SAFETY EVALUATION OF RIGHT TURNS FOLLOWED BY U-TURNS (4 LANE ARTERIALS) AS AN ALTERNATIVE TO DIRECT LEFT TURNS - CONFLICT ANALYSIS

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Safety Evaluation of Right Turns Followed by U-turns at Signalized Intersection (4 Lanes) as an Alternative to Direct Left Turns - Conflict Analysis		5. Report Date March 2005
		6. Performing Organization Code
7. Author(s) Jian John Lu, Fatih Pirinccioglu, and Juan C. Pernia		8. Performing Organization Report No.
9. Performing Organization Name and Address University of South Florida Department of Civil & Environmental Engineering 4202 E. Fowler Av., ENB 118 Tampa, FL 33620		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. BC 353-39
12. Sponsoring Agency Name and Address Florida Department of Transportation Tallahassee, FL 32399		13. Type of Report and Period Covered Final, Technical Report 2002 - 2004
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This project evaluated a research project that evaluated the safety effects of right turns followed by U-turns (RTUT) at signalized intersections and at median openings as an alternative to direct left turns (DLT) from driveways or side streets on four lane arterials. Safety of both alternatives was evaluated based on traffic conflict analysis. Nine types of conflicts were utilized for this study. Five of the conflict types were related to RTUT movements, while the rest of them were related to DLT movements. Over 500 hours data were collected at sixteen sites with the help of video recording equipment. Data collection sites were divided into two sets by geometric criteria. At the first set of sites, the drivers had to complete U-turn movement of RTUT at a signalized intersection. On the other hand, at the second set of sites the U-turns were at median openings. At traffic signal sites, DLT movements generated two times more conflicts per hour than RTUT movements. When the effects of traffic volumes have been taken into consideration, RTUT movements had a 5 percent higher conflict rate than DLT movements. Severity comparison of DLT and RTUT movements indicated that RTUT related conflicts were less severe than DLT related conflicts. At median opening sites, DLT movements generated 10 percent more conflicts per hour than RTUT movements. Furthermore, the other conflict rate, which takes the effect of traffic volumes into consideration, was 62 percent higher for DLT movements as compared to RTUT movements. Severity analysis results indicated that DLT movements had higher average severity scores than RTUT movements

17. Key Word U-turn, Left-turn, Safety, Conflict, Conflict Severity, Signalized Intersection, Weaving Conflict, Conflict Rate	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 115	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

DISCLAIMER

SAFETY EVALUATION OF RIGHT TURNS FOLLOWED BY U-TURNS (4 LANE ARTERIALS) AS AN ALTERNATIVE TO DIRECT LEFT TURNS - CONFLICT ANALYSIS

By

John Lu, Ph.D., Associate Professor

Fatih Pirinccioglu, Research Assistant

and

Juan C. Pernia, Ph.D., Research Associate

Department of Civil and Environmental Engineering,

University of South Florida

Submitted to: Florida Department of Transportation
Traffic Operations Office, MS 36
605 Suwannee Street
Tallahassee, FL 32399

March 2005

Acknowledgement

This project was sponsored by the Florida Department of Transportation. The assistance provided by FDOT is greatly appreciated. The authors also would like to thank the Graduate Research Assistants at the Department of Civil and Environmental Engineering of University of South Florida for their assistance in field data collection and data reduction. Specifically, the authors would like to express thanks to Gary H. Sokolow, and Eric Larson, for their technical support and guidance.

Abstract

This project evaluated a research project that evaluated the safety effects of right turns followed by U-turns (RTUT) at signalized intersections and at median openings as an alternative to direct left turns (DLT) from driveways or side streets on four lane arterials. Safety of both alternatives was evaluated based on traffic conflict analysis. Nine types of conflicts were utilized for this study. Five of the conflict types were related to RTUT movements, while the rest of them were related to DLT movements. Over 500 hours data were collected at sixteen sites with the help of video recording equipment. Data collection sites were divided into two sets by geometric criteria. At the first set of sites, the drivers had to complete U-turn movement of RTUT at a signalized intersection. On the other hand, at the second set of sites the U-turns were at median openings.

At traffic signal sites, DLT movements generated two times more conflicts per hour than RTUT movements. When the effects of traffic volumes have been taken into consideration, RTUT movements had a 5 percent higher conflict rate than DLT movements. Severity comparison of DLT and RTUT movements indicated that RTUT related conflicts were less severe than DLT related conflicts.

At median opening sites, DLT movements generated 10 percent more conflicts per hour than RTUT movements. Furthermore, the other conflict rate, which takes the effect of traffic volumes into consideration, was 62 percent higher for DLT movements as compared to RTUT movements. Severity analysis results indicated that DLT movements had higher average severity scores than RTUT movements.

Table of Contents Page

Acknowlegement…………………………………………………………………... ii

Abstract…………...…………………………………………………………….....iii

Table of Contents……………………………………………………………....iv

List of Tables………………………………………………………………….. vi

List of Figures…………………………..…………………………………...…....viii

Chapter 1. Introduction……........……………………………………………….. 1

1.1 Background…………………………………………………………….. 1

1.2 Research Subject………….….…………………………………………3

1.3 Problem Statement..…………………….………………………………5

1.4 Research Objectives……………………………………………….....6

1.5 Outline of The Report………………………………….……………… 6

Chapter 2. Literature Review …...……………...…….……………………………7

2.1 Direct Left Turn Treatment Studies. ……….……………………………..7

2.2 U-turn Studies……..……….……………………………………………9

2.3 Florida Regulations………………..……………………………………...10

2.3 Conflict Studies ………………………………..................................10

2.4 Conflicts vs. Crashes…………………………………………………13

2.5 Conflict Severity..……………………………………………….……...... 14

Chapter 3. Methodology………… …...……………………………………………16

3.1 Site Selection…………………………………………………………...... 16

3.2 Sample Sizes……………………………………………..……….…… 18

3.3 Types of Conflicts Studied……………………………….…………….....19

3.3.1 Traffic Signal Sites Conflicts ………………………………..19

3.3.2 Median Opening Sites Conflicts…………………………….. 25

3.4 Identification of Traffic Conflicts………………………………………27

3.5 Data Reduction Procedure……………………………………………...... 32

Chapter 4. Data Collection………...……………………………………………..35

4.1 Description of Study Locations……………………….......................... 35
4.1.1 Traffic Signal Site Descriptions…….…………………….. 37
4.1.1 Median Opening Site Descriptions…….……………………..44
4.2 Data Collection Equipment……………………….…………………50
4.3 Field Procedure………………………………………………………51
Chapter 5. Data Analysis…………..…………….……………..……….….. 53
5.1 Traffic Signal Sites…………………………………………………….. 53
5.1.1 Descriptive Analysis……………………………..……….. 53
5.1.2 Conflict Rates…………………..……………...……….......66
5.1.3 Severity Analysis……………....…………………………. 69
5.2 Median Opening Sites…………………………………………………..77
5.2.1 Descriptive Analysis……......................................………. 77
5.2.2 Conflict Rates…………………..……………...……….......88
5.2.3Severity Analysis………...……………...………………………. 91
5.3 U-turn Analysis……………………………………………………98
5.3.1 U-turn Distribution at Median Openings…………………… 98
5.3.2 Right Turn and U-turn Conflict Model………………………104
5.4 Summary…………………………………………...…………... 107
Chapter 6. Summary, Conclusions, and Recommendations…………………….… 108
6.1 Summary……………………………………………………………….. 108
6.2 Conclusions………………………………………………………………..109
6.3 Recommendations……………………………………………………109
References………………………………………………………………………..111

List of Tables

Table Page

Table 2.1 TTC and ROC Score Values. ……………………………………… 15

Table 3.1 Data Reduction Recording Times for Signalized Intersection Sites...29

Table 3.1 Data Reduction Recording Times for Median Opening Sites…….. 32

Table 3.2 Definitions of Different Conflict Rates…..…………………………32

Table 4.1 Signalized Intersection and Median Opening Site Geometric Characteristics…………………………………………………...36

Table 4.2 Signalized Intersection and Median Opening Site U-turn Location Geometric Characteristics…………………………….…………37

Table 5.1 Sample Size Verification for RTUT Movements, Signalized Intersection Sites……………………………………..….…54

Table 5.2 Sample Size Verification for DLT Movements, Signalized Intersection Sites……….…………………………………….…54

Table 5.3 Summary of the Total Number of Observations, Signalized Intersection ………………………………………………........55

Table 5.4 Average Number of Conflicts Used for Analysis, Signalized Intersection ………………………………………………...... 56

Table 5.5 Average Daily Numbers of Conflicts, Signalized Intersection..……57

Table 5.6 Number of Conflicts per Thousand Involved Vehicles, Signalized Intersection ……………………………………...……….69

Table 5.7 Risk of Collision Scores………………………………………… 70

Table 5.8 Sample Size Verification for RTUT Movements, Median Opening Sites……………..…………..………………………….….…77

Table 5.9 Sample Size Verification for DLT Movements, Median Opening Sites…………..……………..…………………………….….…77

Table 5.10 Summary of the Total Number of Observations, Median Opening...78

Table 5.11 Average Number of Conflicts Used for Analysis, Median Opening..79

Table 5.12 Average Daily Numbers of Conflicts, Median Opening ………….. 80

Table 5.13 Number of Conflicts per Thousand Involved Vehicles, Median Opening ……..…………………………………………………….. 91
Table 5.14 Geometric Characteristics of Sites for U-turn Analysis…………… 98
Table 5.15 Table 5.15 U-turn Distribution at Six Sites………………………... 100
Table 5.16 Regression Model Results………………………………………..105

List of Figures

Figure		Page
Figure 1.1	Crash Rates vs. Access Points per Mile……………..……………..	2
Figure 1.2	Conflict points at a four-leg intersections……………..…………	3
Figure 1.3	DLT vs. RTUT at a signalized intersection……………………...	4
Figure 1.4	DLT vs. RTUT at a median opening……………………………….	4
Figure 2.1	Accident Comparisons of the Michigan Study………..…...……….	8
Figure 3.1	Signalized Intersection Components……..…………………………	17
Figure 3.2	Median Opening Components……………..…………………………	17
Figure 3.3	Conflict Type C1……………………………..…………………….	21
Figure 3.4	Conflict Type C2……………………………...…………………….	21
Figure 3.5	Conflict Type C3………………………..………………………..	22
Figure 3.6	Conflict Type C4, Signalized Intersection……..…………………..	22
Figure 3.7	Conflict Type C5, Signalized Intersection ……...………………….	23
Figure 3.8	Conflict Type C6…………………..…………………………….	23
Figure 3.9	Conflict Type C7……………………………………………….	24
Figure 3.10	Conflict Type C8……………..………………………………….	24
Figure 3.11	Conflict Type C9……………..………………………………….	25
Figure 3.12	U-turn Conflicts (C4), Median Opening……………………………	26
Figure 3.13	Slow U-Turn Vehicles, Same-Direction Conflict (C5), Median Opening……………………………………………………….	26
Figure 3.14	Flow Chart Describing Conflict Identification and Data Required by Observers.…………………..….……………………..	29
Figure 3.15	The Form Used for Recording Traffic Conflicts at Signalized Intersection……………..……………………………………………..	30
Figure 3.16	The Form Used for Recording Traffic Conflicts at Median Opening Sites…………………………………………………………	30
Figure 4.1	Tampa Bay Area Sites Map……………………………………....	35
Figure 4.2	Plant City Sites Map……………………………………………..	36

