-turn lane is designed to mitigate the problem of vehicles slowing down in the travel lane to make a U-turn at the median opening. A disadvantage of this type is that narrow median openings may prevent large emergency vehicles from being able to perform a U-turn.

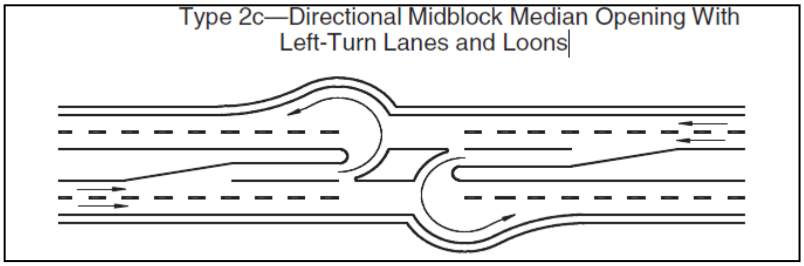

Figure 7: Midblock Median Opening Type 2c (*32*).

Type 2c (Figure 7), which is a directional midblock median opening with left-turn lanes and loons, makes it possible for turning vehicles to make a U-turn without stopping, which reduces conflict between through traffic and turning vehicles. The disadvantage of this design is that the loons require more right-of-way and make maintenance more difficult than other midblock median openings. A loon is an extended paved circular section usually near median openings at narrow roadway sections to provide adequate turning radius for large vehicles.

For the limited access facilities in Florida, the openings designed for emergency use only have a design similar to type 1a median openings. Two signs are posted at these locations; one sign states "For Official Use Only" and the other sign states "No U-turn". Adding channelizing islands, such as in design 2a, 2b, and 2c to the emergency openings could reduce the chance of a vehicle making an illegal U-turn going the wrong way, but it might encourage more vehicles to use the emergency openings. Adding an island might be useful for any locations with a high rate of WWD, but additional signs might be needed to prevent drivers from thinking it is permissible to make a U-turn.

Zhou & Rouholamin (*33*) identified median openings and channelizing islands as two of the geometric features on freeways correlated to WWD crashes. They listed numerous design guidelines for raised medians, channelizing islands, and exit ramps to identify designs that could be either more or less susceptible to WWD. The following are some of the recommended design guidelines that would be less susceptible to WWD:

- Design raised medians on arterial highways intersecting with exit ramps to discourage left-turn wrong-way entry onto exit ramps. Figure 8 illustrates an example of a raised median that discourages wrong-way left turn movements onto the exit ramp. The median creates a hard turning angle for wrong-way left-turning drivers and guides drivers towards the through direction while discouraging the left turn movement.

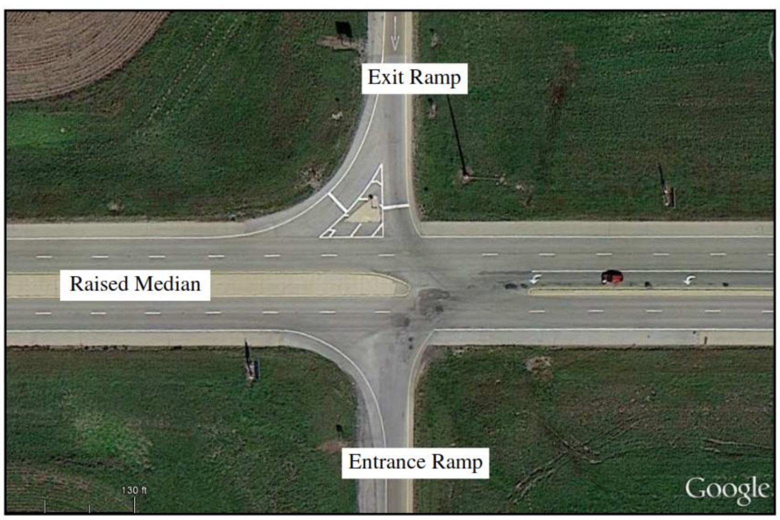

Figure 8: A Non-Traversable Raised Median at the Ramp-Crossroad Intersection (*33*).

- Design narrow median openings on arterial highways intersecting with exit ramps to prevent left-turn wrong-way movements. Figure 9 illustrates an off-ramp intersection before and after designing narrow median openings to prevent drivers from making a left turn onto the off-ramp. Originally, the intersection had no channelization and a wide median opening, which

made the wrong-way left turn movement more likely to occur. After narrowing the median, the wrong-way left turn movement onto the highway is more difficult and the traffic is channelized through the new opening.

Figure 9: Before (left) and After (right) Application of Raised Medians to Prevent Wrong-Way Maneuvers (*33*)

- Design channelizing islands to reduce the width of exit ramps. Reducing the width of the exit ramps makes it less probable that a WWD act would occur.
- Design acute angles to connect exit ramps to one-way streets and right angles to connect exit ramps to two-way roadways to better convey the direction of travel. The exit ramp intersection angle depends on its function to the intersecting crossroad. If the crossroad is a one-way street or left turn movements from the exit ramp are prohibited, then the off ramp should be connected with the crossroad using an acute angle. An acute angle makes it harder for wrong-way drivers to enter the ramp and makes it clear to drivers that the intersecting leg is a ramp exit and not a two-way street. If the crossroad is a two-way street, or left-turn movement is allowed, then the intersection angle should be a right angle to best discourage WWD.

In addition to these designs that are less susceptible to WWD, Zhou and Rouholamin (*33*) also elaborated on median designs, which can be more susceptible to WWD and should be

avoided. One potentially confusing design is the use of raised medians to separate vehicles going the same direction, as shown in Figure 10. This design can be confusing for left-turning vehicles, because drivers might not notice the correct road on the very right of the ramp and instead take the middle lanes, which are for exiting vehicles.

Figure 10: Design Susceptible to WWD (Raised Median Separating Same Direction of Traffic on an Exit Ramp) (*33*)

Noyce (*34*) examined crossover crashes on Wisconsin's divided highways with flushed medians. The study considered crash data from 2001 to 2003 for median entry and flushed median crossover crashes. The two main factors taken into consideration were the median width and the average daily traffic on the selected crash sites. A total of 631 median crossover crashes (about 4% of all crashes) were analyzed; these crashes resulted in 53 fatalities. It was found that most WWD crashes occurred on streets with medians that were 50-60 feet wide. Overall, the data did not reveal a strong correlation between median width and crossover median crashes. Roadways with both narrow and wide median widths exhibited varying median crash rates.

Finley et. al. (*35*) discussed the effectiveness of WWD countermeasures and mitigation methods for raised medians at off-ramps and recommended countermeasures for these medians

using geometric modifications. The study introduced the following guidelines and recommended practices for applications of wrong-way countermeasures:

- Install raised curb medians.
- Design and install channelized medians, islands, and adequate signing.
- Increase the distance from the gore of the exit ramp to the entrance ramp for partial cloverleaf interchanges.
- Reduce the wrong-way turning radius.
- Avoid using off-ramps that join two-way frontage roads.

2.6 Design Guidelines for Median Crossovers

The AASHTO design manual (2011) included several guidelines for the spacing and for locating the median openings for official use only on the limited access facilities (Crossovers) (*23*). Crossovers are potential locations for WWD due to illegal median crossovers by non-official vehicles. These types of openings are installed in numerous locations on the limited access facility network statewide. The manual details location guidelines and recommendations for crossover to combat wrong way drivers crossing through the openings and causing a potential crash. The spacing guidelines are as follows:

1. Emergency openings are not recommended in urban locations, since interchanges are closely spaced in such areas. Interchanges allow emergency vehicles and regular drivers to make a U-turn by exiting the freeway through the interchange and entering the freeway again from the other side of the interchange.

2. The recommended spacing between emergency openings is approximately 2 miles and generally no closer than 0.5 miles between openings. These spacing intervals for emergency openings should be decided based on engineering judgments and safety.

3. The minimum spacing between the emergency opening and any other ramp or access connection should be 1500 ft.

4. Emergency openings should not be constructed on curves.

5. Adequate sight distance should be provided at each emergency opening to allow through traffic drivers to identify the turning vehicle and adjust their speed or path to avoid the turning vehicle.

The guidelines for the construction of emergency openings state that the ends of cable barriers should have a type of protection, such as shock-resistant rubber or metal shields, to protect the barrier system from possible hits.

Furthermore, the FDOT PPM 2017 (*36*) in section (2.14.4-Crossovers on Limited Access Facilities) listed the additional guidelines, other than the guidelines mentioned earlier in the AASHTO Design manual. The additional FDOT design guidelines are:

1. Minimum distance to any interchange is 1.5 miles.

2. Minimum median width is 40'.

3. Where continuous median barrier is present, maximum spacing is 5.0 miles apart.

Moreover, crossovers that do not meet these design criteria require approval by the State Roadway Design Engineer and/or the District Design Engineer. The typical design plans for the crossovers and median barrier opening on limited access facilities from the FDOT PPM are shown in Figure 11 and Figure 12. (*36*)

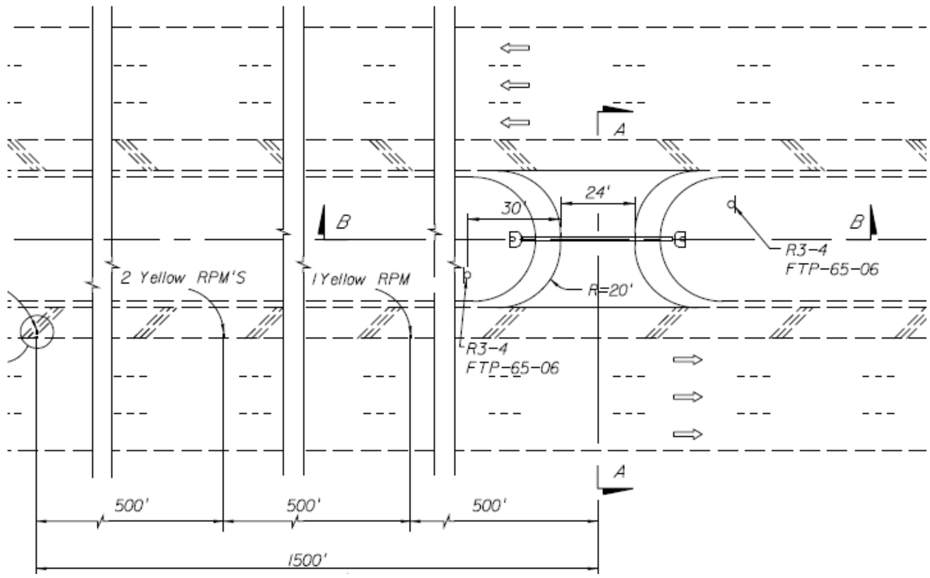

Figure 11: Crossovers on Limited Access Facilities (*36*)

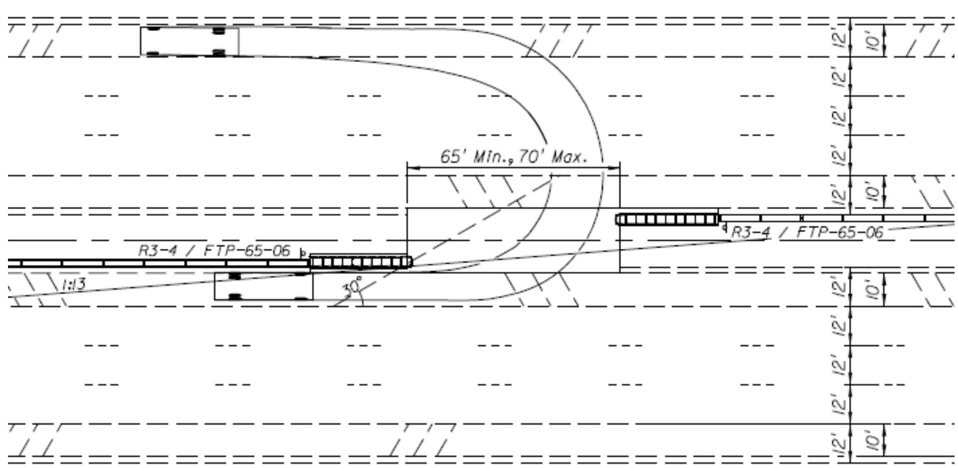

Figure 12: Median Barrier Opening for Crossovers on Limited Access Facilities (*36*)

Another design manual was prepared in Florida specifically for the FTE roadway network. They prepared the Turnpike Plans Preparation and Practices Handbook (TPPPH) that mentions special requirements and design guidelines to be performed on the roadways (*37*). The FTE has a special requirement for the median width opening to be more than 20 ft., and the width of the

median opening to at most 40 ft., in addition to everything mentioned in the AASTHO roadway design manual and the FDOT PPM.

In addition, TxDOT (*29*) in their roadway guideline recommended overlapping the cables at each end to discourage the public to make illegal crossovers through the emergency opening. The overlap, as shown in Figure 13, is done by extending the opposing edges of cable barriers to force vehicles to enter the median opening through the extended cables at an angle parallel to the barrier. This reduces the turning vehicles' speed and prohibits a direct crossover to the other side of the roadway. In addition, overlapping the cable barriers also makes the opening inconspicuous to public traffic, discouraging non-emergency vehicles from making illegal crossovers through the emergency opening.

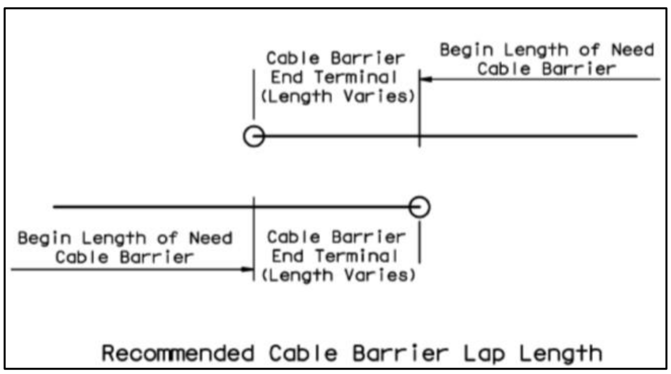

Figure 13: Recommended Cable Barrier Overlap at Emergency Openings (*29*)

To help discourage non-emergency use of the openings, they should be inconspicuous to main traffic and traversable below the road surface, if possible. It was also recommended to design the opening with dimensions that do not invite public use of the openings. The recommended opening width is approximately 20 ft., with return radii of 10 ft. (Figure 14).

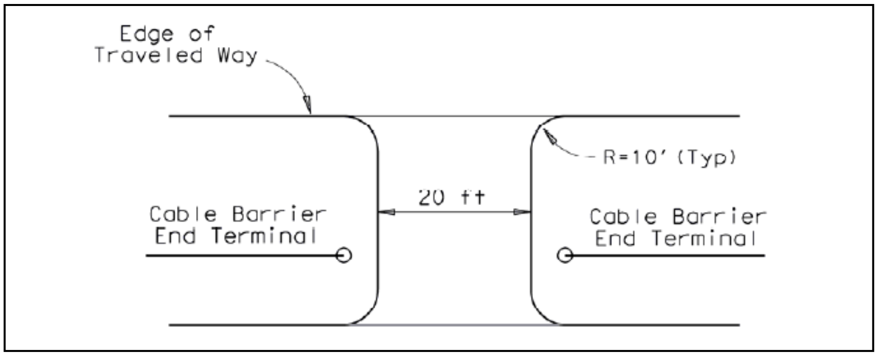

Figure 14: Recommended Emergency Opening Design Dimensions (*29*)

They should also be constructed with a surface that does not invite public use for the openings. According to TxDOT (*29*) it was found that Grade 1 or 2 aggregate or bladed recycled asphalt pavement (RAP) are adequate surface treatments to be used in some applications. For such regard, the FDOT PPM (*36*) listed that the pavement on crossover should have a pavement design similar to the limited access facility shoulder of 1-0.5" Structural Course, Base Group 1 with a 12" Stabilized Subgrade.

2.7 Summary of Literature Review Chapter

The literature review shows that several previous studies on median access management and WWD have been considered. Most of the studies were fairly recent and focused on design recommendations with a scarce of the crash modification factors and traffic impacts resulting from the access through medians on limited access facilities. Studies on the use of advanced ITS countermeasures to prevent WWD at medians and CMF factors for the installation of crossovers on limited access facilities were not found. Therefore, significant research and studies should be considered to analyze the effect of crossover on roadway networks and compare that effect with the resulting benefits and avoided losses that result from that additional access.

However, the AASHTO influenced several states to take the initiative and develop their own guidelines considering crossovers at limited access facilities.

FDOT and TXDOT were two of the states that took the lead in including guidelines and recommendations to encounter the WWD maneuvers at medians openings. The Texas Road Design Manual discussed ways to discourage non-emergency vehicles from using emergency openings by constructing the openings and making locations as inconspicuous as possible to the traveling public. Moreover, Florida adopted the guidelines mentioned in the AASHTO and added additional guidelines in their PPM to fit the needs of the state. The FDOT guidelines and recommendations will be further discussed throughout the scope of the thesis and will be included in the analysis and modeling procedures for the illegal U-turn citations occurring in the state of Florida.

3. CHAPTER THREE: DATA PREPARATION

3.1 Introduction

This chapter reviews the preparation criteria and steps performed as a prerequisite for the analysis of illegal U-turn citations that have occurred on the limited access facilities in central and south Florida regions. The preliminary goal of reviewing the citation dataset was to determine the locations with a high frequency of the WWD illegal U-turn violations and consequently find the areas with high risk of crashes resulting from the illegal U-turn maneuvers.

The WWD citations can be found in a few statutes in the state of Florida. The first citation statute considered is 316.090 (Driving on divided highways) which includes two types of illegal maneuvers. The first type, 316.090(1), is the most dangerous type of WWD, and is cited to drivers illegally driving on the left-side of the road on a divided highway. The second type, 316.090(2), is given to drivers illegally driving over or across the dividing space or section of the divided highways. The WWD maneuvers could be found in the citation statute 316.1515 (Limitations on turning around) this citation is given to drivers illegally committing a prohibited turning movement, such as U-turn maneuver on limited access facilities.

The citations considered in the study are of illegal U-turn maneuvers committed at limited access facilities. Therefore, all potential citations that could include illegal U-turn maneuvers on limited access facilities were considered to avoid missing any citations data or incidents. The citation dataset used in the study was provided by the Florida Highway Patrol (FHP).

3.2 Florida Statutes Considered in the Analysis

As mentioned in section 3.1, two citation statutes were reviewed in the analysis to consider all WWD U-turn maneuvers in the limited access facility network (illegal U-turns). The citations were reviewed from January 2011 until December 2016. As a result, a total of 10,521 citations were included.

The study included citation data after January 2011 only because it was found that the citation recording system in years prior to 2011 was different and included different fields and records than the current citation systems. Therefore, January 2011 was the starting date for citation inclusion. The list below describes the citations statutes included in the analysis.

1. 316.1515, Limitations on turning around.

The driver of any vehicle shall not turn the vehicle so as to proceed in the opposite direction upon any street unless such movement can be made in safety and without interfering with other traffic and unless such movement is not prohibited by posted traffic control signs.

2. 316.090(2), Driving on divided highways.

No vehicle shall be driven over, across, or within any such dividing space, barrier, or section, except through an opening in such physical barrier or dividing section or space or at a crossover or intersection as established, unless specifically authorized by public authority.

3.3 The Study Area for the Median Crossover Analysis

The first step performed to determine the study area was locating the limited access facility network in the state of Florida using the road Shapefiles available from the FDOT Transportation

Data and Analytics Office Website (*38*). A shapefile is a file format used by the GIS software programs for storing the geometric location and associated information of geographic features. The geographic features in a shapefile can be represented by points, lines, or polygons (areas) (*39*). There was no shapefile classification available for the limited access facilities in the FDOT Transportation Data and Analytics Office Website. However, a classification for toll roads and interstates were found among the list of the Road Shapefiles. Therefore, the shapefiles of "Toll Roads" and "Interstates" were combined to determine the limited access facility network in Florida. The total length of toll roads statewide was about 802 miles, and the total length for interstates was about 1,495 miles, the majority of this mileage was in central and south Florida. Figure 15 shows a map of the study network including the toll roads and interstates in the state of Florida.

Figure 15: Map Showing the Toll Roads and Interstates in the State of Florida (Map Created by UCF).

The limited access facility network shown in Figure 15 includes roadways operated by various agencies and authorities such as the FDOT, FTE, the Central Florida Expressway Authority (CFX), the Tampa Hillsborough Expressway Authority (THEA), and other tolling agencies in the state of Florida. The complete network was reviewed to determine the study area to be considered in the analysis.

3.3.1 Selection Methodology of Study Area

In order to determine the study area two steps were followed. The first was to determine the locations with a high frequency of illegal U-turn citations statewide. The second was to classify the limited access roadways by the presence of median barriers on the road.

To start, the location of all potential illegal U-turn citations included in the analysis was determined. The location was determined using the coordinates found in the "GPS_LAT" and "GPS_LNG" fields in each citation. It was found that the majority of the median crossover citations occurred in the central and south Florida. Figure 16 shows a heat map of the complete dataset of all 10,521 median crossover related citations. The purpose of this map was to highlight the areas with frequent violations to determine the finalized study area.

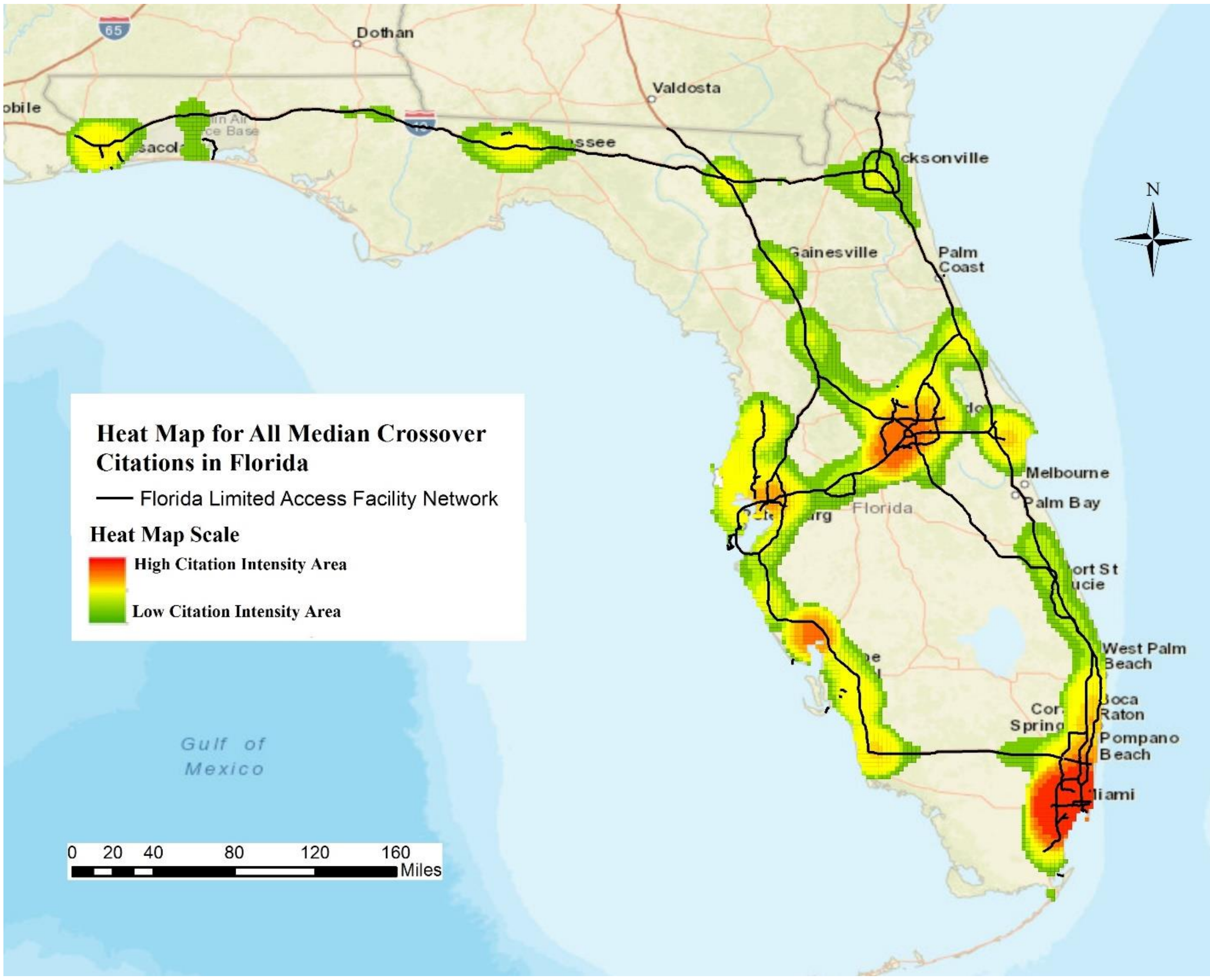

Figure 16: Heat Map Showing the Density of All Median Crossover Related Citations in the State Of Florida (Map Created by UCF)

After reviewing the median crossover citation heat map, the locations with the highest frequency of violations were: the Miami metropolitan area, the Tampa Bay area, and the Orlando metropolitan area (*40*).

The Miami metropolitan area, referred to as South Florida (SF) in this thesis, includes the three counties of Miami-Dade, Broward, and Palm Beach. The Tampa Bay area includes the four counties of Hernando, Hillsborough, Pasco, and Pinellas. The Orlando metropolitan area, also referred to as Central Florida (CF) in this thesis, includes the counties of Lake, Orange, Osceola, Seminole, Volusia, and Polk. Areas in the state with minimal citations were excluded from the

analysis. The areas with minimal citations would have limited risk of crashes, and by result minimal benefit of studying since the occurrence of the illegal U-turn violations is very limited already. Figure 17 shows a map of the three metropolitan areas reviewed in the study.

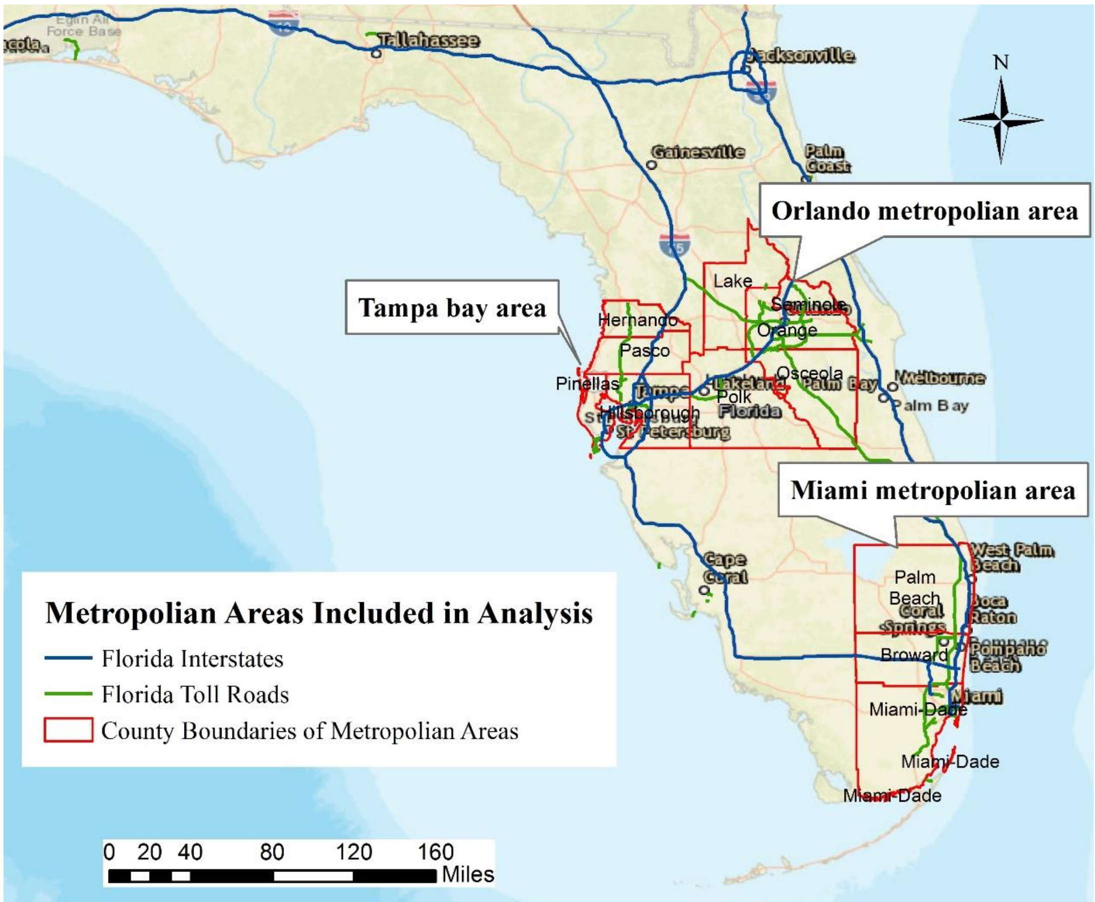

Figure 17: Map Showing the Three Metropolitan Areas Included in the Study (Map Created by UCF)

The second step conducted was classifying the limited access facilities in the included areas by the presence of median barriers that would prevent the median crossover violations and the crashes resulting from the crossover maneuvers.

The roadways included in the analysis do not have a median barrier separating the two opposing directions of traffic. This requirement eliminated a considerable amount of roadways from the analysis statewide, especially after FTE’s project in year 2006 to install median barriers

on their network. The FTE network was the only network included, but the agency controls about 33% of the toll roads statewide (265/802 miles= 33%). The results of that above FTE project reduced the number of crossover crashes in Florida significantly (*41*). As a result, the roadways considered in the study were reduced as well.

The roadways included in the study were first examined to see if they have an adequate length of the traversable medians sections. Afterwards, the roadways were examined to see if they have illegal U-turn citations on the traversable sections to be analyzed and studied.

The classification was performed by studying the aerial photos provided by Google Maps and ArcGIS (*42*). In addition, on the FTE network only, the Final “As-Built” plans for the median barriers and roadway network were provided by FTE and reviewed to verify the results found by Google Maps. Google maps were used to scroll over the roadways included in the study area and classify whether a roadway has a median barrier installed or not. Most of the traversable medians with no median barriers found on the roadway were grass sections, and the median barriers found were either concrete or cable barriers.

A total of 285 miles, 355 miles, and 212 miles of roadways were studied in CF, SF, and Tampa bay area, respectively.

The CF area had about 61 miles (out of 285 miles) of traversable median facilities (21%). The SF area has a total of 24.5 miles (out of 355 miles or 7%) of traversable medians, mostly located on one interstate (1-75). However, in the Tampa bay area it was found that 170 miles out of 212 miles were traversable medians, but the area was not included in the analysis because of the minimal illegal U-turn citations found on the traversable median segments; only 6 illegal U-turn citations were found over approximately 170 miles of traversable medians.

The total length of the traversable median segments in both CF and SF was about 85.5 miles out of 640 miles of limited access facility network studied. Figure 18 shows a map of the two included areas with the median classification of each segment illustrated by color.

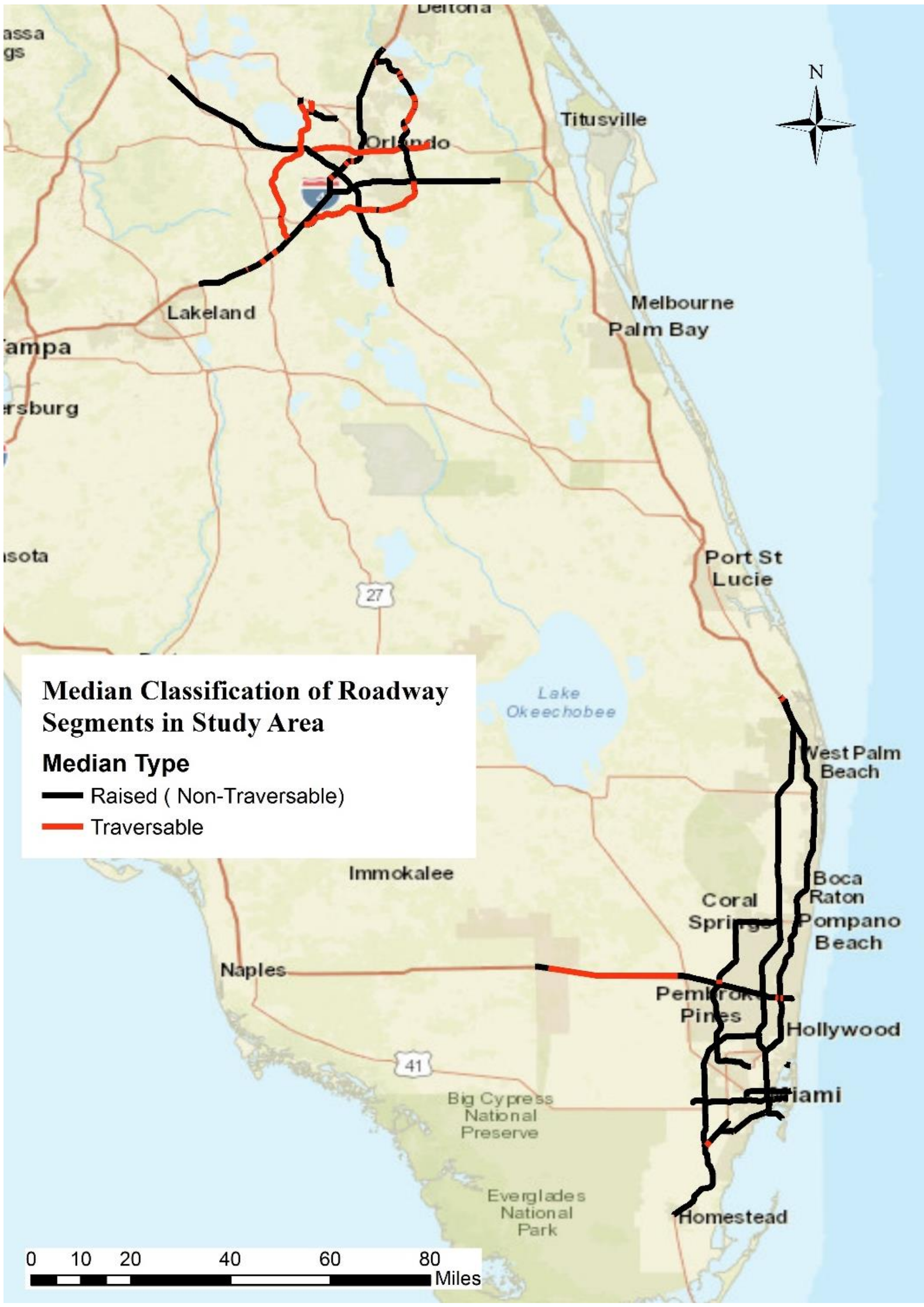

Figure 18: Map of Florida Showing the Median Type of the Included Roadways Segments (Map Created by UCF)

3.3.2 Description of the Study Area of Violations at Traversable Medians

The study area for traversable median included the traversable median segments in CF. This network lays over 21 cities including: Altamonte Springs, Apopka, Auburndale, Belle Isle, Minneola, Oakland, Groveland, Ocoee, Sanford, Orlando, Oviedo, St. Cloud, Kissimmee, Debary, Lake Mary, Eatonville, Lakeland, Leesburg, Maitland, Winter Garden, and Winter Springs.

This study area includes all of CFX network, and a considerable amount of the FTE network as well. In addition, other non-toll roads operated by the FDOT were included, such as Interstate 4 (I-4) and parts of State Road 429 (SR-429).

An advantage of studying such a geographically connected area, is the homogeneity of the road users. They have similar characteristics and reside in the same area. This homogeneity results in a higher potential of more related citations to analyze and a higher correlation in the analyzed data.

As mentioned in section 3.3.2, the segments in the SF area were not included in the traversable median analysis because the majority of the citations occurred at median crossovers openings only. The longest traversable median segment in SF was found on I-75, the roadway included 6 median openings. Five out the 6 median openings had illegal U-turn citations on them. A possible explanation for this would be that drivers would prefer to commit an illegal U-turn at a paved median openings rather than the traversable grass median sections. In addition, the spacing between the openings at this section in SF is almost consistent (about 3 miles) encouraging drivers to commit illegal U-turn maneuvers. Figure 19 shows the section of I-75 with the citations recorded at that roadway.