Figure 4.3 Aerial Photograph of Site 1……………………………………………38
Figure 4.4 Aerial Photograph of Site 2……………………………………………39
Figure 4.5 Aerial Photograph of Site 3……………………………………………40
Figure 4.6 Aerial Photograph of Site 4……………………………………………40
Figure 4.7 Aerial Photograph of Site 5……………………………………………41
Figure 4.8 Aerial Photograph of Site 6……………………………………………42
Figure 4.9 Aerial Photograph of Site 7……………………………………………43
Figure 4.10 Aerial Photograph of Site 8……………………………………………43
Figure 4.11 Aerial Photograph of Site 9……………………………………………44
Figure 4.12 Aerial Photograph of Site 10………………………………………… 45
Figure 4.13 Aerial Photograph of Site 11………………………………………… 46
Figure 4.14 Aerial Photograph of Site 12………………………………………… 47
Figure 4.15 Aerial Photograph of Site 13………………………………………… 47
Figure 4.16 Aerial Photograph of Site 14………………………………………… 48
Figure 4.17 Aerial Photograph of Site 15………………………………………… 49
Figure 4.18 Aerial Photograph of Site 16………………………………………… 49
Figure 4.19 Data Collection System…………………………………….……… 51
Figure 5.1 Number of Daily Conflicts by Type, Site 1, Signalized Intersection 58
Figure 5.2 Number of Daily Conflicts by Type, Site 2, Signalized Intersection 59
Figure 5.3 Number of Daily Conflicts by Type, Site 3, Signalized Intersection 59
Figure 5.4 Number of Daily Conflicts by Type, Site 4, Signalized Intersection 60
Figure 5.5 Number of Daily Conflicts by Type, Site 5, Signalized Intersection 61
Figure 5.6 Number of Daily Conflicts by Type, Site 6, Signalized Intersection 62
Figure 5.7 Number of Daily Conflicts by Type, Site 7, Signalized Intersection 62
Figure 5.8 Number of Daily Conflicts by Type, Site 8, Signalized Intersection 63
Figure 5.9 Average Number of Daily Conflicts by Type, RTUT Movement, Signalized Intersection ………………..……………………………64
Figure 5.10 Average Number of Daily Conflicts by Type, DLT Movement, Signalized Intersection………..……………………………………65

Figure 5.11 Conflicts by time Period, RTUT Movement, Sig. Intersection...….. 67
Figure 5.12 Conflicts by time Period, DLT Movement, Signalized Intersection. 67
Figure 5.13 Conflicts by time Period, DLT and RTUT Movements Comparison, Signalized Intersection ……………………………… 68
Figure 5.14 Number of Conflicts per Thousand Involved Vehicles, Signalized Intersection………………………………………….. 69
Figure 5.15 Distribution of Severity, Conflict Type C1, Signalized Intersection 70
Figure 5.16 Distribution of Severity, Conflict Type C2, Signalized Intersection 71
Figure 5.17 Distribution of Severity, Conflict Type C3, Signalized Intersection 71
Figure 5.18 Distribution of Severity, Conflict Type C4, Signalized Intersection 72
Figure 5.19 Distribution of Severity, Conflict Type C5, Signalized Intersection 72
Figure 5.20 Distribution of Severity, Conflict Type C6, Signalized Intersection 73
Figure 5.21 Distribution of Severity, Conflict Type C7, Signalized Intersection 73
Figure 5.22 Distribution of Severity, Conflict Type C8, Signalized Intersection 74
Figure 5.23 Distribution of Severity, Conflict Type C9, Signalized Intersection 74
Figure 5.24 Average ROC Scores for RTUT Movements, Sig. Intersection……75
Figure 5.25 Average ROC Scores for DLTT Movements, Sig. Intersection…… 76
Figure 5.26 Severity Comparison for DLT and RTUT Movements by ROC, Signalized Intersection …………………………………………. 76
Figure 5.27 Number of Daily Conflicts by Type, Site 9, Median Opening…….. 81
Figure 5.28 Number of Daily Conflicts by Type, Site 10, Median Opening…… 81
Figure 5.29 Number of Daily Conflicts by Type, Site 11, Median Opening….... 82
Figure 5.30 Number of Daily Conflicts by Type, Site 12, Median Opening..….. 83
Figure 5.31 Number of Daily Conflicts by Type, Site 13, Median Opening…… 84
Figure 5.32 Number of Daily Conflicts by Type, Site 14, Median Opening..….. 84
Figure 5.33 Number of Daily Conflicts by Type, Site 15, Median Opening..….. 85
Figure 5.34 Number of Daily Conflicts by Type, Site 16, Median Opening….... 86
Figure 5.35 Average Number of Daily Conflicts by Type, RTUT Movement, Median Opening….………………………………………………86

Figure 5.36 Average Number of Daily Conflicts by Type, DLT Movement, Median Opening….…………………………………………………87
Figure 5.37 Conflicts by time Period, RTUT Movement, Median Opening…….88
Figure 5.38 Conflicts by time Period, DLT Movement, Median Opening…..…. 89
Figure 5.39 Conflicts by time Period, DLT and RTUT Movements Comparison, Median Opening…………………………...………. 89
Figure 5.40 Number of Conflicts per Thousand Involved Vehicles, Signalized Intersection…………………………………………….. 90
Figure 5.41 Distribution of Severity, Conflict Type C1, Median Opening…...…91
Figure 5.42 Distribution of Severity, Conflict Type C2, Median Opening…...…92
Figure 5.43 Distribution of Severity, Conflict Type C3, Median Opening…...…92
Figure 5.44 Distribution of Severity, Conflict Type C4, Median Opening.…...…93
Figure 5.45 Distribution of Severity, Conflict Type C5, Median Opening...……93
Figure 5.46 Distribution of Severity, Conflict Type C6, Median Opening…...…94
Figure 5.47 Distribution of Severity, Conflict Type C7, Median Opening…..… 94
Figure 5.48 Distribution of Severity, Conflict Type C8, Median Opening.….… 95
Figure 5.49 Distribution of Severity, Conflict Type C9, Median Opening…..… 95
Figure 5.50 Average ROC Scores for RTUT Movements, Median Opening…... 96
Figure 5.51 Average ROC Scores for DLTT Movements, Median Opening.….. 97
Figure 5.52 Severity Comparison for DLT and RTUT Movements by ROC, Median Opening……………………………………………………97
Figure 5.53 Median Opening Geometric Characteristics………………………..99
Figure 5.54 U-Turn Distribution by Vehicle Type, Site 9……………………… 101
Figure 5.55 U-Turn Distribution by Vehicle Type, Site 10…………………….. 101
Figure 5.56 U-Turn Distribution by Vehicle Type, Site 11…………………….. 102
Figure 5.57 U-Turn Distribution by Vehicle Type, Site 13…………………….. 102
Figure 5.58 U-Turn Distribution by Vehicle Type, Site 14…………………….. 103
Figure 5.59 U-Turn Distribution by Vehicle Type, Site 15…………………….. 103
Figure 5.60 RT-UT Conflict ………………………..………………………...104

Figure 5.61 RT-UT Conflict Rate Curves Based on the Model…………………106

1. Introduction

1.1 Background

The most important purpose of traffic studies is to improve the safety of the roadway systems. Conventional methods such as widening of roadways will definitely help to achieve the necessary goals of these studies. The problems with conventional methods are the cost of construction and expensive compensation of property by agencies performing the improvements. In addition, the conventional methods are not always possible to apply to current conditions of the roadway systems. In many metro areas of the nation, either the space is very limited and very expensive or there is no space available for conventional improvements. Access management is one of the available solutions for researchers to perform the improvements on the roadway system. Access management techniques have been widely used by engineers and planners to regulate and design the roadways. Access management is defined as the systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway. It also involves roadway design applications, such as median treatments and auxiliary lanes, and the appropriate spacing of traffic signals. The benefits of access management are improved safety, improved traffic flow and fuel economy, increased capacity and reduced delay and vehicle emissions *(1)*. The "Access Management, Location and Design, Participant Notebook" indicates that effective application of access management techniques can improve the safety by reducing the crashes by as much as 50%, improve the capacity by 23-45%, and reduce travel time and delay as much as 40-60% *(2)*

Access management deals with driveway and median design by managing the movement ingress and egress of the driveways, spacing and placement of driveways and median openings. Several studies have shown that an increase on the number of access points on arterials increased the crash rates. Figure 1.1 shows impacts of access management on safety based in the results from the NCHRP 420 report *(3)*. These driveway spacing, placement, and movement's ingress and egress of the driveways are directly related to the safety of the arterials. Moreover, applications not only affect the safety but also have impacts on the capacity of the arterials. Driveway movements cause 10% of total crashes and 70% of intersection crashes in United States *(1)*.

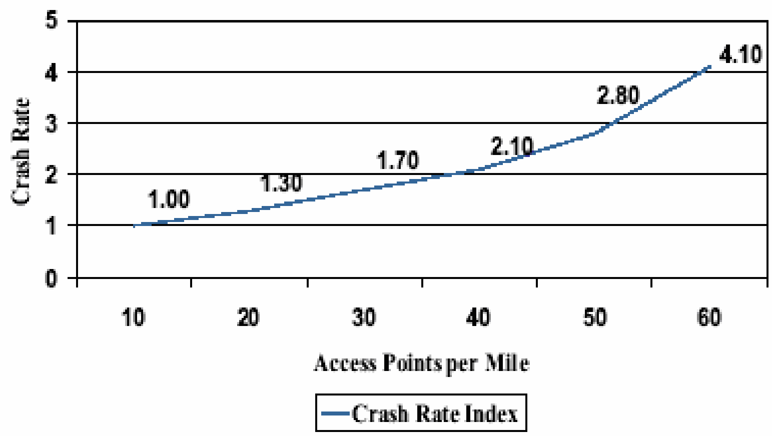


Figure 1.1 Crash Rates vs. Access Points per Mile *(3)*

Researchers have been developing new methods to improve the safety of the driveway movements. In this regard, direct left turns from driveways have been a concern as one of the major sources of operational and safety problems. Research studies have been conducted addressing the safety and operational problems related to direct left turn (DLT) movements. In this matter, alternatives to direct left turns have been developed and studies have been conducted to point out the safety and operational benefits of these alternatives. The state of Florida designs their new or redesigned roadways with posted speed of 40 mph or higher with directional median openings, which prevent direct left turns from driveways. In theory, replacing full median openings with directional (restricted median opening) will force the driveway users to make a right turn from the driveway and search for the next possible U-turn movement bay available down-stream of the driveway. This median treatment accomplishes one of the principles of access management techniques, which is to reduce the number of conflict points. Conflict points are defined as points at which traffic movements intersect with each other. The reduction of conflict points results in less complex driving environment and the chance of being involved in conflicts with other vehicles from the driver perspective. Figure 1.2 shows conflict points at a typical four leg unsignalized intersection and directional median opening location. Without a treatment, unsignalized intersections have 32 conflict points. However, if this intersection is treated with a directional median opening, only 8 conflict points remain *(1)*.

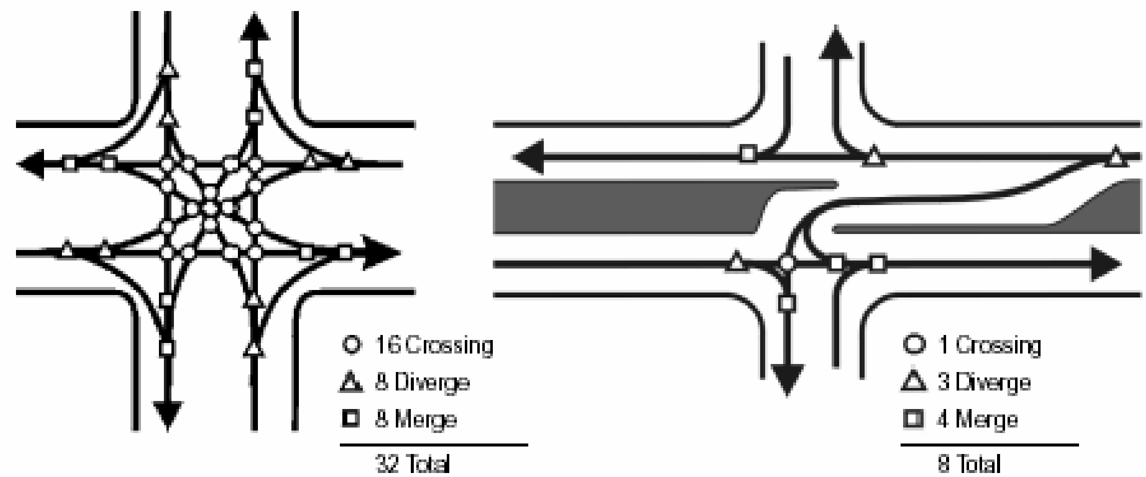


Figure 1.2 Conflict points at four-leg intersections

1.2 Research Subject

In 2001 and 2004, two research projects were performed by Dr. John Lu and his colleagues at the University of South Florida and sponsored by the Florida Department of Transportation (FDOT) to evaluate access management techniques *(4,5)*. These two projects evaluated and quantified operational and safety effects of right turns followed by U-turns as an alternative to direct left turns from driveways and side streets. The study locations in these projects were driveways on six or eight lane arterials. The difference between the two projects was the location of U-turn maneuvers. The project performed in 1999 focused on U-turns at median openings after right turns from the driveways and the side streets. On the other hand, the project performed in 2004 focused on U-turns at signalized intersections after right turns. Results from these research projects indicate that right turn followed by U-turn movements had safety benefits and also operational benefits under certain traffic conditions as compared to direct left turns.

Another alternative to this geometric condition is four lane arterials. The change in width and characteristics of the main road needed to be considered as another research project and the results needed to be quantified and compared with earlier projects. One consideration behind this thinking is the shorter crossing distance needed by direct left turn vehicles in the case of 4-lane roadways since crossing 2 lanes at a time may not be as difficult as crossing three lanes. It may therefore be advisable to separately evaluate direct left turns and right turns followed by U-turns on 4-lane facilities. It is also necessary to develop recommendations for U-turn locations on 4-lane roadways since such locations might have limited physical space (ex. narrow medians) to complete the maneuver, which was not an issue in the case of 6 lane roadways. Such tight locations on 4-lane roadways may also require extra pavements as well to complete the U-turn. Two geometric conditions studied and DLT and RTUT movements, which were focused in this research project, are illustrated in Figures 1.3 and 1.4.

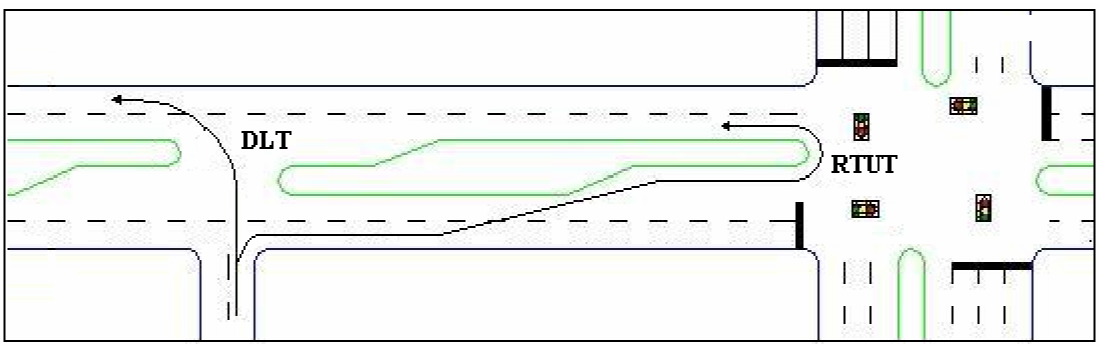


Figure 1.3 DLT vs. RTUT at a signalized intersection

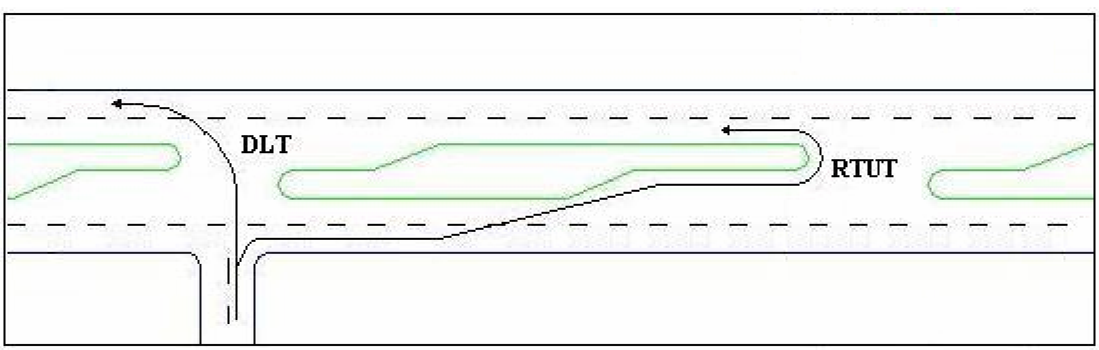


Figure 1.4 DLT vs. RTUT at a median opening

1.3 Problem Statement

The state of Florida has been applying access management techniques on its roadway network for more than a decade. As mentioned earlier, the current design standards mandate that newly improved arterials with a design speed of 40 mph or higher will be constructed with raised medians and restricted median openings. Geometric restrictions such as closing driveways and converting full median openings to restricted median openings arise issues with them. Business owners concerned of loosing customers by access management modifications can oppose those improvements although it has been documented by many studies that safety and capacity will be dramatically enhanced and business impacts are small. In Florida, several surveys have been done to evaluate the impacts of the access management techniques on drivers and businesses *(6)*. The majority of the drivers found these changes safer and indicated that they would not be affected in the selection of businesses they usually used. The studies conducted on the economic impacts of access management on businesses found that in general access management improvements do not affect businesses in a negative way *(7)*.

Although previous studies clearly stated the safety benefits of restriction of DLT movements from driveways, there is a need to compare these movements and quantify the safety benefits under different geometric conditions such as four lane arterials. The main concerns about the RTUT movements are as follows: First, drivers may not find RTUT at a signalized intersection movement convenient because of the delay time at a traffic signal. Second, at four lane arterials, the turning radius for the U-turn movements can be small and this situation can make the U-turn maneuvers a challenge and unsafe. Finally, weaving maneuvers to reach the exclusive left turn lane after right turns from driveways could be a problem for drivers under heavy traffic conditions. Distance between the driveway and the traffic signal or downstream U-turn bay has to be long enough for the drivers to safely weave into and reach the left turn lane of the traffic signal without significant conflicts. The impacts from both operational and safety perspectives for two geometric alternatives are quantified in this study to enlighten the concerns about DLT and RTUT movements on four lane roadways.

1.4 Research Objectives

This project focused on four lane roadways with two geometric conditions. The primary purpose of this project was to conduct a detailed evaluation and investigation on a widely used access management technique: right-turns followed by U-turns at a signalized intersection and right-turns followed by U-turns at a median opening as the alternatives to direct left turns from a driveway. This research took two main approaches to evaluate this specific access management technique including operational analysis and conflict analysis. Conflict analysis was chosen over crash analysis because of the advantages conflict analysis. Some advantages are shorter data collection time than crash data and the effectiveness of a countermeasure can be evaluated in a shorter time. Safety affects of a right turn followed by a U-turn at signalized intersection and median opening will be quantified in this report through field studies and data collection. Safety analysis has included comparisons of conflict rates and conflict severities. More specifically, the objective consists of the following parts:

1. To estimate the average number of traffic conflicts for both DLT and RTUT maneuvers,
2. To estimate the average conflict rates for each of the two left turning alternatives from driveways,
3. To evaluate the severity of conflicts generated by DLT and RTUT and to compare the severities.

1.5 Outline of the Report

This report consists of six chapters. Chapter 1 provides an introduction to the research project. Chapter 2 summarizes the review of literature in this area. Chapter 3 describes the methodologies utilized to reach the objectives of the study. Chapter 4 describes the procedures followed to complete data collection in an efficient and appropriate way. Chapter 5 includes analysis results and findings of the research. Chapter 6 provides summary, conclusions and recommendations of this research.

2. Literature Review

In this chapter, the current standards, regulations, and applications for the state of Florida were reviewed. Also, projects and studies conducted by Transportation Research Board (TRB), The National Cooperative Highway Research Program (NCHRP), American Association of State Highway and Transportation Officials AASHTO, and other researchers in the nation, were reviewed. There are no previous studies regarding the safety impacts of right turn followed by U-turns at signalized intersections or median openings considering conflicts other than the previous studies conducted at University of South Florida by Dr. John Lu and his colleagues.

2.1 Direct Left Turn Treatment Studies

Many states of the nation have several different applications and regulations to prevent direct left turn movements. The state of Michigan installed directional median openings to prevent direct left turns from driveways for more than two decades *(3)*. Those states commonly used the solution of either closing the full median opening or converting it to a directional median opening. Those solutions diverted the left turn traffic to the next U-turn bays. Several studies have been conducted to evaluate impacts of those treatments.

The study conducted at University of South Florida in 2001 evaluated right turns followed by U-turns at median openings as an alternative to direct left turns from the driveways on six or more lane arterials. This study found that, right turn followed by U-turn movements generated fewer conflicts as compared to direct left turn movements. Also severities of the conflicts were less for right turn followed by U-turn movements *(4)*. Another study by University of South Florida completed in 2004 evaluated right turns followed by U-turns at signalized intersections as an alternative direct left turns (5). This study also found that RTUT at signalized intersection movements were safer than DLT movements and severities of RTUT movements were less than DLT movements.

Vargas and Gautam *(8)* performed a case study regarding right turns followed by U-turns as an alternative to direct left turns in Florida. Several closely spaced median openings were closed and directional median openings were installed in advance of traffic signals. This study measured crash frequency distribution. Results of the study found that the overall number of crashes was reduced by 22 %.

There are several studies to evaluate the safety impacts of direct left turn treatments in the state of Michigan. One study, by Maki *(9)*, used traffic crashes to measure the safety improvements when replacing four full median openings in the city of Detroit. In that study, before and after comparison of several types of crashes were analyzed. Results of the study as illustrated in Figure 2.1, are the following: 17.1% reduction in rear end crashes, 95.5% reduction in side angle crashes, which are mainly caused by direct left turns and cause injuries and fatalities because of the speed difference of the vehicles involved in these kinds of crashes, and 60.6 % reduction in side swipe crashes. Another additional important measure of safety, which are injuries, were reduced by 74.6 % after the improvements.

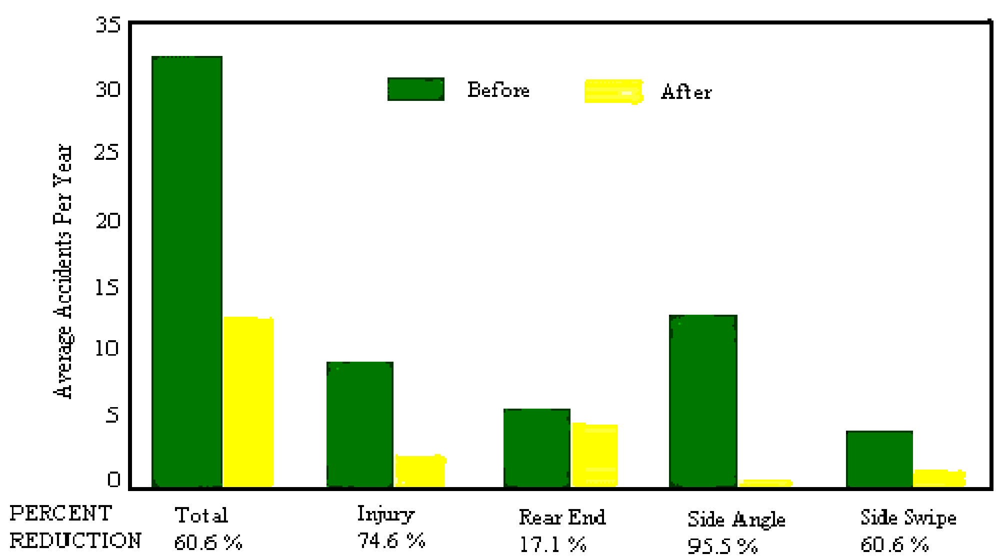


Figure 2.1 Crash Comparisons of the Michigan Study *(9)*

Another study in Michigan, that was conducted by Kach *(10),* compared the crash rates of full median openings with directional median openings and related injuries caused by those crashes. Results of the study indicated that the average rate of crashes for directional median openings were 15 percent less as compared to full median openings. Also, injuries related to crashes were 30 percent less for directional median openings.