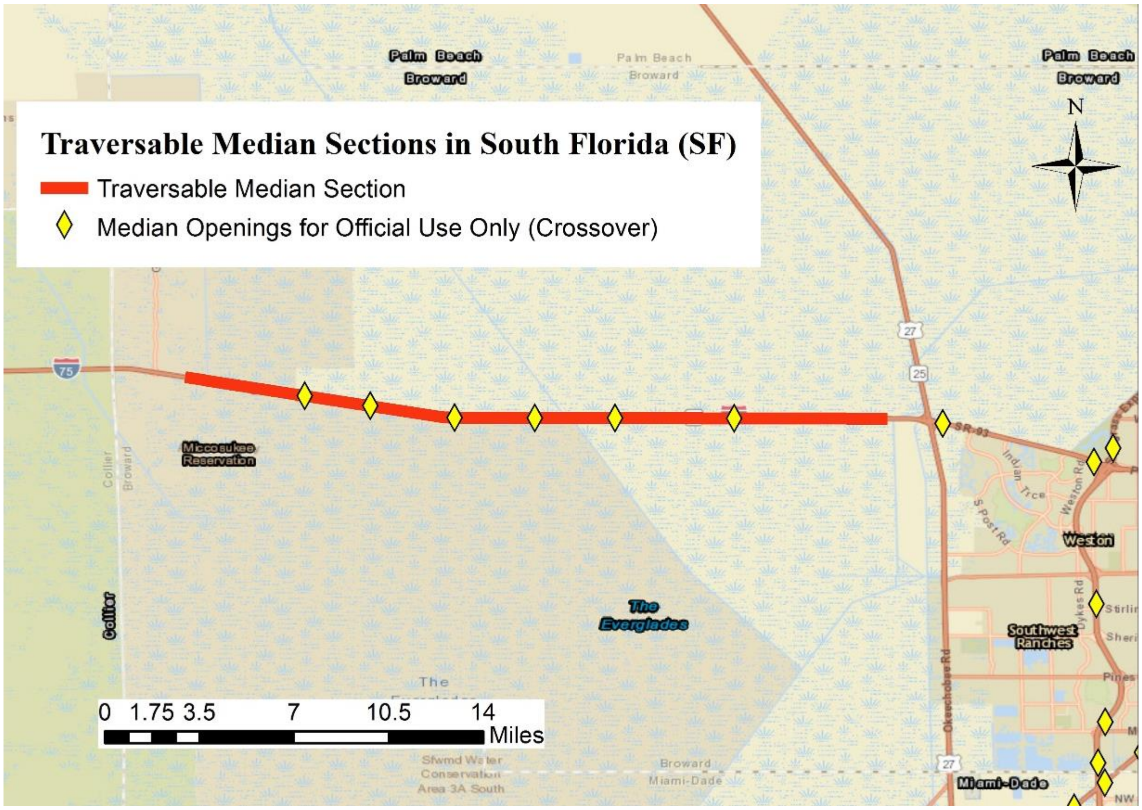

Figure 19: A Zoomed Map Showing the Traversable Segment on I-75 in the SF area.

The traversable median segments in SF area were included in the model that analyzed all types of median facilities statewide. The differences between the modeling methodologies are described in chapter five.

3.3.3 Description of Study Area of Median Crossovers for Official Use Only.

As mentioned in earlier in section 3.3.1, the roadways included did not have a physical median barrier separating the two opposing directions of traffic and preventing the illegal U-turn maneuver. However, the presence of a physical median barrier cannot prevent the violations occurring at median openings (crossovers) for official use. Therefore, all median openings on limited access facilities in CF and SF were considered in the analysis to determine the contributing factors that would encourage or discourage drivers to perform such violations.

The total number of median crossovers found in both CF and SF areas was 168 crossovers. A total of 73 median crossovers were found in CF and 95 were found in SF. Figure 20 shows a map of the 168 median crossovers for official use only included in the study area, with the color of the operating agency responsible for the network where the opening is installed.

Figure 20: Map of Median Openings (Crossovers) in CF and SF (Map Created by UCF)

The median openings included exist on roadways operated by different agencies. However, it was noticed that the majority of the median openings included were on roadways operated by FTE. A total of 91 out of the 168 openings included (54%) were found on the FTE roadway network (SR 91), although only 21% of the overall included network is operated by FTE (139 miles out of the 640 miles of the limited access facilities included). Some openings were found on the Homestead Extension of Florida's Turnpike (HEFT) network such as SR 821, which are operated by FTE. However, for the purpose of identifying the properties of each roadway, both SR 821 and SR 91 were analyzed separately. The number of median openings found on each roadway, the percentage of median openings out of the total, the length of roadway studied with median openings presence, and the average distance per opening for each roadway are shown in Table 1.

Table 1: Number of Median Openings on Each Roadway.

Roadway Name	No. of Crossovers	% of Total Crossovers	Length (mile)	Avg. Dist./Opening*
SR 91	91	54.2%	139	1.53
SR 821	20	11.9%	47.6	2.38
I-75	12	7.1%	50.8	4.23
SR 429	8	4.8%	59.5	7.44
SR 417	7	4.3%	110.3	15.76
SR 528	6	3.6%	64.5	10.75
I-4	6	3.6%	125.7	20.95
I-95	5	3.0%	88.8	14.80
SR 869	5	3.0%	20.7	4.14
SR 408	3	1.8%	46	15.33
SR 874	2	1.2%	7.9	3.95
SR 414	1	0.6%	10.7	10.70
SR 414/429	1	0.6%	3.3	3.30
SR 112	1	1%	4.6	4.60
Grand Total	**168**	**100%**	**779.4**	**Average = 8.77**
***** Avg. Dist./Opening = Length of Segment/No. of Median Openings				

To identify the significant contributing factors that influence the WWD illegal U-turn violations at the median openings, median openings were included in both the analysis and modeling phase.

3.4 Summary of Data Preparation

This chapter included three main sections describing the data preparation procedure performed to prepare the datasets for analysis and modeling in the proceeding steps.

The first section discussed the citation preparation procedure, and it included the datasets of two citation statutes: 316.1515 (Limitations on turning around) and 316.090(2) (Driving on divided highways) from January 2011 to December 2016.

The second section reviewed the preparation of study area. The study area included the limited access facility network in Florida determined from the GIS shapefiles provided by the FDOT website. Due to the wide range covered by the limited access facility network, a selection methodology was introduced by using heat maps generated by ArcGIS plotting the locations of the recorded citations to determine the areas with the highest frequency of this type of violation. The areas that have a higher amount of citations have higher risks of crashes occurring and have the highest advantage and benefit of being analyzed and studied.

The selection methodology resulted in CF and SF regions to be included in the study and analyzed. The analysis for the traversable medians mostly included the median segments from central Florida because of the considerable length of roadways without median barriers in central Florida. Moreover, the analysis for the median openings included both CF and SF areas.

The third section reviewed the traversable median segments included in the analysis, and contained 37 traversable median segments in CF only. In addition, 7 medians segments found in SF would be analyzed separately in the combined model statewide with traversable medians and median openings. Furthermore, 168 median openings were found in Florida (73 in CF and 95 in the SF). The majority of the median openings were found on SR 91 and SR821.

This section was prepared as a prerequisite for the analysis chapter 4 (next) where the properties and characteristics of the illegal U-turn incidents will be studied and analyzed. Moreover, this chapter defined the median facilities that will be included in the modeling phase, where several explanatory variables were examined to verify their expected correlation with the illegal U-turn incidents at the limited access facility network.

4. CHAPTER FOUR: WWD CITATION DATA ANALYSIS

4.1 Introduction

The citation dataset described in chapter three, included 10,521 citations statewide from January 01, 2011 until December 31, 2016. The complete dataset had 576 citations with missing values, which constitutes about 5% of the total data; therefore, would not have any significant effect on the results. As such, they were excluded from the analysis which reduced the number of citations down to 9,929.

As mentioned in chapter 3, the WWD illegal U-turn citations were not found in one specific citation statute. Therefore, to assure including all related citations in the study, the citations were selected using two different selection methodologies and then combined to have one complete collection of all illegal U-turn citations.

The first selection methodology was to select citations by location, using the coordinates recorded in the "GPS_LAT" and "GPS_LNG" fields. This methodology was conducted to include the citations located at the median facilities included in the study areas in CF and SF. It was found that about 72% of the citations were located within the boundaries of the two study areas mentioned with a total of 7,182 citations.

The second selection methodology was to select citations by description. The selection was done by manually reviewing the description of all 10,521 citations in the dataset to find all U-turn related violations by finding related key words in the "VIOLATION_LOC_TX" or "OTH_COMMENTS_TX" fields. Several key words were used in the filtering process such as "U-turn", "turn around", "crossover", "crossing", "official use only", etc. A majority of the median crossover citations were addressed to drivers that had illegally crossed the taper or the painted median section at the gore area to merge into the mainline from the off-ramps or vice

versa. The gore area is the flushed marked area prior to the exit ramp that separates the ramp from the mainline. Also, a considerable amount of the citations were addressed to drivers using the median section to pass stopped vehicles, mostly due to non-recurring congestion resulting from traffic incidents occurring downstream on the roadway. Both of these violations mentioned here were excluded from the analysis. This selection methodology was conducted to avoid not including the citations that were located in the study area, but had an error in the recorded coordinates of the location of the incident.

The selection methodology by description resulted in a total of 682 illegal U-turn related citations in Florida. However, 552 out of the 682 were located on the interstates or toll roads as defined by the FDOT GIS shapefile statewide (*38*).

Afterwards, the locations described in the 552 citations and their coordinates were manually reviewed and verified to match with the text location descriptions included. A total of 301 out of the 552 citations were found on the limited access facility network included in the study. About 221 out of 301 were found in CF, and the 80 remaining citations were in SF. The remaining 251 citations were distributed around the state as shown in Figure 21. About 30 citations were found in the Tampa bay area, 22 citations were found in Naples area, 24 in Cape Coral area, and 26 near to Port St. Lucie. Other locations in North Florida such as Gainesville, Tallahassee, and Pensacola also had about 20 citations each. In addition, the areas in North Florida and Naples area had only limited access facility crossings through that area, which would not be adequate for analysis purposes. Therefore, CF and SF were the only two areas included in the analysis because of the high intensity of citations in these areas. The heat map shown in Figure 21, plots the 552 illegal U-turn citations on limited access facilities and exemplifies the high intensity of the illegal U-turn citations in CF and SF areas.

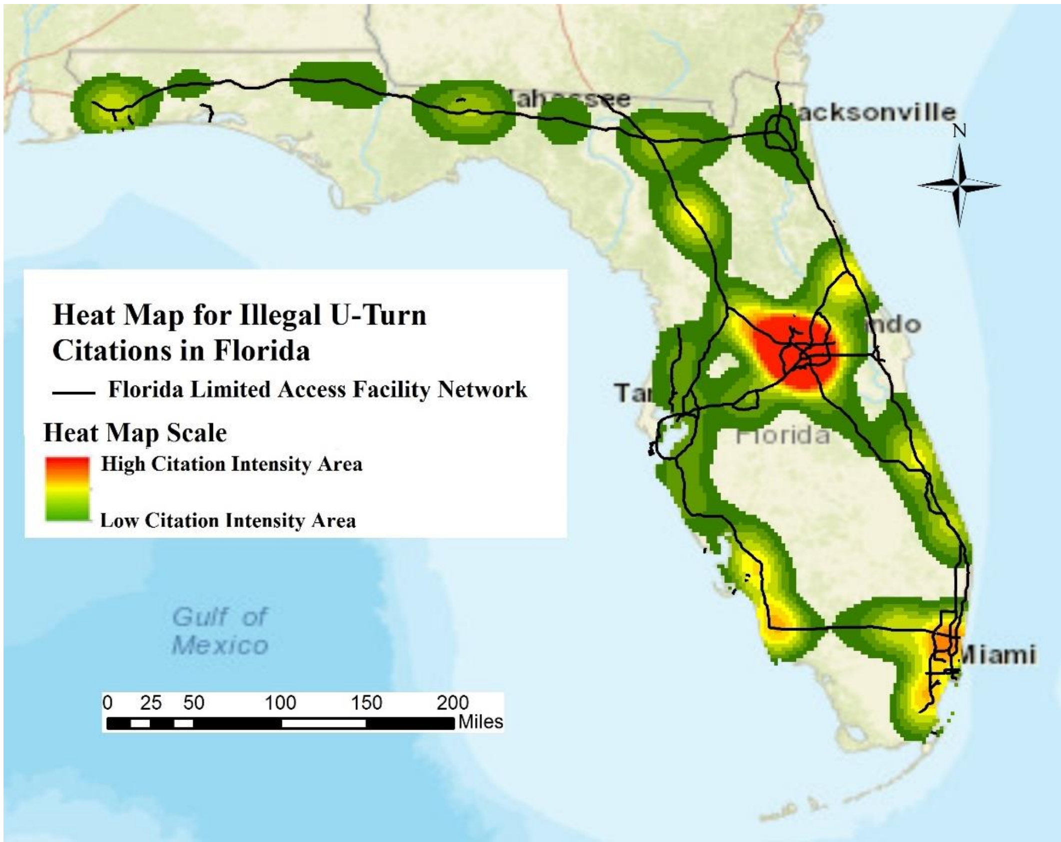

Figure 21: Heat Map Showing the Filtered illegal U-turn Citations by Description on the Limited Access Facilities in Florida (Map Created by UCF).

The heat map showed in chapter 3 (Figure 16), plotted all 10,521 median crossover related citations, but this heat map plotted the filtered illegal U-turn citations by reviewing the description of the listed citations. As shown in Figure 21, the CF area is the area with the highest risk of WWD illegal U-turn violations compared to SF area that was shown as the dominant area in Figure 16 that plotted all median related violations statewide.

The previous discussion was a simple explanation showing the difference between the two conclusions resulting from analyzing the two datasets. However, to have a more comprehensive understanding of the illegal U-turn violations a segment based analysis was conducted in the following sections of the chapter.

4.2 Description of the Citation Classification Procedure

As described in chapter 3, the illegal U-turn citations were studied on two different median facilities: the traversable medians segments and the median openings for official use only (crossovers). Therefore, two types of citations were required to be determined: citations at the traversable grass medians, and citations at the median crossovers for official use only.

Two selection procedures were introduced to find the complete citation dataset for illegal U-turn citations. The two procedures were: selection by citation location and selection by citation description.

The selection by location procedure selected all citations located on the study network in CF and SF, using the feature of "selection by location" provided by ArcGIS (*42*). The used ArcGIS feature defines a target layer to select from and a source layer that is taken as a reference for the selection procedure.

The citations included in the traversable median analysis were selected first. For such purpose, the target layer defined in the selection feature was all 9,929 citations in the study area, and the source layer was defined to be the traversable medians located in the study area. The location of all traversable medians was showed in chapter 3. Afterwards, all citations located within a 1000-foot distance from both sides of the centerline of the traversable medians in both CF and SF were included. A screenshot from the selection methodology is illustrated in Figure 22.

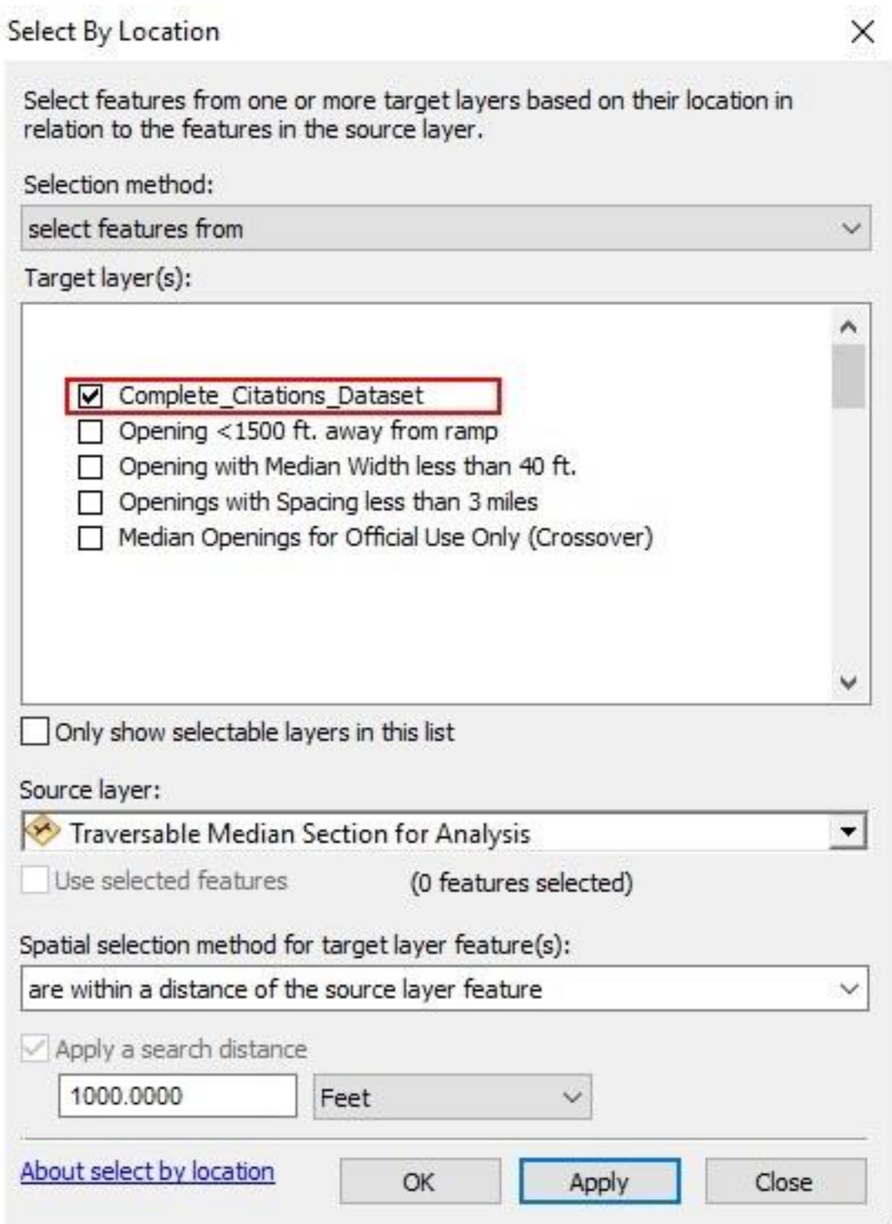

Figure 22: Screenshot of the ArcGIS Software Selection by Location Tool

The maps of the traversable medians and illegal U-turn citations analyzed in CF and SF are shown in Figure 23 and Figure 24 respectively. A total of 196 illegal U-turn related citations were found in both CF and SF. The CF area included 150 citations, and the SF area included 46.

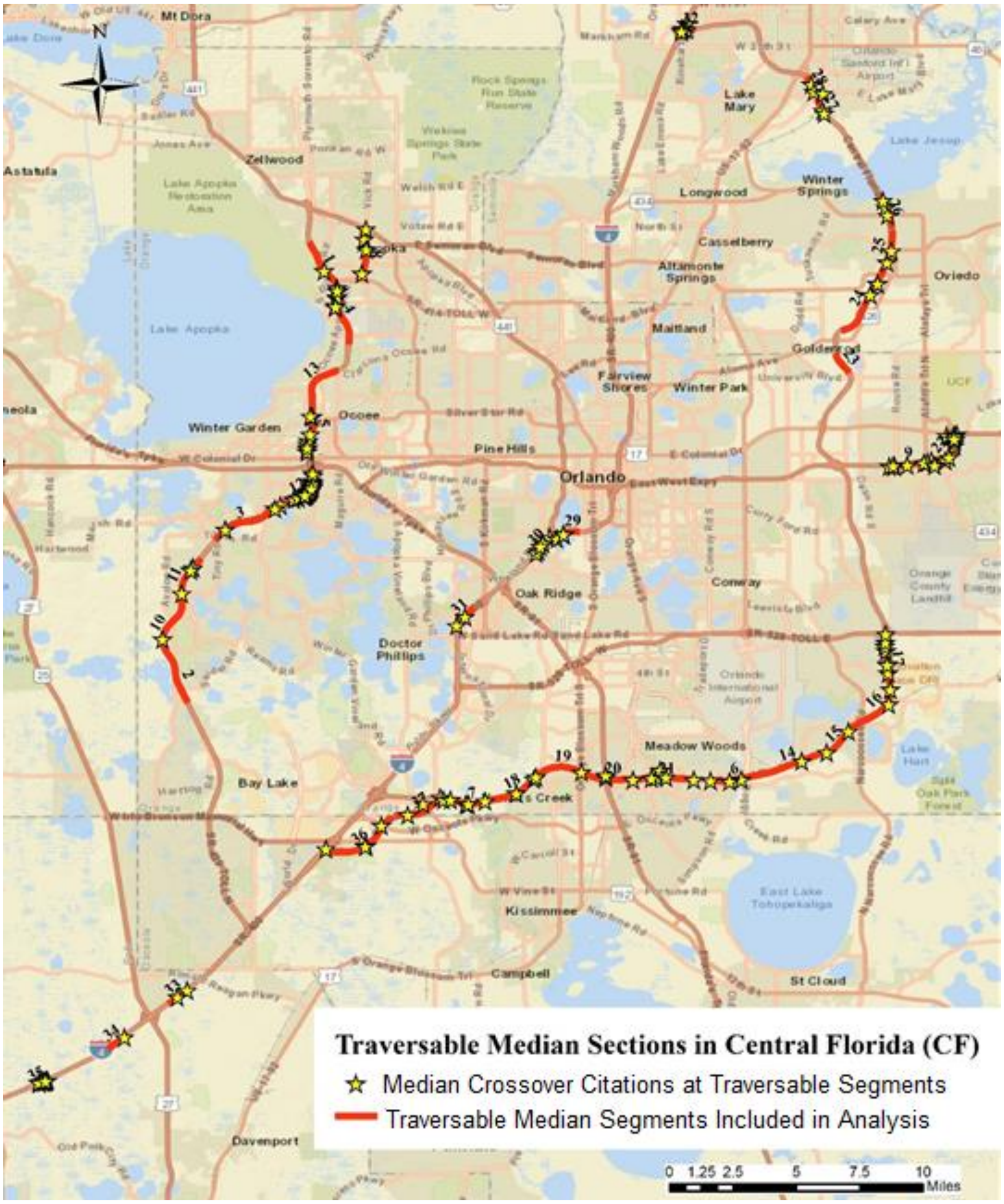

Figure 23: Map of CF Area with the Traversable Median Sections and Their Illegal U-turn Citations (Map Created by UCF)

Figure 24: Map of SF Area with the Traversable and Raised Median Sections and their Illegal U-turn Citations (Map Created by UCF)

The second type of citations was the citations at the median openings (crossovers) for official use only. Similar to the citations at the traversable median citation, the "selection by location" feature in ArcGIS was used to determine the included citations. The study included all citations located within a 1000 ft. distance from each median opening included, out of the complete dataset of 9,929 citations. The selection resulted in a total of 1,092 median crossing related citations in both CF and SF areas. The median crossovers locations with the included citations are shown in CF and SF are shown in Figure 25 and Figure 26 respectively. Afterwards, the description in the fields of the 1,092 citations were reviewed to determine the type of violation assigned to the citation. The review resulted to include a total of 251 U-turn citations, 91 in CF and 160 in SF.

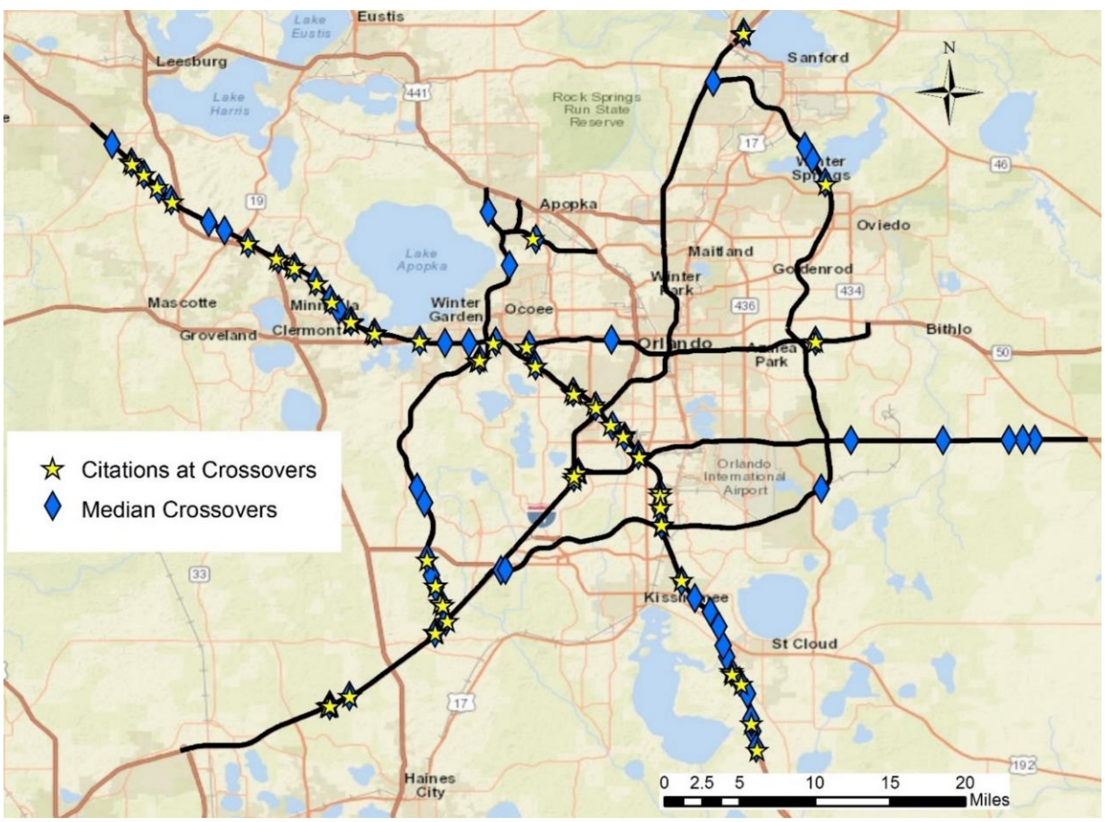

Figure 25: Map of CF Area with the Median Crossovers and Their Citations Locations (Map Created by UCF)

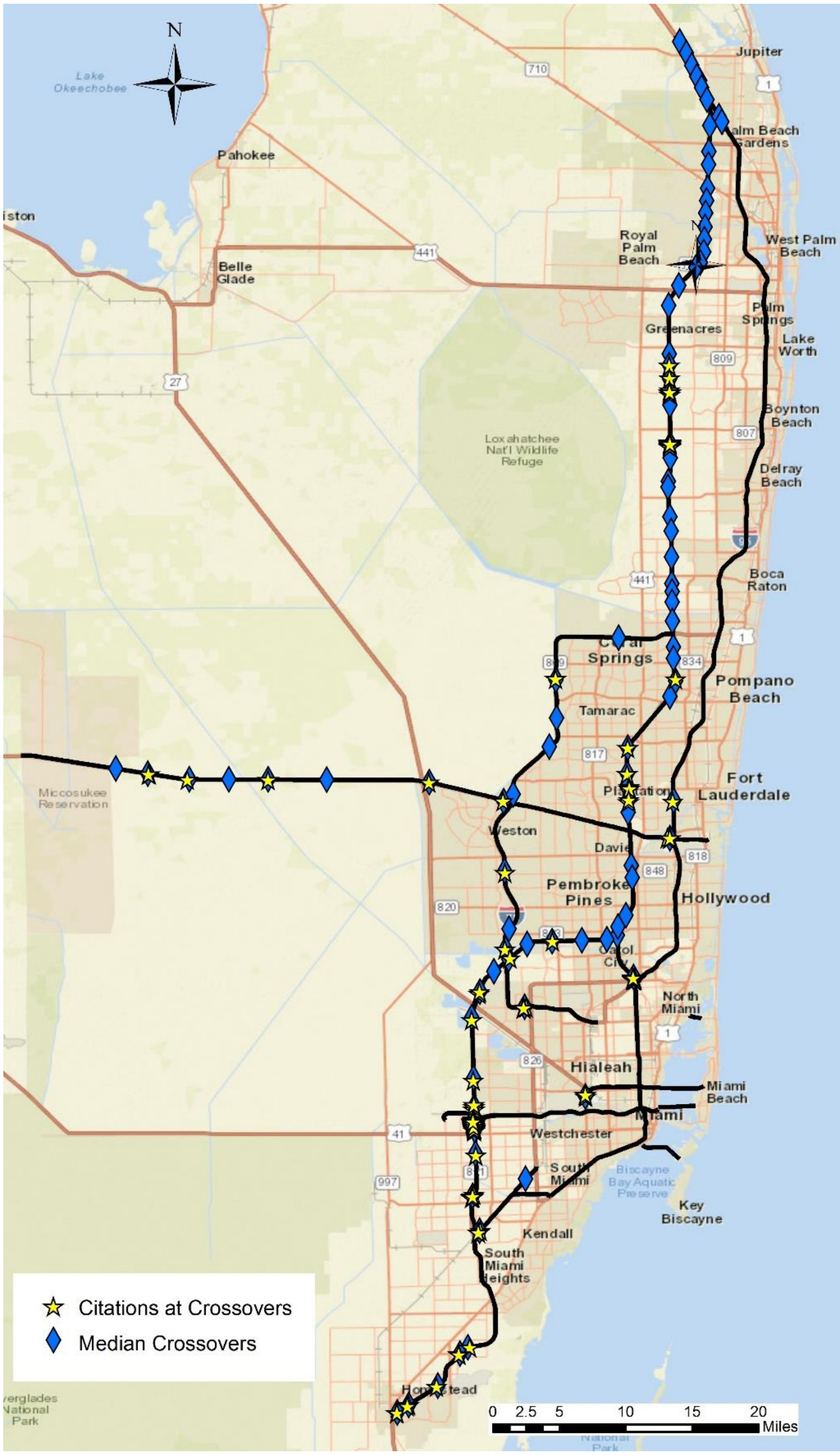

Figure 26: Map of SF Area with the Median Crossovers and Their Citations Locations (Map Created by UCF)

The second selection procedure was the selection by description. As mentioned in the introduction section 4.1, all illegal U-turn citations were included in the datasets, and the locations described in the citations agreed with the recorded coordinates of the citations. Therefore, the citation dataset was filtered to only include the citations located in the limited access facility network in both CF and SF. Afterwards, the citations found from both selection procedures were combined to have a complete illegal U-turn citation dataset.

Two different datasets were prepared to analyze the citations on each type of the median facility separately. The median facilities analyzed were the traversable median segments and the median openings for official use only. The result from the two selection methodologies resulted in the 240 citations at traversable median segments and 380 citations at median openings for official use only. The details on the two combined datasets are described in Section 4.4.

The reason why drivers perform illegal U-turn violations is ambiguous, but one possible reason is that such violations are performed by lost drivers or drivers who have entered the limited access facility by mistake and want to return and correct their path quickly without using the off-ramp and on-ramp at the nearest interchange to leave and enter the facility again. Another possible reason is to avoid getting charged at the toll booths on the on-ramps and off-ramps of the tollways. A driver who leaves the facility by the off-ramp usually gets charged at the off-ramp exit tool booth and would be charged again after entering the facility through the on-ramp to correct his or her path. However, this charging criteria is not designed at all exits but yet is assigned at a considerable number of the off-ramps and on-ramps of the toll roads in the state of Florida. An example of the case described before for getting charged while exiting and entering the facility is shown in Figure 27.

Figure 27: Aerial Photo of a Location on SR528 Exit 20, where Toll Booths are installed on the Off-Ramp and the On-Ramp (Google Maps).

This location is on SR-528 exit 20 going east bound and west bound. All of the mentioned possible factors were studied and included in the modeling phase to prove or reject the hypothesis and find the significant contributing factors for such violation.

4.3 Description of Crash Data

In Florida, before the year 2006, there were several severe median crossover crashes occurring on the Florida limited access highway network. It was found that 7 crossover crashes occurred on the FTE network by drivers attempting to do illegal U-turns from the period of 2003-2005 only (*41*). However, after 2006 the FTE started implementing median barriers on their system, thus reducing the number of crossover crashes on their network.

The crash dataset recording system adopted by FDOT after year 2011 does not include the illegal U-turn maneuver as one of the event types that occurred during the crash. As a result, the

illegal U-turn maneuver might have numerous potential records and event type depending on the police officer's decision at the crash site. To overcome this problem, the narrative and crash diagram of the potential crash reports from year 2011 to 2016 were manually reviewed to find the median crossover crashes resulting from drivers attempting to commit an illegal U-turn maneuver. The crash reports were downloaded from the signal four analytics website developed by the GeoPlan Center at the University of Florida (*43*).

After reviewing the crashes from year 2011 to 2016 to find crashes related to illegal U-turn related violations on the limited access facilities in the CF, it was found that median crossover crashes are still occurring on FTE. From year 2011 to 2016, 6 median crossovers crashes occurred in CF only. Three out these were located at the crossover openings installed on the FTE roadway network.

In order to have clear conclusions about this comparison, further investigation is required to clarify the effect of implementing median barriers on illegal U-turn violations and the drivers' behavior on the limited access facility network. This will be reviewed in details in the data analysis chapter. The remaining three crashes occurred traversable grass median segments on SR408, SR 417, and I-4.

An interesting case reviewed for a car making an illegal U-turn and causing another vehicle to crash with a truck adjacent to the vehicle and the illegal U-turn violator leaving the scene unharmed. The drawing of the median crossover crash obtained from the crash report is found in Figure 28.

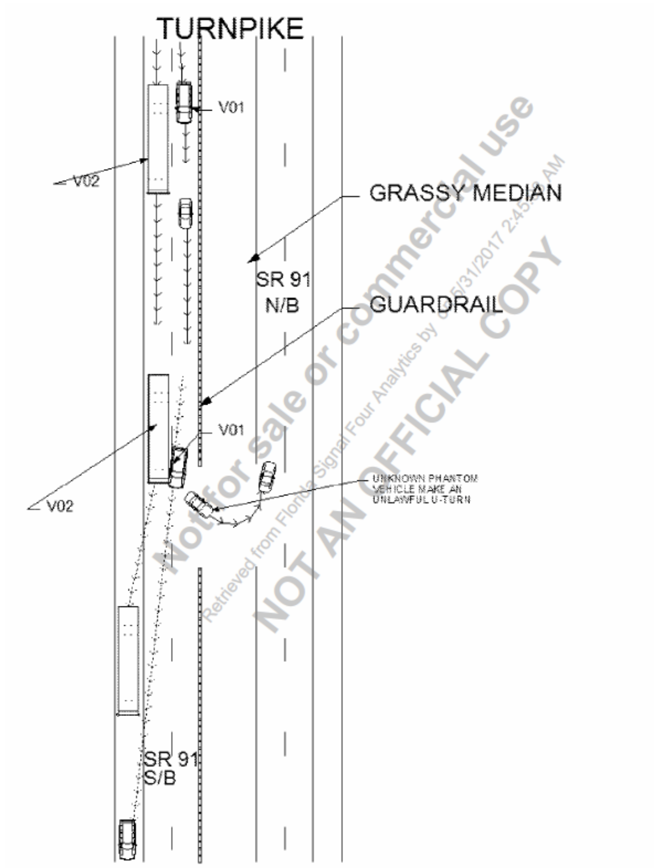

Figure 28: Crash Drawing of Median Crossover Causing Two Vehicles to Crash

Due to the limited sample of crossover crashes, analyzing the citation data was the criterion adopted to predict the location of illegal U-turn maneuvers resulting in crossover crashes as the one noticed in the diagram.

4.4 Description of the Citation Data

4.4.1 Citations at the Traversable Median Segments

The citations at the traversable median segments were collected by two different methods to guarantee including all illegal U-turn citations at the traversable median segments. The first method was selecting citations by location and the second method was selecting citations by

description. The two datasets were combined to have a total of 240 citations after deleting the overlapping citations in both datasets.

The final number of citations included in the CF area was 173, and the final number in the SF area was 67 citations.

4.4.1.1 Location and Time of Occurrence of Traversable Median Citations

The final study area for traversable median segment analysis included the limited access facilities in both CF and SF. The roadways that had the majority of the citations were state roads SR429 and SR417 with a total of 120 citations out of the 240 citations. The number of citations that occurred on the CFX roadway section was 112 out of the 240 citations mentioned earlier. Table 2 shows where the citations included in the study occurred.

Table 2: Number and Location of Traversable Median Citations Included In Each County

Roadway	**Length**	**Traversable Median Segment Length**	**Number of Citations**	**Citations/mile**
SR 429	57.9	17.1	75	4.39
SR 417	111	32.6	45	1.38
I-75	50.8	23.5	31	1.32
I-4	125.7	4.1	30	7.32
I-595	12.8	0.28	16	57.14
SR 408	45.5	3.15	14	4.44
SR 91	186	5.3	14	2.64
SR 528	72	0.2	5	25.00
SR 874	7	0.21	4	19.05
SR 451	4.3	2.1	4	1.90
SR 569	20.7	0.23	2	8.70

Furthermore, Figure 29 shows a bar chart of the distribution of citations on each roadway with the number of citations that occurred on it.

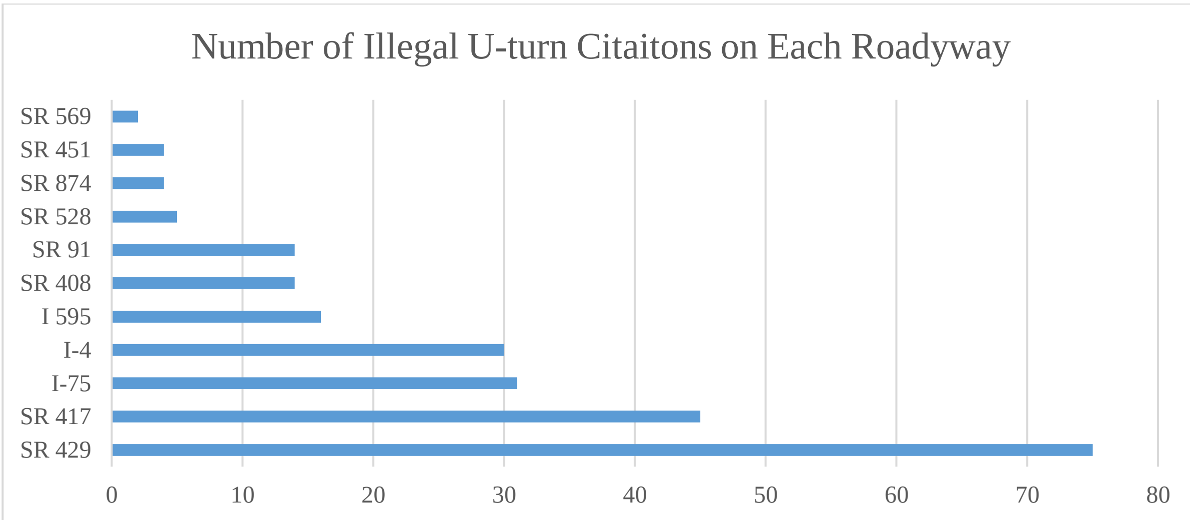

Figure 29: The Number of Illegal U-Turn Citations at Traversable Medians on Each Roadway

The citations were found over a 6 year period starting from January 2011 until December 2016 (see Table 3). Citations were distributed over the years except for 2016 which had noticeably less citations than the previous years with only 22 citations. Table 3 shows the number of illegal U-turn citations on traversable medians recorded each year.