2.2 U-turn Studies

The safety of U-turn maneuvers was focused in several projects. Generally, these projects either focused on U-turns at signalized intersections or U-turns at unsignalized intersections. NCHRP Project 17-21 *(11)* was conducted on the subject of "Safety of U-turns at unsignalized intersections". Findings of this study indicated that urban arterials had 0.41 U-turn plus left turn accidents per median opening per year and rural arterials had 0.20 U-turn plus left turn accidents per median opening per year. This project concluded that there were no major concerns about the safety of U-turns at median openings.

NCHRP 524 Report *(12)* also focused on safety of U-turns at unsignalized intersections. This report included intensive safety evaluation of U-turns by traffic conflicts and crash rates for different types of median openings and the places of the median openings on the major roads. The data related to three major conflicts and crash types were analyzed in that report. These are explained as follows:

1. Conflicts and crashes between the major road vehicles and the vehicles turning from the major road to the median opening.
2. Conflicts and crashes at within the median opening.
3. Conflicts and crashes between the major road vehicles and the vehicles turning from the median opening onto the major road.

The data analysis of the report found that for most types of median openings, most observed traffic conflicts were between major road vehicles and the vehicles turning onto the major road from the median opening.

Another study conducted by Philips et al. *(13)* focused on operational and safety effects of increased U-turns on divided facilities. The safety part of the study found that 65 out of 78 sites had no collisions related to U-turns. The remaining 13 sites ranged from 0.3 to 3.

2.3 Florida Regulations

Florida is heavily encouraging restrictive medians on its higher designed at-grade arterial roadways *(14)*. The 1993 Multi-lane Facilities Median Policy required that all new or reconstructed multilane highways with a design speed over 40 mph must be designed with a restrictive median. It also directs designers to find ways to use restrictive medians in all multi-lane projects, even those below the 40 mph design speed *(15)*. One of the major purposes of installing restrictive medians is to eliminate left turn movements. By closing existing median openings in some major arterial roads or replacing them with directional median openings, left-turn exits onto major arterials are prohibited and the left turn egress movements would be made by turning right onto the arterial road and then making a U-turn at downstream median opening or signalized intersection.

2.4 Conflict Studies

Traffic conflicts have been surrogate measures for traffic crashes and have been used since the 1970's for safety assessment purposes. The traffic conflict technique was invented by General Motors Company. The car manufacturer wanted to use the technique for evaluating details of vehicle design's influence on risks. Parker and Zeeger defined the conflicts as a traffic event involving the interaction of two or more road users usually motor vehicles, where one or both drivers take evasive action, such as braking or swerving, to avoid a collision *(16,17)*. The traffic conflict technique is a methodology for field observers to identify conflict events at intersections by watching for strong braking and/or evasive maneuvers. The traffic conflict technique has a long history of development, including research on *(18)*:

- Data collection methods.
- Data collection standards.
- Definitions of various types of conflicts
- Severity measures
- Relationship between conflicts and crashes
- Conflicts' are related to specific crash types

Traffic conflicts were used for other purposes other than being safety measures for a location. An ITE study found that 33 percent of the reporting agencies used a left-turn conflict rate of four conflicts per 100 left-turn vehicles as a warrant for implementing the left turn phase in signal phasing. The operational quality of service has an affect on the number of the conflicts. The result of the study that intended to comprehend the relationship between traffic operations and safety at signalized intersections found that average stopped delay significantly affects the vehicle and lane change conflicts. Also, those types of conflicts decrease as the average total delay increases *(19,20)*.

Sayed *(21)* described the application of the traffic conflict technique for the estimation of safety at an unsignalized intersection. In this study, a computer simulation was used to simulate critical traffic events. Data was collected from 30 different surveys to establish the traffic conflict frequency and the severity standards. The standards established by this study allow the relative comparison of the conflict risk at different intersections *(22)*. Another research by Sayed established frequency and severity standards for signalized intersections acquiring data from 94 conflict surveys. The study developed an intersection conflict index to compare the conflict risk at signalized intersections.

Weerasuriya and Pietrzyk *(23)* used traffic conflicts to analyze intersections and develop expected conflict value tables for future studies where intersections do not have a history of crashes. Various types of intersections with varying lane numbers and volumes were analyzed in that research. The tables resulted from this study provided mean, variance, and 90th and 95th percentile conflict rates. It was proposed that those tables could be used to estimate the safety problems at different intersections.

The relationship between traffic volumes and conflicts has been another subject for researchers to investigate. Salman and Almaita *(24)* had a research on three leg intersections. The summation of all volumes entering the intersection and the square root of the product of the volumes that generated the conflicts were used to correlate conflicts and volumes. It was found that the correlation between the conflicts and the square root of the product of volumes was higher than that of the summation of volumes. Migletz. et al. *(25)* defined the traffic volumes depending on the conflict types, which were through cross traffic conflicts, opposing left turn conflicts and same direction conflicts. For opposing left-turn conflicts the volume was defined as the square root of the product of the left turn volume and opposing through volume summed over two approaches at unsignalized intersections. Through cross-traffic conflicts were related to the through cross traffic volume, which was defined as the square root of the product of through cross traffic from right (or left) volume with the through volume summed over the four approaches at both signalized and unsignalized intersections. Same direction conflicts were related to the same direction volume, which was defined as sum of the volumes of all the approaches. Katamine *(26)* worked on 15 four leg unsignalized intersections to define the relationship between traffic volumes and conflicts. Eleven types of conflicts were related to thirteen different volume definitions. The study found that the total volume entering the intersection was significantly correlated to most conflict types but using the total volume cannot explain the different conflicts' occurrence at the intersections.

2.5 Conflicts vs. Crashes

The main purpose of the traffic studies is to enhance the safety of traffic locations or the movements at those locations. As it was mentioned in the previous chapter, reducing the number of crashes will reduce the injuries and fatalities related to them. Since the main purpose is to reduce the number of crashes, researchers have been using crashes to assess safety problems. However, problems have been documented with crashes. Firstly, the number of crashes at a specific site is usually too small to do any kind of analysis. Many years are required to obtain crash data from a specific site. Secondly, some property damage crashes have never been reported to the police. Also, the crash data may include human errors or may be missing. Thirdly, a reduction in the number of crashes may be the result of a successful counter measure, or to the fact that the period before the measure had randomly high number of crashes *(16,17,27,28,29)*.

On the other hand, traffic conflicts have some advantages as compared to traffic crashes: First, a researcher can collect the conflict data required for a site in a short period of time so it is not necessary to wait several years to make any improvements to a location *(16,17,29)*. Second, the data collected can be used as supplementary data to crash data for analysis purposes *(16,17)*. Third, the effectiveness of a countermeasure can be evaluated in a short time and can be changed in a short time with traffic conflicts *(16,17)*. Fourth, traffic conflict provides information about volume; frequency of different kinds of conflicts and severity of conflicts while the crash data can only give information on property damage and injury severity *(30)*. Fifth, conflict data includes human factors because the conflict data collection requires observation of the drivers at the field *(31)*.

Though researchers have intensely studied the correlation between crashes and conflicts, they have shown minute success in distinguishing their relationship to each other. Migletz et al *(32)* found a 10% correlation between crashes and conflicts. Engel *(33)* found that the relationship between the total crashes and the total conflicts was not significant, but if different types of crashes and conflicts were studied the relationship would have been significant. Glauz et al *(34)* stated that the conflicts can be used to estimate the number of crashes in a particular year but it will not predict an actual number. Therefore, traffic conflicts can be used as a replacement of the crashes.

2.6 Conflict Severity

Obtaining the conflict data and comparing the conflict rates are one part of traffic conflict safety evaluation studies. The other measure is severity of conflicts that assess how close the conflicts are to be crashes. The researchers developed several methods to measure the severity of conflicts. The most widely used measure is the time to collision (TTC), which has been proposed by Hayward *(35)*. It has been defined as the time to collision of two vehicles if they continue on the same path without any evasive maneuver such as braking or swerving. The other measures were defined as the following *(18)*:

- *Gap Time (GT):* Time lapse between completion of encroachment by turning vehicle and the arrival time of crossing vehicle if they continue with same speed and path.

- *Encroachment Time (ET):* Time duration during which the turning vehicle infringes upon the right-of-way of through vehicle.

- *Deceleration Rate (DR):* Rate at which crossing vehicle must decelerate to avoid collision.

- *Proportion of Stopping Distance (PSD):* Ratio of distance available to maneuver to the distance remaining to the projected location of collision.

- *Post-Encroachment Time (PET)*: Time lapse between end of encroachment of turning vehicle and the time that the through vehicle actually arrives at the potential point of collision.

- *Initially Attempted Post-Encroachment Time (IAPT):* Time lapse between commencement of encroachment by turning vehicle plus the expected time for the through vehicle to reach the point of collision and the completion time of encroachment by turning vehicle.

Some researchers have indicated that TTC is *the* surrogate measure of safety, while others refute that lower TTC indicates higher severity of crashes, primarily because speed is not included in the measure *(36,37)*. That is to say that lower TTC certainly indicates a higher probability of collision, but cannot be directly linked to the severity of the collision. Some research indicates deceleration rate (DR) as the primary indicator of severity instead of TTC *(38,39)*.

Sayed et al *(21)* stated that if only objective methods were used, the risk factor could be over estimated. Hence, it was recommended to use both objective and subjective methods and combine them to obtain a more reasonable risk value. A subjective value denominated, Risk of Collision (ROC) was divided into three categories of risk consists of low, medium and high risk. In regard to TTC, this measure was categorized in three time intervals: 0 to 1 second, 1 to 1.5 seconds, and more than1.5 seconds.

Table 2.1 TTC and ROC Score Values

TTC and ROC Scores		
Score	TTC (seconds)	ROC
1	1.50 <	Low Risk
2	1.00 – 1.50	Medium Risk
3	0.00 – 0.99	High Risk

3. Methodology

3.1 Site Selection

Sixteen sites were selected for data collection in the Tampa Bay Area and Plant City. Data collection sites were divided into two sets by geometric criteria. The difference between the two sets was the location of the U-turn maneuvers. At the first set of sites, the drivers had to complete U-turn movement of RTUT at a signalized intersection. These types of sites are named as “Signalized Intersection Sites” in this report. On the other hand, at the second set of sites the U-turns were at median openings and these sites are named as “Median Opening Sites”. Since, two different geometric conditions were considered, two different site selection criteria were considered for site selection. Site selection criteria for signalized intersection sites are as follows:

1. The arterial or major road must have two lanes in each direction.
2. Traffic volume on the driveway should be relatively high so that the adequate turning vehicles could be studied.
3. The minimum distance between the driveway and upstream signal should be at least 200 ft, which is the median value of the distance traveled during driver perception-reaction time and the impact distance due to a right turning vehicle
4. The downstream signal should be located at an appropriate distance away from the driveway in order to avoid the effects of possible spillbacks.
5. Posted speed on the major road is equal to or greater than 40 MPH.
6. Downstream signal has protected left turn phase to prevent the conflicts between the upstream traffic and the U-turn traffic at the signalized intersection.
7. No protective island and exclusive lane for right turn movements from the cross road at the signalized intersection to observe the conflicts between U-turning vehicles and right turning vehicles from the cross road.
8. Right turn on red is allowed at the signalized intersection to observe the conflicts between U-turning vehicles and right turning vehicles.

Figure 3.1 illustrates the location of traffic signals and direction of traffic streams at a typical signalized intersection site.

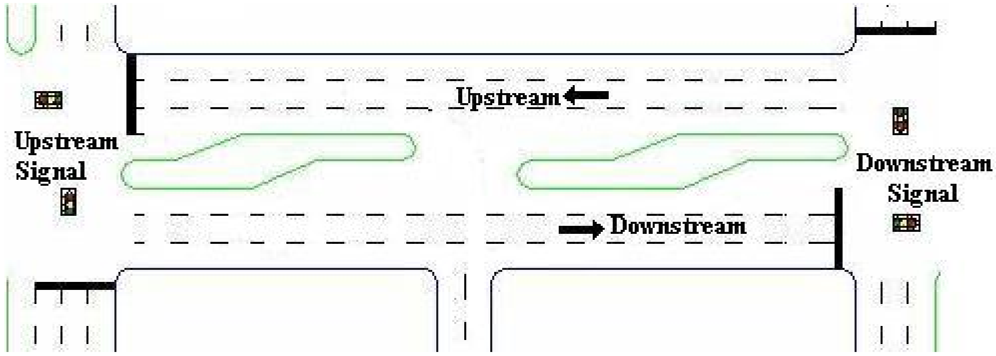


Figure 3.1 Signalized Intersection Site Components

Site selection criteria for median opening sites are as follows:

1. The arterial or major road must have two lanes in each direction.
2. Traffic volume on the driveway should be relatively high so that adequate turning vehicles could be studied.
3. The minimum distance between the driveway and upstream signal should be at least 200 ft, which is the median value of the distance traveled during driver perception-reaction time and the impact distance due to a right turning vehicle *(3).*
4. The downstream signal should be located at an appropriate distance away from the driveway in order to avoid the effects of possible spillbacks.
5. Posted speed on the major road is equal to or greater than 40 MPH.

Figure 3.2 illustrates the location of traffic signals and direction of traffic streams at a typical median opening site.

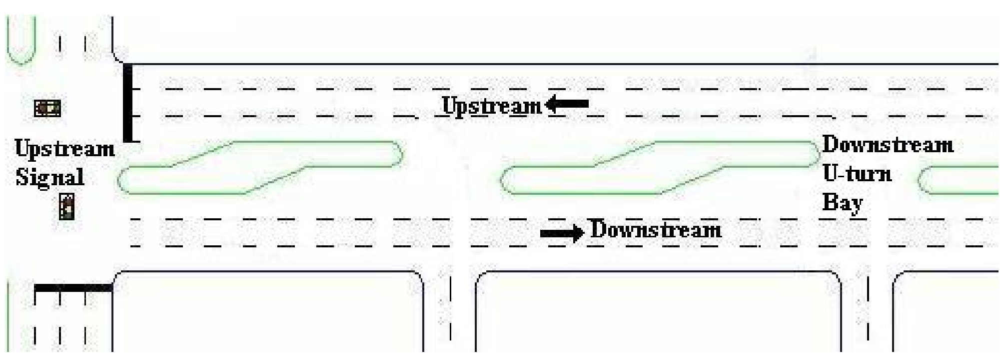


Figure 3.2 Median Opening Site Components

3.2 Sample Sizes

Sample size, as in all engineering studies related to statistics, was required to be calculated prior to data collection. The procedure to calculate the sample size depends on the conflict rates to be analyzed. Engineers use two types of conflict rates for conflict studies: conflicts per unit time and conflicts per vehicle observed. There are two procedures to calculate the sample size based on the conflict rates *(40)*.

The first procedure is based on the conflict per unit time as presented in Equation 3.1. The outcome for this procedure is the minimum number of hours that the data will be collected at the field. This procedure requires error of the mean and variance from the past studies, which used the same methodology and geometric conditions. Also, level of significance and level of error are required to perform the procedure.

$$n = \left(100 \times \frac{t}{p}\right) \times \frac{\sigma_e^2}{Y^2} \qquad 3.1$$

where,

n = number of hours of observation needed,

t = statistic from the normal distribution related to the selected level of significance ,

p = error of the hourly mean,

σ^2 = hourly variance of conflicts estimated from previous studies, and

Y = hourly mean number of conflicts of a specific type

The second procedure based on the conflict per vehicles observed is shown in Equation 3.2. Sample size, which is calculated by this procedure, is the minimum number of vehicles to be observed. This procedure requires conflicting rate, level of significance and level of error.

$$n = p \times (1 - p) \times \left(\frac{z}{D}\right)^2 \qquad 3.2$$

where,

n = number of vehicles to be counted,

p = expected proportion of vehicles observed that are involved in a conflict,

z = statistic that is based on the level of significance desired,

D = permitted level of absolute error of sample size.

In this study both conflict rates mentioned previously were considered. For the first procedure, mean and variance values were unknown from the past studies because there were no past studies available that used the same methodology and geometric conditions. Although, Parker and Zeeger established the tables that included the mean and variance values for signalized and non-signalized intersections *(17)*, these values may not be used for the movements studied in this project. For the second procedure, conflicting rate is not known but could be conservatively assumed based on the calculation of 385 vehicles. After the data collection, sample size can be verified by Equation 3.2.

$$n = 0.50 \times (1 - 0.50 \times \sqrt{\frac{1.96}{0.50}} = 384 \text{ Approach vehicles}$$

3.3 Types of Conflicts Studied

As mentioned earlier, this project focused on two different geometric conditions. The difference between the two geometric conditions was the location of the U-turn maneuvers. Nine types of conflicts were used for safety evaluation of both geometric conditions. Conflicts related to direct left turn maneuvers were the same for both signalized intersection and median opening sites. On the other hand, right-turn followed by U-turn related conflicts differed by two types of conflicts which were related to U-turn maneuvers at signalized intersection and median opening sites.

3.3.1 Conflicts of Signalized Intersection Sites

1) Right-Turn Out of the Driveway (C1), occurs when a vehicle waiting at a driveway, turns to the right and gets onto the major road, placing another vehicle (conflicting vehicle) on the major-road with increased potential of a rear-end or sideswipe collision.

2) Slow-Vehicle, Same-Direction Conflict (C2), occurs when a right turning vehicle is already on the major road and begins to accelerate while on the path of a major road vehicle, thus, the major road vehicle is encountered with increased potential of a rear-end collision.

3) Lane Change Conflict (C3), occurs when a vehicle from a driveway that turned to the right changes from one lane to another (weaving) until it reaches the U-turn bay. This maneuver may place through-traffic vehicles with increased potential of rear-end and sideswipe collisions.

4) U-turn Conflict (C4), occurs when a vehicle is making a u-turn at a signalized intersection, the vehicle behind the u-turn vehicle begins to accelerate while the U-turn vehicle is trying to make a U-turn. The vehicle behind the u-turn vehicle encounters potential of a rear end collision

5) U-turn and right turn across the street (C5), occurs when a vehicle is making a u turn at a signalized intersection, while another vehicle from the cross the street is making a right turn into same direction with a increased potential of sideswipe or angle collision.

6) Left-Turn Out of Driveway: Conflict From Right (C6), occurs when a vehicle on the driveway turns to the left and places a major-road vehicle with the right-of-way with increased potential of sideswipe and right-angle collision,

7) Direct-Left Turn and Left-Turn in From-Right Conflict (C7), occurs when a left turning vehicle from the driveway places a vehicle turning into the same driveway with increased potential of sideswipe or angle collision,

8) Direct-Left-Turn and Left-Turn in From-Left Conflict (C8), occurs when a left turning vehicle from the driveway places a vehicle turning into the opposite driveway with increased potential of sideswipe or angle collisions.

9) Left-Turn Out of Driveway: Conflict From Left (C9), occurs when a left turning vehicle located on the median storage area places an oncoming major-road vehicle with increased potential of a rear-end or sideswipe collision.

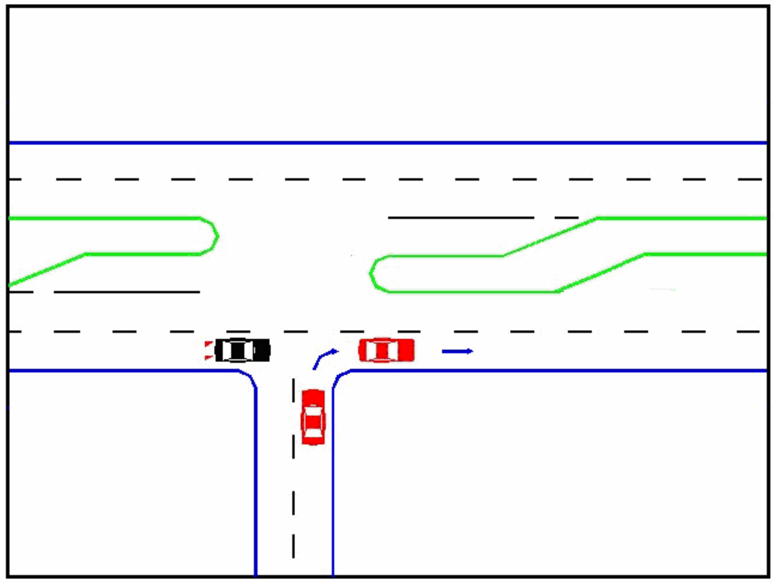


Figure 3.3 Right-Turn Out of the Driveway (C1)

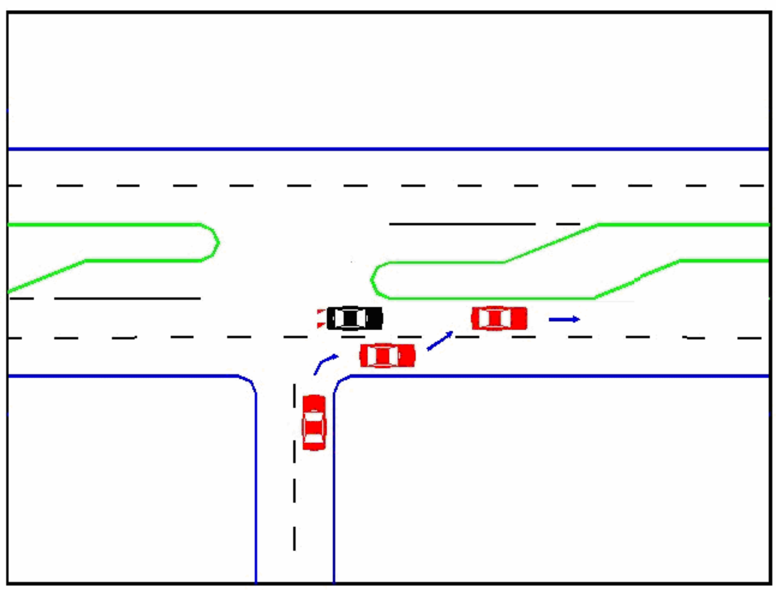


Figure 3.4 Slow-Vehicle, Same-Direction Conflict (C2)

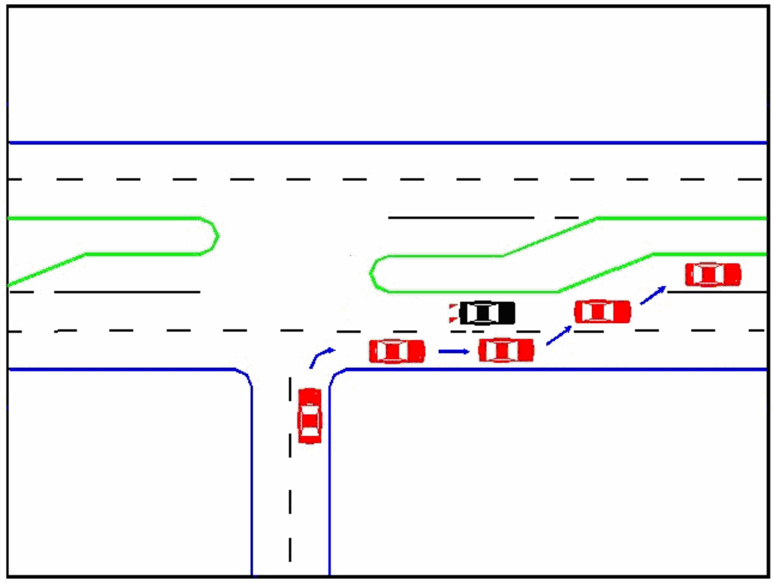


Figure 3.5 Lane Change Conflict (C3)