Table 3: Number of Citations that Occurred Each Year

Year	Total
2011	43
2012	40
2013	49
2014	46
2015	40
2016	22
Grand Total	**240**

The citations' frequency by month shows that the number of citations through the months are within a similar range expect for October, where there was a noticeable drop in the total number of citations in that month over the six years. In addition, it was found that May was the month with the most number of citations as well. This increase in number of citations is expected and agrees with the findings of Rogers' study for WWD events in Florida (*41*). Figure 30 shows the distribution of the citations that occurred over the study period.

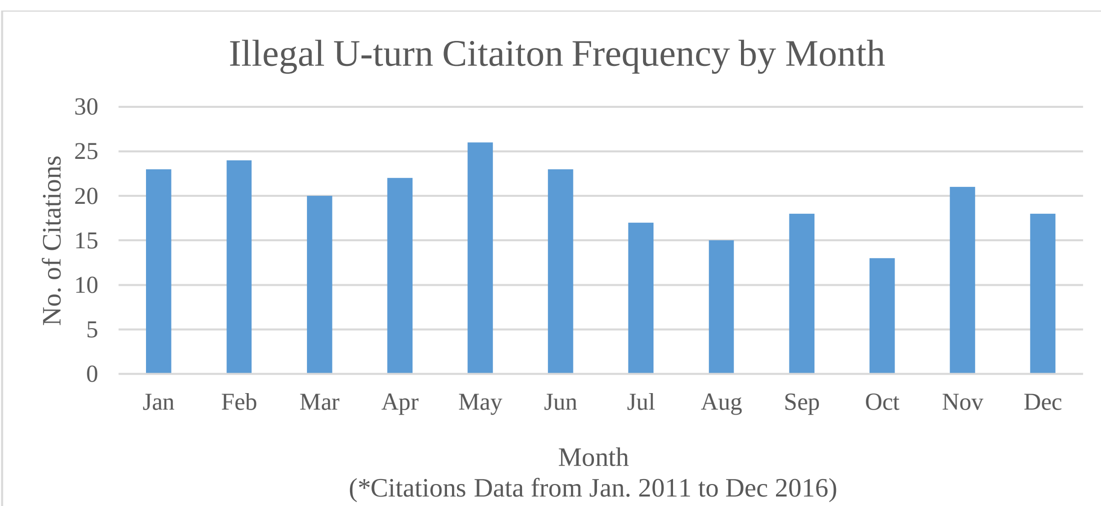

Figure 30: Number of Illegal U-Turn Citations at Traversable Medians That Occurred Each Month Over the Study Period

It was found that the citations occurred randomly over the week days with a slight increase found on Thursdays. This finding indicates that this type of citation does not occur on a specific day of the week and is a violation occurring randomly. The weekday breakdown of the citations is found in Figure 31.

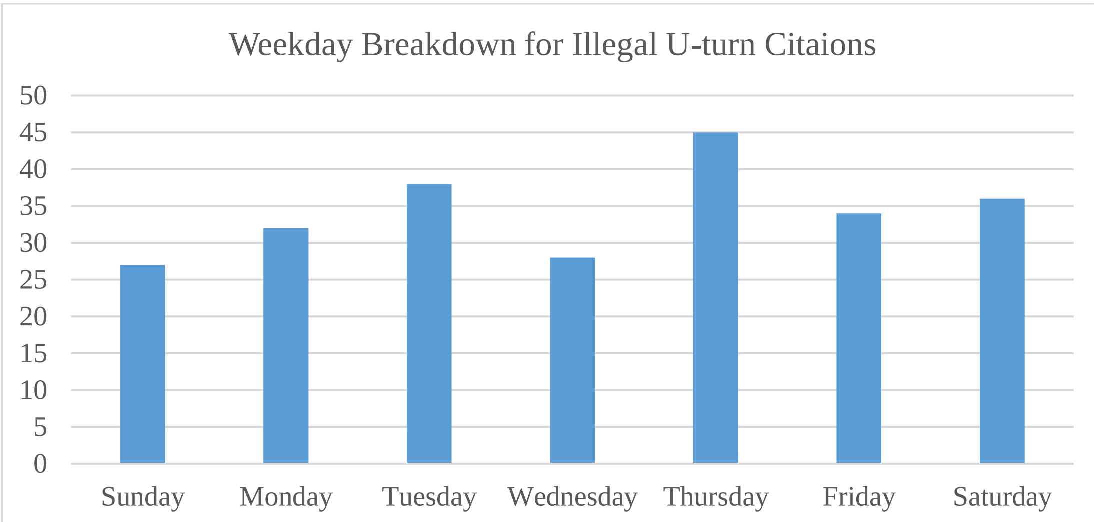

Figure 31: The Weekday Breakdown of the Illegal U-turn Citations Over the Study Period

In addition, it could be noticed from Figure 32 that the majority of the citations had occurred during the day, starting from 9 am until 6 pm with a peak period from 12 to 4 pm. This could be explained that drivers are less patient during the day and would be more susceptible to commit such violation to save time. Furthermore, during the day, police officers and highway patrols might have more presence and would be more alert for violations and illegal driving on those roadways. In addition, it was found that the volume of traffic during the day is significantly larger than the volume at night (*44*), and could have 7 times more traffic than at night time. This leads to traffic congestion (recurring and non-recurring) and drivers trying to change their routes impatiently by committing such illegal U-turn violations. As a result, the chance of a citation occurrence during the day compared to the night time would be much higher. However, other

contributing factors affect the driver's decision in committing such type of violation, therefore, the day to the night traffic volume ratios are not necessarily similar to violation occurrence ratio.

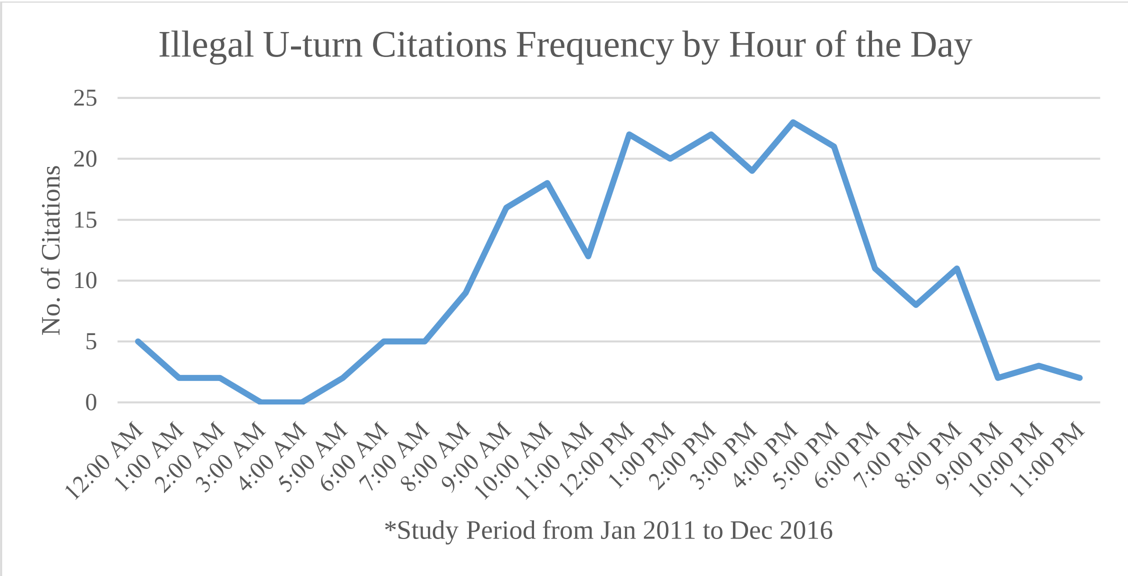

Figure 32: Hourly Median Crossover Citations on Study Network from 2011-2016

In order to find the actual day to night ratio, the sunrise and sunset times in both Orlando and Miami were reviewed, since the two cities were the major cities included in the areas described in chapter 3. The data was downloaded from the Astronomical Applications Department website (*45*). It was found for year 2013, that the earliest sunrise occurred at 6:30 AM in June, and the latest sunrise occurred at 7:20 AM in January. In addition, it was found in the same year that the earliest sunset occurred at 5:30 PM in December, and the latest sunset occurred at 8:27 PM in June. The average time for sunrise and sunset times were 6:55 AM and 7:02 PM respectively. The total number of citations that were cited from 7:02 PM until 6:55 AM are 24 citations. Therefore, the day to night ratio of citations is 5.5 which is less than the approximated traffic volume ratio. The complete table with the sunrise and sunset times is shown in APPENDIX B.

This finding also could be an indicator that the drivers would commit the illegal U-turn maneuver intentionally to reduce the travel time while they are sober. This would require applying countermeasures that combat intentional drivers who are willing commit such violation. The countermeasures suggested are described in details in chapter 6.

To have an overall view for when the citations occurred over the study period, Figure 33 illustrates the number of citations that occurred each month of the study period.

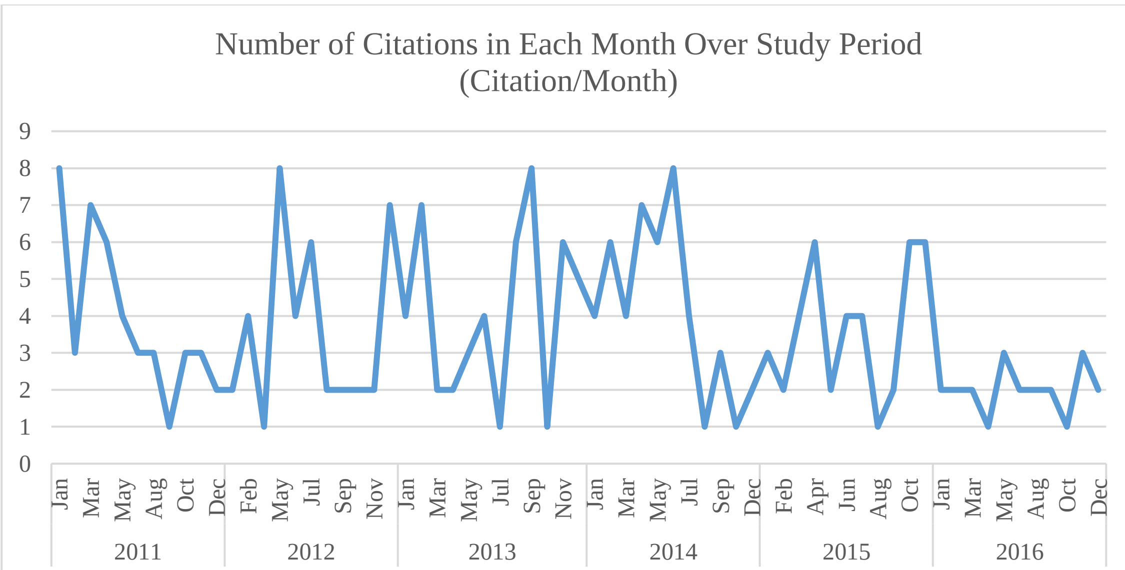

Figure 33: Monthly Median Crossover Citations on Study Network from Jan. 2011 to Dec. 2016

As shown in Figure 33, the number of citations fluctuate throughout the study period but have a common increase during the period of May, June, and July. The peak period for the number of citations is similar to the peak periods found by other researchers before (*41*). The reason of this peak could be due to increased enforcements on the highway patrol system during later months of the fiscal year but this needs further evidence by collecting actual hours police spends on each highway which is very difficult to track. It should be mentioned that there are other factors which could have contributed to the change in frequency of the number of citations from month to month,

such as the increase in other types of violations or crashes on the roadways that resulted in an increased alert by the enforcement agencies, or even the change in weather conditions effecting the attitudes of drivers.

4.4.1.2 <u>Driver Characteristics of the Illegal U-turn Citations at Traversable Medians</u>

Another important aspect that was considered was the characteristics of the drivers conducting such type of violations. The purpose of conducting such type of analysis was to determine the type of drivers performing such violation and determine the appropriate countermeasure to be performed to combat the occurrence of such violations.

It should be mentioned that the citation database saves limited information about the driver characteristics and attributes. Therefore, limited analysis could be performed to find the characteristics of the drivers that most commonly commit such violation.

The first reviewed aspect was the driver's age category. The results showed that more than 50% of the citations were conducted by drivers between the ages of 25 to 44. A possible reason why the number of older drivers conducting such type of violation is limited is that elderly drivers are usually more responsible drivers and would be more hesitant to perform such type of illegal maneuver on the limited access facilities. Afterwards, the age exposure rate was estimated using the total numbers of licensed drivers in the state of Florida from FHWA (*46*). The exposure rates did not vary significantly from the percentage of total citations as the exposure confirmed that the most risky age group was from 25-34, followed by the age group 35-44. In addition, it was found that the oldest groups of drivers (age 65-74) and (age 75-85) have the lowest exposure rates, as shown in Table 4. The detailed calculation for the age exposure is found in APPENDIX

A. Based on this finding, agencies may want to focus their illegal U-turns countermeasure on younger drivers.

Table 4: Drivers' Age Categories of the Illegal U-turn Citations (Jan. 2011 to Dec. 2016.)

Driver Age	Total	Percentage	Age Exposure Rate*
15-24	27	11%	1.82
25-34	63	26%	2.76
35-44	59	25%	2.67
45-54	46	19%	1.78
55-64	30	13%	1.21
65-74	8	3%	0.41
75-85	7	3%	0.73
Grand Total	**240**		***Cit./100,000 drivers**

The other driver characteristic reviewed was the gender, where the majority of citations were made by male drivers. This would be expected since male drivers have the ratio of 3.41 to 1 compared to female driver in performing reckless driving violations (*47*). This ratio agrees with the ratio found in this study of 3.35 male drivers to 1 female driver in Florida in terms of citations at traversable median, as shown in Table 5. The male-to-female ratio was calculated by considering the total number of drivers from each gender as provided by FHWA (*46*). The detailed gender exposure calculation table is found in APPENDIX C.

A more precise exposure rate could be calculated by finding the vehicle miles of travel (VMT) by each gender group since one might argue that the VMT for males would be higher than females, but this detailed VMT values were not found in the FHWA website or database. The summarized results are presented in Table 5.

Table 5: Gender Breakdown for Drivers with Illegal U-turn Citations at Traversable Medians.

Driver Gender	Total	%	Gender Exposure Rate*	Ratio
F	57	24%	0.78	3.35
M	183	76%	2.62	
Grand Total	**156**	**100%**	**Cit./1 M driver**	

Figure 34 shows a bar chart with the groups of ages and genders combined.

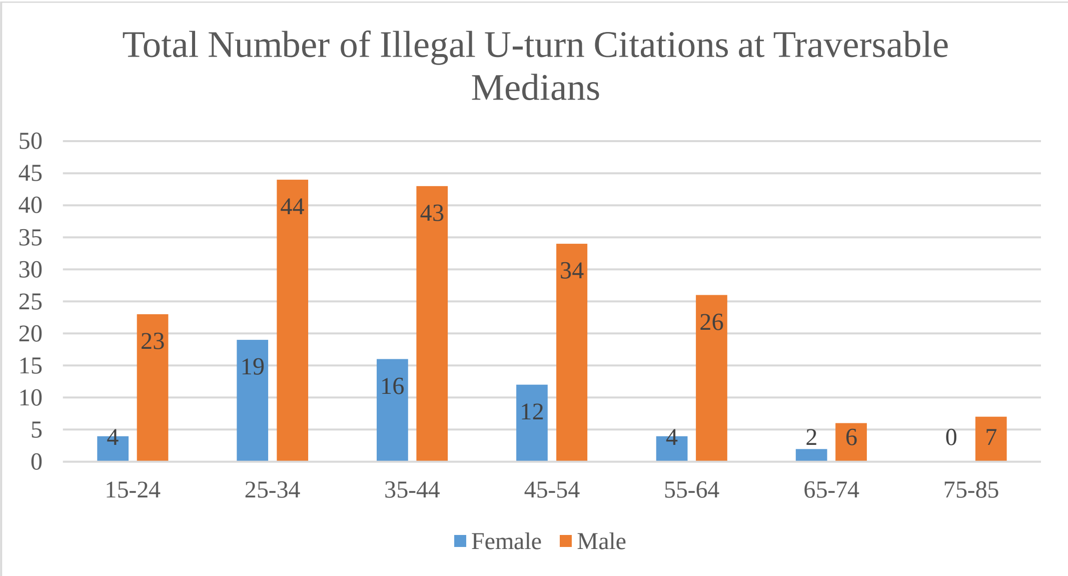

Figure 34: Age and Gender Breakdown for Drivers' with Illegal U-turn Citations at Traversable Medians from Jan. 2011 to Dec. 2016.

As shown in the figure, both genders have the same age distribution over the different age groups, indicating that drivers from both genders act similarly.

Furthermore, the race data was analyzed in the citation dataset. It was found that the majority of the citations were assigned to White and Hispanic drivers. The race exposure factors was found by considering the different race populations found in the Orlando metropolitan area and Miami metropolitan areas from the Census website (*20*). It was found that the race with the highest citation rate was the white race followed by the black race. The population data was used

as a substitute of the driver's data because the drivers' data does not include the race category in the record. The race exposure rates are shown in Figure 35.

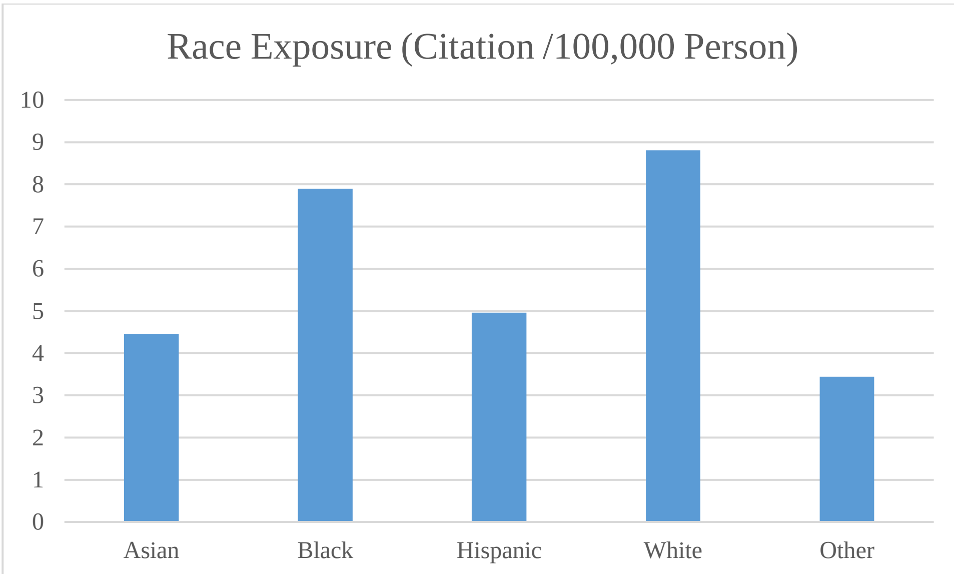

Figure 35: Race Exposure Rates for Citations at Traversable Medians

4.4.1.3 <u>DMVT Exposure Calculation Methodology for Traversable Medians</u>

It was found in the previous section that the illegal U-turn citations mostly occur during the day, when the traffic volume is the highest. Therefore, to have a more comprehensive understanding for the occurrence of this type of WWD, the Daily Vehicle Miles Traveled (DVMT) exposure rates were estimated in this section.

The DVMT exposure measures the exposure of the illegal U-turn citations in relation to the traversable median length. Usually exposures are estimated for random incidents where the incidents are uncontrolled or unintentional. In addition, it is expected that the number of citations would increase with the increase of the number of vehicles passing by that section.

However, in the case of illegal U-turn citation such simple conclusion might not be accurate because drivers commit the illegal U-turn maneuvers intentionally. Therefore, additional

analysis was conducted later in chapter 5 as an attempt to determine the locations with the higher WWD risk.

The calculation methodology for the DVMT exposure rates for traversable medians is found by dividing the number of illegal U-turn citations over the product of the length of the traversable median segment and the AADT on each roadway. The exposure rate represents the rate of occurrence per miles driven at traversable medians (citations/miles driven at traversable segment). This exposure helps determine the locations of the highest occurrence rate. However, this would not be the only aspect analyzed, other aspects such as interchange spacing, speed, etc. would be considered in the modeling section described in chapter five.

As described in chapter three, the traversable median segments were determined using the as-built design plans provided by the FTE and the aerial photos provided by Google maps and ArcGIS. Using the ArcGIS software the length of each traversable segment in the network was measured separately.

The traversable median segments in the study area were shown previously in Figure 23 and Figure 24. The maps showed the traversable median segments highlighted in red and the included citations that occurred on the access median segments shown on the map. The shown citations are the citations selected to be included in the study after the review and examination was conducted on the complete citation dataset.

Afterwards, the AADT on each roadway segment was obtained from the geographic information system (GIS) shapefile “Annual Average Daily Traffic” provided by the FDOT Data Shapefiles website (*38*). The AADT records found on the website were for year 2015, and the citations analyzed were included from 2011 until 2016.

However, since the study period is relatively short (difference between the beginning and end of the study period, the AADT different between year 2011 and 2016, is less than 0.1%) and

for ease of calculation the average AADT for all 6 years was used in the analysis to estimate AADT for June 2013 (the mid-range of the analysis period). According to City of Orlando (*48*), the Orlando area in year 2011-2014 had an average growth rate of 2.5%, therefore, this percentage was used for estimation.

All values obtained from the website (year 2015) were reduced by the growth rate of 2.5% over 1.5 annual periods to estimate the average AADT in June 2013. The exponential population growth equation was used as a substitute of the actual estimate counts in that year. The growth equation is shown in equation 4.1.

$$P(t) = Po * e^{k\,(t)} \tag{4.1}$$

Where:

AADT (t) = AADT after duration t

AADT (o) = AADT at duration 0 (Initial conditions)

k = Growth rate

t = Duration of growth

After obtaining both factors, the DVMT exposure rate was calculated by dividing the number of citations at each road over the product of the average AADT passing times the length of the traversable median segment. Equation 4.2 shows the equation used to calculate the DVMT exposure rate.

$$DVMT\ Exposure\ Rate = \frac{No.of\ Citaitons\ at\ Median\ Segment}{Length\ of\ Median\ Segment\ (Miles) * AADT\ at\ that\ section} \tag{4.2}$$

Where:

DVMT Exposure Rate: Citation / miles driver at traversable median segments

As mentioned in chapter 3, the study area had 44 separate median segments that can provide access for the driver to commit an illegal U-turn, each segment is a continuous median segment with no control or separation that limits the drivers' accessibility. The DVMT exposure rate was calculated for all median segments. The results of the exposure rates for the traversable median segments are shown in Table 6.

Table 6: Overall Median Exposure Rates for All Included Roadways

St. Name of segment	AADT	Segment L (Miles)	Avg. No. of Citations / Year	DVMT Exposure Rate*
I-4	84000	0.172	1.83	1.27
SR-429	45000	2.434	8.17	0.75
SR-451	10900	2.134	0.67	0.29
I-595	202000	0.116	0.67	0.28
SR-408	34500	1.576	1.17	0.22
SR-429	22500	2.084	1.00	0.21
SR-429	27000	2.527	1.33	0.20
SR-869	37000	0.234	0.17	0.19
SR-429	28000	1.738	0.83	0.17

*DVMT Exposure unit = Citation/ 100,000 Vehicle-Miles Driven at traversable median segments each year

As shown in Table 6, the segment with the highest citation occurrence per traversable mile is found on I-4 which is different from the overall roadway ranking. Moreover, 4 segments on SR429 were found in the highest 10 segments with the DVMT exposure rate.

The evaluated segments are illustrated in the map shown in Figure 36 and Figure 37. The map shows the traversable median segments with their DVMP exposure rates presented by the color scale described in the legend.

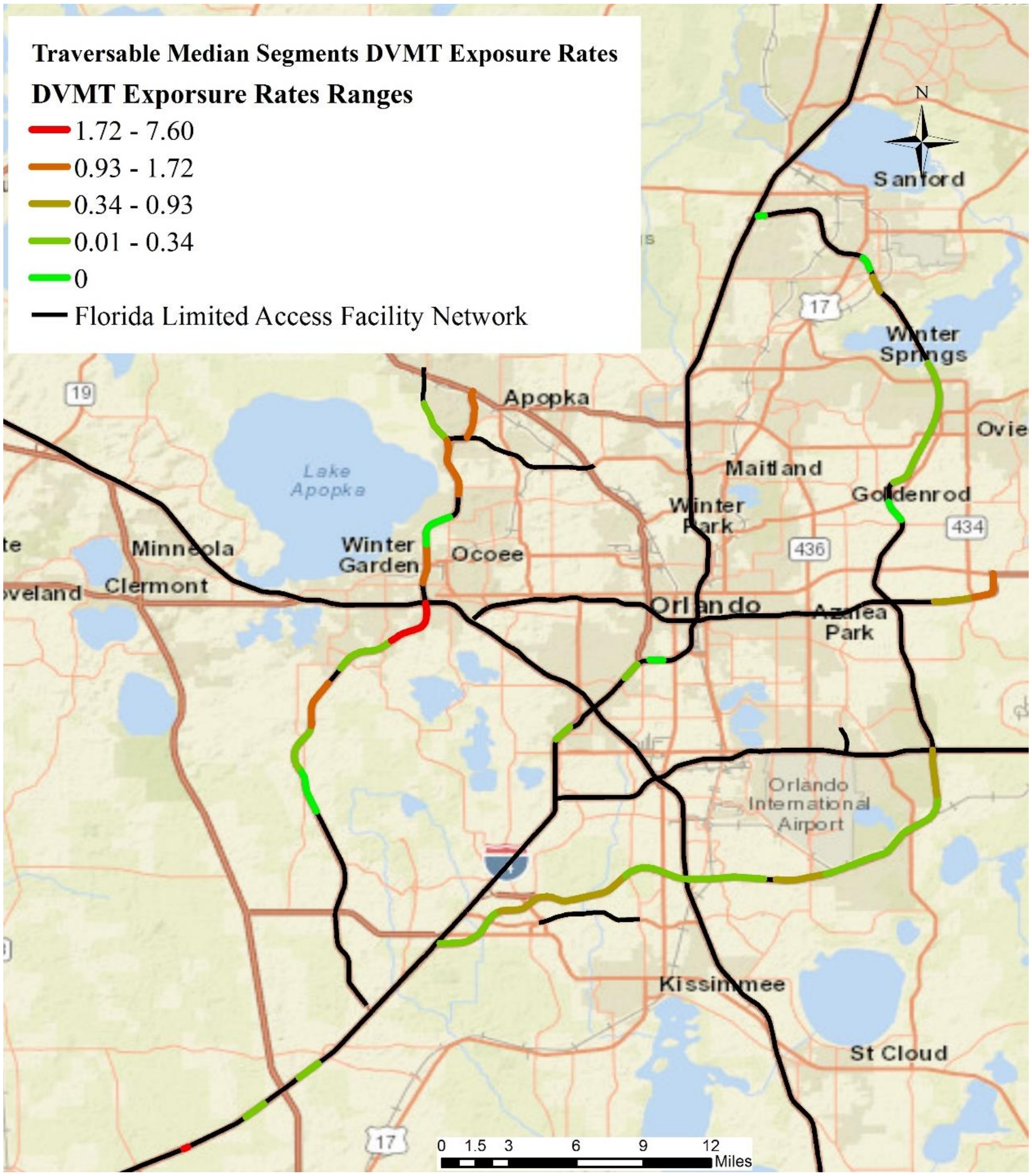

Figure 36: Map Showing the Traversable Median Segments and Their DVMT Exposure Rates in CF (Map Created by UCF)

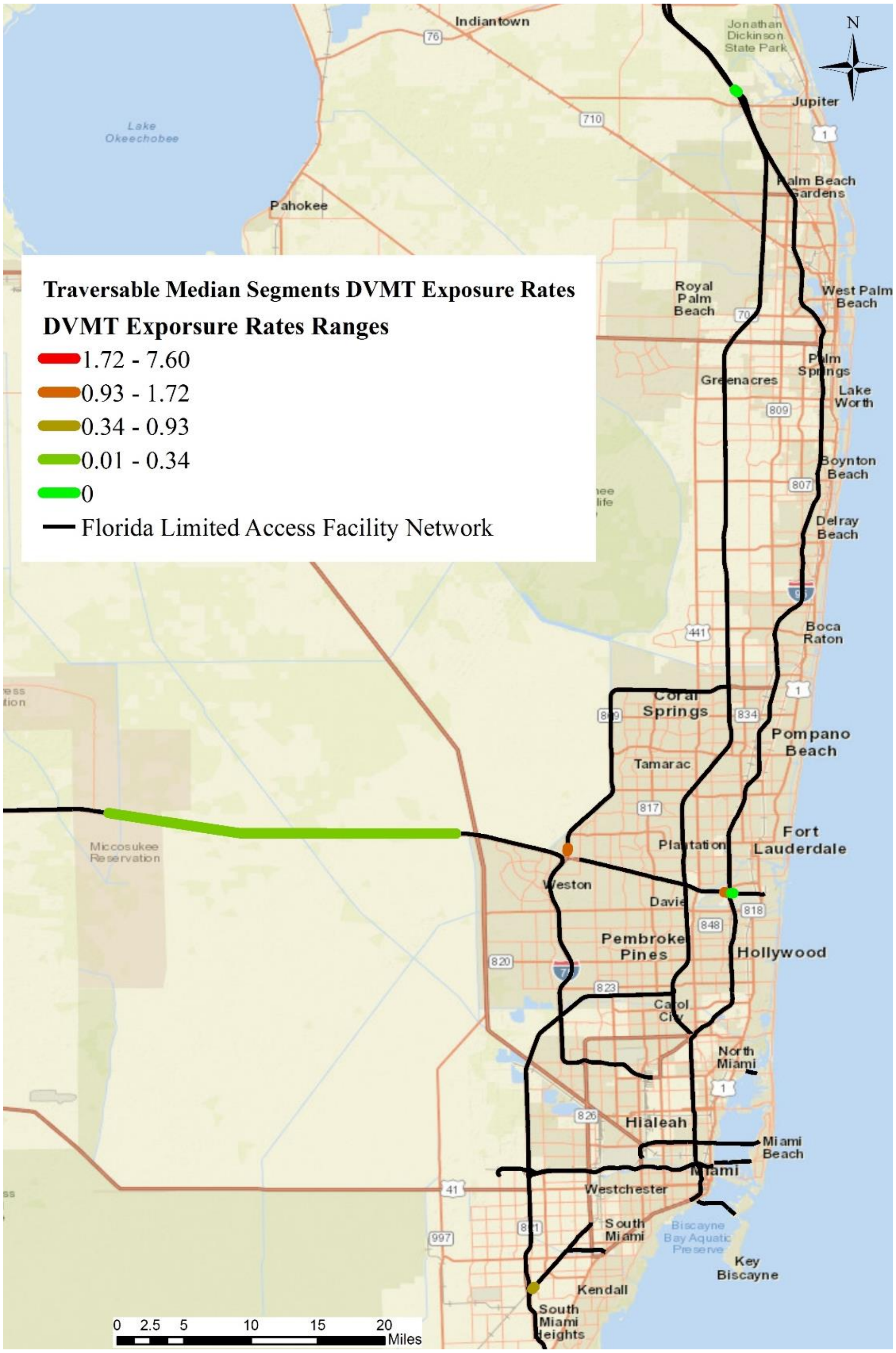

Figure 37: Map Showing the Traversable Median Segments and Their DVMT Exposure Rates in SF (Map Created by UCF)

4.4.2 Citations at the Median Openings for Official Use Only

Similar to the citations at the traversable median segments, the citations were selected using two different methods. The first method was by citation location, and the second was by citation description. The two datasets were combined and the total citations were 380 after deleting 65 citations repeated in both datasets. The CF area included 187 citations and SF area included 193 citations.

The number of illegal U-turn citations occurring at median openings was 380 citations in both CF and SF networks, and the total number of median openings analyzed in Florida was 168 openings. 73 median openings were installed in the CF area network, and 36 out of these openings had citations occurring on them (49%). Furthermore, in the SF network, 95 median openings were installed, and 31 of those openings had illegal U-turn citations on them (33%). Figure 38 and Figure 39 show the locations of the medians openings in the CF and SF networks respectively with the illegal U-turn citations occurring at those openings.

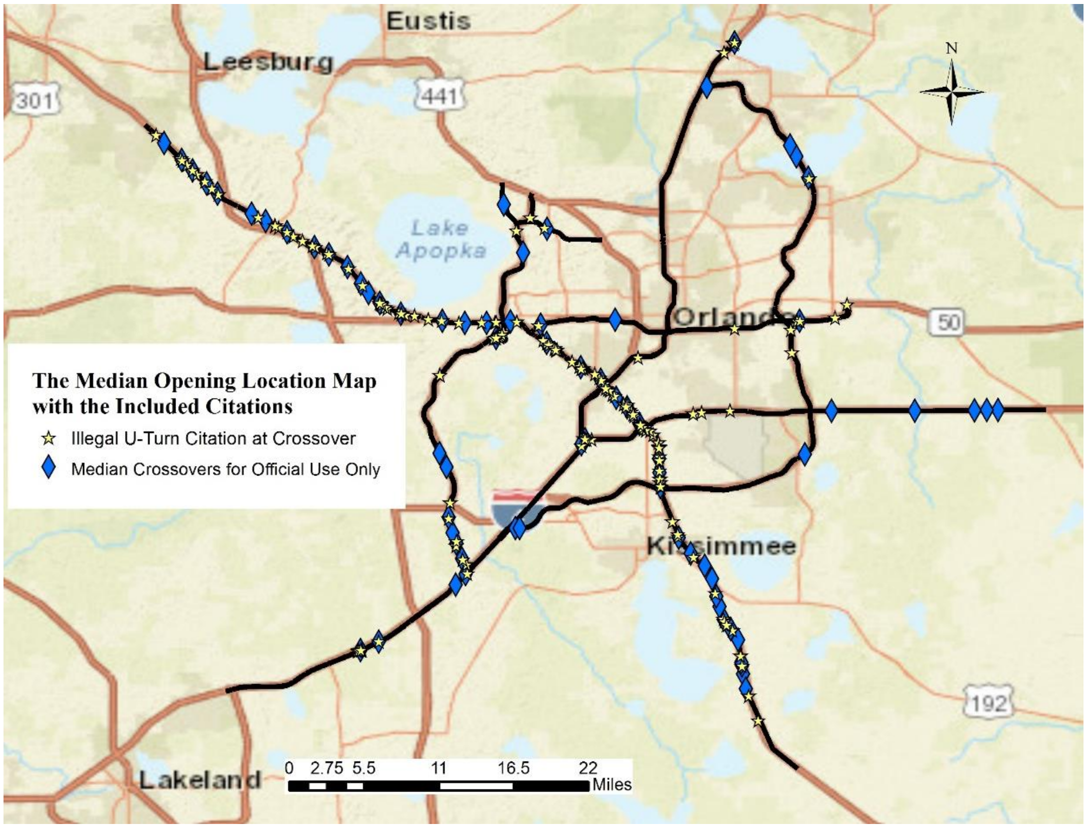

Figure 38: Map Showing the Median Opening Locations in CF and the Included Citations Occurring at the Median Openings (Map Created by UCF)

Figure 39: Map Showing the Median Opening Locations in SF and the Included Citations Occurring at the Median Openings (Map Created by UCF)

When combining both areas in the state, 67 out of the 168 median openings had illegal U-turn movements occurring at these locations (about 40%). This is an indication of the frequency of occurrence for such type of violation and the need for further investigation to determine the contributing factors for such type of violation.

4.4.2.1 Location and Time of occurrence of the Median Opening Citations

A total of 380 citations were found, distributed over 67 median openings in the study area. The distribution of the median openings was described in chapter 3. It was found that about 193 citations occurred in the SF area (about 51% of total citations) and 187 citations in the CF area (49% of total citations); the number of median openings in the SF was 95 (about 56% of total openings) and in the CF was 73 (about 44% of total openings).

The simple percentage comparison indicates that the CF area has a higher percentage of occurrence than the SF area because the CF contains only 44% of the openings and has about 50% of the citations, in comparison with SF that contains 56% of the openings and has only 50% of the citations.

These values just give a general idea but more accurate comparison would be investigated in the following sections. The detailed breakdown of the citation analysis where each citation occurred and the number of openings on each roadway with the number of citations are shown in Table 7. The table shows that the highest percentage of occurrence is on I-4 roadway with more than 65% percentage of occurrence, followed by I-95 with a percentage of occurrence of 50%. Therefore, a roadway scale comparison would be a more accurate method to evaluate the frequency of occurrence in the study area.