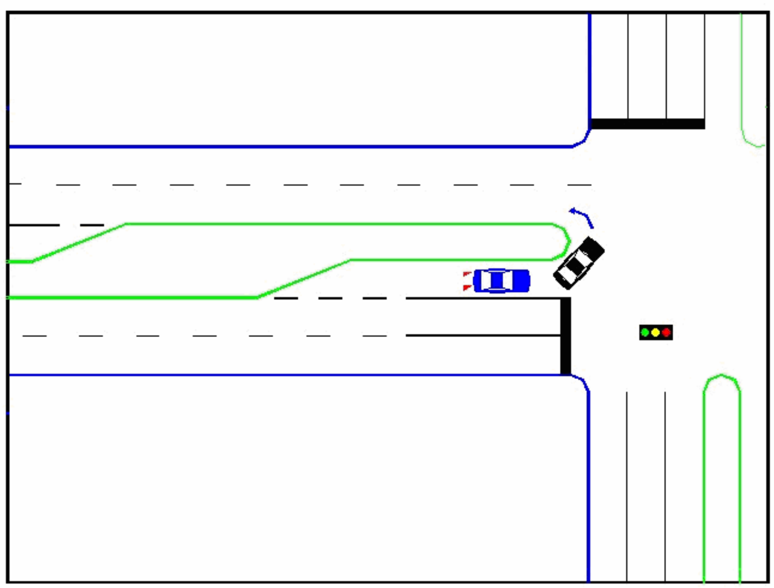


Figure 3.6 U-turn Conflict (C4), Signalized Intersection

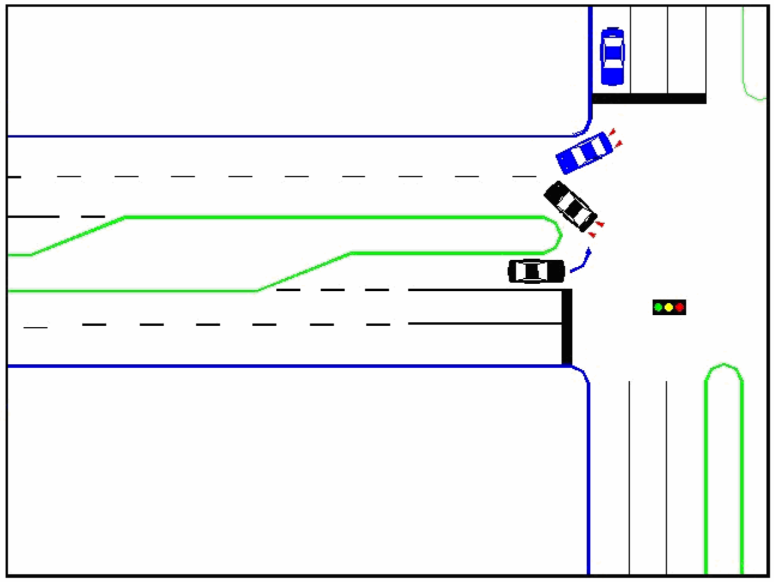


Figure 3.7 U-turn and right turn across the street (C5), Signalized intersection

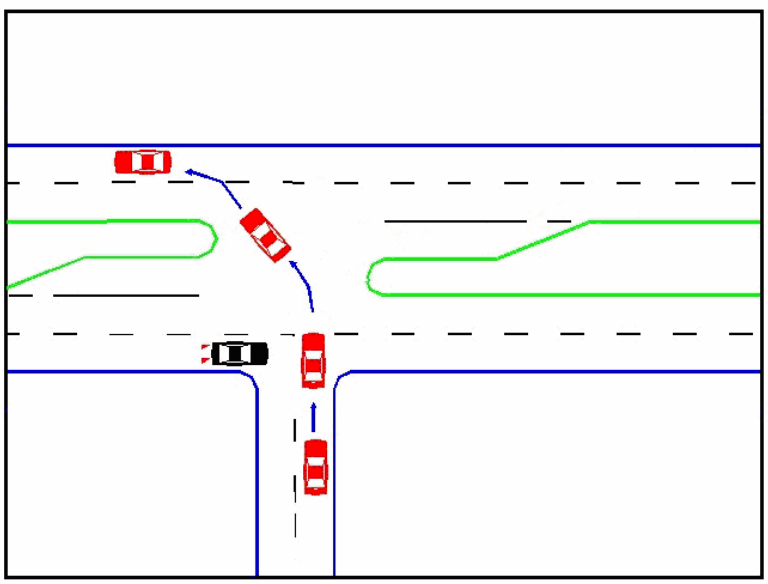


Figure 3.8 Left-Turn Out of Driveway: Conflict From Right (C6)

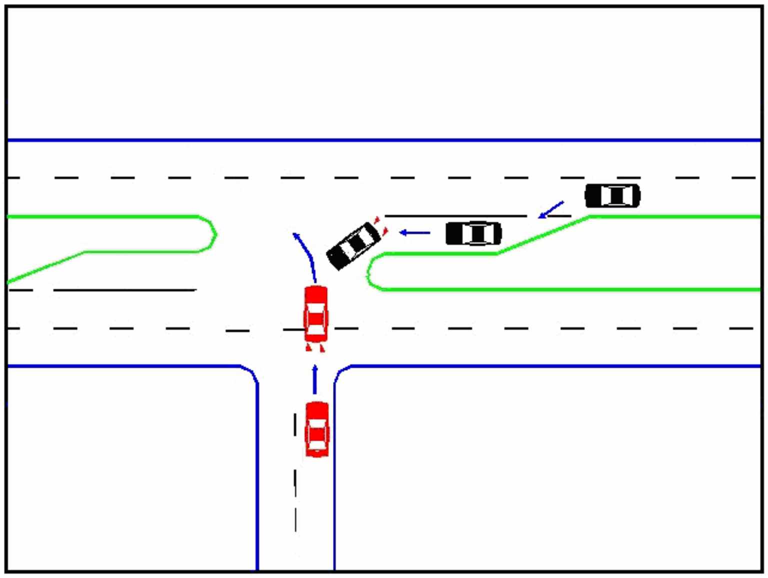


Figure 3.9 Direct-Left Turn and Left-Turn in From-Right Conflict (C7)

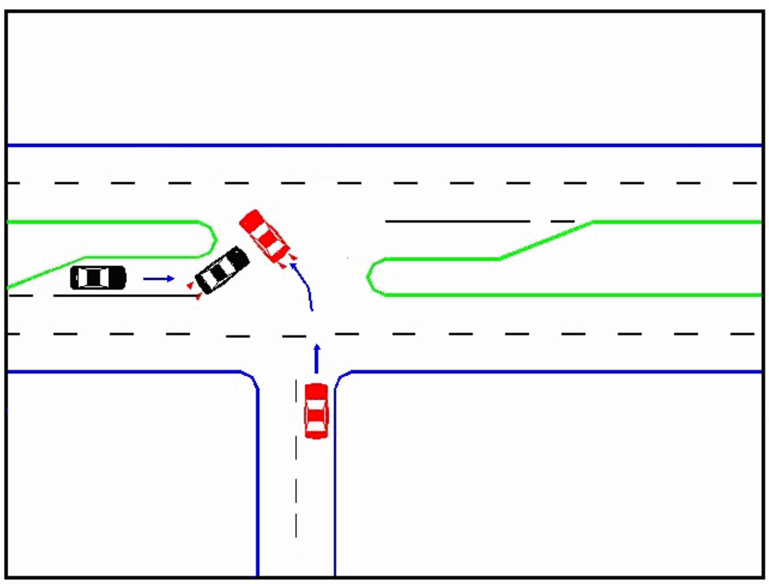


Figure 3.10 Direct-Left-Turn and Left-Turn in From-Left Conflict (C8)

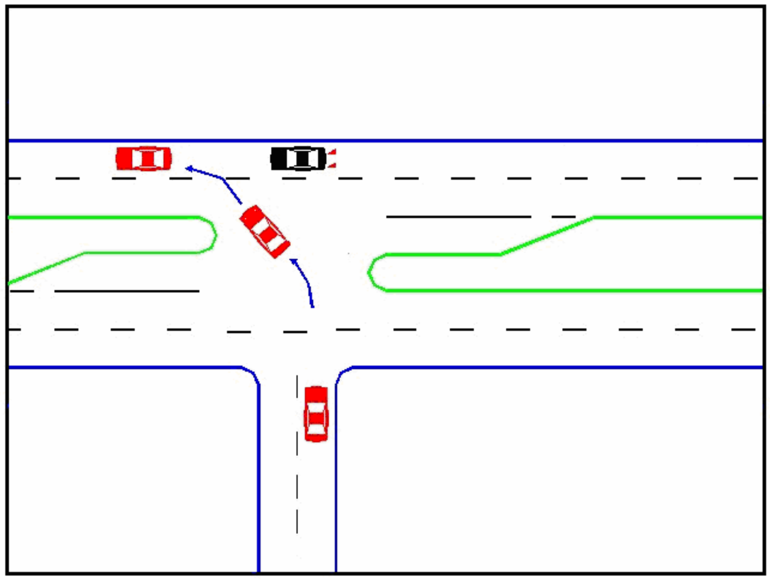


Figure 3.11 Left-Turn Out of Driveway: Conflict From Left (C9)

3.3.2 Conflicts of Median Opening Sites

Nine types of conflicts were studied for median opening sites. Conflicts types C6, C7, C8, and C9, which were related to direct left turn movements, were the same with signalized intersection sites conflicts. Also, conflict types C1, C2 and C3, which were related to right turn followed by U-turn movements, were the same with signalized intersection sites. These conflicts were explained in the previous section. Two different conflicts related U-turn maneuvers at median openings are explained as follows:

1) U-turn Conflict (C4), occurs when a vehicle making a U-turn places vehicles coming from the opposite direction with increased potential of a sideswipe or angle accident. This type of conflict is illustrated in Figure 3.12.

2) Slow U-Turn Vehicle, Same-Direction Conflict (C5), occurs when a vehicle that completed the U-turn maneuver and accelerates: placing an oncoming major-road vehicle with increased potential of a rear-end collision. This type of conflict is similar to conflict type C2, but it was exclusively designated for vehicles making U-turn. In this type of conflict the speed differential involved could be even more dangerous than that of conflict type C2 because U-turn maneuvers are usually made at a very low speed making the stop distance greater. This type of conflict is graphically illustrated in Figure 3.13.

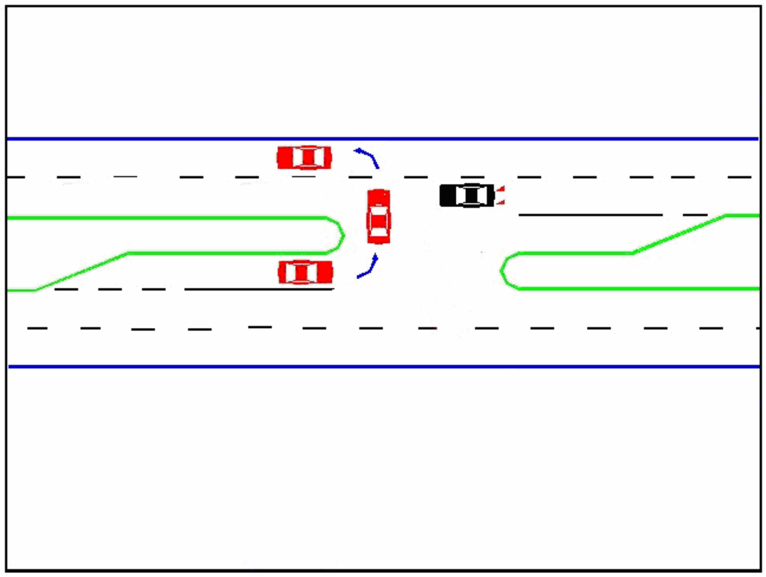


Figure 3.12 U-turn Conflict (C4), Median Opening

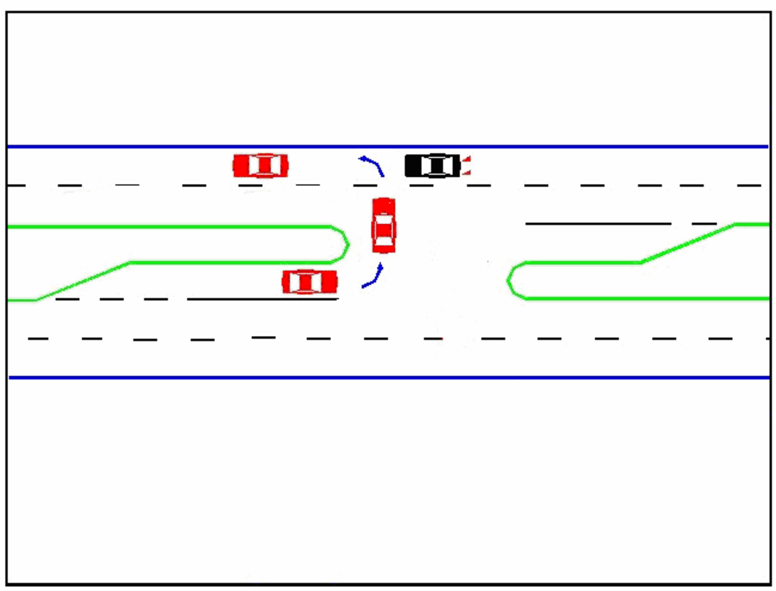


Figure 3.13 Slow U-Turn Vehicle, Same-Direction Conflict (C5), Median Opening

3.4 Identification of Conflicts

Conflicts, unlike accidents, do not have consequences after they occur. The observer has to identify the conflict during the indication of the conflict being observed. The traffic does not stop and the vehicles continue to flow after the conflict. Conflicts are defined as evasive maneuvers to avoid collision. Indicators of conflicts are applying brakes, swerving and noticeable deceleration of vehicles.

Brake applications are frequently used to identify conflicts. Observers should not only be aware of vehicles’ brake lights, but also the speed of the vehicles and conditions to identify a conflict. Hence, there are some situations where drivers may apply brakes for several different reasons other than a conflict situation. Especially, at signalized intersection sites of this study, following the downstream of driveways, signalized traffic intersections are present. The vehicles, which travel on major roadways, apply brakes to slow down as they approach to the signalized intersection. This precautionary brake application may be interpreted as a traffic conflict; although, a conflict did not occur between the vehicles. Another condition is that drivers may apply brakes cautiously even when a conflict is not present in a situation (40).

Swerving is another indicator of a traffic conflict. Drivers may change the direction of the vehicle or the lane they traveled instead of applying brakes to avoid collision. Swerving does not occur as frequent as brake applications because the drivers might put their selves into another conflict situation by swerving. The driver has to decide an evasive maneuver in an instant of time. Brake application is usually safer than swerving because of the fact that the driver does not have the time to check the side lanes to change the lane in case of a conflict. The observer, in identifying a conflict by swerving, has to be careful not only to check if the vehicle swerves but also if the driver avoids collision by swerving (20).

Noticeable deceleration is more of a subjective indicator and it is rarely used in the cases of a vehicle’s brake lights having a mechanical failure, when the brake lights are obstructed or not able to be seen from the angle of a video camera. Both swerving and noticeable deceleration is more subjective and harder to identify compared to applying brakes (19,20).

Traditionally, conflict studies were conducted at the field. Trained observers were required to conduct the studies. Conflicts had to be identified and recorded in very short periods of time. In this study, by recording the data to the video tapes, the time pressure was reduced for the observers, therefore a conflict could be watched more than once and the problems mentioned above about the indicators of conflicts can be reduced in exchange of the time spent on data reduction.

Identifying the conflicts is a time consuming process. A systematic and efficient procedure was developed in previous studies (4,5). For this procedure an algorithm shown in Figure 3.14 is used to identify the conflicts. Once the conflict was identified it had to be recorded, Traffic Conflict Technique: Observer’s Guide included a standard form for conflict studies but the conflicts in this study were slightly different from the conflicts explained in that guide (17). Some modifications were made to the conflict forms so that they could be used in this study. The conflict forms which were used for signalized intersections sites and median opening sites are illustrated in Figures 3.15 and 3.16.

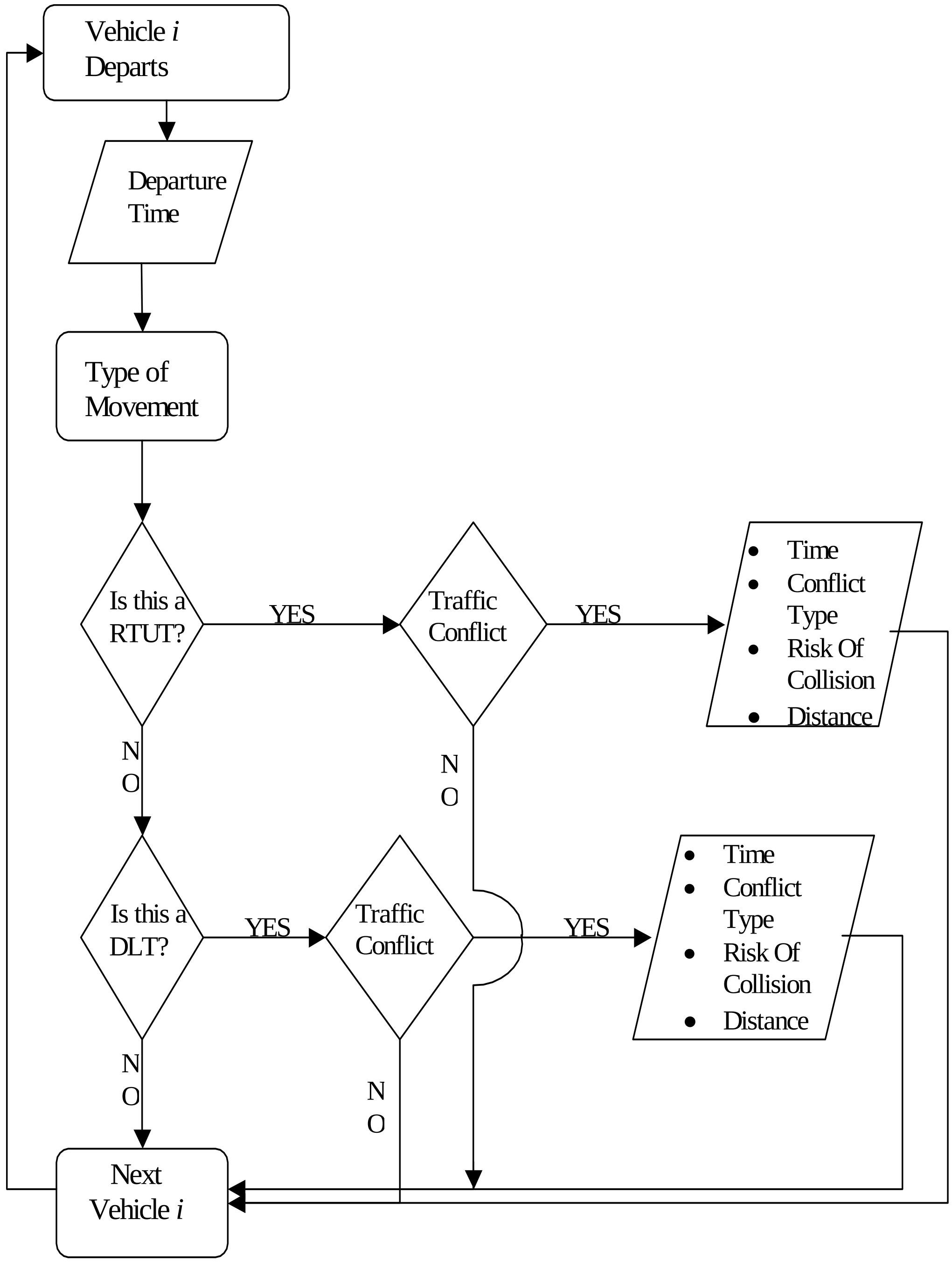


Figure 3.14 Flow Chart Describing Conflict Identification and Data Required by Observers.

Data Collection Date : ______________________
Date of Data Analysis : ______________________
Observer : ______________________

WB	☐
NB	☐
SB	☐

	Time Lecture			RTUT										DLT								Roc Score
				1		2		3		4		5		6		7		8		9		
	Hour	Minute	Second	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	
1																						
2																						
3																						
4																						
5																						
6																						
7																						
8																						
9																						
10																						
11																						
12																						
13																						
14																						
15																						
16																						
17																						
18																						
19																						
20																						
21																						
22																						
23																						
24																						
25																						

C : Conflict
SC : Secondary Conflict

Figure 3.15 The Form Used for Recording Traffic Conflicts at Signalized Intersection Sites

Data Collection Date : ______________________
Date of Data Analysis : ______________________
Observer : ______________________

WB ☐
NB ☐
SB ☐

	Time Lecture			RTUT										DLT								Roc Score
				1		2		3		4		5		6		7		8		9		
	Hour	Minute	Second	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	
1																						
2																						
3																						
4																						
5																						
6																						
7																						
8																						
9																						
10																						
11																						
12																						
13																						
14																						
15																						
16																						
17																						
18																						
19																						
20																						
21																						
22																						
23																						
24																						
25																						

C : Conflict
SC : Secondary Conflict

Figure 3.16 The Form Used for Recording Traffic Conflicts at Median Opening Sites

3.5 Data Reduction Procedure

Data reduction was a long process, so it had to be done in a systematic way to increase the time efficiency. The data collected for safety analysis were initially checked for accuracy and quality purposes at the end of every data collection day. Data reduction process started with identifying the vehicles, which were making RTUT and DLT movements. The tapes that covered the entire study locations were watched and all the vehicles egress of the driveways were observed. If a vehicle made a DLT, the times for the specific vehicle were recorded. The same procedure was applied to RTUT making vehicles as well. Those times for DLT and RTUT vehicles are shown in Table 3.1 and 3.2. All of the times are required to be in second's accuracy for the reason that those times were used for different purposes with different tapes. By identifying RTUT and DLT vehicles, the traffic volumes of these movements were obtained at the same time without extra work.

Table 3.1 Data Reduction Recording Times for Signalized Intersection Sites

	DLT	RTUT
Time 1	Vehicle leaves the driveway	Vehicle leaves the driveway
Time 2	Vehicle enters the median opening	Vehicle enters the queue at the signalized intersection
Time 3	Vehicle leaves the median opening	Vehicle makes the U-turn

Table 3.2 Data Reduction Recording Times for Median Opening Sites

	DLT	RTUT
Time 1	Vehicle leaves the driveway	Vehicle leaves the driveway
Time 2	Vehicle enters the median opening	Vehicle enters the queue at U-turn bay
Time 3	Vehicle leaves the median opening	Vehicle makes the U-turn

After the initial reduction of data, these movements were carefully observed for indicators of conflicts. In case a conflict related to the studied movements was observed, its time of the occurrence, type and severity were recorded. This procedure was conducted until all the DLT and RTUT movements were observed for safety analysis. When all of the vehicles were studied for conflicts and recorded, conflict data was checked for accuracy and errors. A conflict can be recorded more than once because two different cameras especially for the DLT movement's median conflicts can cover the same conflicts.