Table 7: Summary Table of the Citations at Median Openings in Florida.

Street Name	No. of Openings	No. of Citations	Percentage of Citations	No. of Openings with Citations	% Openings with Citations
SR 91	89	243	64%	43	48%
SR 821	20	19	5%	15	75%
I-75	13	23	6%	11	85%
I-4	6	28	7%	5	83%
I-95	6	8	2%	3	50%
SR-429	8	31	8%	4	50%
SR-528	6	6	2%	2	33%
SR 417	7	6	2%	3	43%
SR 869	5	3	1%	1	20%
SR-408	3	6	2%	2	67%
SR 874	2	3	1%	1	50%
SR-414	1	1	0%	1	100%
SR-414/429	1	2	1%	1	100%
SR-112	1	1	0%	1	100%
Total	**168**	**380**	**of 380**	**93**	**of Each Roadway**

The citations were found in all years of the study, expect for year 2016 where a noticeable increase was found. The reason for this sudden increase is unknown, but many assumptions could be considered such as the increase of police presence, the increase of the number of median openings installed, or other data related issues. Figure 40 shows the number of citations found in the past 6 years.

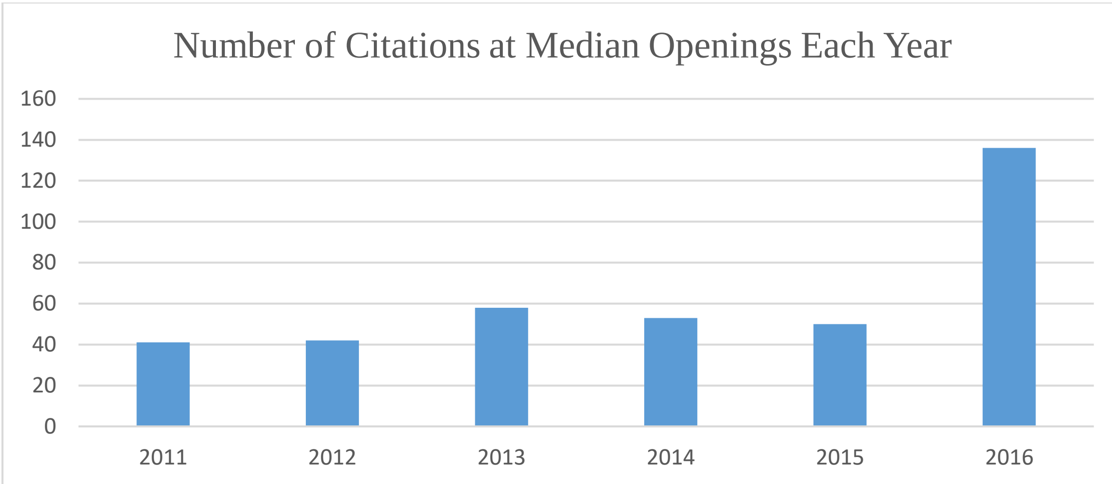

Figure 40: The Number of Illegal U-turn Violations at Median Openings Each Year (2011-2016)

The monthly breakdown for the citation occurrence was found to be occurring throughout the year with a peak occurring during the months of May, July, and September, as shown in Figure 41. This breakdown indicates that this type of violation is active over the year and should be considered all year long.

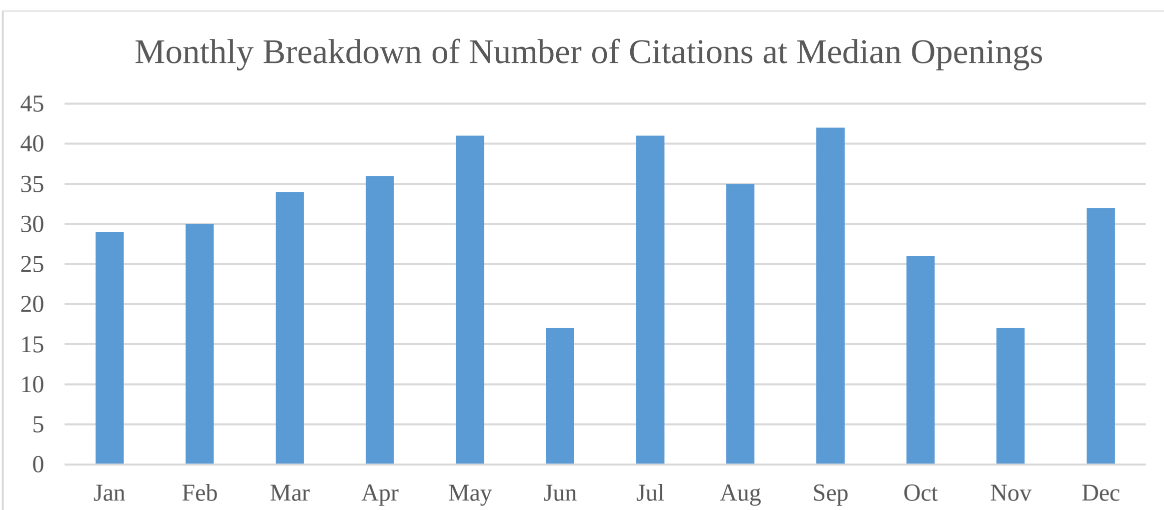

Figure 41: The Number of Illegal U-Turn Citations Occurring Each Month at the Median Openings (2011-2016)

Figure 41 shows a plot with the number of citations occurring each month throughout the study period from January 2011 to December 2016. Most of the months had a considerable amount of citations with only June and November with a noticeable drop in the number of citations. As for the day of the week when the citations occurred, Friday was found to be the most active day of the week with this citation, followed by Wednesday. Probably this could be explained that usually drivers on Friday that would be in a rush commuting more than other weekdays or weekends and would be more susceptible for committing such violation. Figure 42 shows a bar chart of the total number of citations occurring during the week.

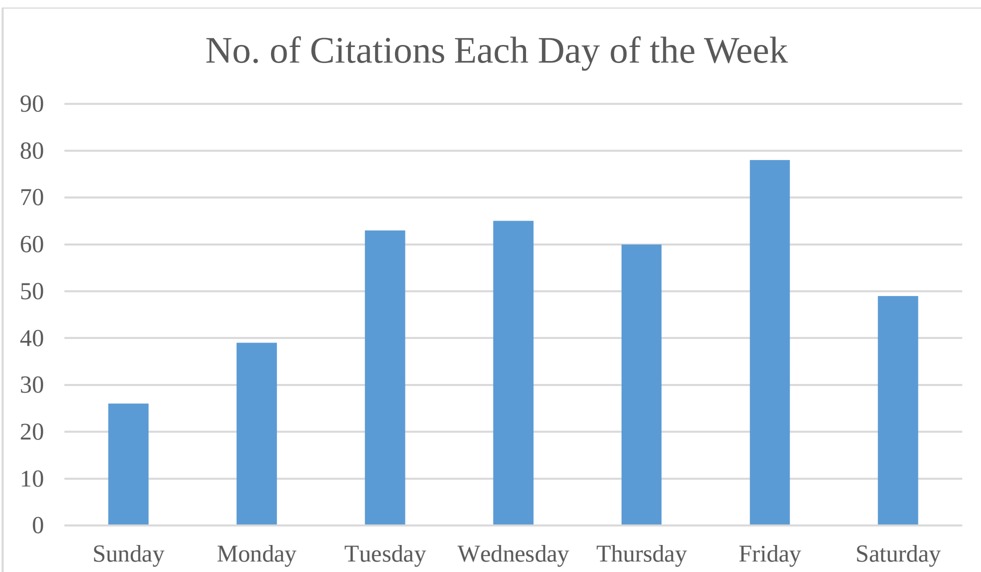

Figure 42: The Total Number of Citations Occurring Each Day of the Week (2011-2016)

4.4.2.2 <u>Driver Characteristics of the Illegal U-turn Citations at Median Openings</u>

The first reviewed aspect was the driver's age category. The results showed that more than 53% of the citations were committed by drivers between the ages of 25 to 44. Therefore, the total percentage of drivers younger than 55 was about 85% of the total sample. In order to define the age group with the highest citation rate, the age exposure rate was calculated by considering

the total number of drivers from each age group. The age exposure calculation table is found in APPENDIX A. The age exposure rate was estimated using equation (4.3)

$$Age\ Exposure\ Rate = \frac{Number\ of\ citaitons\ from\ age\ group\ "n"}{Total\ number\ of\ drivers\ from\ age\ group\ "n"} \tag{4.3}$$

Where:

n = 15-24, 25-34, 35-44, 45-54, 55-64, 65-74, 75-85

However, it was found that the conclusion from the percentage of citations per age group and from the age exposure rate is the same. The number and percentage of drivers in each age group in Florida was found from the FHWA report (*46*). The summarized breakdown for the age exposure rates is presented in Table 8.

Table 8: The Drivers' Age Categories of the Illegal U-turn Citations at Median Openings

AGE	No. of Citations	Percentage	Age Exposure Rate*
15-24	50	13%	3.36
25-34	103	27%	4.51
35-44	99	26%	4.47
45-54	66	17%	2.55
55-64	41	11%	1.65
65-74	14	4%	0.72
75-85	7	2%	0.73
	*Number of Citations/100,000 Driver		

The second driver's characteristic reviewed was the gender, where the majority of citations were found to be committed by male drivers, but with a higher percentage and age exposure of female drivers than the ones found at the traversable medians.

The previously found ratio for males to females citations at traversable medians was 3.47, which agreed with the general violation rate for male and female drivers (ratio=3.4). However, in this case the female involvement was relatively higher than the usual male to female driver ratio to be 2.99, compared to the previous ratio of 3.47, as shown in Table 9. This increase in the percentage of female drivers conducting such type of violations could be explained as female drivers might feel more comfortable in using the paved median opening than using the traversable with grass median segment to make a U-turn maneuver and cross over to the other side of the road. Therefore, median openings would be more attractive for females to conduct an illegal U-turn rather than the traversable median grass segments.

Table 9: Gender Breakdown for Drivers with Illegal U-turn Citations Though Median Openings

Driver Gender	Total	%	Age Exposure*	Ratio
Female	98	26%	1.35	2.99
Male	282	74%	4.03	
Grand Total	**118**	**100%**	***/Million Driver**	

The male to female ratio found for the citations at the median openings was significantly lower than the ratio found for the traversable medians, with a 95% of confidence level and a p value = 0.00026 and Z score equal to 3.469. This indicates that the percentage of female drivers that commit the illegal U-turn maneuver at median openings is significantly higher than the percentage of female drivers at the grass traversable median segments.

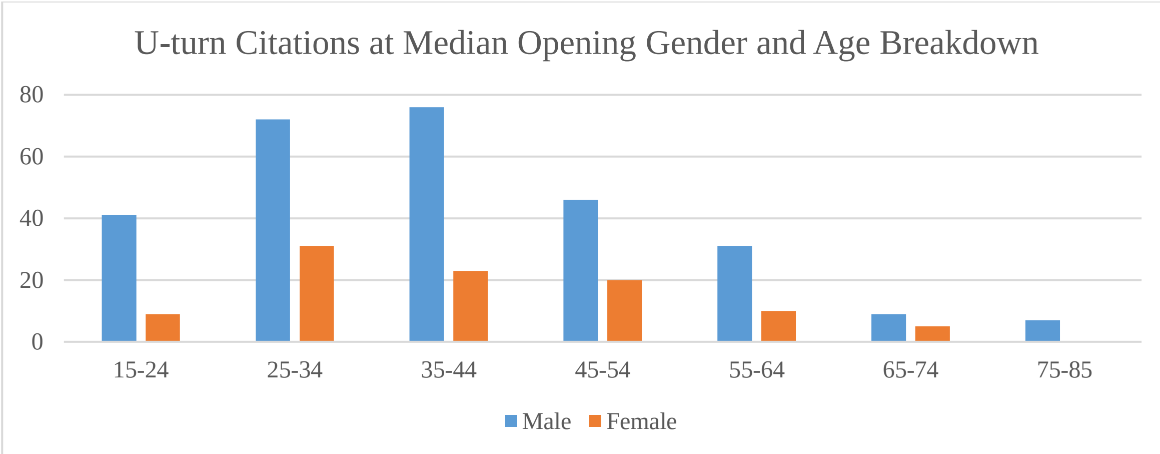

Figure 43: Age and Gender Breakdown for Drivers' with Illegal U-turn Citations at Medians Openings from Jan. 2011 to Dec. 2016

As shown in Figure 43, the grouping of age and gender shows that both genders follow a similar trend of age distribution among the drivers, with an increase in the violations for the younger ages and decrease for the older ages.

In addition, the driver race information was analyzed as well. Since the median openings included were a combination of openings at both Orlando and Miami metropolitan areas, a weighted average was estimated depending on the number of median openings each area has. The total number of median citations opening analyzed was 380 opening, 193 in CF and 187 in SF. Therefore, the population estimated for each race was a weighted average of 51% from CF and 49% from SF. It was found for the citations at median openings for official use only, that the race with the highest race exposure rate in the white race followed by the black race. The Asian race was found to be the race with the least contribution of such type of violation. Figure 44 illustrates the exposure rates for all races considered.

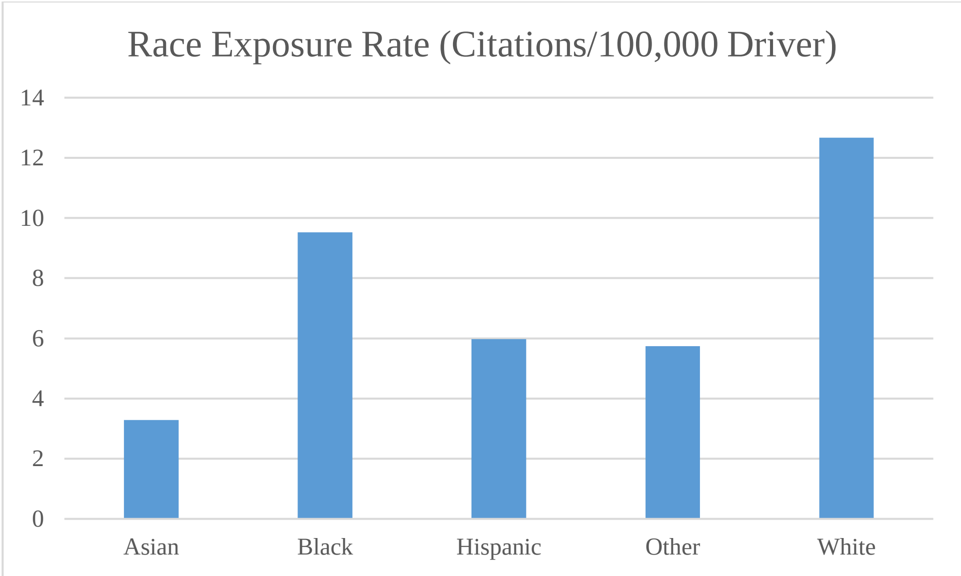

Figure 44: Race Exposure Rates for Citations at Median Openings

4.4.2.3 AADT Exposure Calculation Methodology for Citations at Median Openings

The DVMT exposure rate is not applicable to the citations at the median openings. The median openings could be considered as point facilities on the roadway segment, not as longitudinal segments like the traversable median facilities. Therefore, the length component of the DMVT exposure rate calculation methodology was not included, and the AADT exposure rate was calculated instead. Similarly to the DVMT exposure rate, the AADT values were obtained from the FDOT website *(38)*.

As a result, the AADT exposure rate was calculated to find the number of citations per 100,000 vehicles passing by each median openings using the equation (4.4).

$$AADT\ Exposure\ Rate = \frac{No.\ of\ Citaitons\ at\ the\ Median\ Opening}{AADT\ passing\ by\ that\ Median\ Opening\ (\ in\ terms\ of\ 100{,}000)} \tag{4.4}$$

Where:

AADT Exposure Rate: Citations / 100,000 vehicles passing the median opening

The median openings with the highest 10 AADT exposure rates are shown in Table 10.

Table 10: AADT Exposure Rates on Each Median Opening

No.	The Street the Opening is Located	Avg. No. of Cit./ Year	AADT	AADT Exposure Rate*
1	SR429 - CF	3.33	45000	7.40
2	SR 91 - SF	4	85600	4.67
3	SR 417 - CF	0.33	9200	3.62
4	SR-429 - CF	0.5	14900	3.35
5	SR-429 - CF	0.5	17000	2.94
6	SR 91 - CF	1.33	48649	2.74
7	SR-429 - CF	0.33	14900	2.23
8	SR 91 - CF	1.83	83100	2.20
9	SR 91 - CF	1	48649	2.05
10	I-75 - SF	0.5	25537	1.95

*AADT Exposure = Citation / 100,000 vehicles passing the median opening per year

The AADT exposure factor is the number of citations on each median opening divided by calculated AADT to find the rate of citations occurring each year at a median opening /number of 100,000 vehicles passing by that segment.

As shown in Table 10, the median openings roadway segments on SR429, SR 91, SR 417, and I-75 have the highest AADT exposure rates; this could be considered as the opportunity a citation would occur from the traffic passing by the median opening.

4.5 Summary of Data Analysis Chapter

The section reviewed the methodology adopted in selecting the suitable citations to be included in the study. The first step performed was determining the median segments with traversable medians and median openings. The CF region had a higher share in the traversable median citations and SF had slightly more median openings than the CF area. Very limited

number of crashes was found in the Florida network; therefore, analyzing the citation data was the adopted approach to understand the contributing factors for this violation and predict the locations with high potential of citations and accordingly high potential of crashes. The majority of the citation data on the traversable segments were found on SR429 and SR417. It was also found that the citations occurred equally over the years in the study period. Furthermore, the majority of citations occurred during the mid-day time. In addition, the citations were spread over the weekdays and months without any considerable peaks in the citations.

The driver characteristics of the people who conducted illegal U-turn violations were also reviewed, and it was confirmed that the age group with the highest exposure rate were the age group of 25-34 years, followed by the age group of 35-44 years. Additionally, the age group with the lowest exposure rate was the age group of 66-75 years. Furthermore, the male to female ratio found confirms the ratio found in the literature, that male drivers have a higher violation ratio; about three times more than the female drivers.

The DMVT exposure rates that considers the length of the traversable segments and the AADT passing by those segments were calculated to find the number of citation for each 100,000 miles driven at traversable grass medians. The DVMT exposure calculations indicated that the three traversable segments with the highest DMVT exposure rates were found in CF at I-4, SR 429 and SR 451.

The citations for the illegal U-turn violations at median openings for official use only were analyzed separately. The number of citations was about 380 citations. The simple percentage comparison showed that the openings in the CF area are more likely to have citations than the SF, but the roadway based analysis showed that FTE in CF had the highest percentage of openings with median citations, followed by the I-95 segment near to the SF area. However, a noticeable increase in year 2016 was found in the records for illegal U-turns at median openings. The reason

for this increase is unknown. Moreover, it was found that the months with the highest number of citations were May, July, and September.

In regards to the driver characteristics for the median opening citations, the age group that had the highest age exposure rates was similar to the traversable median segment citations, to be age group 24-35. As for the gender classification, the male to female ratio found for the citations at the median openings was significantly lower than the ratio found for the traversable medians, with a 95% of confidence level.

In addition, the AADT exposure rates were calculated for the median openings to find the number of citations that considers the length of the traversable segments and the AADT passing by those segments were calculated to find the number of citations each year for every 100,000 miles driven at the median opening. The AADT exposure rate calculations indicated that the three median openings with the highest rates were found in CF at SR 429, SR 91, and SR 417.

5. CHAPTER FIVE: ILLEGAL U-TURN VIOLATION PREDICTION MODELS

5.1 Introduction

The modeling methodology adopted in the study used three different approaches to model the occurrence of the illegal U-turn violations on the limited access facilities. The first approach analyzed the illegal U-turn violations at the traversable median facilities, the second approach analyzed the illegal U-turn violations at the median openings for official use only, and the last approach combined both types of violations in one dataset to find the common significant factors among the three modeling procedures. Each approach had different modeling techniques and outcomes described in the following sections.

5.2 Theory and A-Priori Expectations of the Modeling Procedure Outcomes

One of the main goals of this thesis was to model the WWD illegal U-turn citations to find the significant contributing factors that encourage or discourage drivers to commit such type of illegal maneuvers. In order to accurately analyze the U-turn violations, the modeling methodology separated the illegal U-turn violations to two categories: violations at traversable median segments and violations at median openings. Accordingly, each type of the two violations had its unique modeling methodology and research variables to be investigated.

As a preliminary assumption, several roadway features and characteristics were expected to have correlation with the occurrence of illegal U-turn violations. However, the exploratory research variables considered in the analysis were roadway characteristics that the operating agencies could measure or contract. Therefore, the research variables included several geometric design features and traffic conditions associated with the roadway segments analyzed.

As a result, the significant variables found would be the aspects recommended to be considered by officials and operating agencies in the median facilities planning (pre-installation) and evaluation (post-installation) phases. In addition, the anticipated findings would guide and assist the agencies to determine the locations with higher potential of violation occurrence and accordingly select the high priority locations for countermeasure implementation and adjustments.

The following sections describe the explanatory research variables studied for each type of violations. Moreover, these sections explain the modeling criteria performed to analyze the research variables and conclude the significant models that determine the locations with higher potential of violation occurrence. The final modeling conclusions would suggest the high priority locations for countermeasure implementation and adjustments.

5.3 Modeling Approach for Citations at Traversable Medians

The modeling approach used for the illegal U-turn violations at the traversable medians included two regression models to identify the significant variables, and perform a variable selection analysis to determine the most effective variables in the model.

In order to achieve our objective, the sequential analysis technique was conducted. Sequential analysis is achieved by performing more than one modeling criteria to define the final model for the analysis. However, the sequential analysis for the illegal U-turn at traversable medians included the Poisson regression followed by the LASSO selection methodology.

The first regression model, which was the Poisson regression, was used to examine the data and determine the significant variables in the model. The hypothesis assumed was that the Poisson regression would create a significant relationship between the violations occurring on the limited access facility and the roadway conditions associated with each segment on the network.

Poisson regression was selected because of its proven ability to model rare events occurring in a certain time period such as crashes (*49*). Moreover, it was found that the Poisson regression revealed more significant results than the negative binomial regression, regarding the fact that both deal with overdispersion in the analyzed data. The overdispersion occurs when the mean and standard deviation in the sample are not equal, and numerous variables included suffer from overdispersion, as shown in the following sections.

The second model in the sequential analysis was the Least Absolute Shrinkage and Selection Operator (LASSO) regression analysis, which was used to determine and include the most significant variables in the model and determine the significance of the model through the Analysis of Variance (ANOVA) method that is not provided by the Poisson regression analysis. The LASSO selection analysis was first introduced by Tibshirani in 1996. The analysis method selects and defines the number of independent variables to be included in the model given a specific degree of shrinkage parameter (a constraint that determines the number of variables included in the model) (*50*). Moreover, the method efficiently evaluates large numbers of independent variables (can analyze more than 40 independent variables in one model), and illustrates the correlation between the variables after their inclusion in the model. In addition, the illustration created displays the effect of each variable separately in predicting the outcome variable for the ease of interpretation (*50*).

The Poisson regression and the LASSO regression analyze the data with different techniques and analysis procedures, as the Poisson regression specifically analyzes the significance of the variables included in the model and the LASSO regression selects the most significant variables and analyzes the overall model significance. However, the two modeling techniques produce the same numerical outcome variable, which is the number of illegal U-turn citations found per year on each traversable median segment. The two models were applied

sequentially to find the finalized model that predicts the frequency of the illegal U-turn violations on the traversable median segments. The finalized model would be accredited for implementation and recommendations.

5.3.1 Exploratory Variables Studied in the Traversable Medians Model

The traversable median segments were first segmented, where each segment is a continuous traversable median segment that provides access to drivers to commit an illegal U-turn without including any obstacles preventing such access. The total length of traversable medians in the study area is 85.5 miles, 61 miles in CF and 24.5 miles in SF.

The analysis included 44 median segments found in both areas, each segment was analyzed and studied individually to differentiate between the various segments over the included network. In the CF area, 37 traversable median segments were found over various roadways and locations. Moreover, in the SF area had 6 traversable segments, with one 23.5 mile-long segment found in I-75. Figure 45 and Figure 46 show maps of the traversable median segments found in the CF and SF respectively, with each segment having a unique color and number.

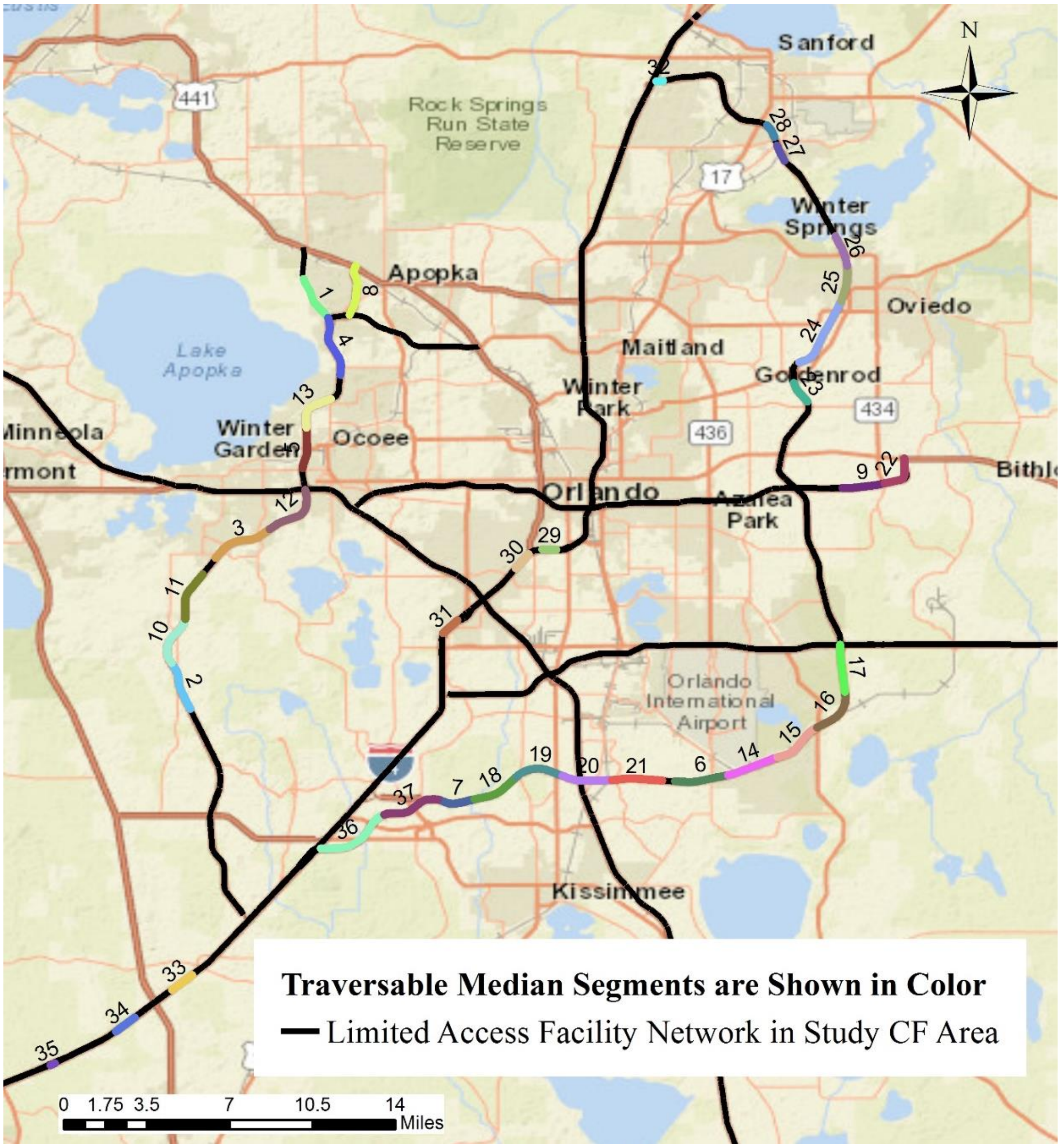

Figure 45: A Map Showing the Traversable Median Segments in Colors in the CF Area (Map Created by UCF)

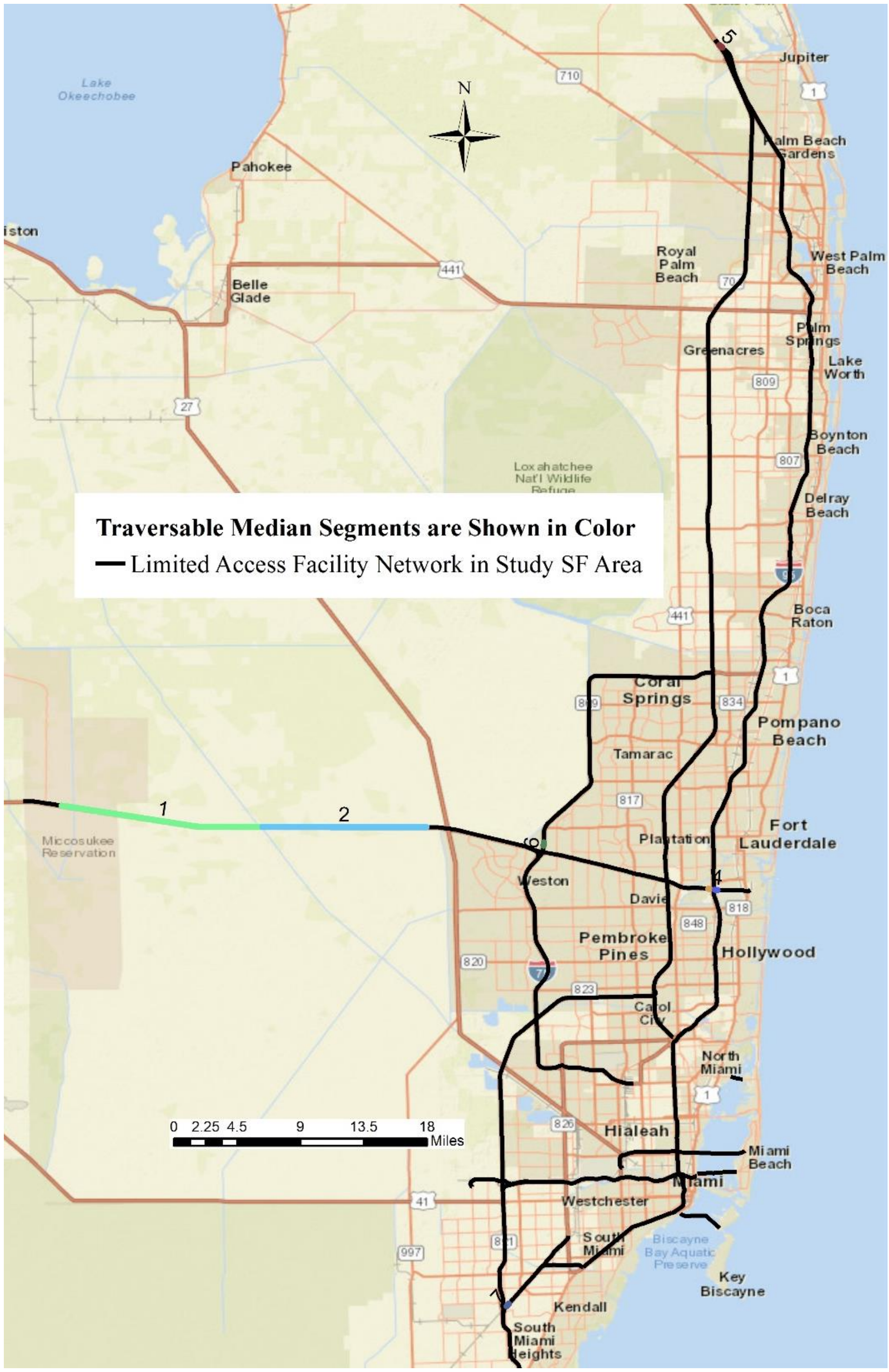

Figure 46: A Map Showing the Traversable Median Segments in Colors in the SF Area (Map Created by UCF)

In order to proceed with the model examination, the properties of all segments included in the study areas were measured and calculated to prepare the dataset used in the modeling procedure.

The dataset prepared included all explanatory variables that need to be tested for correlation with the occurrence of the illegal U-Turn violations. The variables included 9 geometric design features and 2 traffic characteristics associated with the traversable median segments in the study area. The majority of the geometric design features were measured manually using the aerial photo and the measurement tools provided by ArcGIS and Google Maps. Moreover, the traffic characteristics included were extracted from the shapefiles provided by the FDOT Traffic Data GIS shapefile website (*38*).

The list of all exploratory variables included in the analysis are shown below.

1. Length of median traversable segment
2. Distance from center of segment to nearest major interchange
3. Number of lanes
4. Number of access points in the segment
5. Number of median openings in the segment
6. The type of median opening in the segment
7. The average distance between the access points
8. The distance to the next closest traversable median segment on the roadway
9. Median width
10. Average Annual Daily Traffic (AADT)
11. The speed limit

Afterwards, the outcome dependent variable was assigned to be the number of citations per year on each traversable median segment. This variable represents crash risk. Crash

prediction was not used because the number of crashes is very small and makes it difficult to predict with statistical significance.

5.3.2 The Justification and Preparation Methodology of the Exploratory Variables

This section describes the methodology and criteria of selecting and measuring each of the included variables in the citation prediction model at the traversable median segments. The order used in listing the variables in the previous section was used in describing each variable as well.

Length of median traversable segment

The length is in miles. This length was obtained for each segment from the shape properties provided by the ArcGIS software. This variable was included to verify the influence of continuous traversable median segments to encourage drivers to commit an illegal U-turn maneuver through the grass traversable median segment. This is expected because the continuous traversable segment would give the driver an adequate time to prepare and find an acceptable gap in the opposite traffic to commit the illegal U-turn maneuver.

Distance from center of segment to nearest major interchange

The distance is in miles, and was measured using the ArcGIS measure tool that is found in the "tools" toolbar. This variable was included to confirm that the illegal U-turn maneuvers are expected to occur at locations near to major interchanges by lost drivers or drivers who got into the wrong exit and are willing to impatiently and illegally correct their path. An example of how the distance was measured for segment number 3 is illustrated in Figure 47.

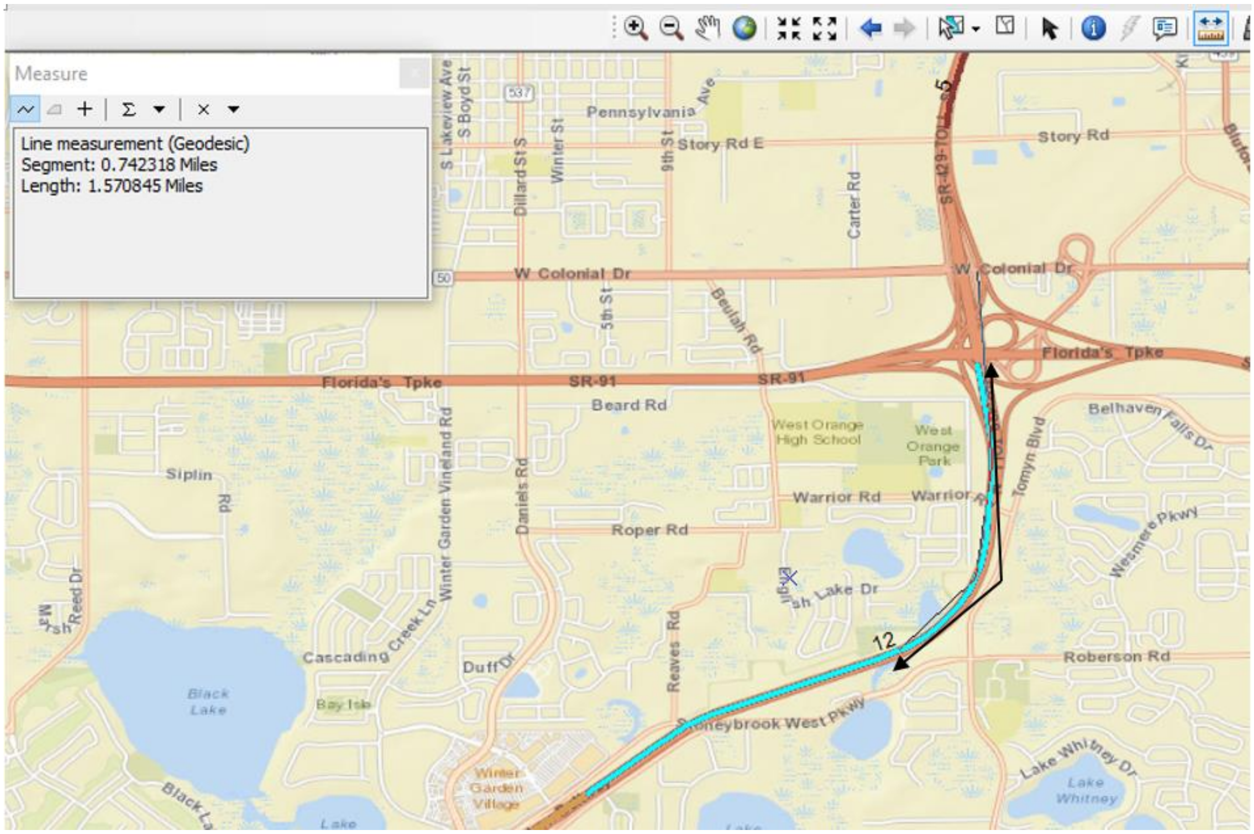

Figure 47: A Screenshot from ARCGIS Software While Measuring the Distance from Middle of Segment 3 to the Nearest Interchange.

Number of lanes

This was obtained using Google maps in assistance with the FDOT shapefile “Number of Lanes” on each road in the State, with the values of 2, 3, 4 and 5 lanes. This variable was included to verify that roadway segment with less number of lanes are more likely to have more illegal U-turn violations, since roadway segments with numerous lanes are less likely to have adequate gaps for drivers to commit an illegal U-turn maneuvers, although this assumption might not be valid in late night operating conditions.

Number of access points in the segment

This variable was found manually by counting the number of access points (these are defined as on-ramps or off-ramps on each segment). It is expected that the median segments with

less number of access points would have more illegal U-turns due to the limited access provided for the drivers to correct their path and the excessive traveling distance required to reach an exit ramp to leave the facility and return to it so they can correct their paths. Figure 48 shows segment number 3 with 2 locations of different access points into the limited access facility, the yellow diamond represents the point where the on-ramp merges into the mainline and the off-ramp diverges from the mainline.

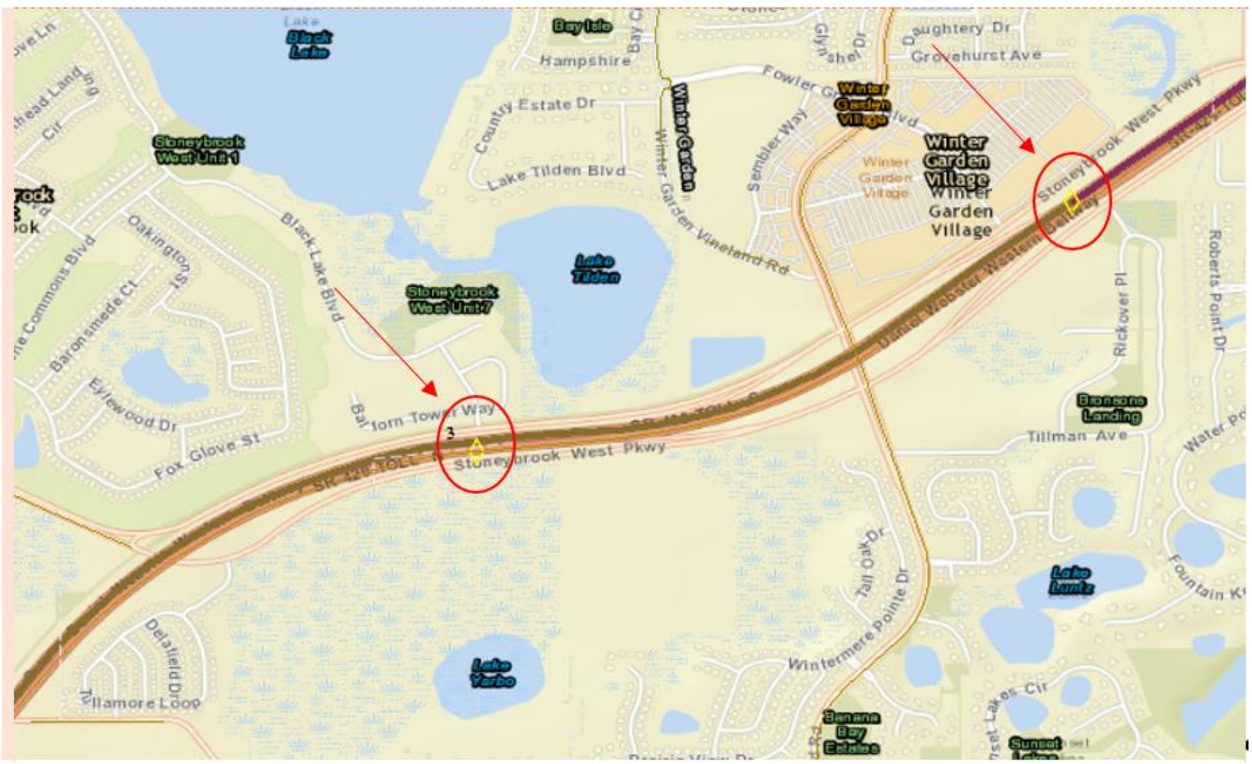

Figure 48: A Screenshot from ARCGIS Software Showing the Location of the Two Access Points into the Mainline At Segment 3 on SR429.

<u>Number of median openings in the segment.</u>

This variable was calculated by counting the number of median openings in each traversable median segment. The variable was included to verify the expectation that median

openings attract drivers to commit an illegal U-turn maneuver to reduce their travel distance and time to reach their destination.

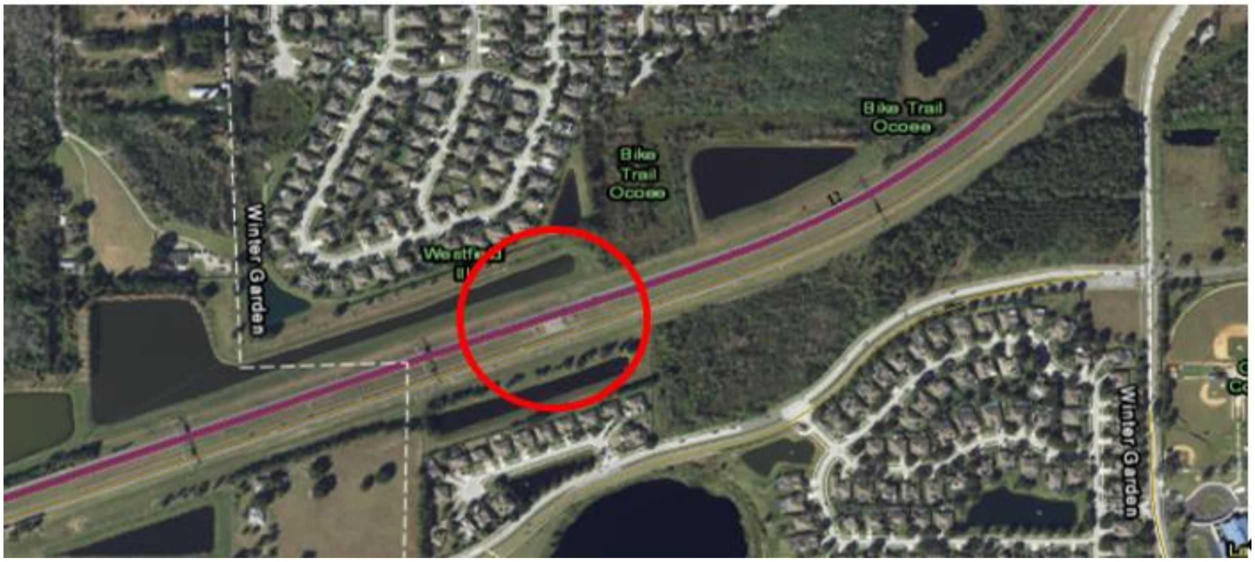

Figure 49: A Screenshot from ARCGIS Software Showing a Median Opening Found on Segment 12 on SR429.

<u>The type of median opening in the segment</u>

This variable is a discrete variable with four possible values 0, 1, 2, and 3. The hypothesis assumed for this variable is that each type of median crossover would influence the drivers to commit illegal U-turn violation in different ways. However, for the sake of modeling different types of median openings, each type was assigned a number in the model. The value of 0 indicates that there is no median openings in the segment, 1 indicates that there is an opening in the median barrier that is paved and has a median width less than 40 ft., 2 indicates there is a paved median opening (crossover) in the segment with median barriers and with a median width larger than 40 ft, and 3 indicates there is a graded unpaved area dedicated for official use only. The description and illustration of the three types of median crossovers is shown below.

The first two types of median openings were described in section 2.14 of the FDOT PPM guidelines to suggest the types of median openings to be installed on the limited access facility (*36*). The third type (or type 3) which is the grass unpaved path dedicated for official use only was not included in the PPM design guideline. However, all types of median openings should be located following the guidelines suggested in the latest FDOT PPM for median crossovers.

For the modeling purpose in this thesis, median type 1 was referred to paved openings in the median barrier with a median width less than 40 feet. This type of median openings is expected to discourage drivers from committing an illegal U-turn violation since no sufficient median width is provided for the drivers to slow down and wait for an acceptable gap in the opposing traffic to commit the U-turn maneuver. An example of median Type 1 is shown in Figure 50.

Figure 50: A Picture from Google Maps of a Paved Opening in Median Barrier for Official Use Only (Type 1) On Florida Turnpike near Exit 255 (taken in December, 2016)

The paved median openings (or crossovers) were referred to as median opening type 2. This opening includes all openings designed in the median section with a median width at least 40 feet. However, this type of opening is expected to attract illegal U-turn violations because the

large median width accommodates storage for turning vehicles waiting for an acceptable gap to merge into the opposing traffic. An example of a median crossover is shown in Figure 51.

Figure 51: A Picture from Google Maps of a Crossover Opening for Official Use Only (Type 2) on SR429 between Exit 19 and 22 (taken by UCF Research Team in December, 2016)

The third type of median openings found in the study area is an unpaved or grass area assigned for official use only. This is different than the median crossover (type 2) in the sense that it is unpaved and does not include designed features other than an unpaved path with a sign located at the entrance of the path stating for official use only. In a sense, this type is less inviting to drivers who want to commit the illegal U-turn maneuver. Figure 52 illustrates an example of the median Type 3 opening.

Figure 52: A Picture from Google Maps of an Unpaved Median Opening for Official Use Only (Type 3) On I4 between Exit 48 and 55 (Taken by UCF Research Team in May, 2017)

The average distance between the access points

This distance is measured in miles and it indicates the average distance between the access points in the segment. This was found by measuring the distances between all access points in the segment, and calculating the average of all distances measured. This variable was included to verify the expectation that the segment that has the access points largely separated from each other would encourage drivers to commit illegal U-turn because of the excessive travel distance and time required to travel in the opposing direction in case drivers want to reroute or correct mistakes in navigating their trip paths.

The distance to the closest traversable median segment on the roadway

This distance is in miles, and it measures the distance between the edge of one segment and the next closest edge of another segment on the roadway. This variable was included to find whether the isolated traversable median segments would attract drivers to commit an illegal U-turn or not.

The median width

This variable was measured from the aerial photo of the roadway section provided by Google Maps and confirmed with the GIS Shapefiles provided by the FDOT website (*38*). The variable was included in the analysis to verify the expectation that large median widths would encourage drivers to commit the U-turn maneuver due to the sufficient storage provided by the median.

Annual Average Daily Traffic (AADT)

This variable was found from the GIS Shapefiles provided by the FDOT website (*38*). The variable was included in the analysis to confirm the expectation that roadway segment with lower AADT values would have more acceptable gaps for merging and may result more illegal U-turn violations.

The speed limit

This variable was found from the GIS Shapefiles provided by the FDOT website (*38*). The variable was included in the analysis to validate the expectation that roadway segments with lower speed limits would make it easier for drivers to slow down to relativity low speed before they can commit the illegal U-turn maneuver while traveling on the roadway in comparison with roadway that has higher speed limits where it is more difficult to make such illegal maneuver.

5.3.2.1 Test of Correlation between Variables in Traversable Median Model

Before performing any modeling efforts, the included variables were tested for correlation. Correlation is a statistical measure to show if there is a relationship between the variables, and is usually measured by the coefficient of correlation (R) that ranges from -1 to 1. The closer the coefficient (r) is to 1 or -1, the stronger the relationship is. Researchers did not agree on what

range of r value should be considered to determine whether a relationship between two variables is strong or weak. However, Evens (*51*) suggested the following ranges to describe the strength of correlation between variables.

0.00 to 0.19: very week

0.20 to 0.39: weak

0.40 to 0.59 moderate

0.60 to 0.79 strong

0.80 to 1.0 very strong

The same ranges are applicable for both positive and negative values. The shown ranges of correlation were adopted to describe the correlation between the variables.

The correlation was measured using the PROC CORR built in the statistical software SAS, and the detailed correlation table resulting from PROC CORR for the analyzed dataset is found in the APPENDIX D.

The correlation table revealed that there is a strong correlation between the AADT and the number of lanes with a value of 0.7, which is logical because the traffic volume will increase with the increase of the number of lanes available. In addition, the variable of number of lanes was found to have a moderate correlation with the length of the flushed segment (-0.59) and the median width (0.54). The two mentioned correlations do not have a clear explanation, but a possible explanation for the median width would be that the section with less number of lanes would have a wider median reserved for the right of way for future expansion and construction of additional lanes. Furthermore, considering the issue from another aspect, since the sections with less number of lanes would have an adequate median width there would be an adequate separation between the two directions of traffic, and as a result the need to install physical barriers on the roadway section would be less compared to sections with restricted median width. This case is found

mostly in SF, where most of the roadway sections have a large number of lanes with a median barrier separating the two directions of traffic on a restricted width containing the barrier and the minimum clearance from each side due to the limited right of way available and the high traffic volume in that area.

Another correlation was found between the segment length with the average distance between access points and the distance to the next flushed median, both having the value of 0.65 and -0.61 respectively. The correlation between the variables is strong but with no direct relationship explaining these correlations. However, both of the variables were included in the modeling procedure where the variable selection method would illustrate the effect of variable in the model and visualize the interaction between the two variables to understand the type of relationship between the variables. All other variables had weak correlation with values less than 0.4.

All explanatory variables (correlated and uncorrelated) were included in the analysis. As described later in the thesis, the significant variables found are included in the LASSO variable selection method. This selection method would examine all variables for correlation, and would not include two highly correlated variables in the final model to increase the accuracy of the model (*52*).

5.3.2.2 *Summary of Variables Included in Traversable Medians Model*

This section summarized description of both the dependent and explanatory variables with the expected effect to be positive or negative for each variable in the model. All exploratory variables are included in the analysis, and would be included in the modeling produce to find the finalized citation prediction model. The summary is shown in Table 11.

Table 11: Variable Description for the Traversable Medians' Model

Variable Name in Model	Type	Description of Variable	Expected Effect	Mean	S.D
Dependent Variables					
No_Cit.[Citation /year]	Discreate	No. of Citations per year on each segment.	**N/A**	3.6	7.32
Explanatory Variables					
Segment_L [mile]	Continuous	Length of traversable median segment	**+ve**	1.65	0.71
DIST_INT [mile]	Continuous	Distance from center of segment to nearest major interchange	**-ve**	2.26	2.97
N_Lanes	Discrete [2,3,4]	Number of lanes in each direction	**-ve**	2.27	0.56
No_of_Acc	Continuous	Number of access points in the segment	**-ve**	1.84	1.24
N_OPEN	Discrete [0,1,2]	Number of median openings in the segment	**+ve**	0.24	0.49
MED_TYP	Discrete [0,1,2,3]	The type of median opening in the segment	**N/A**	0.38	0.83
	0	No median openings	**- ve**		
	1	Opening in Barriers	**- ve**		
	2	Paved Median Crossover	**+ ve**		
	3	Unpaved opening for officials	**++ ve**		
AVGDIS_PT [mile]	Continuous	The average distance between the access points in the segment	**+ ve**	1.03	0.68
Dist_Flush [mile]	Continuous	The distance to the closest traversable median segment	**+ ve**	0.64	1.2
Med_W. [ft.]	Continuous	Median width	**+ ve**	89.27	44.74
AADT [*1000]	Continuous	AADT on segment	**- ve**	47.91	34.89
Speed	Discrete [65,70]	Speed limit posted	**- ve**	69.46	1.57

5.3.3 Poisson Regression Model Estimates for Traversable Medians Model

The variables described in Table 11 were all included in the explanatory modeling phase using the Poisson model to determine the significant variables considered in the variable selection

analysis. The Poisson regression assumes that the counts follow the Poisson distribution, which means that the mean and standard deviation are equal. Therefore, a scale parameter with was introduced to adjust the distribution of the data provided to be fitted with the Poisson distribution. The transformation of distribution of the data to the Poisson distribution is done using PROC GENMOD in the SAS software to be included in the model. The results from modeling the described dataset showed that 7 variables out of the 11 analyzed were found significant with a p-value less than 0.001. The scale parameter was found to be 1.82 which indicates a slight overdispersion in the data since it's larger than 1. This scale value is found by dividing the deviance over the degrees of freedom in the model (DOF=32). However, this overdispersion is adjusted in the model to fit the data to have a Poisson distribution with a scaled deviance equal to 32.0 that will result in the scale value = 1.00, as shown in Table 12.

Table 12: Assessing Goodness of Fit for Poisson Regression Model for Traversable Medians

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	32	106.8056	3.3377
Scaled Deviance	32	32.0000	1.0000

Table 13: Poisson Model Estimates for Illegal U-Turn Violations on Median Traversable Segments

Variables		Coefficient	Std. Error	95% Conf. Limits		Pr > ChiSq
Intercept		2.6011	0.2781	2.0559	3.1462	<.0001
No. of LANES	2	Reference				
N. of LANES	3	-1.1283	0.2525	-1.6231	-0.6335	<.0001
N. of LANES	4	1.0602	0.2729	0.5253	1.5951	0.0001
Segment L		2.6384	0.2136	2.2198	3.0570	<.0001
MED TYP	0	Reference				
MED TYP	1	1.8786	0.4788	0.9401	2.8170	<.0001
MED TYP	2	0.9945	0.1131	0.7728	1.2161	<.0001
MED TYP	3	1.7963	0.3335	1.1427	2.4499	<.0001
Dist. to Inter.		-0.1231	0.0219	-0.1661	-0.0801	<.0001
No of Acc. points		-1.3626	0.1337	-1.6247	-1.1004	<.0001
Avg. Dis/Acc. Pt.		-2.3247	0.2420	-2.7990	-1.8504	<.0001
Speed	65	Reference				
Speed	70	-1.1369	0.1487	-1.4283	-0.8454	<.0001
Scale		1.8269	-	-	-	

As shown in Table 13, the variables that had a discrete set of values such as the number of lanes, median type, and speed variables were defined as categorical variables. The categorical

variable analysis requires a reference value to be defined to compare each of the categories with the reference value. Therefore, each coefficient shown is the value resulting from comparing the reference values with the other categories in the same variable. The reference value defined is shown in Table 13.

All variables included in the table were found significant with a P-value less than 0.001. This indicates the high significance of the exploratory variables in predicting the number of citations on each roadway segment.

However, the significant variables from the Poisson regression were included in the LASSO regression, which is a variable selection method, to compare the effectiveness of each variable in the model. The detailed results of the LASSO regression are shown in section 5.3.4.

The Poisson regression model could be presented with the formula shown in (5.1).

$$No.of\ Citations = \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots) \qquad (5.1)$$

Where:

βn: The variable coefficient for the variable include in the model, where n = 0 to ∞

Xn: The variable included in the model, where n = 0 to ∞

Afterwards, the second regression model in the sequential modeling approach was performed in the following sections, using the LASSO regression model selection methodology.

5.3.4 LASSO Regression Model Estimates and Results for Traversable Medians Model.

The selection method seeks to minimize the sum of the absolute values of the model parameters while considering a constraint to include coefficients less than a certain parameter that controls what variables to be included in the model. In addition, the LASSO selection method detects the nuisance of non effective variables might show as significant variables due to the small sample size and the incidental occurrence of the violations found in the study area (*50*).

The selection methodology used by the LASSO selection method includes identifying the most effective variable in the model first, then the second most effective and so on until a certain defined threshold is reached to include the most significant variables within that threshold. The Threshold could be defined as a shrinkage value that defines the acceptable range of correlation of the independent variables with the dependent variable to be included in the model. For the ease of interpretation, The LASSO method illustrates at what shrinkage value the independent variable is included and also displays the interaction between the independent and dependent variables by a standardized coefficient showing the contribution of the variable in the model. The selection methodology for including the significant variables in the LASSO method is similar to the stepwise selection procedure implemented in the logistic regression models. However, the difference between the two models is that the logistic regression model produces discrete or binary outcome variables, and the LASSO selection method produce continuous rate outcome variables. Hence, this is a new contribution of LASSO type models.

The significant variables found from the Poisson regression model were included in the LASSO selection procedure to find the most effective variables in the model. Using the SAS software PROC GLMSELECT and the selection criterion of LASSO, the variables were included in the LASSO model to evaluate the effect of each variable on the overall model significance. The LASSO variable selection summary is shown in Table 14.

Table 14: LASSO Variables Selection Summary for Traversable Median Model

LASSO Selection Summary				
Step	Variable Entered	Variable Removed	Number Variables in Model	Adjusted R^2
0	Intercept		1	0.0000
1	MED_TYP_3		2	0.8474
2	MED_TYP_2		3	0.8825
3	Dist. to. Inter.		4	0.8907
4	N_LANES_3		5	0.8884
5	Speed_70		6	0.8885
6	Avg. Dist. / Acc. Pt.		7	0.8885
7	No. of. Acc. Pts.		8	0.8902
8	N_LANES_4		9	0.8869
9	MED_TYP_1		10	0.8877
10	Segment L		11	0.8860
11		MED_TYP_1	10	0.8954*
* Optimal value achieved for adjusted R^2				

The table shows the steps, and shows the variables included or removed at each step in the model. Moreover, the table shows the adjusted R^2 value or the model after including or removing a variable. The adjusted R^2 is a modified version of R^2 that adjusts the value of R^2 for the number of exploratory variables included in the model. For example, the adjusted R^2 increases only if the additional exploratory variable included improves the accuracy of the model. The value of adjusted R^2 indicates the proportion of the data that could is explained appropriately by model. Therefore, the higher the adjusted R^2 value the better the model is in explaining the data.

It could be noticed that median type 1 variable was removed from the model in step 11 to indicate the median type 1 is the least effective variable included in the model, and that is when the highest R^2 for the model was achieved. Although not all variables must be included in the final model, the intention to include all variables was to show the effect of each variable on the model and to have an overall understanding of the effect of each variable separately. The effectiveness of each variable is illustrated in the coefficient progression diagram shown in Figure 53, which is a figure generated by the LASSO selection methodology to visualize the performance of each variable in the model after being included in the model.

The figure has a standardized coefficient on the y-axis indicating the effect of the variable, and the x-axis could be defined as the shrinkage parameter (t). The shrinkage parameter defines when and what variables are to be included in the model. As shown in the figure the higher the shrinkage parameter is the more variables are allowed to be included in the model. The lower figure illustrates the change in the adjusted R^2 value of the model after including and removing each variable as illustrated in Figure 53. The figure shows the coefficient progression for the LASSO model.

The coefficient progression is the illustration that shows the steps where the variables are included or removed from the model and how the variables interact with the dependent variable represented by the standardized coefficient. The illustration also shows when each variable is included in the model, at what shrinkage parameter [|b|/ Final |b|], where |b| is the least square estimate in the model (the sum of the squares of the residuals). However, the value [|b|/ Final |b|] could be also considered as a tolerance factor that provides additional space for the other less significant variables to be included in the model. The standardized coefficient is shown in the y-axis of the upper illustration in the figure, and shows the effect of the exploratory variables

included in the model. The shrinkage parameter is the x-axis in both illustrations shown in the figure below.

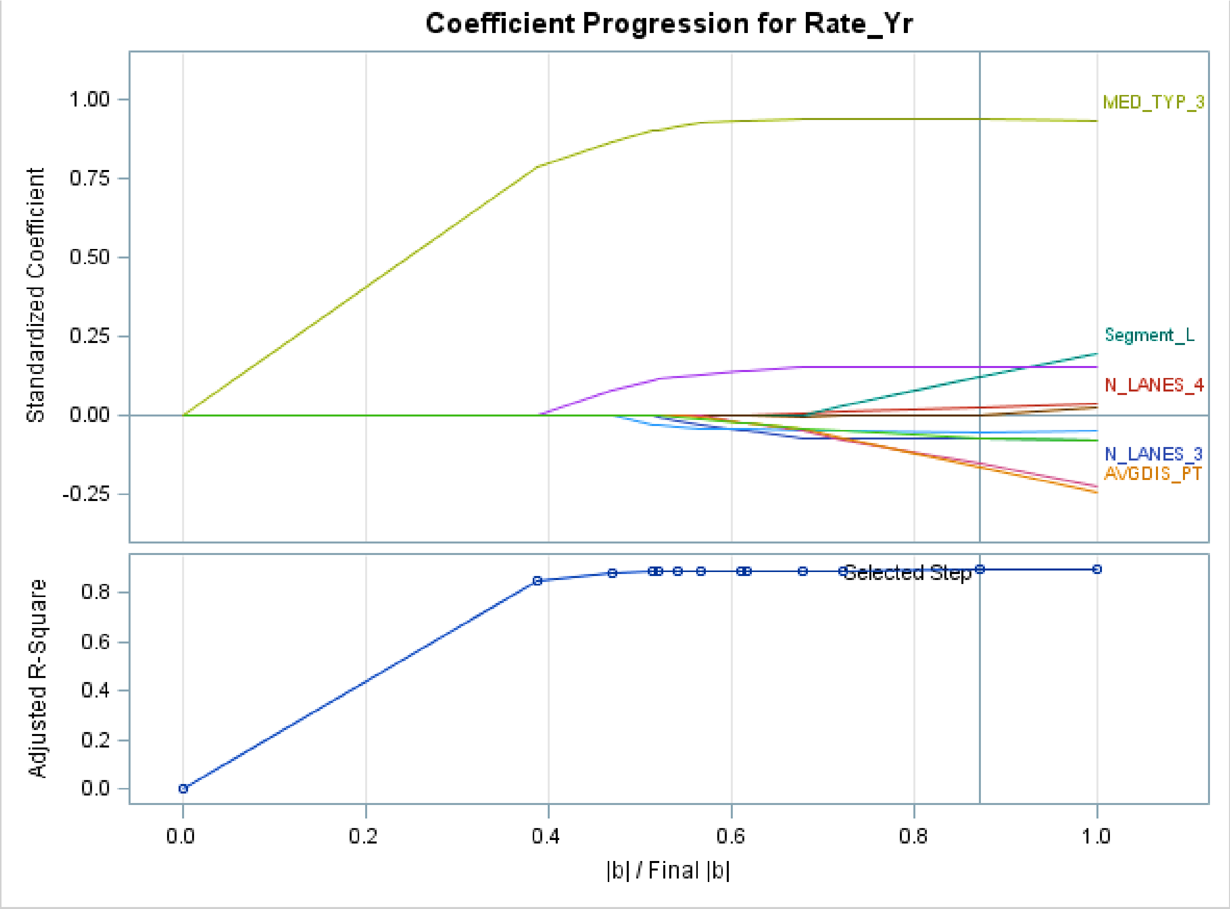

Figure 53: LASSO Coefficient Progression for the Median Traversable Number of Citations/Year Model

The figure shows a vertical line where the highest R^2 values occurred at step 11. The positive variables (variables with positive standardized coefficients) indicate a direct proportional effect to the predicted number of citations occurring each year, and the negative variables (variables with negative standardized coefficients) indicate a positive effect with the predicted number of citations occurring each year. In addition, the variables with higher effect and significance in the model have higher absolute values of standard coefficients.

However, it was found from the LASSO selection method that the most effective exploratory variable in the model is the grass median opening with the largest standardized coefficient. The variables with less effect were the segment length, the average distance per access point, the number of access points per segment and the median type 2.

The analysis of variance table and the parameter estimates for the model are found in Table 15 and Table 16 respectively. The F value for the model is larger than the F critical for the same degrees of freedom. Therefore, it could be concluded that the overall effect of the model is significant.

Table 15: Analysis of Variance for LASSO Model

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	F Critical (α=0.05)
Model	9	88.70271	9.85586	35.25	2.25
Error	27	7.55000	0.27963		
Corrected Total	36	96.25271			

Table 16: Parameters Estimates of the LASSO Regression model

Parameter	Estimate
Intercept	1.032164
MED_TYP_2	0.729335
MED_TYP_3	9.339409
Segment_L	0.286778
N_LANES_3	-0.328102
N_LANES_4	0.195797
DIST_INT	-0.028519
No_of_Acc	-0.202919
AVGDIS_PT	-0.394418
Speed_70	-0.366124

The selection methodology for this model was defined to stop when the highest adjusted R2 value is found. However, this does not represent the optimal model for all four criteria used in the LASSO regression selection methodology. The four criteria used in the LASSO selection are the Adjusted R^2, the Akaike's Information Criteria (AIC), the Corrected Akaike's Information Criteria which is the corrected AIC model that measures the goodness of fit of the model for small sample sizes (AICC), and Schwarz Bayesian Criteria (SBC) which is another criterion for comparison between models and is similar to the AICC, and the model with the lowest AICC and SBC is preferred. Each criterion measures the difference between the predicted values in the model and the true values used to develop the model. Figure 54 shows the step at which each of the four criteria's optimal value is obtained. Each circle on the line represents one step where one variable is included in or excluded from the model. The star found on each figure shows the step

where the optimal value for each criterion occurred in the model, and this also represents the stopping point for each fit criterion for the model. Moreover, the horizontal line represents the stopping point where the optimal adjusted R^2 value occurred in the model. The variable included or excluded at each step was illustrated in Table 14.

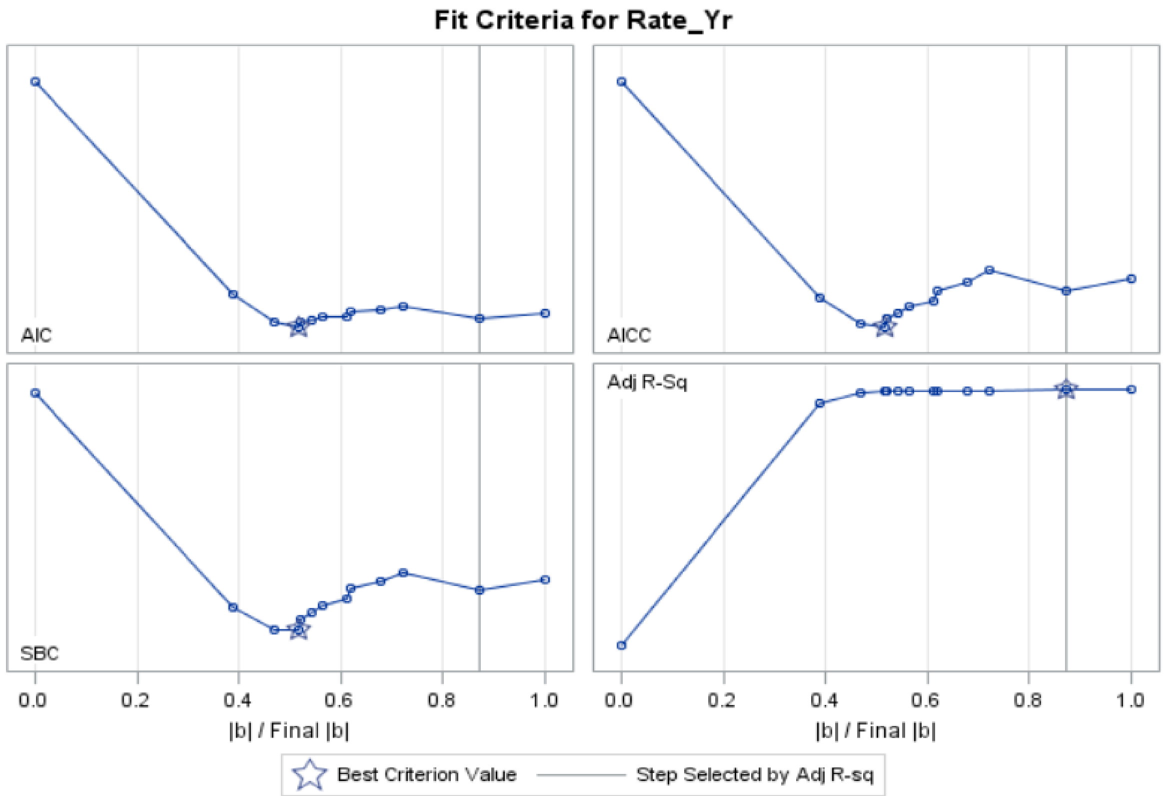

Figure 54: The Four Fit Criteria for the LASSO Model with the Optimal Value of Each Criterion

The LASSO regression has a simple linear function, therefore the general model function has the format shown in Equation 5.1.

$$Rate\ of\ Citations\ (Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots . + e \qquad \text{Equation 5.1}$$

Where:

Rate (Y): Number of Illegal U-turn citations per mile per year at each segment

β_n: Coefficient of model variables, where n = 0 to ∞

X_n: Variables included in the model, where n = 0 to ∞

e: error

As found in the Table 16, most of the significant variables included are related to geometric conditions. Therefore, the geometric condition variables are explained first below.

The median type 3 variable was found to be the most significant variable (grass opening). The median type variable was defined as a categorical variable with the reference to not having a median opening with a positive estimate (median type 0). Therefore, the interpretation of this variable (variable coefficient = 9.33) is that installing one grass median opening on a segment that has no openings is expected to result in an increase by 9 citations per year. Similarly, for median type 2 variable, which is the crossover median opening, the variable was found to have positive effect (variable coefficient = 0.73) which means an increase in the number of violations is expected to occur in the presence of a median opening (crossover). The expected increase of citations resulting from one crossover opening is about 1 citation per year.

The second significant variable found was the segment length, the coefficient has a positive value (variable coefficient = 0.29) and it could be interpreted that the continuous flushed segments encourage drivers to perform illegal U-turns, where it is predicted that each additional 1 mile of traversable medians would result in an increase in approximately 1 citation every 3 years. The next variable is the average distance per access point, this variable has the negative effect (variable coefficient = -0.40) indicating that the presence of on-ramps or off-ramps near to each other would encourage drivers more to commit a U-turn to leave the facility using the nearby access point, this does agree with the prior modeling exceptions as it was expected that access points close to each other would encourage drivers to commit an illegal U-turn to correct their path. The number of access points was also found as a significant variable with negative effect, this negative impact would be explained that the larger the number of access points provided in the segment the less drivers would have to make a U-turn to correct their path, and instead use an access point to leave the facility, this agrees with the prior modeling exceptions. The number of

lanes was also one of the significant factors and had a reference of having two lanes in each direction in comparison to having 3 or 4 lanes. The 3-lane variable had a negative value compared to 2-lane segments, indicating that 2-lane segment would result in more violations than the 3-lane segment. Moreover, the results also indicate that violations occur more often on 4-lane facilities than on 2-lane facilities. This could be explained that the three lane segment has higher speeds than the 2-lane segment, therefore it would have shorter acceptable gaps for merging. However, for the four lane segments, additional lanes provide more space and acceptable gaps for drivers to commit illegal U-turn maneuvers, which differs from what was expected in the prior modeling expectations. Moreover, the distance to the nearest interchange was found to be the next significant variable in the model, and the estimate is negative. This could be explained that drivers tend to perform the illegal U-turn violations near the major interchanges, which agrees with our prior modeling expectations. This is likely to be performed by lost drivers or drivers who made a navigation error by missing their anticipated exit and want to correct themselves quickly without using the off-ramp and on-ramp facilities.

The last significant variable included in the model was a traffic control device feature on the roadway or the speed limit of 70 mph with a negative value. The variable was defined as a categorical variable with a reference of 65 mph speed limit, which indicates that drivers tend to perform more violations on the lower speed roads than the higher speed roads.

5.3.5 Comparison between the Poisson Regression Model and the LASSO Regression Model

The two methodologies revealed different models to predict the number of citations occurring at each segment. The summary comparison table is found in Table 17.

Table 17: Comparison between the Coefficients in the Poisson and LASSO Models

Variable	Poisson Coefficient	Variable	LASSO Coefficient
Intercept	2.6011	Intercept	1.032164
MED TYP0	Reference = 0	MED TYP0	Reference = 0
MED TYP1	1.8786	MED TYP1	Not significant
MED TYP2	0.9945	MED TYP 2	0.729335
MED TYP3	1.7963	MED TYP 3	9.339409
N LANES 2	Reference = 0	N LANES 2	Reference = 0
N LANES 3	-1.1283	N LANES 3	-0.328102
N LANES 4	1.0602	N LANES 4	0.195797
Segment L	2.6384	Segment L	0.286778
DIST INT	-0.1231	DIST INT	-0.028519
No of Acc.	-1.3626	No of Acc.	-0.202919
AVGDIS PT	-2.3247	AVGDIS_PT	-0.394418
Speed 65	Reference = 0	Speed 65	Reference = 0
Speed 70	-1.1369	Speed 70	-0.366124
Scale	0.5000		

The variation in the variable coefficients is something expected since the LASSO regression is a linear regression model and the Poisson regression is a log regression model.

However, it could be noticed that both models found coefficients with similar positive and negative signs for both models indicating that the interpretation for both models would be similar and each variable has similar effects on the expected number of violations occurring on each location.

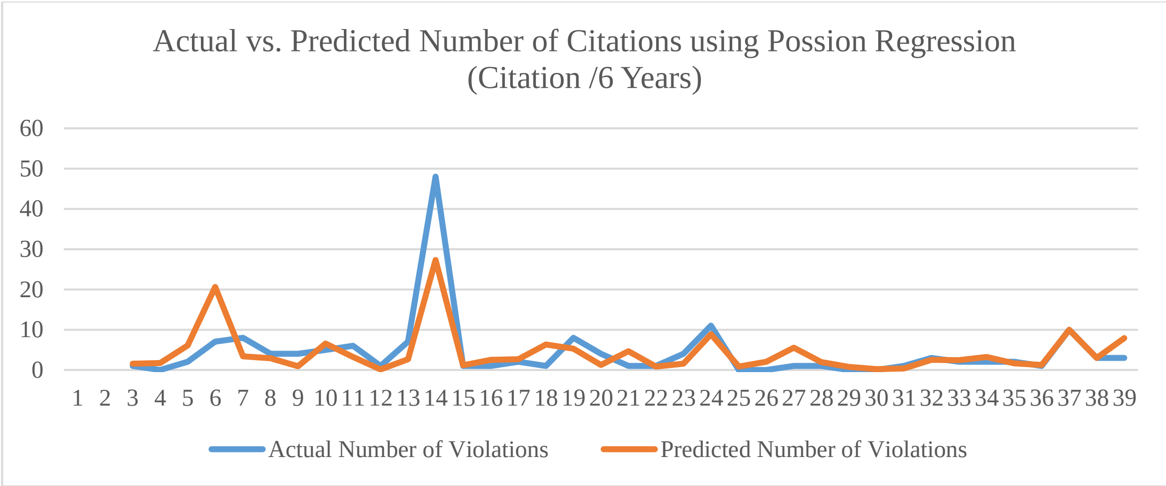

Figure 55: Actual vs Predicted Values Using Poisson Regression Model

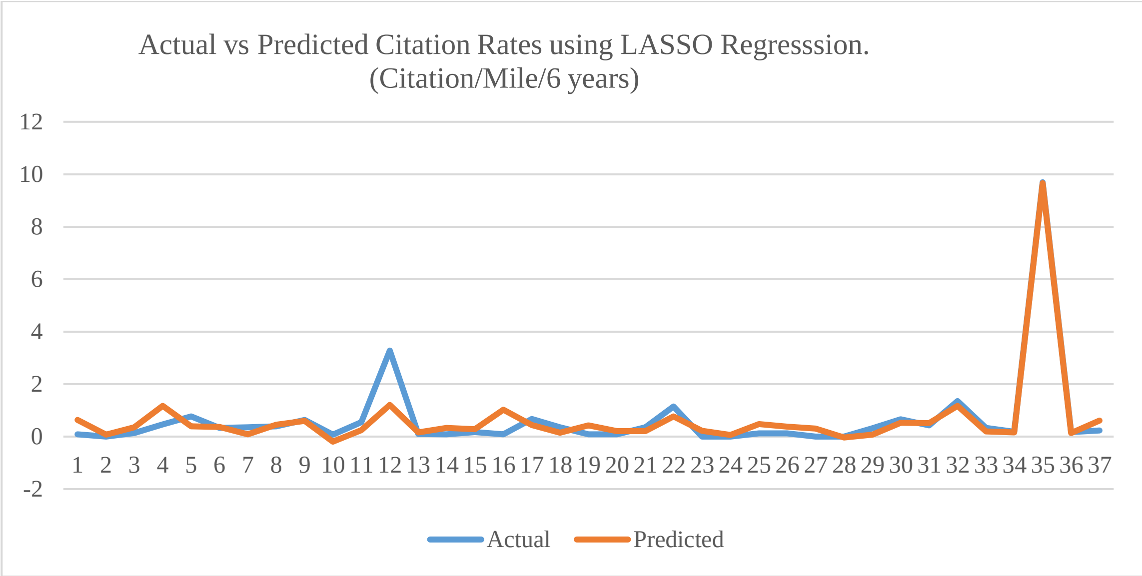

Figure 56: Actual vs Predicted Rates for the LASSO Regression Model

As shown in Figure 55 and Figure 56, both the Poisson and LASSO regressions predict the values in a trend that follows the increases and decreases in citations occurring at each location.

It's inaccurate to compare both models using the same evaluation factor. The two models perform different modeling techniques, and therefore have different evaluation criteria.

The Poisson regression assumes a Poisson distribution for the data, and predicts the number of events occurring over a certain period of time, and the LASSO fits a linear regression model and finds the most correlated variables with the dependent variable. The Poisson regression aims to minimize the residual squared errors, and the LASSO aims to find the best selection of variables that have the best value of whatever fits creation selection. In order to achieve that objective the LASSO model starts with all coefficients equal to zero and determines the variable that has the highest correlation with the dependent variable and afterwards continuously increases the coefficient of that included variable until the correlation of the variable is equal to the correlation of the second most correlated variable with the dependent variable. After that the combined least squares of both variables are increased until their correlation is equal to another variable in the model. This way, every variable included will still be evaluated for correlation and be a potential for removal.

Therefore, to find the citation prediction model that would predict the WWD risk at the traversable median segments, the model from the LASSO selection method is recommended to be studied on the median segments to determine the locations with the highest WWD risk, and accordingly allocate the appropriate countermeasures to the assigned locations.

5.4 Modeling Approach for Citations at Median Crossovers

The modeling approach for the illegal U-turn violations at the median openings applied a logistic regression model to find the significant variables to determine the probability of the citation occurrence at each opening. This methodology was selected instead of the Poisson or LASSO regression that predicts the number of citations occurring at each opening, because of the large number of median openings that had zero or only one illegal U-turn citation over the study

period. Only 15 openings out of the 168 analyzed median openings had more than two citations in the past 6 years (2011 – 2016), compared to 67 opening that had at least one citation on them.

The logistic regression produces a binary outcome that is defined to be either 1 (event) or 0 (non-event). Several selection steps have been performed in the regression to conclude the final model that predicts the probability of a violation occurrence on each median opening. Both CF and SF areas were modeled separately, and afterwards combined to find any differences in the citation record in the different area.

5.4.1 Exploratory Variables Studied in Median Crossovers Model

The locations of all 168 median openings (crossovers) for official use only in the studied roadway network were previously determined in Chapter 3. The term crossover is generally used for a median opening for official use only. However, in this section because the section studies all types of median openings, the term crossover is used only for a specific type of median opening that is a paved segment over a median more than 40 feet wide. An example of a median crossover is shown in Figure 57.

Figure 57: Street view of a Median Crossover on SR528 in Florida (Google maps, 2017)

In order to find the significant factors that influence the occurrence of illegal U-turn violation at the median openings, numerous exploratory variables were considered. The exploratory variables included several the geometric and traffic characteristics that are expected to encourage drivers to commit the illegal U-turn maneuver at those segments. The variables considered were calculated and measured for all 168 crossovers included in the study area. Most of the geometric design features were measured manually using the aerial photo and the measurement tools provided by ArcGIS and Google Maps. Moreover, the traffic characteristics included were extracted from the shapefiles provided by the FDOT Traffic Data GIS shapefile website (*38*). The list of all exploratory variables included in the median opening analysis are shown below.

1. The type of median opening
2. Distance to the closest median opening
3. Distance to the second closest median opening
4. Distance to the closest toll plaza
5. Distance to the closest access point
6. If the median opening is at a traversable median [Binary, Yes=1, No=0]
7. Number of Lanes
8. Average Annual Daily Traffic (AADT)
9. The Speed limit

Afterwards, the outcome variables were selected to represent the potential risk of WWD due to illegal U-turns at the median openings. The outcome variables are listed below.

1. Number of citations that have occurred at openings
2. If a citation had occurred at median opening in the past 6 years [Binary, Yes=1, No=0]
3. If a crash had occurred at median opening in the past 6 years [Binary, Yes=1, No=0]

5.4.2 The Justification and Preparation Methodology of the Exploratory Variables in the Median Openings Model

This section describes the methodology and criteria of selecting and measuring each of the included variables in the incident prediction model at the median openings. The order used in listing of the variables in the previous section was used in describing each variable as well.

The type of median opening [Discrete, Type= 1, 2, 3]

This variable was described in the traversable median segment. However, the value of 0 was not included because this indicates the type of design for the median openings. Similar to the definitions for the traversable median segment, 1 indicates that there is an opening in the median barrier with median width less than 40 feet, 2 indicates there is a design median opening (crossover) in the segment with median width at least 40 feet, and 3 indicates there is a graded unpaved area dedicated for official use only. The description and illustration of the three types of median crossovers are below. An example of median Type 1, Type 2, and Type 3 are shown in Figure 58, Figure 59, and Figure 60 respectively.

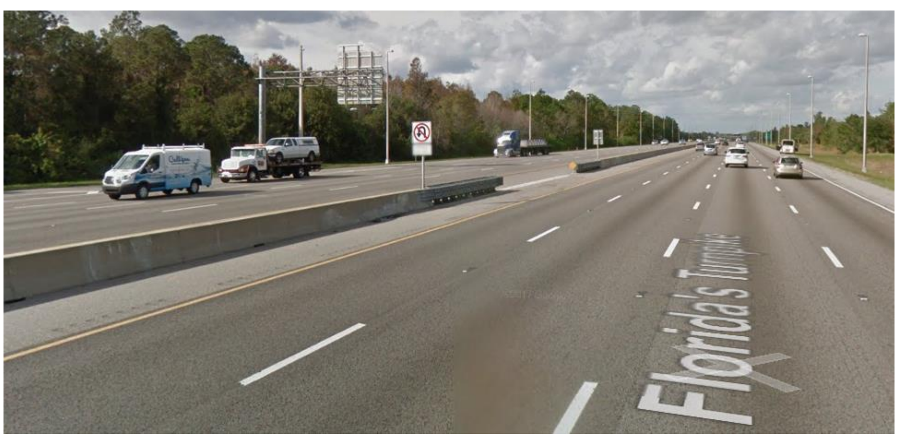

Figure 58: A Picture from Google Maps of an Opening in Median Barrier for Official Use Only (Type 1) On Florida Turnpike near Exit 255 (taken by UCF Research Team in December 2016)

Figure 59: A Picture from Google Maps of a Crossover Opening for Official Use Only (Type 2) on SR429 between Exit 19 and 22 (taken by UCF Research Team in December 2016)

Figure 60: A Picture from Google Maps of an Unpaved Median Opening for Official Use Only (Type 3) On I4 between Exit 48 and 55 (taken by UCF Research Team in May 2017)

Distance to the nearest interchange

The distance in miles, and was measured using the ArcGIS measure tool that is found in the “tools” toolbar. This variable was included to verify that the illegal U-turn maneuvers are expected to occur at median openings near to major interchanges by lost drivers or drivers who got in to the wrong exit and are willing to impatiently correct their path.

Distance to the first closest median opening

This variable was measured in miles, and it measures the distance from the studied median opening to the next closet median opening from either direction. The variable was measured to study if the spacing between the openings has any influence on drivers for committing illegal U-turns and median openings for official use only. It is expected in this case that larger spacing between medians would mean longer limited access facilities segments, therefore, this would a short cut for drivers to impatiently correct there path.

Distance to the second closet median opening

This variable was measured in miles, and it measures the distance from the studied median opening to the closet median opening from the opposite direction of the first closet median opening. Including both the 1st closet variable and the 2nd closet variable in the analysis would embrace the spacing from both sides of the median opening. Similar to the first closet median opening, larger distances are expected to attract driver to commit the illegal U-turn violation.

Distance to the closest toll plaza

This variable was measured in miles, and measures the distance to the closet mainline toll plaza in the network. The variable was included to study the influence of toll plazas on drivers trying to avoid paying tolls and turn around to exit at the nearest exit.

Distance to the closest access point

This variable was measured in miles, and measures the distance to the closet off-ramp or on-ramp into the mainline. The variable was included to study the influence of the access points on drivers turn around to exit from the off-ramp in the opposite direction or drivers who got on the mainline by mistake and would like to leave the facility from the off-ramp on the opposing direction without taking the burden to drive until the next off-ramp and possibly paying additional tolls.

If the median opening is at a traversable median [Binary: 0, 1]

This variable had two possible values yes (1) or no (0). The variable was included to study the influence of the presence of traversable medians on the U-turn violation, where it is expected that grass traversable medians would encourage drivers to commit an illegal U-turn maneuver because median opening at traversable segment to not have surrounding structures that the driver might be afraid to hit while committing a U-turn maneuver at high speed.

Number of Lanes

The variable presents the number of lanes in each direction at the location where the median opening is located, as found from the FDOT Shapefiles website. It is expected that segments with less numbers of lanes would have lower speeds, therefore, would be easier for drivers to commit the U-turn maneuver.

Average Annual Daily Traffic (AADT)

The variable presents the AADT on the roadway where the median opening is located, as found from the FDOT Shapefiles website. The variable was included in the analysis to confirm the expectation that roadway segment with lower AADT values would have more acceptable gap for merging and by result more illegal U-turn violations.

Speed Limit

This variable was found from the GIS Shapefiles provided by the FDOT website (*38*). The variable was included in the analysis to validate the expectation that roadway segments with lower speed limits would easier for drivers to slow down to relativity low speed to commit the illegal U-turn maneuver while traveling on the roadway in comparison with roadway that have higher speed limits were the general traffic in both directions would be travelling in high speed.

Median Width

This variable was measured from the aerial photo of the roadway segment provide by Google Maps and confirmed with the GIS Shapefiles provided by the FDOT website (*38*). The variable was included in the analysis to verify the expectation that large median widths would encourage driver to commit the U-turn maneuver due to the sufficient storage provided by the median.

5.4.2.1 Test of Correlation between Variables in Median Openings Model

The listed variables were tested for correlation in the combined dataset including both CF and SF areas in the dataset with a total of 168 openings analyzed. The detailed correlation table for the dataset is found in the APPENDIX D. The correlation table revealed that there is correlation between the AADT and the Number of lanes with a value of 0.72 similar to the traversable median segment dataset. Moreover, the variable of distance to the nearest interchange and the distance to the access point were slightly correlated as well with a value of 0.59. The two variables might have some overlap since all major interchanges are access point but all access points are interchanges. Each variable estimates a different factor, the first indicates the influence of major interchanges on the illegal U-turn maneuver, and the second measures the influence of the access points (each on-ramp and off-ramp).

5.4.2.2 Summary of Variables Included in Median Opening Model

This section summarizes description of both the dependent and explanatory variables of the median openings model with the expected effect on the dependent variable to be positive or negative for each variable in the model. The summary is shown in Table 18.

Table 18: Variable Description Summary for Median Opening Model

Variable name in model	Type	Description	Expected Effect	Mean	S.D
Dependent Variables					
Cit_No	Continuous	No. of Citations on each opening/year.	N/A	0.68	2.06
Cit_Occ	Binary	If a citation occurred on the Opening in the past 6 years. (Yes=1, No=0)	N/A	0.32	0.47
Explanatory Variables					
MED_TYP	Discrete	Median Opening Type (1, 2, 3)	N/A	1.53	0.53
DIST_INT [mile]	Continuous	Distance from the opening to the nearest major interchange	-ve	4.36	5.52
DIST_OPNG [mile]	Continuous	Distance from the opening to the next nearest opening	+ve	1.39	1.07
DIST_OPNG2 [mile]	Continuous	Distance from the opening to the 2nd nearest opening	+ve	2.62	1.99
DIST_TOLL [mile]	Continuous	Distance to the nearest mainline toll plaza	-ve	10.67	16.69
DIST_ACC [mile]	Continuous	Distance to the nearest on-ramp or off-ramp	- ve	2.62	3.73
FLUSHED	Binary	If the opening on an traversable segment (Yes=1, No=0)	+ ve	0.10	0.30
N. Lanes	Discrete	Number of lanes	- ve	2.70	0.89
MED_W [ft.]	Continuous	Median width	+ ve	51.55	42.36
AADT [*1000]	Continuous	AADT on segment	- ve	75.76	45.98
SPEED	Discrete	Speed limit posted	- ve	67.59	4.24

5.4.3 Logistic Regression Model Estimates for Median Openings Model

The variables described in Table 18 were analyzed using a logistic regression model. The logistic regression is a reliable modeling methodology that models binary dependent variables and predicts the probability of an event (*53*). The dependent variable in this model was either citation or non-citation for an illegal U-turn citation at a median opening.

This model could be used by the agencies during the planning phase before installing new median openings on the roadway, to compare between the different options and select the location with the least probability of citation occurrence. Furthermore, the model could also be used to evaluate the existing median openings for high possibility of illegal U-turn citations occurring at them and find the location with higher priority to install countermeasures to reduce the frequency of occurrence of these violations.

The Logistic regression model follows the formula shown in Equation (5.2).

$$P(x) = \frac{1}{1+\exp-(\beta_0+\beta_1 X_1+X_2\ldots)} \quad (5.2)$$

Where:

P(x): The probability of a citation occurring at the median opening

βn: Estimate of variable n, , n=0 to ∞

Xn: Exploratory variable n, n=0 to ∞

Therefore, increasing the value of a negative coefficient would reduce the probability of a citation to occur. An increase in the exponential value that already has a negative value would reduce the probability of occurrence at the median opening.

Using PROC LOGISTIC in the SAS software, the dataset of the median opening characteristics and the outcome variables for the citation occurrence were analyzed to find the significant variables to predict the probability of a citation occurring at each opening. Each of the CF and SF areas were analyzed separately and found to have different significant variables in each area.

5.4.3.1 The Logistic Regression Model for Central Florida

The results of modeling the Central Florida (CF) area for the median openings showed that 3 variables out of the 11 variables were selected in the stepwise selection procedure to find the

variables with significance level less than p=0.20. The variables included were the AADT, the distance to the nearest access point, and the distance to the farthest median opening. The purpose of the stepwise selection is a starting point for the modeling procedures to understand the effect of each variable on the citation occurrence at the median openings.

Afterwards, additional modeling efforts were performed to find the significant variables that predict the illegal U-turn citations with p value less than 0.05. However, the significant variables found in the CF model at the median openings are shown in Table 19.

Table 19: Model Estimates for Violations on Median Traversable Segments for CF Model

Analysis of Maximum Likelihood Estimates						
Parameter		**DF**	**Estimate**	**Std Error**	**Wald x^2**	**Pr > ChiSq**
Intercept		1	0.6734	1.1805	0.3254	0.5684
SPEED	65	1	-4.5523	1.8196	6.2587	0.0124
SPEED	70	1	-2.8442	1.2132	5.4966	0.0191
AADT		1	0.0253	0.0118	4.6474	0.0311

The degrees of freedom shown in the table are required to define the value for the Wald x^2 test shown in the 2nd column from the right. The Wald x^2 is a test to measure the significance of the explanatory variables, and has the null hypothesis that the variable estimate is equal to zero. The last column shows the probability to reject the null hypothesis if lower than a certain probability and conclude there is no sufficient evidence that the variable estimate is not significant.

In this model two exploratory variables were found significant, the speed and the AADT. The final significant variables might vary from the variables included in the step wise procedure,

because the variables interact in the same model to result in different significance levels for the variables.

However, the first variable (speed) was found as expected to have negative coefficient, indicating that the higher the speed the less the lower the probability of the citation to occur at the opening, where the U-turn maneuvers are harder and more dangerous to perform on high speed. This would discourage people to commit such dangerous maneuvers at the median openings.

However, the second variable (AADT) was found to have a positive coefficient, which is the opposite of what was expected before the modeling. The results indicate that the possibility of an illegal U-turn violation is higher at locations with high traffic volume. This could be interpreted that locations with excessive traffic volume would have more congestion and travel time. The excessive delay and confession would bother drivers and make them impatient to commit an illegal U-turn to avoid the congested traffic.

5.4.3.2 The Logistic Regression Model for South Florida

Similar to the CF model, the dataset for the SF was preliminary analyzed using the stepwise procedure to indicate the most significant variables in the model.

A stepwise selection procedure was performed to conclude the final model for the SF area for the median openings. The preliminary model included 5 variables: the distance to nearest access point, the distance to the nearest median opening, the AADT, the number of lanes, and the distance to the nearest major interchange in the SF model for median openings.

However, the final logistic model to predict the probability of violations occurring at the median crossovers had a significance level more 90%. The model included two exploratory

variables: the distance to nearest access point and the distance to the nearest median opening. The significant variables found in the SF model are shown in Table 20.

Table 20: Model Estimates for Violations on Median Openings in South Florida

Analysis of Maximum Likelihood Estimates					
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald x^2**	**Pr > ChiSq**
Intercept	1	-1.7715	0.4214	17.6684	<.0001
DIST_OPNG	1	0.3263	0.1807	3.2602	0.0710
DIST_ACC	1	0.2187	0.1141	3.6730	0.0553

As shown in the Table 20, the coefficient for the distance to the nearest opening variable is found to be positive, indicating that the spacing between the openings encourage drivers to commit illegal U-turn violation at the openings. This estimate was found similar to what was expected.

However, in contrast with the CF model the distance to the nearest access point was found to positive, meaning that the farther the next exit is the more likely the opening to have a citation on. In this case a possible explanation for that would be similar to the explanation on the distance to the nearest median opening that openings in isolated areas from any access are more likely to have citations. This could be a result of the network design properties in the SF area, where the network's design and controlled access influence drivers towards performing this violation at isolated median openings to avoid traveling for long distances on the network.

5.4.3.3 *Comparison between the CF Model, the SF Model*

The three models shown different significant variables to estimate the probability of a citation occurring at a median opening. All variables included have significance level more than 90% with p value less than 0.1. The CF model had the speed and the AADT as the significant variables. On the other hand, the SF model had the distance to the nearest access point and the distance to the nearest opening, the number of lanes.

The CF model reveals better significance results to explain the data, since it had the higher receiver operating characteristic (ROC) value. The ROC is used to compare between the logistic-regression models, and it assesses the logistic model's performance in classifying the binary pairs in the model. The closer the ROC value is to 1 the better the model is in classifying the data.

Table 21: The Significant Variable for Each of the Two Logistic Models

Central Florida Model		South Florida Model	
Variable	Coefficient	Variable	Coefficient
Intercept	0.6734	Intercept	-1.7715
SPEED_65/60	-4.5523	DIST_OPNG	0.3263
SPEED_70/60	-2.8442	DIST_ACC	0.2187
AADT	0.0253		
ROC	0.719	ROC	0.682
Score test	0.0069	Score test	0.0027

The logistic regression model found for each areas discovered different variables in each model, this could be an indicator that significant differences are present in the driver behavior, the constructed network, or other uncounted issues is causing the models to be significantly different.

However, this could be a recommendation and guideline for the agencies to analysis each area separately. This consideration would be more efficient to combat the illegal U-turn violation that possibly result in head on crashes and cause severe disturbance in traffic.

5.5 Modeling Approach of All Types of Illegal U-Turn Citations in the State of Florida

This approach models the combined dataset for citation at both median openings and traversable medians. This model analyzed the same exploratory variables included in the traversable medians model with including the citations that occurred at the median openings found in the traversable median segment. The model included 44 different segments in both CF and SF areas.

The segments were analyzed similarly to the traversable median segments using the Poisson regression to predict the number of citations per year occurring on each segment by determining the geometric and traffic characteristics of the segment.

5.5.1 Exploratory Variables Studied in the Combined Model

The combined model analyzed the properties and roadway characteristics of 43 traversable median segment found in the study area. The description of the variables are explained in segment 5.3.1. However the repeated list of all exploratory variables included in the analysis are shown below.

1. Length of median traversable segment
2. Distance from center of segment to nearest major interchange
3. Number of lanes
4. Number of access points in the segment

5. Number of median openings in the segment

6. The type of median opening in the segment

7. The average distance between the access points

8. The distance to the next closest traversable median segment on the roadway

9. Median width

10. Average Annual Daily Traffic (AADT)

11. The speed limit

Afterwards, the outcome dependent variable was assigned to be the number of citations per year on each traversable median segment.

5.5.2 Justification and Preparation Methodology of the Exploratory Variables

The variables included in the modeling methodology were similar to the variables included in the traversable median segment analysis in chapter 5.3.2. Therefore, the justification and preparation methodology for the variables will not be repeated and instead, it could be referred to chapter 5.3.2.

5.5.2.1 Test of Correlation between Variables

The listed variables in chapter 5.5.1 were tested for correlation by the PROC CORR built in the statistical software SAS for the combined dataset including all citations occurring on 44 median segments in the state of Florida. The complete correlation table for the dataset is found in the APPENDIX D.

The highest correlation found in the data was the segment length and the average distance per access point with a value of 0.9. This correlation was not significant in any of the previous

models. The variables will be analyzed by a variable selection model (LASSO) and will show the interaction between the variables after entrance in the model. Therefore, it is expected that the final model would detect the correlation and remove one of the two variables, and this correlation was considered in the modeling steps. On the other hand, the other variables that had high correlation where the speed with the number of lanes with a correlation coefficient r=-0.6, the number of median openings with segment length with a correlation coefficient r=0.67, and the distance to the next traversable median with the number of lanes. All of the mentioned correlations were considered in the variable selection model between the AADT and the Number of lanes with a value of 0.72 similar to the traversable median segment dataset. The variable of distance to the nearest interchange and the distance to the access point were slightly correlated as well with a value of 0.59. The two variables might have some overlap since all major interchanges are access points but all access points are not interchanges. Each variable estimates a different factor, the first indicates the influence of major interchanges on the illegal U-turn maneuver, and the second measures the influence of the access points (each on-ramp and off-ramp).

5.5.2.2 Summary of Variables Included in Combined Citations Model

The variables included in the combined model, their means, standard deviations, and expected effect are shown in Table 22.

Table 22: Variable Description for Model of Combined Facilities

Variable	**Type**	**Description**	**Expected Effect**	**Mean**	**S.D**
Dependent Variable					
No. of Citations	Continuous	No. of Citations per year on each segment.	N/A	0.66	7.45
Explanatory Variables					
L. of segment [mile]	Continuous	Length of traversable median segment	+	1.99	3.45
Dist. to interchange [mile]	Continuous	Distance from center of segment to nearest major interchange	-	2.18	2.94
N. Lanes	Discrete (2,3,4)	Number of lanes in each direction	-	2.4	0.69
N. Access Pts.	Continuous	Number of access points in the segment	-	1.67	1.23
N. Median Openings	Discrete (0,1,2)	Number of median openings in the segment	+	0.42	1.01
Median Type	Discrete (0,1,2,3)	The type of median opening in the segment	N/A	0.53	0.96
Avg. Dist. per Access Pt. [mile]	Continuous	The average distance between the access points	+	1.18	1.83
Dist. to next segment [mile]	Continuous	The distance to the closest traversable median segment.	+	1.00	1.76
Median W. [ft.]	Continuous	Median width	+	79.19	47.32
AADT [*1000]	Continuous	AADT on segment	-	54.38	42.17
Speed Limit	Discrete (65,70)	Speed limit posted	-	68.84	2.40

5.5.3 Poisson Regression Model Estimates for the Significant Variables in the Combined Model

The results from modeling the described dataset showed that seven variables out of the eleven variables were found significant with a p-value less than 0.001. In addition, a scale

parameter was introduced to the Poisson model to overcome this problem and was set to the value of 0.5 to adjust the overdispersion in the data.

Table 23: Model Estimates for Citations on Median Facilities in the Combined Model

Variable		**Coefficient**	**Standard Error**	**95% C.L**		**Pr > x^2**
Intercept		0.6491	0.1475	0.3600	0.9382	<.0001
N_LANES	3	-2.7409	0.3079	-3.3444	-2.1375	<.0001
N_LANES	4	-2.7708	0.3495	-3.4557	-2.0859	<.0001
N_LANES	5	-1.3450	0.3589	-2.0484	-0.6416	0.0002
AADT		0.0097	0.0022	0.0054	0.0140	<.0001
AVGDIS_PT		-0.3111	0.0922	-0.4917	-0.1305	0.0007
Segment_L		0.2328	0.0467	0.1412	0.3245	<.0001
DIST_INT		-0.2154	0.0237	-0.2619	-0.1688	<.0001
MED_W		0.0128	0.0013	0.0103	0.0154	<.0001
Scale		0.5000	0.0000	0.5000	0.5000	

As shown in Table 23, all variables included had a P-value less than 0.001 to indicate the high significance of the variables. Also, it was found that both variables that had high correlation were included in the model as significant variables. Including both variables in the final model might result in inaccurate estimations because of the high correlation. Therefore, it is not recommended to include both variables in the final model. Similar to the modeling approach adopted in analyzing the traversable medians, the significant variables from the Poisson regression were also included in the LASSO regression. The detailed results of the LASSO regression are shown in the following section.

5.5.4 LASSO Regression Model Estimates and Results of the Combined Model.

The significant variables found from the Poisson regression model were evaluated again using the LASSO model to compare between the variables and find the most effective variables in the model. The selection methodology used in the LASSO model was described in detail in section 5.3.4. The procedure used in this model was to select the model that produces the highest adjusted R^2. The summary of the variable selection process performed by LASSO is shown in Table 24.

Table 24: LASSO Variables Selection Summary for Selected Variables from the Combined Model

LASSO Selection Summary				
Step	**Effect Entered**	**Effect Removed**	**Number Effects In**	**Adjusted R^2**
0	Intercept		1	0.0000
1	MED_W		2	0.3683
2	N_LANES_4		3	0.3847
3	AVGDIS_PT		4	0.4126
4	DIST_INT		5	0.4269*
5	N_LANES_5		6	0.4151
6	N_LANES_3		7	0.4068
* Optimal Value Of Adjusted R^2				

Therefore, the most effective variable in the model is the median width with the largest standard coefficient followed by the number of lanes (4 lanes), the average distance per access point, and finally the distance to the nearest interchange. The order by how the variables were included in the model does not mean they are the most significant variables in the model, because

the variables have interaction with each other and as a result including one variable could affect the effect of another variable that was included before. In Figure 61, it could be noticed that the standard coefficient changes for the average distance per access point (the pink line), changes its slope (become more significant effect) after including the variable for the segment length. This sudden change in slope illustrates the high correlation found before between the two variables indicating high level of interaction as shown by the standardized coefficient.

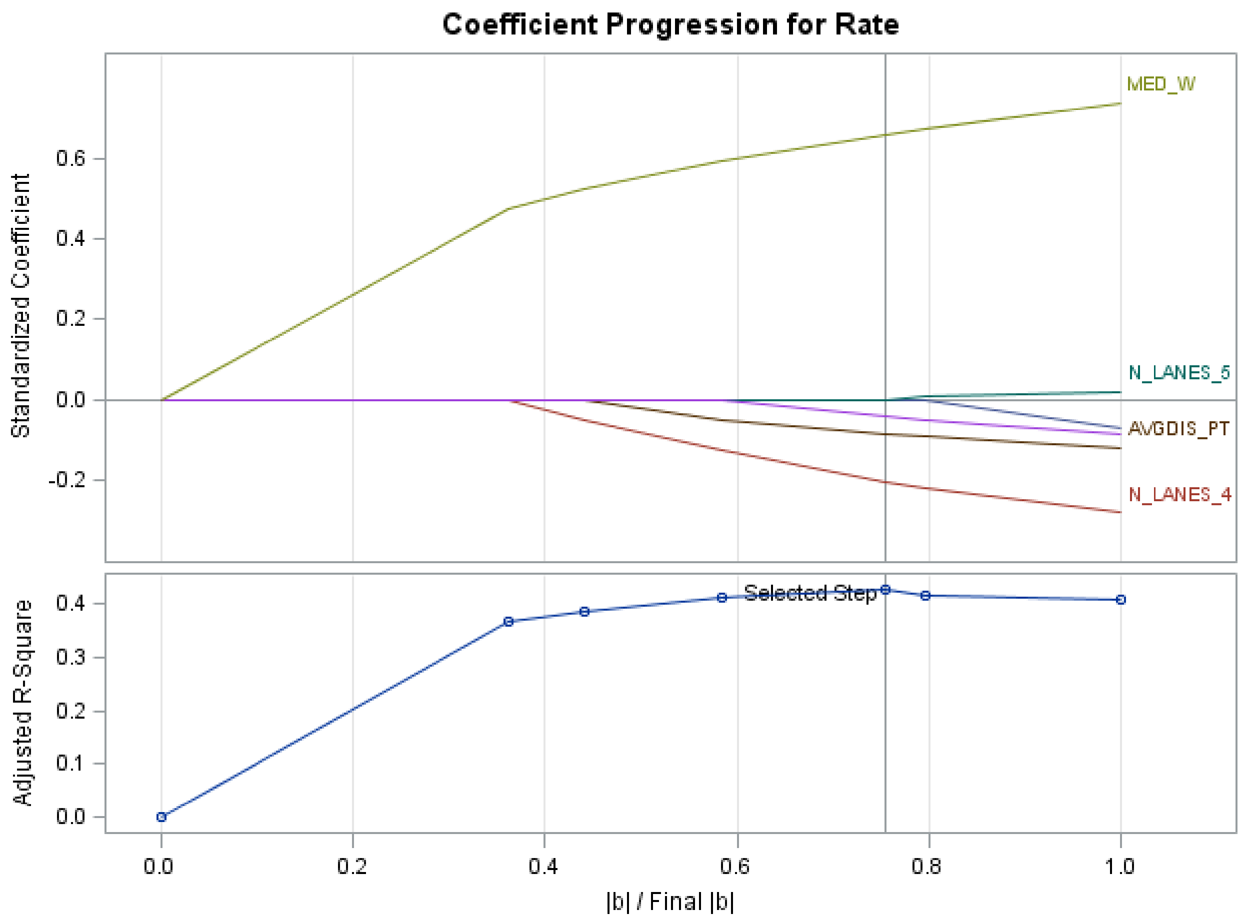

Figure 61: LASSO Coefficient Progression for the Selected Variables in Combined Model

For the model of both the traversable medians and median openings, it was found that the most significant variable was the median width with a positive coefficient. The positive effect

indicates an increase in the expected number of citations with the increase of the median width, which agrees with the previous separated models. Moreover, the number of lanes of 4 lanes has a negative effect indicating a decrease of the expected number of citations on a segment with 4 lanes in comparison with the 2 lane segment, or in other words a decrease in the expected number of citations with the increase of the number of lanes. The variable were the selection procedure stopped was the average distance between access points with a negative effect, indicating that the numbers of citation is expected to increase at locations were the spacing between the access points is minimal. The final variable in the model was the distance to a major interchange with a negative effect, indicating an increase in the predicted number of citations near the locations of the interchanges from drivers that have mistaken their exit or ramp and are willing to go back urgently and correct their path with traveling for a long distance to reach an off-ramp to leave the facility and possibly get charged at the exit ramp toll booth. All of the mentioned variable were explained in the previous models.

5.5.5 Comparison between the Models for the Combined Illegal U-turn Citations.

This section includes two models each modeling its unique dataset. The first model was a Poisson regression model that analyzed all variables to find the combination of significant variables that predict number of citations each year. The second model analyzed the significant variables from the Poisson Regression with the P value less than 0.001 using the LASSO regression selection method. In order to have a better understanding of the various models, the significant variables of each model with their coefficients were listed in Table 25.

Table 25: Comparison between the Coefficient in the Poisson and LASSO Models in the Combined Model

Poisson Model with Significant Variables		**LASSO Model for Significant Variables in Poisson Model**	
Variable	Coefficient	Variable	Coefficient
Intercept	0.6491	Intercept	-5.124914
N_LANES_3	-2.7409	-2.354455	-2.354455
N_LANES_4	-2.7708	N_LANES_4	-8.990300
N_LANES_5	-1.3450	Not Significant in LASSO Model	
DIST_INT	-0.2154	DIST_INT	-0.134966
AVGDIS_PT	-0.3111	AVGDIS_PT	-0.440251
MED_W	0.0128	MED_W	0.131625
Segment_L	0.2328	Not Significant in LASSO Model	
AADT	0.0097	Not Significant in LASSO Model	

All of the common variables between the models have similar signs and accordingly having the same interpretation. However, it should be mentioned that the proximity in the value of the coefficient cannot be simply explained because the different modeling methodologies for each model, therefore the mentioned interpretation discusses the signs and the effect of the increase or the decrease of each variable.

5.6 Practical Example for Implementing the Significant Models

The previous models described could be used as effective planning tools to select the appropriate locations for installing new median openings and reevaluating the existing median

openings to select (or keep) locations with the lowest probability of illegal U-turns (these are locations with the lowest potential risk). For example, an operating agency constructs a new highway or recently installed median barriers on their roadway network and needs to determine the locations where to install emergency crossovers. Numerous guidelines have been included in the AASHTO roadway design manual *(23)*, and several states prepared more detailed guidelines for their engineers to follow, such as the Florida *(27)* and Texas *(29)* for spacing, location, and installation requirements. Therefore, the first step would be to examine all potential locations that agree with adopted guidelines. However, since all the crossovers are installed already they all would be approved by the district engineer, and this would be an example to find the location with the lowest expected probability of violations. The example shown in **Error! Reference source not found.** is located in SF near the intersection of SR 75 with SR 869.

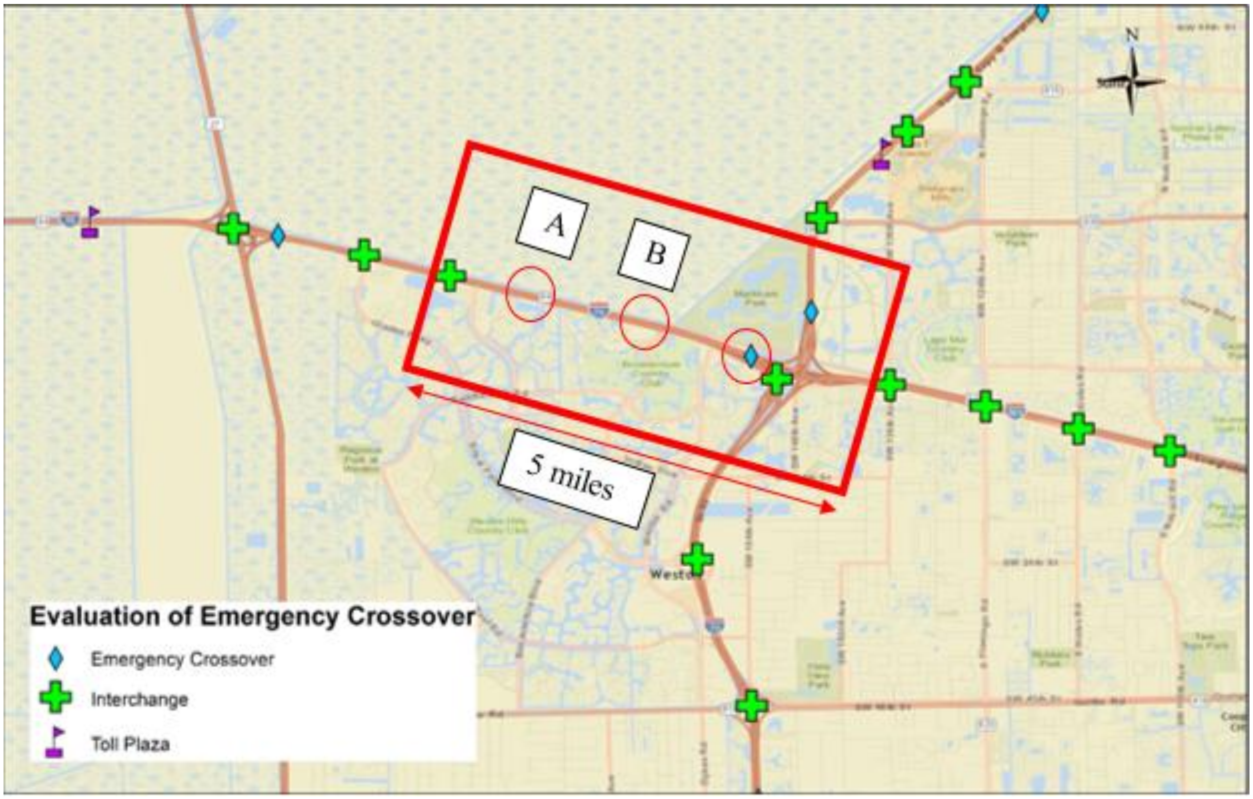

Figure 62: Example Location on SR75 to Evaluate the Emergency Crossover Locations.

Since the location is in SF, then the model found for SF will be used in this example with the coefficient found in table 19.

The equation to be used to find the probability of a violation at specific location of a crossover is shown below.

$$P(x) = \frac{1}{1+\exp -(-1.7715+0.3263*\mathrm{DIST_{OPNG}}+0.2187*\mathrm{DIST_{ACC}})} \quad (5.3)$$

Table 26: Calculation Example for Crossover Location in SF

Option	**Distance to Opening (X1)**	**Distance to Access Point (X2)**	**Probability of Violation**
Existing	0.8	0.4	80.58%
A	2.5	1	67.64%
B	2.2	1.1	69.28%

The existing crossover has p=80%, by measuring the distance from the opening nearest interchange and the nearest toll plaza. Option A had p=67%, and option B had p=69%. Therefore, since all crossovers agree with the guidelines and spacing requirements the recommended location to install an emergency crossover would be at option A.

This shows an example of how the models found could be used in evaluating the existing conditions and installed openings to determine the locations with the lowest probability of violations and accordingly the lowest risk of WWD crashes.

5.7 Summary of Modeling Chapter

This chapter included all the statistical modeling procedures and described the a priori expectations for the exploratory variables that have correlation with the occurrence of illegal U-turn violations. The modeling methodology adopted three modeling approaches to find the most accurate prediction models for the illegal U-turn citations on the limited access facility network in the state of Florida.

The first modeling approach was prepared for the illegal U-turn Citations on the traversable median segments. This approach included a sequential analysis method using the Poisson regression followed by the LASSO regression analysis. The preparation steps started with justifying the exploratory variables included in the model. Afterwards, the values of the exploratory variables and the correlation between the variables in the dataset were measured and calculated. It was found that the few variables had correlation between them, some explainable and others are not. As an example of an explainable correlation is the AADT with the number of lanes, and an example of the misunderstood correlations would be segment length with the average

distance between access points and the distance of the next flushed median. After that, using the Poisson regression analysis 7 variables out the 11 variables analyzed were found significant with a p value less than 0.0001. The LASSO regression method was performed afterwards on the 7 significant variable from the Poisson model, and found that the most effective variables that influence the illegal U-turn violations on the traversable median segments were the grass median type, the segment length, the average distance between access points, and the crossover median opening.

The second modeling approach was used to predict the probability of citation occurrence at median openings using a logistic regression model. Similar to the first model the correlation between the variables was measure and found a high correlation between the number of lanes and traffic volume similar, in addition to other moderate correlations in the data.

This logistic model was used to analyze three areas: CF, SF, and the both areas combined. The model for the CF area found two significant variables: the speed and the AADT. The model for the SF area also found 2 significant variables: the distance to the nearest median opening, and the distance to the nearest access point.

The third modeling approach combined the citations on median openings statewide. This model found that only median width was the significant variable in the model. This was the first time the median width was included among the significant variables.

Finally the same modeling procedure of the traversable median model was performed on a new dataset that combined citations at median openings and traversable medians in the same dataset. The correlation was measured in that model and found a strong correlation between the segment length and the average distance between access points (r=0.9). In this combined dataset model, two models were performed: the Poisson regression model to analyze all variables for significance, the LASSO regression model to analyze the significant variables in the Poisson

regression and find the highest adjusted R^2 possible for that model. The variables of the median width, number of lanes, the average distance per access point, and the distance to the nearest major interchange were found the most significant exploratory variables in the model.

6. CHAPTER SIX: SUGGESTED COUNTERMEASURES

6.1 Introduction

This chapter discusses the potential countermeasures to prevent WWD at limited access facilities. In addition, the chapter reviews various locations on the CFX and FTE road networks as examples where some designs could be more susceptible to WWD. The countermeasures suggested could be applicable for various locations and cases on the limited access facility network in the state of Florida and possibly other states on roadways segments with similar properties and traffic conditions. The locations studied and reviewed for median related WWD on the limited access network in the Florida region, can be categorized into three groups:

1. WWD illegal U-turn violations at emergency median openings (crossovers).
2. WWD median illegal U-turn violations at traversable medians.
3. WWD entries at off–ramp intersections.

6.2 WWD Median Illegal U-turn Violations at Emergency Openings

Emergency openings, such as the one illustrated in Figure 63 on the next page, are openings in the median that are designed for official use only (law enforcement, fire rescue, etc.). Drivers who perform illegal U-turns at these openings, which can sometimes result in WWD illegal U-turns, often do these maneuvers intentionally to take a shortcut or avoid paying tolls or for other reasons. Potential countermeasures for this situation should reduce the likelihood of non-emergency drivers making an illegal U-turn while still allowing unhindered access for emergency vehicles.

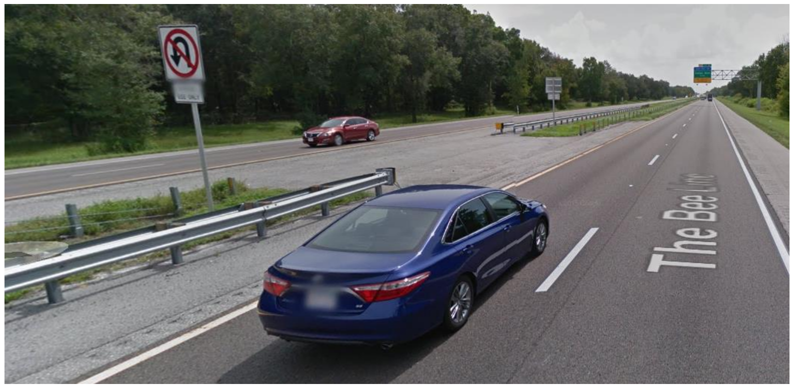

Figure 63: Emergency Opening on SR 528 before Exit 24 (Google Maps, 2016)

After studying the roadway network, it was found that most of the emergency openings in the CF area have similar conditions to the emergency opening shown in Figure 63. Therefore, the recommended countermeasures would be appropriate for any emergency opening on any limited access facility with similar design characteristics. These countermeasures are summarized in the following section.

6.2.1 Countermeasures for Median Crossovers at Emergency Openings

The AASTHO (*23*) and Florida plans preparation manual (PPM) (*36*) discussed numerous guidelines regarding the spacing, location, and construction of emergency openings. The detailed guidelines were discussed in chapter 2 section 2.5. These guidelines were developed to make the emergency openings less likely to be used by the general public.

Additional guidelines were found in The Texas Department of Transportation (TxDOT) (2014) Roadway Design Manual (*29*), recommending overlapping the median barriers to create an inconspicuous opening for the public, as shown in Figure 66. Moreover, Figure 67 shows the recommended dimensions for emergency openings, with a total opening width of 40 ft. The emergency openings on CFX roadways have an average opening width of 50 ft. However, after reviewing the design plans and the TPPPH (*37*) the max opening width for median openings was

40 feet which agree with the suggested width. The design for emergency crossovers from the TPPPH is shown in Figure 64.

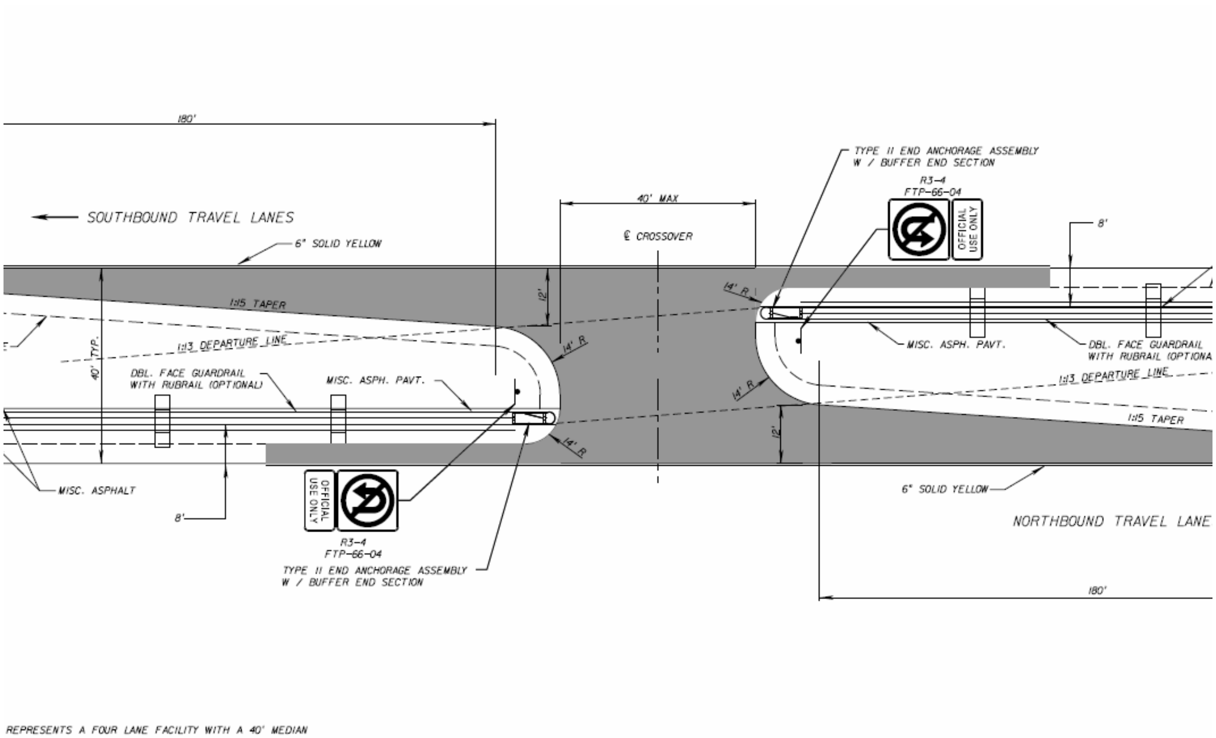

Figure 64: The Emergency Crossover Design for FTE Networks (*54*).

Moreover, it was found that opening width suggested by the FDOT PPM to be within the range of 65 to 70 ft as shown in Figure 65.

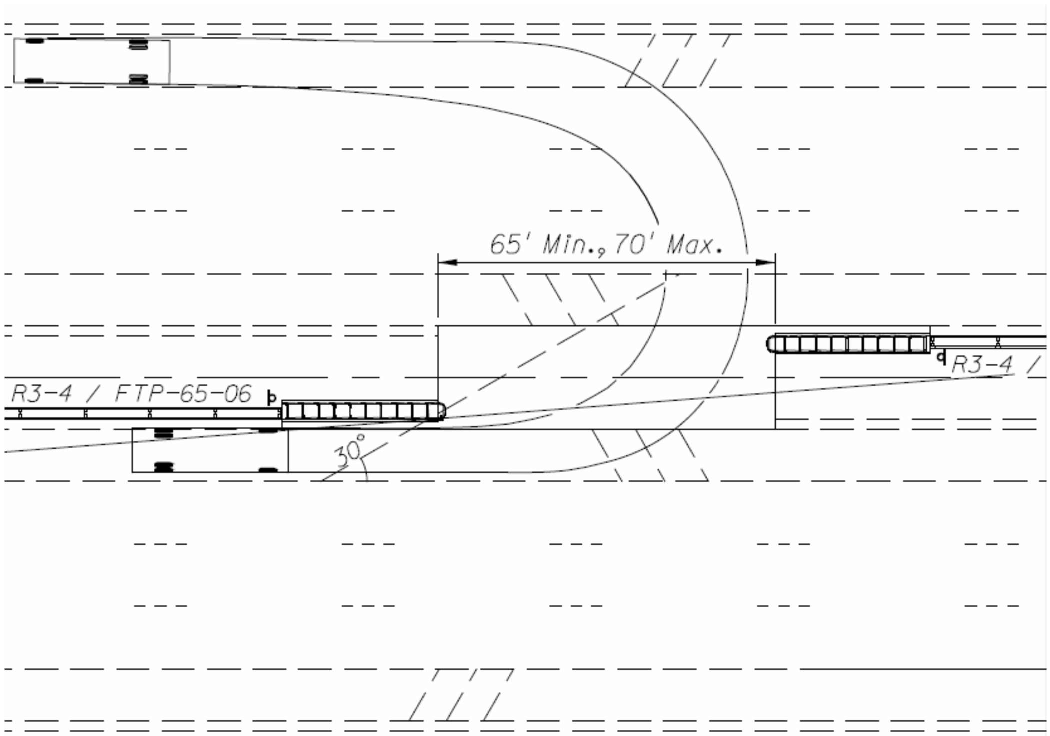

Figure 65: The Emergency Crossover Design for FDOT PPM (*36*).

This is to accommodate fire trucks and large vehicles when they have to turn around in response to an emergency. However, this can also make the opening more noticeable to non-emergency vehicles. Furthermore, the recommended guideline in the FDOT PPM and TxDOT design manual is to use a poorer surface treatment on these emergency openings that does not invite non-emergency vehicles to use the openings.

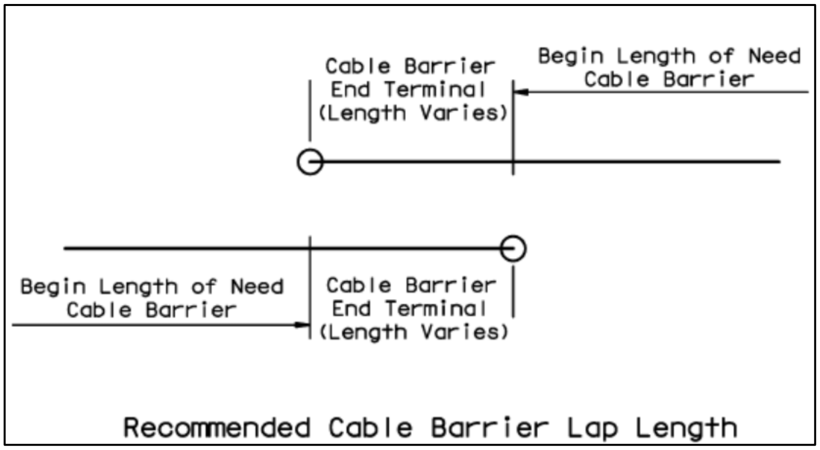

Figure 66: Illustration of Recommended Cable Barrier Overlap (*29*)

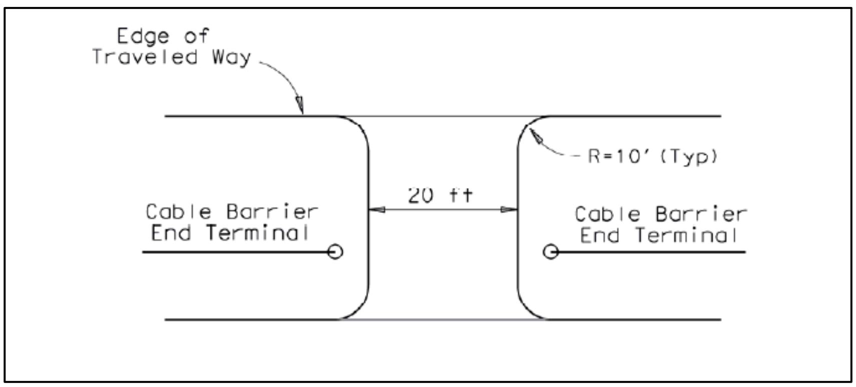

Figure 67: Recommended Emergency Opening Design Dimensions (*29*)

The design guidelines discussed are only recommendations that could reduce the chance of non-emergency vehicles from using the opening to perform a U-turn. However, drivers intentionally using the emergency opening to avoid a toll or take a shortcut will probably not be discouraged by these suggestions. Various levels of additional countermeasures could be employed to attempt to prevent these drivers from using the emergency opening. Some examples of low-cost countermeasures include installing surveillance cameras on the emergency openings as shown in Figure 68, along with additional regulatory signs, such as a sign showing the amount of the fine for making an illegal U-turn and a sign stating that the opening is photo enforced (Figure 69). These countermeasures could discourage some drivers from performing illegal U-turns.

Figure 68: Camera Installed at Emergency Opening (Barkingside 21 Website, 2012)

Figure 69: Examples of Additional Regulatory Signs (MUTCD, 2016)

For openings with high frequencies of WWD median crossovers, it might be necessary to install more advanced countermeasures. One option is to install automatic gates that can only be opened by authorized users. There are two possible gate designs that could be used at emergency

openings on the limited access facilities. Figure 70 shows barrier emergency gates that slide sideways to create an opening for an emergency vehicle to turn around. These gates blend in with the standard median barrier, helping to hide the opening from regular vehicular traffic.

Figure 70: Barrier Emergency Gate (Barrier Systems, Inc., 2016)

The other gate design option consists of poles that slide into the ground following activation by official authorities, as shown in Figure 71. This design could be more useful for median openings not surrounded by barriers.

Figure 71**:** Slide-in Gate (Portcullis Gate Automation Ltd. Website, 2016)

6.2.2 Emergency Openings with Special Design Considerations

The total number of emergency openings found on the studied limited access facility network was 168 openings. It should be mentioned that in the SF area numerous roadways have

construction projects being conducted, and it is recommended to reevaluate the geometric conditions after the construction is done and all managed lanes have been implemented.

The spacing and location guidelines for median openings included in both the AASTHO and FDOT PPM2017 are found in the following list:

1. The openings must not be spaced closer than 3.0 miles apart.

2. The openings must be located only in areas with above-minimum stopping sight distance and without superelevated curves.

3. The openings must not be located within 1,500 feet of the end of a speed-change taper (of a ramp or facility widening/narrowing) or any structure (bridge, overpassing facility or overhead sign).

4. Not located where the median width is less than 25 feet.

As mentioned in the FDOT PPM, violating any of the listed criteria require official approval of the State roadway design engineer and FHWA.

Furthermore, additional guidelines were included for the crossovers on FDOT limited access facilities and openings, the additional guidelines are listed below:

1. Not located within 1.5 miles of any interchange.

2. Not located where the median width is less than 40'.

3. Not located in urban areas.

4. Where continuous median barrier is present, openings for crossovers should not be greater than 5.0 miles apart between Interchanges.

However, any median opening or crossover that does not meet the requirements needs approval by the district design engineer.

After evaluating the existing median openings in both CF and SF, numerous median openings were found to not follow the first spacing requirement with a minimum of 3 miles

between the openings. It was found that 154 out the 168 median openings have a spacing less than 3 miles between the openings. The median openings that do not meet this requirement are shown on the maps in Figure 72 and Figure 73.

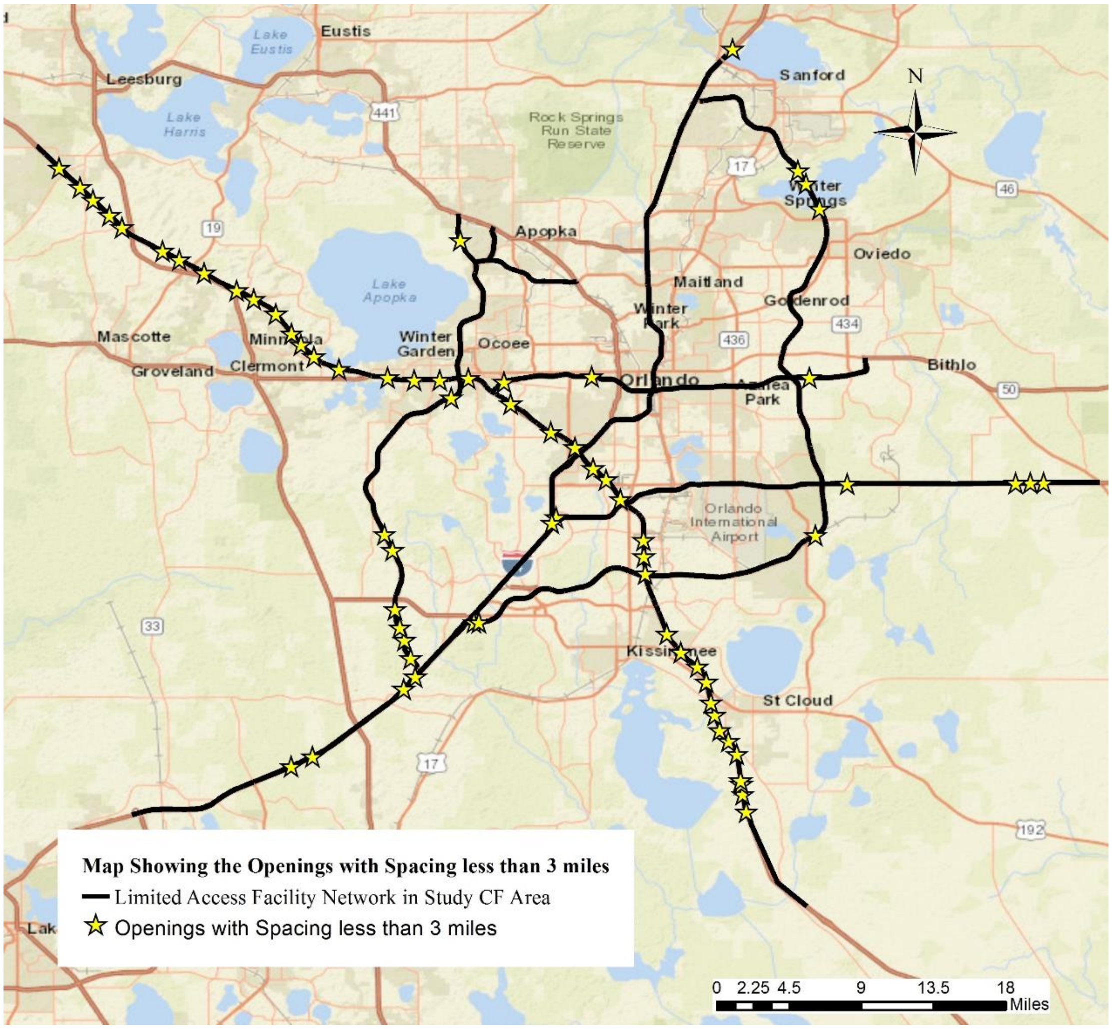

Figure 72: Map of the Median Openings in CF that have a Spacing Less Than 3 miles.

Figure 73: Map of the Median Openings in SF that have a Spacing Less Than 3 miles.

From the 154 median openings that do not meet the spacing requirement, 50 openings had at least one citation on them in the past 6 years, with a percentage of 33% out of the 154 openings and a percentage of 30% out of all median openings analyzed. The median opening spacing coefficient found in the SF model for median openings had a positive value, indicating that the farther the spacing between the openings the more likely the openings would have a citation. This percentage agrees with modeling results since only 30% of the openings that had citations, have a spacing distance less than 3 miles. However, after considering the percentage of openings that were included (154 out of 168=91.1%) and the number of openings that had citations on them (50 out of 55=90.9%), it was found that the locations with spacing less than 3 miles do not demonstrate a significant attraction to illegal U-turn citations, since the percentage of included openings is equal to the percentage of openings that have citations.

It was found that 65 median openings out of the 168 openings were installed on a median less than 40 feet wide. From the 65 median openings 13 median openings had at least one citation that has occurred on them in the past 6 years, with a percentage of 20% of the included sample. The low percentage agrees with the finding from the models for the median openings statewide, where the median width had a positive coefficient indicating that larger median widths would be more susceptible to crossover violations. In addition, the percentage of median openings included (65 out of 168 = 38%) versus the percentage of the included median openings that have citations (13 out of 55=24%) is additional proof of the finding from the models in chapter 5 that median openings with low median widths are less likely to have illegal U-turn citations on them. The results for the AASHTO requirement to have a minimum of 25 feet have the same conclusion as well. Figure 74 and Figure 75 show the 65 median openings included.

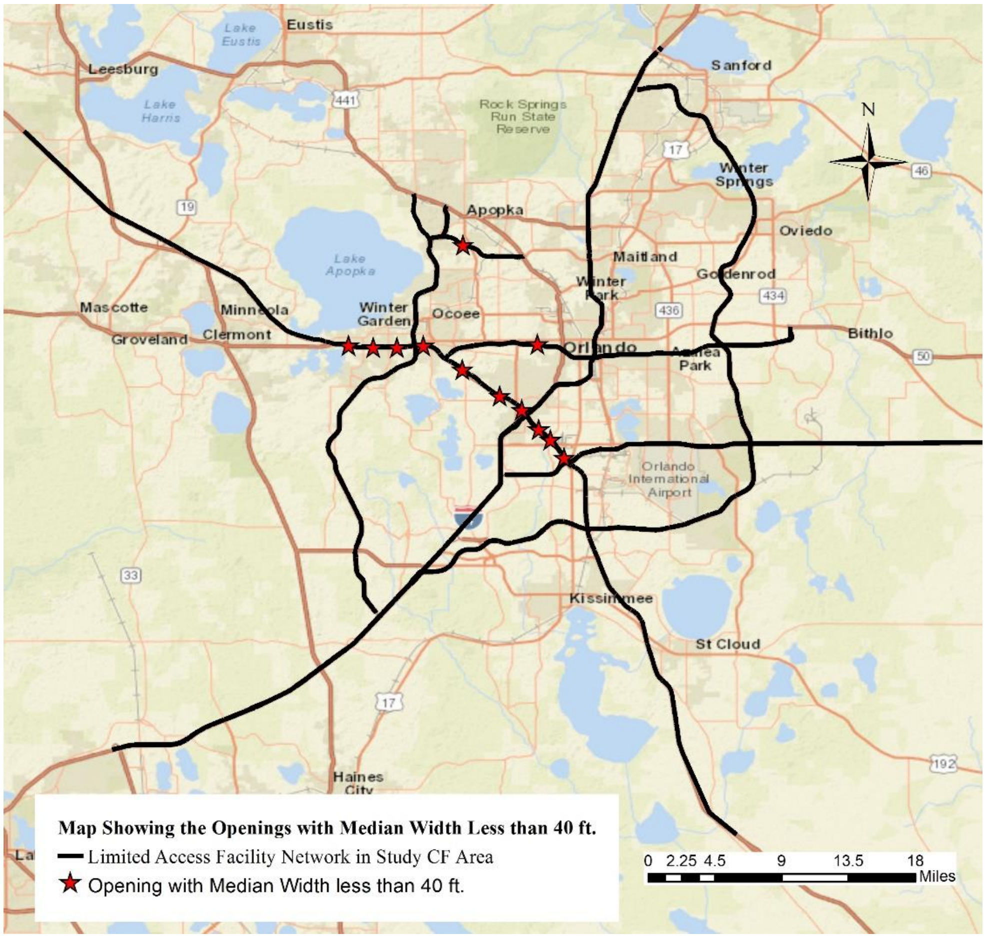

Figure 74: Map of the Median Openings Installed in CF on Medians Less than 40 feet Wide

Figure 75: Map of the Median Openings Installed in SF on Medians Less than 40 feet Wide.

Furthermore, in regards the minimum spacing from the on-ramp and off-ramp facilities, 23 median opening were found to be closer than 1500 ft. from any ramp facility. The 23 openings are about 13.6% of all median openings analyzed, and that percentage of median openings include about 16.4% of the citations included indicating an overrepresentation of the citations data and

confirming the modeling finding in the CF model for the distance to access point variable to have a negative sign meaning that the closer the median opening to an access point the more likely for the opening to have a citation to occur on it. The median openings that do not meet this requirement are shown in Figure 76 and Figure 77.

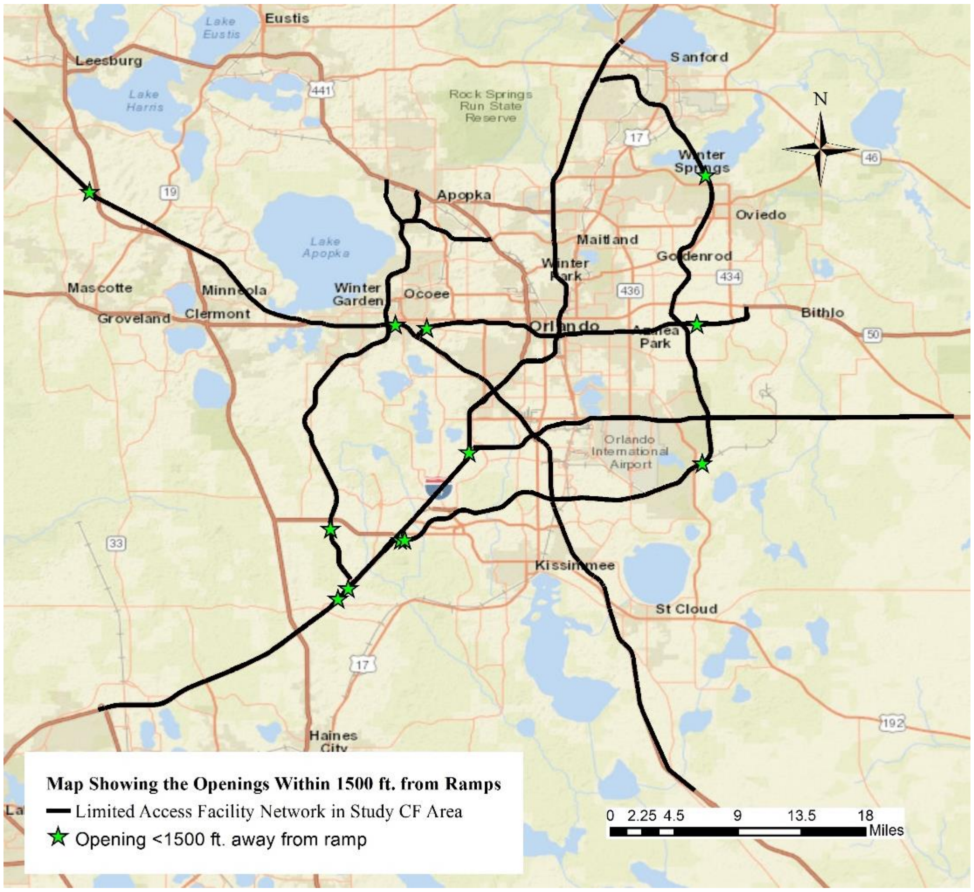

Figure 76: Map of the Median Openings Installed in CF within a Distance Less than 1,500 ft. From any Ramp.

Figure 77: Map of the Median Openings Installed in SF within a Distance Less than 1,500 ft. From any Ramp.

The final requirements for median openings to have a maximum spacing of 5 miles when a continuous median segment is present and not installing median openings on super elevated curve segments has been followed statewide.

6.3 WWD Median Crossovers at Traversable Medians

In addition to emergency openings, WWD due to median crossovers can also occur at traversable median segments that could be flushed grass segments. For example, the majority of the traversable medians on the CFX roadway network are grass depressed medians, which discourage median crossovers since vehicles could potentially get stuck in the low point of the median. However, there are some locations with undepressed flushed medians that could have the potential for WWD median crossovers. One example is on SR 408 near Exit 21, as shown in Figure 78 below. At this location, an impatient or confused driver could easily cross the median into opposing traffic without any restrictions, especially at night when traffic volumes are low.

Figure 78: Flushed Median at SR 408 near Exit 21 (Google Maps, 2016)

6.3.1 Countermeasures for WWD Median Crossovers at Traversable Medians

The best way to prevent WWD median crossovers at flushed medians is to depress the median, install a barrier, or plant green lateral separation to make it difficult for drivers to cross

the median. Figure 79 shows a flushed median that utilizes all three countermeasures to prevent WWD crossovers. If it is desired to have turnaround access for emergency vehicles, a median opening can be designed following the recommendations previously discussed and using appropriate countermeasures.

Figure 79: Recommended Design for Flushed Medians (*55*)

6.4 WWD Entries at Off–Ramp Intersections

This section elaborates on the most common type of WWD, where a driver would travel in the opposite direction of traffic with the influence of the median segment separating the two directions of traffic on the off-ramp facility.

One of the main sources of WWD on highways is wrong-way entries at off-ramps. Median design can be a major factor in the likelihood of a vehicle traveling the wrong way up an off-ramp. Since every off-ramp intersection is unique, the most effective and applicable countermeasures

will vary for each ramp. However, there are some general design guidelines mentioned in literature review chapter (chapter 2), by Zhou and Rouholamin (*33*) to avoid confusing drivers and reduce the probability of WWD at off-ramp intersections. As mentioned before, to make ramps less susceptible to WWD, it is recommended to use raised medians on arterial highways intersecting with exit ramps to discourage left-turn wrong-way entry onto exit ramps. As shown in Figure 8 previously.

Another guideline mentioned was using channelized median openings at exit ramp intersections to prevent left-turn wrong-way movements. Figure 9 illustrated a recommended median channelization to be implemented at the off-ramp intersections.

In addition, as described earlier in chapter 2, the use of raised medians to separate vehicles going in the same direction is not recommended to be installed at off-ramp facilities, as shown in Figure 10.

After considering these design guidelines, one off-ramp intersection located near SR 417 Exit 17 with SR 530/527A was found to be susceptible to WWD, shown in Figure 80. The median design on SR 530 makes it easy for drivers to turn left onto the exit ramp. To reduce this WWD potential, the median should be redesigned to make a wrong-way left turn onto the exit ramp more difficult by either extending the median or changing its end radius.

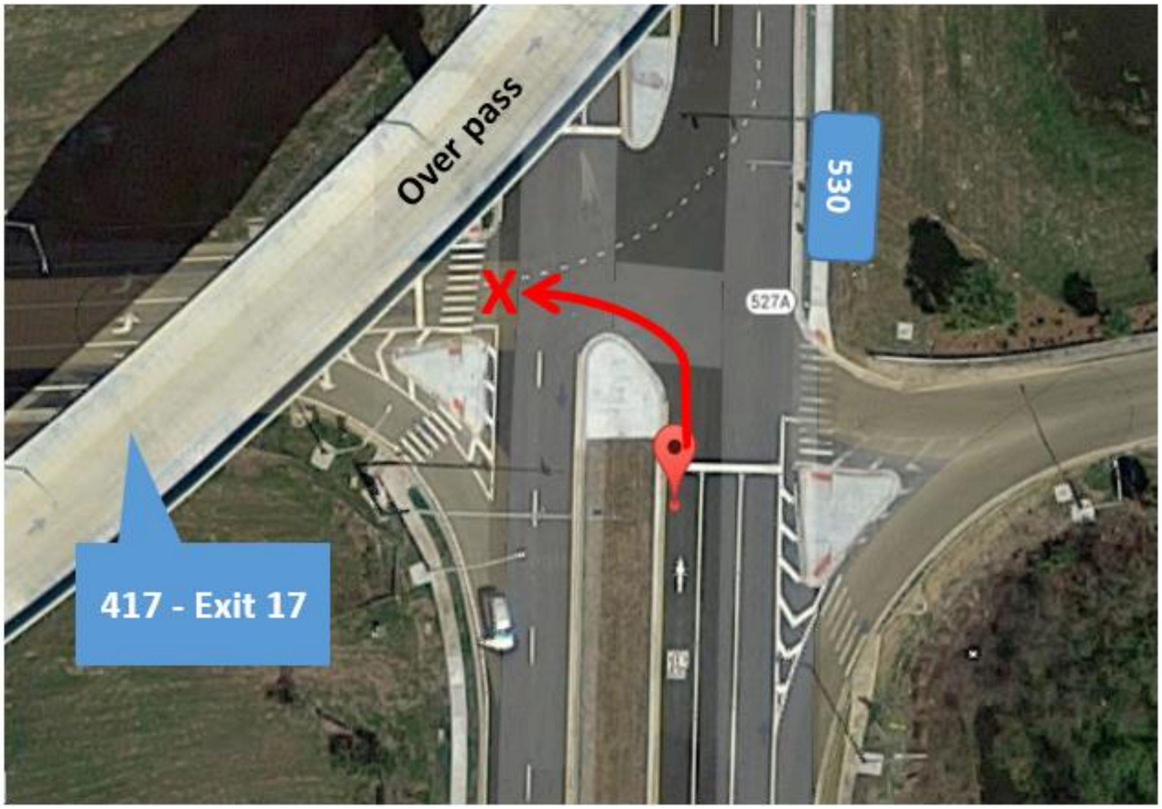

Figure 80: Intersection Design that is More Susceptible to WWD at SR 417 Exit 17 Off Ramp (Google Maps, 2016)

An example of an intersection that is less susceptible to WWD is the intersection at SR 417 Exit 38 off ramp and SR 426 (Figure 81). This median design makes the intersection less susceptible to WWD, since the median is long enough and angled appropriately to make it difficult for drivers to turn left onto the exit ramp.

Figure 81: Less Susceptible Design to WWD at SR 417 Exit 38 off Ramp (Google Maps, 2016)

6.4.1.1 Susceptible Locations for WWD to Avoid Tolls or Take a Shortcut

In addition to the examples previously discussed, there are some locations on the CFX network near toll plazas or interchanges that could be used by intentional wrong-way drivers to avoid tolls or take a shortcut. The following four studied locations have increased potential for WWD in their current situation; however, countermeasures could be applied to reduce the likelihood of WWD.

6.4.1.1.1 Traversable Median Crossover to Avoid Toll on SR 528

This potential WWD location is on SR 528 near the mainline toll plaza before Exit 11 (eastbound) or before Exit 9 (westbound). Figure 82 shows this toll plaza approach as an aerial and street view, respectively. The median WWD act could occur at the traversable median before the toll plaza to either make a U-turn to avoid the toll plaza and exit SR 528 at exit 11 or to pass

through the toll plaza in the wrong direction. The latter is less probable due to the presence of opposing traffic, but it could occur at night when there is less traffic. The recommended countermeasure at this location is to install a barrier along the segment to prevent a median WWD crossover.

Figure 82: Aerial View of SR 528 Toll Approach with Potential for WWD (Google Maps, 2016)

6.4.1.1.2 WWD at Off-Ramp with Traversable median to Avoid Toll Plaza at SR 417 Exit 11

This potential WWD location at SR 417 Exit 11 is shown in Figure 83 and Figure 84. It is possible that drivers could go the wrong-way up the exit ramp and then cross over the traversable median after the toll plaza to get on the on-ramp without paying a toll. This scenario creates two hazardous situations: a wrong-way entry from the intersecting street to the off-ramp and an illegal crossover of the traversable median from the off-ramp to the on-ramp. Low cost countermeasures for this location include installing a raised curb along the entire ramp median or installing a barrier in the traversable median. Figure 84 shows that the raised curb does not extend all the way along the ramp, providing an opportunity for intentional wrong-way drivers to cross over to the on-ramp. A costlier countermeasure would be to relocate the toll plaza closer to the mainline to make it

more difficult to avoid the plaza. Another possibility is to remove on-ramp toll plazas altogether and find a way to charge entering drivers once they enter the mainline. This change could also reduce the potential for WWD at the next two locations as well.

Figure 83: Aerial View of Potential WWD to Avoid Toll Plaza at SR 417 Exit 11 (Google Maps, 2016)

Figure 84: Street View of Potential WWD to Avoid Toll Plaza at SR 417 Exit 11 (Google Maps, 2016)

6.4.1.1.3 WWD at On-Ramp to Take Shortcut and Avoid Toll plaza at SR 528 Exit 20

Another potential location for WWD, shown in Figure 85, is the interchange at SR 528 and International Corporate Park (ICP) Blvd. (Exit 20). The green path shown in Figure 85 indicates the correct travel path for drivers exiting SR 528 westbound. These drivers must pay a

toll near the end of the off-ramp. To avoid this toll, drivers could follow the red path in the diagram, which involves continuing on SR 528 westbound and making a wrong-way entry onto the on-ramp from ICP Blvd. This path would not only allow drivers to avoid the toll, but also provide a shortcut for drivers who are traveling north on ICP Blvd. While WWD at on-ramps is less severe than WWD at off-ramps since the opposing vehicles do not have as high a speed as vehicles exiting the freeway, there is still potential for crashes to occur. Due to the nature of this WWD maneuver, it would be difficult to effectively implement low cost countermeasures. However, redesigning the interchange to provide a shorter exit ramp for drivers going north on ICP Blvd. and replacing the off-ramp toll plaza with some mainline tolling strategy, as discussed for the previous location, could reduce the attractiveness of a WWD maneuver.

Figure 85: Potential WWD to Avoid Toll at SR 528 Exit 20 (Google Maps, 2016)

6.4.1.1.4 WWD at On-Ramp to Avoid Toll Plaza at SR 408 Exit 14

The fourth location with the potential for WWD is at the interchange of SR 408 westbound and Semoran Blvd. (Exit 14), shown in Figure 86. Similar to the previous example, a driver could

follow the red arrow and drive the wrong way on the on-ramp to avoid the exit ramp toll. The best way to prevent this WWD maneuver would be to replace the toll plaza with a mainline tolling strategy, as previously discussed.

Figure 86: Potential WWD to Avoid Toll at SR 408 Exit 14 (Google Maps, 2016)

7. CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

The goal of this thesis was to review the WWD illegal U-turn maneuvers on limited access facilities, and understand the contributing factors that may lead drivers to commit such type of violation. Afterwards, develop a modeling methodology to predict the location of the illegal U-turn violations and determine the locations with potential risks resulting from this illegal maneuver.

Limited literature considered the illegal U-turns at the limited access facilities and the impacts resulting from the installation of median openings on the operational and safety conditions on the network. Therefore, the study anticipates increasing the awareness of the agencies and authorities for the operational and safety effects of installing median openings for official use only on limited access facilities.

The study area included the Orlando metropolitan area and Miami metropolitan area, the two areas with the highest frequency of WWD. Both areas were analyzed for illegal U-turn violations at traversable medians segments (flushed grass median), and for illegal U-turn violations through median openings intended for official use only.

It was found that most of the citations occurred in May, July, and September. Moreover, the day that had the highest number of citations was Friday, for violations at traversable medians. In addition, drivers from age 25-34 years were found to be the most to commit illegal U-turn violations at traversable medians, and from age 16-25 year to be the most to commit illegal U-turn violations at median openings for official use only. For gender classification, it was found that the percentage of female drivers who commit illegal U-turn maneuvers at paved median openings is significantly higher at the grass traversable median segments, with a significance level of 95%

The modeling chapter at first described all exploratory variables included in the analysis which are expected to have correlation with the illegal U-turn violations. Afterwards, the modeling methodology adopted three modeling approaches to find the most accurate prediction models for the illegal U-turn citations on the limited access facility network in the state of Florida. The first model for traversable medians used a sequential analysis of a Poisson model and LASSO selection method. The model found 7 significant variables, with the unpaved median opening (type3), the segment length, the average distance between access points, and the paved crossover median opening (type 2) to be the most effective variables. The second model was logistic regression model which was used to find the probability of a citation at median openings. The model analyzed two areas separately: CF, SF. The model found the speed and the AADT as the significant variables in CF, and the distance to the nearest median opening, and the distance to the nearest access point as the significant variables in SF.

In should be mentioned that a majority of the states in the US follow the AASHTO guidelines for the limited access facilities design. Some states have modified these AASHTO guidelines to suit their state needs such as Florida and Texas; however, without substantial changes. This similarity would make the recommendations in this study applicable to other states in the US.

This study successfully demonstrated numerous potential contributing factors and the significant traffic and geometric configurations that predict the illegal U-turn violations committed by drivers at limited access facilities, through both median openings and traversable medians. However, the modeling results indicated that there are some unaccounted for contributing factors which could be causing unpredicted errors in the data. These models could be a starting point for future research to improve and enhance on these models and/or to create

newer models with higher accuracy that consider other additional contributing factors that may not have been accounted for in this thesis.

It should be mentioned that unexplainable errors or sometimes counterintuitive results may be expected in predicting human behavior. One of the main reasons of the unexplainable errors is the humans' emotionally driven decisions, which might result in unpredicted actions causing uncertainty and errors in the modeling results (*56*).

Limited data was available for the analysis up to this time; therefore, the models should be revaluated and considered in the future after collecting additional data from the state of Florida or possibly other states with similar roadway characteristics and geometric conditions.

It should be mentioned that the results of this study in the Central Florida area should be verified in the near future after the ultimate I-4 project is completed. This project would include major improvements and installation of managed toll lanes on the interstate, which will highly affect the traffic conditions and design characteristics in the area. Therefore, countermeasures and additional analysis should be taken into consideration during and after finishing the project.

Finding specific WWD countermeasures to apply at emergency openings to prevent vehicles from traveling the wrong way is difficult. Adding directional islands to the medians could reduce the likelihood of WWD, but also suggests to non-emergency vehicles that they can make U-turns at that location. It is also believed that many people making these illegal U-turns do it intentionally to take a shortcut or avoid tolls. Drivers could also cross over traversable medians at exit ramps to avoid tolls. Therefore, each case should be evaluated separately to find the most suitable countermeasure from the list of suggested countermeasures mentioned in the study.

Nowadays, massive technologies are getting introduced in the market. Within a few years, major contributions and well-recognized acts will start to take effect in our everyday lives to

minimize the human error and increase the safety conditions on the roadway networks. The new intelligent transportation technologies could provide better access for emergency vehicles and minimize their response time, and most likely with implementing the driver assistant technologies they could reduce the number of crashes and emergencies that occur on the roads. The connected and automated vehicle technologies would most likely change the safety and operational concerns that have been highly considered in the past years. This would also create new concerns during the transition phase from human controlled vehicles to fully automated vehicles, thus leading the path for the future generations toward achieving the zero deaths vision foreseen by the National Strategy on Highway Safety (*57*).

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APPENDIX A:
AGE EXPOSURE RATE CALCULATION TABLES

Table 27 : Age Group Exposure Rate Calculation Summary Table for Traversable Medians

Age	# of Drivers	total citations	(cit./total number of drivers) x100,000
19 >	453,780	27	1.815323
20-24	1,033,559		
25-29	1,159,413	46	2.013549
30-34	1,125,111		
35-39	1,081,283	37	1.671731
40-44	1,131,992		
45-49	1,231,314	30	1.160775
50-54	1,353,167		
55-59	1,306,544	10	0.402084
60-64	1,180,498		
65-69	1,102,358	3	0.154651
70-74	837,499		
75-79	582,219	3	0.312185
80-84	378,749		
85<	305,229	0	-
TOTAL	14,262,715	156	-

Table 28 : Age Group Exposure Rate Calculation Summary Table for Median Openings

AGE	No. of Citations	Percentage	Drivers	Age Exposure Rate
15-24	50	13%	1,487,339	3.36
25-34	103	27%	2,284,524	4.51
35-44	99	26%	2,213,275	4.47
45-54	66	17%	2,584,481	2.55
55-64	41	11%	2,487,042	1.65
65-74	14	4%	1,939,857	0.72
75-85	7	2%	960,968	0.73

APPENDIX B:
SUNRISE AND SUNSET TIME TABLES

Location: W080° 13′, N25° 47′

MIAMI, FLORIDA
Rise and Set for the Sun for 2013

Astronomical Applications Dept.
U. S. Naval Observatory
Washington, DC 20392-5420

Eastern Standard Time

	Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.	
Day	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
01	0708	1742	0704	1805	0644	1823	0612	1838	0544	1852	0529	1908	0533	1916	0547	1907	0601	1840	0613	1807	0629	1739	0651	1729
02	0708	1742	0704	1806	0643	1823	0611	1838	0543	1853	0529	1909	0534	1916	0548	1906	0602	1839	0614	1806	0630	1739	0651	1729
03	0708	1743	0703	1806	0642	1824	0610	1839	0542	1853	0529	1909	0534	1916	0548	1905	0602	1838	0614	1805	0631	1738	0652	1730
04	0708	1744	0703	1807	0641	1824	0609	1839	0542	1854	0529	1910	0534	1916	0549	1905	0602	1837	0615	1804	0631	1737	0653	1730
05	0709	1745	0702	1808	0640	1825	0608	1840	0541	1854	0529	1910	0535	1916	0549	1904	0603	1836	0615	1803	0632	1737	0653	1730
06	0709	1745	0702	1808	0639	1825	0607	1840	0540	1855	0529	1910	0535	1916	0550	1903	0603	1835	0615	1802	0633	1736	0654	1730
07	0709	1746	0701	1809	0638	1826	0606	1840	0540	1855	0529	1911	0536	1916	0550	1903	0604	1833	0616	1801	0633	1736	0655	1730
08	0709	1747	0701	1810	0637	1826	0605	1841	0539	1856	0529	1911	0536	1916	0551	1902	0604	1832	0616	1800	0634	1735	0656	1730
09	0709	1747	0700	1810	0636	1827	0604	1841	0538	1856	0529	1912	0536	1916	0551	1901	0604	1831	0617	1759	0635	1734	0656	1731
10	0709	1748	0659	1811	0635	1827	0603	1842	0538	1857	0529	1912	0537	1916	0552	1900	0605	1830	0617	1758	0635	1734	0657	1731
11	0709	1749	0659	1812	0634	1828	0602	1842	0537	1858	0529	1912	0537	1915	0552	1900	0605	1829	0618	1757	0636	1734	0657	1731
12	0709	1750	0658	1813	0633	1828	0601	1843	0537	1858	0529	1913	0538	1915	0553	1859	0606	1828	0618	1756	0637	1733	0658	1731
13	0709	1750	0657	1813	0632	1829	0600	1843	0536	1859	0529	1913	0538	1915	0553	1858	0606	1827	0619	1755	0638	1733	0659	1732
14	0709	1751	0657	1814	0631	1829	0559	1844	0536	1859	0529	1913	0539	1915	0554	1857	0606	1826	0619	1754	0638	1732	0659	1732
15	0709	1752	0656	1814	0630	1830	0558	1844	0535	1900	0529	1914	0539	1915	0554	1856	0607	1825	0620	1753	0639	1732	0700	1732
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17	0709	1753	0654	1816	0628	1831	0556	1845	0534	1901	0529	1914	0540	1914	0555	1854	0608	1822	0621	1751	0640	1731	0701	1733
18	0709	1754	0653	1816	0627	1831	0555	1846	0534	1901	0530	1915	0541	1914	0555	1854	0608	1821	0621	1750	0641	1731	0702	1734
19	0709	1755	0653	1817	0626	1832	0554	1846	0533	1902	0530	1915	0541	1913	0556	1853	0608	1820	0622	1749	0642	1731	0702	1734
20	0709	1756	0652	1818	0625	1832	0553	1847	0533	1902	0530	1915	0541	1913	0556	1852	0609	1819	0622	1748	0643	1730	0703	1735
21	0708	1757	0651	1818	0624	1833	0552	1847	0532	1903	0530	1915	0542	1912	0557	1851	0609	1818	0623	1748	0643	1730	0703	1735
22	0708	1757	0650	1819	0622	1833	0551	1848	0532	1903	0530	1915	0542	1912	0557	1850	0610	1817	0623	1747	0644	1730	0704	1736
23	0708	1758	0649	1819	0621	1834	0550	1848	0532	1904	0531	1916	0543	1912	0558	1849	0610	1816	0624	1746	0645	1730	0704	1736
24	0708	1759	0648	1820	0620	1834	0550	1849	0531	1904	0531	1916	0543	1911	0558	1848	0610	1815	0625	1745	0646	1730	0705	1737
25	0707	1800	0648	1821	0619	1835	0549	1849	0531	1905	0531	1916	0544	1911	0558	1847	0611	1814	0625	1744	0646	1730	0705	1737
26	0707	1800	0647	1821	0618	1835	0548	1850	0531	1905	0532	1916	0544	1910	0559	1846	0611	1813	0626	1744	0647	1729	0706	1738
27	0707	1801	0646	1822	0617	1835	0547	1850	0530	1906	0532	1916	0545	1910	0559	1845	0612	1811	0626	1743	0648	1729	0706	1738
28	0706	1802	0645	1822	0616	1836	0546	1851	0530	1906	0532	1916	0545	1909	0600	1844	0612	1810	0627	1742	0648	1729	0706	1739
29	0706	1803			0615	1836	0545	1851	0530	1907	0532	1916	0546	1908	0600	1843	0612	1809	0628	1741	0649	1729	0707	1740
30	0705	1803			0614	1837	0545	1852	0530	1907	0533	1916	0546	1908	0600	1842	0613	1808	0628	1741	0650	1729	0707	1740
31	0705	1804			0613	1837			0530	1908			0547	1907	0601	1841			0629	1740			0707	1741

Add one hour for daylight time, if and when in use.

Figure 87: The Sunrise and Sunset times in Miami year 2013 (*45*)

Location: W081 23, N28 32 (longitude 81°23′ W, latitude 28°32′ N)

ORLANDO, FLORIDA
Rise and Set for the Sun for 2013

Astronomical Applications Dept.
U. S. Naval Observatory
Washington, DC 20392-5420

Eastern Standard Time

	Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.	
Day	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
01	0718	1740	0713	1805	0650	1826	0615	1844	0545	1901	0528	1919	0532	1927	0547	1916	0604	1847	0619	1811	0638	1740	0701	1728
02	0718	1741	0713	1806	0649	1826	0614	1844	0544	1901	0528	1919	0532	1927	0548	1915	0604	1845	0619	1810	0638	1739	0702	1728
03	0719	1742	0712	1807	0648	1827	0613	1845	0543	1902	0528	1920	0532	1927	0548	1915	0605	1844	0620	1809	0639	1739	0702	1728
04	0719	1743	0712	1808	0647	1828	0612	1845	0542	1903	0528	1920	0533	1927	0549	1914	0605	1843	0620	1808	0640	1738	0703	1729
05	0719	1743	0711	1809	0646	1828	0611	1846	0541	1903	0528	1921	0533	1927	0550	1913	0606	1842	0621	1806	0641	1737	0704	1729
06	0719	1744	0710	1809	0645	1829	0610	1846	0541	1904	0527	1921	0534	1927	0550	1912	0606	1841	0621	1805	0641	1737	0705	1729
07	0719	1745	0710	1810	0644	1829	0608	1847	0540	1904	0527	1922	0534	1927	0551	1911	0607	1840	0622	1804	0642	1736	0705	1729
08	0719	1746	0709	1811	0643	1830	0607	1848	0539	1905	0527	1922	0535	1927	0551	1911	0607	1838	0622	1803	0643	1735	0706	1729
09	0719	1746	0708	1812	0642	1831	0606	1848	0539	1906	0527	1922	0535	1926	0552	1910	0608	1837	0623	1802	0644	1735	0707	1729
10	0719	1747	0707	1812	0641	1831	0605	1849	0538	1906	0527	1923	0535	1926	0552	1909	0608	1836	0624	1801	0644	1734	0707	1729
11	0719	1748	0707	1813	0639	1832	0604	1849	0537	1907	0527	1923	0536	1926	0553	1908	0609	1835	0624	1800	0645	1734	0708	1730
12	0719	1749	0706	1814	0638	1832	0603	1850	0537	1908	0527	1924	0536	1926	0553	1907	0609	1834	0625	1759	0646	1733	0709	1730
13	0719	1750	0705	1815	0637	1833	0602	1850	0536	1908	0527	1924	0537	1925	0554	1906	0610	1832	0625	1758	0647	1733	0709	1730
14	0719	1750	0704	1815	0636	1834	0601	1851	0535	1909	0527	1924	0537	1925	0555	1905	0610	1831	0626	1757	0647	1732	0710	1731
15	0719	1751	0703	1816	0635	1834	0600	1851	0535	1909	0528	1925	0538	1925	0555	1904	0611	1830	0626	1756	0648	1732	0711	1731
16	0719	1752	0703	1817	0634	1835	0559	1852	0534	1910	0528	1925	0539	1924	0556	1903	0611	1829	0627	1755	0649	1731	0711	1731
17	0719	1753	0702	1818	0633	1835	0558	1853	0534	1911	0528	1925	0539	1924	0556	1902	0612	1828	0628	1754	0650	1731	0712	1732
18	0719	1754	0701	1818	0631	1836	0557	1853	0533	1911	0528	1926	0540	1924	0557	1901	0612	1826	0628	1753	0651	1731	0712	1732
19	0718	1755	0700	1819	0630	1836	0556	1854	0533	1912	0528	1926	0540	1923	0557	1900	0613	1825	0629	1752	0651	1730	0713	1733
20	0718	1755	0659	1820	0629	1837	0555	1854	0532	1912	0528	1926	0541	1923	0558	1859	0613	1824	0630	1751	0652	1730	0713	1733
21	0718	1756	0658	1820	0628	1838	0554	1855	0532	1913	0529	1926	0541	1922	0558	1858	0614	1823	0630	1750	0653	1730	0714	1734
22	0718	1757	0657	1821	0627	1838	0553	1856	0531	1913	0529	1926	0542	1922	0559	1857	0614	1822	0631	1749	0654	1729	0714	1734
23	0717	1758	0656	1822	0626	1839	0552	1856	0531	1914	0529	1927	0542	1921	0559	1856	0615	1820	0631	1748	0655	1729	0715	1735
24	0717	1759	0655	1822	0625	1839	0551	1857	0530	1915	0529	1927	0543	1921	0600	1855	0615	1819	0632	1747	0655	1729	0715	1735
25	0717	1800	0654	1823	0623	1840	0550	1857	0530	1915	0530	1927	0543	1920	0600	1854	0616	1818	0633	1746	0656	1729	0716	1736
26	0716	1800	0653	1824	0622	1840	0549	1858	0530	1916	0530	1927	0544	1920	0601	1853	0616	1817	0633	1745	0657	1729	0716	1736
27	0716	1801	0652	1824	0621	1841	0548	1858	0529	1916	0530	1927	0545	1919	0601	1852	0617	1816	0634	1744	0658	1729	0717	1737
28	0715	1802	0651	1825	0620	1841	0547	1859	0529	1917	0531	1927	0545	1919	0602	1851	0617	1815	0635	1743	0659	1728	0717	1738
29	0715	1803			0619	1842	0546	1900	0529	1917	0531	1927	0546	1918	0602	1850	0618	1813	0636	1743	0659	1728	0717	1738
30	0714	1804			0618	1843	0546	1900	0529	1918	0531	1927	0546	1917	0603	1849	0618	1812	0636	1742	0700	1728	0718	1739
31	0714	1804			0616	1843			0528	1918			0547	1917	0603	1848			0637	1741			0718	1740

Add one hour for daylight time, if and when in use.

Figure 88: The Duration of Daylight Hours in Orlando year 2013 (*45*)

APPENDIX C:
GENDER EXPOSURE RATE CALCULATION TABLES

Table 29 : Gender Exposure Rate Calculation Summary Table for Traversable Medians

Gender	Total	Total Number of drivers	Gender Exposure rate (per Million Driver)
F	57	7274553	0.78355
M	183	6988162	2.61871
Grand Total	240		Ratio: 3.3421

Table 30 : Gender Exposure Rate Calculation Summary Table for Median Openings

Gender	Total	Total Number of drivers	Gender Exposure Rate (per Million Driver)
F	98	7274553	1.347162
M	282	6988162	4.035396
Grand Total	380		Ratio: 2.99548

APPENDIX D:
RACE EXPOSURE RATE CALCULATION TABLES

Table 31 : Race Exposure Rate Calculation Summary Table for Traversable Medians

Race	**No. Drivers**	**Miami Population**	**Orlando Population**	**Average population[1]= 0.72xOrlando + 0.28xMiami**	**Race Exposure Rate[2]**
Asian	5	144617	99466	112108.28	4.459974
Black	48	1224160	368087	607787.44	7.897498
Hispanic	61	2632792	685451	1230706.48	4.956503
Other	5	184150	130315	145388.8	3.439054
White	121	1911761	1165172	1374216.92	8.805015

*[1]: The average population for traversable medians was found by calculating the weighted average for the population in the two areas from the percentage of actual citations found in the dataset. For example: 72% of the citations at the traversable medians were found in CF (Orlando) and 28% were found in SF (Miami), therefore the average population had 72% of the population in CF and 28% of SF.

*[2]: Race Exposure rate unit = Number of drivers cited (Number of Citations) / 100,000 drivers from that particular race.

Table 32 : Race Exposure Rate Calculation Summary Table for Median Openings

Race	**Number**	**Miami Population**	**Orlando Population**	**Average population[1] = 0.51*Orlando + 0.49*Miami**	**Race Exposure Rate[2]**
Asian	4	144617	99466	121589.99	3.289744493
Black	75	1224160	368087	787562.77	9.523050461
Hispanic	98	2632792	685451	1639648.09	5.976892273
Other	9	184150	130315	156694.15	5.743673264
White	194	1911761	1165172	1531000.61	12.67145152

*[1]: The average population for median openings was found by calculating the weighted average for the population in the two areas from the percentage of actual citations found in the dataset. For example: 51% of the citations at the traversable medians were found in CF and 49% were found in SF, therefore the average population had 51% of the population in CF and 49% of SF.

*[2]: Race Exposure rate unit = Number of drivers cited (Number of Citations) / 100,000 drivers from that particular race.

APPENDIX E:
DATASET CORRELATION TABLES

Table 33 : Correlation Results from the Dataset for Citations at Traversable Medians CF Area

Pearson Correlation Coefficients, N = 37
Prob > |r| under H0: Rho=0

	N_LANES	AADT	Segment_L	MED_TYP	DIST_INT	MED_W	No_of_Acc	N_OPEN	AVGDIS_PT	Dist_Flush	Speed	Rate_Yr	Crash_Occ	Cit_No	Rate_6Yr	Rate_5Yr
N_LANES	1.00000	0.69988	-0.58509	0.07280	-0.24200	0.54010	-0.21571	-0.04334	-0.33520	0.40946	0.17029	0.19258	-0.14529	-0.10702	0.19258	0.19258
		<.0001	0.0001	0.6685	0.1490	0.0006	0.1998	0.7989	0.0426	0.0118	0.3136	0.2535	0.3909	0.5284	0.2535	0.2535
AADT	0.69988	1.00000	-0.52244	-0.12142	-0.22906	0.41087	-0.19024	-0.19555	-0.34811	0.14661	0.12435	0.16240	0.03095	-0.04568	0.16240	0.16240
	<.0001		0.0009	0.4741	0.1727	0.0115	0.2594	0.2461	0.0347	0.3866	0.4634	0.3369	0.8557	0.7884	0.3369	0.3369
Segment_L	-0.58509	-0.52244	1.00000	-0.07274	0.22000	-0.48937	0.37332	0.11390	0.65269	-0.61664	-0.19941	-0.32065	-0.00782	0.19338	-0.32065	-0.32065
	0.0001	0.0009		0.6688	0.1907	0.0021	0.0229	0.5021	<.0001	<.0001	0.2367	0.0530	0.9634	0.2515	0.0530	0.0530
MED_TYP	0.07280	-0.12142	-0.07274	1.00000	-0.16640	0.35095	-0.01979	0.78591	-0.15099	0.36192	0.05470	0.63138	-0.13755	0.38786	0.63138	0.63138
	0.6685	0.4741	0.6688		0.3250	0.0332	0.9074	<.0001	0.3724	0.0277	0.7478	<.0001	0.4169	0.0177	<.0001	<.0001
DIST_INT	-0.24200	-0.22906	0.22000	-0.16640	1.00000	-0.09444	-0.08378	-0.24172	0.26592	-0.20058	0.17938	-0.08744	0.05800	-0.17144	-0.08744	-0.08744
	0.1490	0.1727	0.1907	0.3250		0.5782	0.6220	0.1495	0.1116	0.2339	0.2881	0.6068	0.7331	0.3103	0.6068	0.6068
MED_W	0.54010	0.41087	-0.48937	0.35095	-0.09444	1.00000	-0.35575	0.12622	-0.29578	0.54065	0.12047	0.72935	-0.09606	0.02864	0.72935	0.72935
	0.0006	0.0115	0.0021	0.0332	0.5782		0.0307	0.4566	0.0755	0.0006	0.4776	<.0001	0.5717	0.8664	<.0001	<.0001
No_of_Acc	-0.21571	-0.19024	0.37332	-0.01979	-0.08378	-0.35575	1.00000	0.24794	-0.31957	-0.30670	-0.26041	-0.23479	0.12069	0.03192	-0.23479	-0.23479
	0.1998	0.2594	0.0229	0.9074	0.6220	0.0307		0.1390	0.0538	0.0648	0.1196	0.1619	0.4767	0.8512	0.1619	0.1619
N_OPEN	-0.04334	-0.19555	0.11390	0.78591	-0.24172	0.12622	0.24794	1.00000	-0.02568	0.21251	-0.18318	0.33129	0.05484	0.26871	0.33129	0.33129
	0.7989	0.2461	0.5021	<.0001	0.1495	0.4566	0.1390		0.8801	0.2067	0.2778	0.0452	0.7472	0.1078	0.0452	0.0452
AVGDIS_PT	-0.33520	-0.34811	0.65269	-0.15099	0.26592	-0.29578	-0.31957	-0.02568	1.00000	-0.34012	-0.13722	-0.27786	-0.13618	-0.00932	-0.27786	-0.27786
	0.0426	0.0347	<.0001	0.3724	0.1116	0.0755	0.0538	0.8801		0.0394	0.4180	0.0959	0.4216	0.9564	0.0959	0.0959
Dist_Flush	0.40946	0.14661	-0.61664	0.36192	-0.20058	0.54065	-0.30670	0.21251	-0.34012	1.00000	0.12977	0.37305	-0.13585	-0.06946	0.37305	0.37305
	0.0118	0.3866	<.0001	0.0277	0.2339	0.0006	0.0648	0.2067	0.0394		0.4440	0.0230	0.4227	0.6829	0.0230	0.0230
Speed	0.17029	0.12435	-0.19941	0.05470	0.17938	0.12047	-0.26041	-0.18318	-0.13722	0.12977	1.00000	0.02105	-0.21545	-0.06808	0.02105	0.02105
	0.3136	0.4634	0.2367	0.7478	0.2881	0.4776	0.1196	0.2778	0.4180	0.4440		0.9016	0.2003	0.6889	0.9016	0.9016
Rate_Yr	0.19258	0.16240	-0.32065	0.63138	-0.08744	0.72935	-0.23479	0.33129	-0.27786	0.37305	0.02105	1.00000	-0.06168	0.44009	1.00000	1.00000
	0.2535	0.3369	0.0530	<.0001	0.6068	<.0001	0.1619	0.0452	0.0959	0.0230	0.9016		0.7169	0.0064	<.0001	<.0001
Crash_Occ	-0.14529	0.03095	-0.00782	-0.13755	0.05800	-0.09606	0.12069	0.05484	-0.13618	-0.13585	-0.21545	-0.06168	1.00000	-0.04606	-0.06168	-0.06168
	0.3909	0.8557	0.9634	0.4169	0.7331	0.5717	0.4767	0.7472	0.4216	0.4227	0.2003	0.7169		0.7866	0.7169	0.7169
Cit_No	-0.10702	-0.04568	0.19338	0.38786	-0.17144	0.02864	0.03192	0.26871	-0.00932	-0.06946	-0.06808	0.44009	-0.04606	1.00000	0.44009	0.44009
	0.5284	0.7884	0.2515	0.0177	0.3103	0.8664	0.8512	0.1078	0.9564	0.6829	0.6889	0.0064	0.7866		0.0064	0.0064
Rate_6Yr	0.19258	0.16240	-0.32065	0.63138	-0.08744	0.72935	-0.23479	0.33129	-0.27786	0.37305	0.02105	1.00000	-0.06168	0.44009	1.00000	1.00000
	0.2535	0.3369	0.0530	<.0001	0.6068	<.0001	0.1619	0.0452	0.0959	0.0230	0.9016	<.0001	0.7169	0.0064		<.0001
Rate_5Yr	0.19258	0.16240	-0.32065	0.63138	-0.08744	0.72935	-0.23479	0.33129	-0.27786	0.37305	0.02105	1.00000	-0.06168	0.44009	1.00000	1.00000
	0.2535	0.3369	0.0530	<.0001	0.6068	<.0001	0.1619	0.0452	0.0959	0.0230	0.9016	<.0001	0.7169	0.0064	<.0001	

Table 34 : Correlation Results from the Dataset for Citations at Median Openings in FL area

Pearson Correlation Coefficients, N = 169 Prob > |r| under H0: Rho=0									
	DIST_INT	DIST_OPNG	DIST_TOLL	DIST_ACC	AADT	DIST_OPNG2	N_Lanes	SPEED	Med_W
DIST_INT	1.00000	-0.04299 0.5790	-0.02157 0.7807	0.59295 <.0001	-0.39400 <.0001	-0.14960 0.0522	-0.38020 <.0001	0.34564 <.0001	0.01195 0.8774
DIST_OPNG	-0.04299 0.5790	1.00000	0.04820 0.5338	0.06247 0.4198	-0.06854 0.3759	0.43453 <.0001	0.03050 0.6938	-0.03034 0.6954	0.21875 0.0043
DIST_TOLL	-0.02157 0.7807	0.04820 0.5338	1.00000	-0.05856 0.4495	0.28951 0.0001	-0.03143 0.6850	0.23111 0.0025	-0.09517 0.2184	0.26170 0.0006
DIST_ACC	0.59295 <.0001	0.06247 0.4198	-0.05856 0.4495	1.00000	-0.32855 <.0001	0.00200 0.9794	-0.26961 0.0004	0.25595 0.0008	0.04268 0.5817
AADT	-0.39400 <.0001	-0.06854 0.3759	0.28951 0.0001	-0.32855 <.0001	1.00000	-0.03946 0.6105	0.71512 <.0001	-0.23680 0.0019	0.08228 0.2875
DIST_OPNG2	-0.14960 0.0522	0.43453 <.0001	-0.03143 0.6850	0.00200 0.9794	-0.03946 0.6105	1.00000	0.07424 0.3374	-0.02717 0.7259	0.24538 0.0013
N_Lanes	-0.38020 <.0001	0.03050 0.6938	0.23111 0.0025	-0.26961 0.0004	0.71512 <.0001	0.07424 0.3374	1.00000	-0.17991 0.0193	0.07777 0.3149
SPEED	0.34564 <.0001	-0.03034 0.6954	-0.09517 0.2184	0.25595 0.0008	-0.23680 0.0019	-0.02717 0.7259	-0.17991 0.0193	1.00000	0.07245 0.3493
Med_W	0.01195 0.8774	0.21875 0.0043	0.26170 0.0006	0.04268 0.5817	0.08228 0.2875	0.24538 0.0013	0.07777 0.3149	0.07245 0.3493	1.00000

Table 35 : Correlation Results from the Dataset for Combined Citations at Traversable Medians in FL area

Pearson Correlation Coefficients, N = 44 Prob > |r| under H0: Rho=0										
	N_LANES	AADT	Segment_L	DIST_INT	MED_W	No_of_Acc	N_OPEN	AVGDIS_PT	Dist_Flush	Speed
N_LANES	1.00000	0.54124 0.0001	-0.34101 0.0235	-0.30631 0.0432	0.42692 0.0039	-0.30558 0.0437	0.00195 0.9900	-0.26151 0.0864	0.58762 <.0001	-0.60386 <.0001
AADT	0.54124 0.0001	1.00000	-0.34422 0.0221	-0.30429 0.0446	0.32989 0.0287	-0.28483 0.0609	-0.12066 0.4353	-0.28370 0.0620	0.12032 0.4366	-0.00569 0.9708
Segment_L	-0.34101 0.0235	-0.34422 0.0221	1.00000	0.41440 0.0052	-0.08394 0.5880	0.21245 0.1662	0.69742 <.0001	0.92291 <.0001	-0.31180 0.0394	0.15182 0.3252
DIST_INT	-0.30631 0.0432	-0.30429 0.0446	0.41440 0.0052	1.00000	-0.05058 0.7444	0.00155 0.9920	0.08858 0.5675	0.39568 0.0078	-0.24717 0.1058	0.14619 0.3437
MED_W	0.42692 0.0039	0.32989 0.0287	-0.08394 0.5880	-0.05058 0.7444	1.00000	-0.26728 0.0794	0.05535 0.7212	-0.05622 0.7170	0.39494 0.0080	0.01550 0.9204
No_of_Acc	-0.30558 0.0437	-0.28483 0.0609	0.21245 0.1662	0.00155 0.9920	-0.26728 0.0794	1.00000	0.12966 0.4015	-0.00333 0.9829	-0.37136 0.0131	0.10998 0.4773
N_OPEN	0.00195 0.9900	-0.12066 0.4353	0.69742 <.0001	0.08858 0.5675	0.05535 0.7212	0.12966 0.4015	1.00000	0.69781 <.0001	0.12697 0.4115	-0.13309 0.3891
AVGDIS_PT	-0.26151 0.0864	-0.28370 0.0620	0.92291 <.0001	0.39568 0.0078	-0.05622 0.7170	-0.00333 0.9829	0.69781 <.0001	1.00000	-0.23343 0.1273	0.11548 0.4554
Dist_Flush	0.58762 <.0001	0.12032 0.4366	-0.31180 0.0394	-0.24717 0.1058	0.39494 0.0080	-0.37136 0.0131	0.12697 0.4115	-0.23343 0.1273	1.00000	-0.50690 0.0004
Speed	-0.60386 <.0001	-0.00569 0.9708	0.15182 0.3252	0.14619 0.3437	0.01550 0.9204	0.10998 0.4773	-0.13309 0.3891	0.11548 0.4554	-0.50690 0.0004	1.00000

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