Usually, conflict studies are considered eleven hours in one day, starting at 7:00 AM and ending at 6:00 PM (17). Traffic Conflict Technique for safety and Operation's - Engineer's Guide recommends adjusting the data for the periods which data were not collected. Equation 3.3 is used to calculate the number of conflicts for the non-observed periods.

$$ANOC = \frac{C_1 + C_2}{2} \times \frac{(TTNOP)}{RP} \qquad 3.3$$

where,

ANOC = adjusted non-observed period conflicts,

C1 = number of conflicts occurred before the non-observed period,

C2 = number of conflicts occurred after the non-observed period,

TTNOP = total time of non-observed period,

RP = duration of recording period

After calculating adjusted non-observed period conflicts, the daily numbers of conflicts were obtained by adding all observed and non-observed conflicts. Application of this procedure made the data needed ready for calculation of several types of conflicts rates. Two types of conflict rates used in this study are illustrated in Table 3.3.

Table 3.3 Definition of Different Conflict Rate

Rate	Definition
Conflicts per Hour	$CR_1 = \frac{\text{Number of conflicts}}{\text{Number of hours}}$
Conflicts per Thousand Involved Vehicles	$CR_2 = \frac{\text{Number of conflicts}}{\sqrt{(V_1)\times(V_2)}} \times 1000$

where,

CR_1 = conflict rate 1.

CR_2 = conflict rate 2.

V_1 = traffic volume on arterial, according to conflict type.

V_2 = volume of RTUT/DLT maneuver, according to conflict type

4. Data Collection

4.1 Description of Study Locations

Data were collected at sixteen sites for two geometric criteria. Eight signalized intersection sites were selected in Tampa Bay Area and Plant City. These sites were numbered from one to eight. Three of the signalized intersection sites had directional median openings opposite the driveways that restrict direct left turns from the driveways. Five of the signalized intersection sites had full median openings opposite the driveways. Also, eight median opening sites were selected in Tampa Bay Area and Plant City. These sites were numbered from nine to sixteen. Four of the median opening sites had a directional median opening opposite the drives and the other four sites had full median openings opposite the driveways. Figure 4.1 and 4.2 show the locations of all sites in Tampa Bay Area and Plant City Maps. Table 4.1 presents geometric characteristic of all sites and Table 4.2 presents geometric characteristics of U-turn locations at all sites.

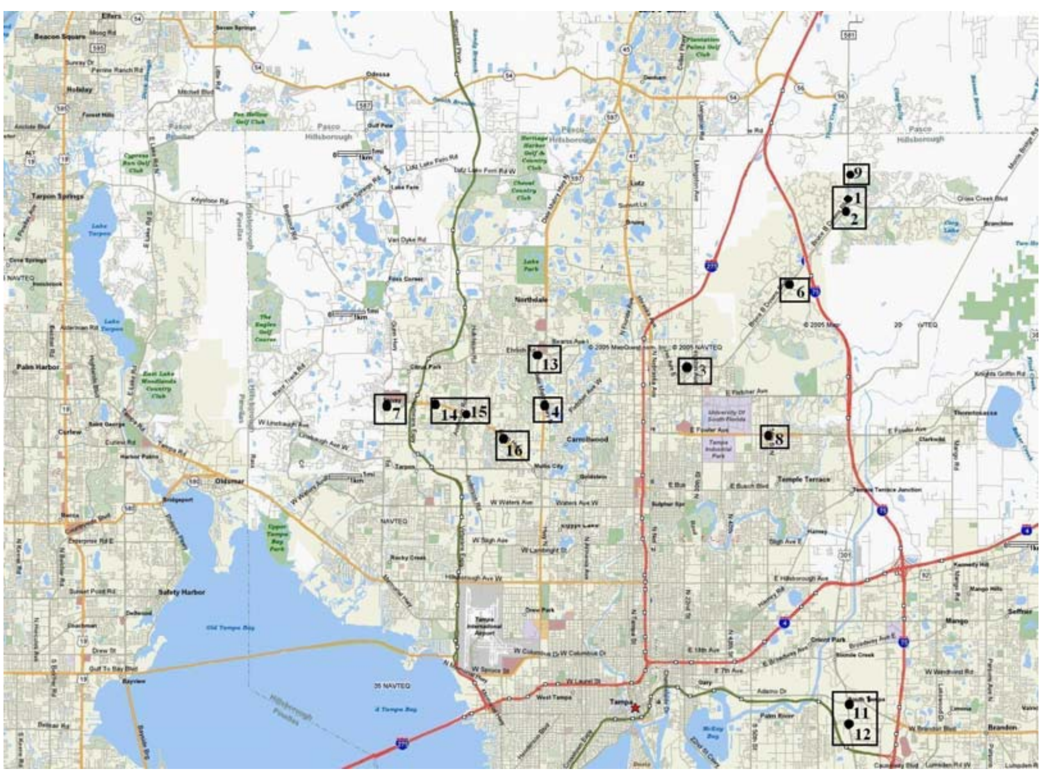


Figure 4.1 Tampa Bay Area Sites Map

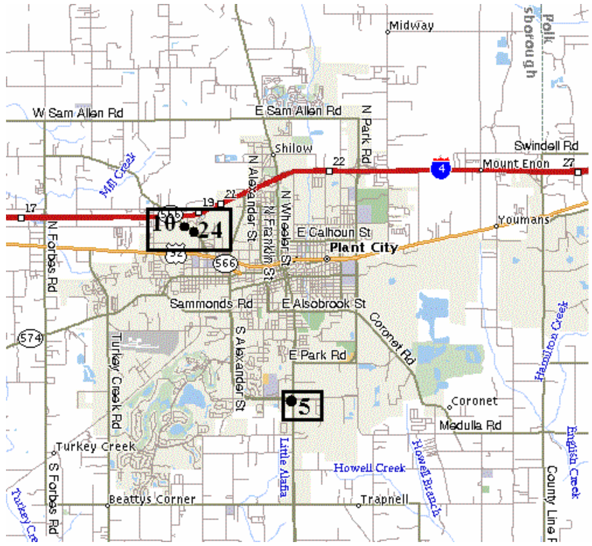


Figure 4.2 Plant City Sites Map

Table 4.1 Signalized Intersection and Median Opening Site Geometric Characteristics

Signalized Intersection Sites							
Site			N_1	N_2	Sp	Median Type	l(ft)
Arterial		Location					
1	Bruce B. Downs Blvd.	New Tampa Blvd.	4	Single	45	D	930
2	Bruce B. Downs Blvd.	Cross Creek	4	Single	45	F	885
3	Bearss Ave.	22^{nd} st.	4	Single	45	F	510
4	Fletcher Ave.	Dale Mabry Hwy.	4	Dual	45	F	570
5	Alexander	Redman	4	Single	40	F	285
6	Bruce B. Downs Blvd.	Tampa Palms	4	Dual	45	D	655
7	Gunn Hwy.	Sheldon	4	Single	45	F	785
8	56^{th} St.	Fowler Ave.	4	Dual	50	D	290
Median Opening Sites							
Site			N_1	N_2	Sp	Median Type	l(ft)
Arterial		Location					
9	Bruce B. Downs Blvd.	Pepple Creek.	4	N/A	45	D	800
10	Thonotosassa Rd.	Goldfinch Dr.	4	N/A	45	D	665
11	US 301	SR 60	4	N/A	45	D	695
12	US 301	Brittany	4	N/A	45	F	575
13	Bearss Ave	Dale Mabry Hwy	4	N/A	45	F	1150
14	Gunn Hwy.	Normandie	4	N/A	45	F	540
15	Gunn Hwy.	Anderson	4	N/A	45	F	850
16	Thonotosassa Rd.		4	N/A	45	FD	590

N1: # of through lanes; N2: # of exclusive left turn lanes at signalized intersection (single or dual) Sp: the speed limit of the selected arterial; D: directional median opening; F: Full median opening; l: the offset distance from subject driveway to downstream signal.

Table 4.2 Signalized Intersection and Median Opening Site U-turn Location Geometric Characteristics

Signalized Intersection Sites					
Site			N	R (ft)	
Arterial		Location		R_1	R_2
1	Bruce B. Downs Blvd.	New Tampa Blvd.	4	23	60
2	Bruce B. Downs Blvd.	Cross Creek	4	19	58
3	Bearss Ave.	22nd st.	4	5	29
4	Fletcher Ave.	Dale Mabry Hwy.	4	3	33
5	Alexander	Redman	4	16	24
6	Bruce B. Downs Blvd.	Tampa Palms	4	19	35
7	Gunn Hwy.	Sheldon	4	8	40
8	56th St.	Fowler Ave.	4	15	60
Median Opening Sites					
Site			R (ft)		
Arterial		Location	R_1	R_2	R_3
9	Bruce B. Downs Blvd.	Pepple Creek.	47	24	N/A
10	Thonotosassa Rd.	Goldfinch Dr.	3	24	8
11	US 301	SR 60	25	24	12
12	US 301	Brittany	8	24	21
13	Bearss Ave	Dale Mabry Hwy	18	24	0
14	Gunn Hwy.	Normandie	45	25	N/A
15	Gunn Hwy.	Anderson	21	25	N/A
16	Thonotosassa Rd.				
N: # of through lanes; R_1:Median width; R_2: Main road width					

4.1.1 Signalized Intersection Site Descriptions

Site 1 is located in the city of Tampa, on Bruce B. Downs Boulevard and New Tampa Boulevard. Bruce B. Downs connects the University of South Florida area to the New Tampa area and it is a major arterial with two lanes southbound and northbound. The studied driveways are Bruce B. Downs Boulevard, which serves a shopping plaza with a Circuit City electronics store, a gas station, restaurants and some small businesses. The median opening opposite the driveway is a directional median opening, which restricts direct left turn movements. From the driveway to join northbound traffic of Bruce B.

Downs Boulevard, drivers had to make a right turn at the driveway followed by a U-turn at the signalized intersection of Bruce B. Downs Boulevard and New Tampa Boulevard. Posted speed is 45 mph on Bruce B. Downs Boulevard.

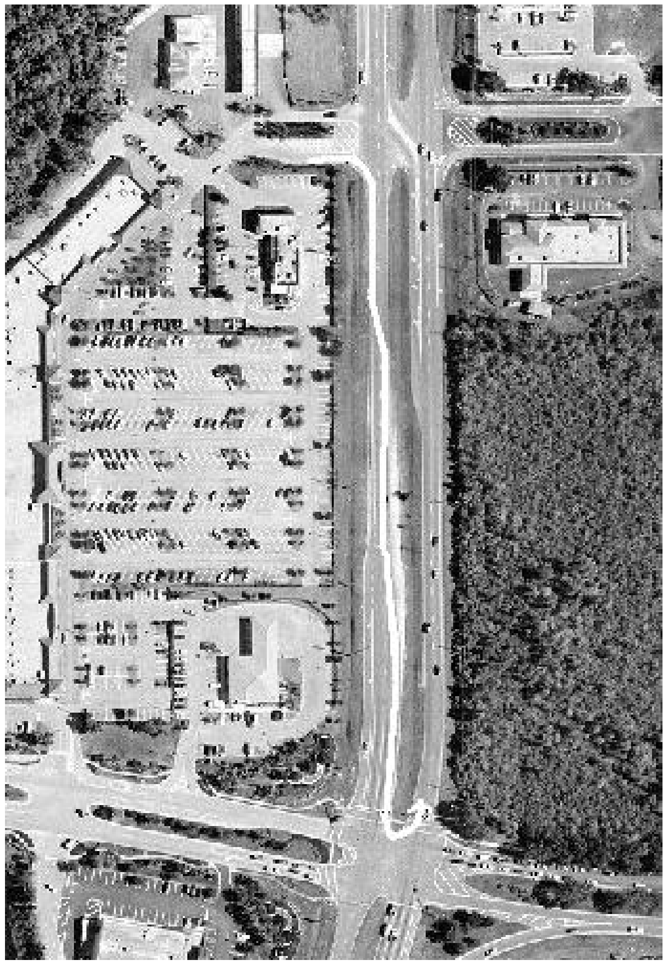


Figure 4.3 Aerial Photograph of Site 1

Site 2 is located in the city of Tampa, on Bruce B. Downs Boulevard and Cross Creek Boulevard. The driveway is located on Bruce B. Downs Boulevard and it is a side street that connects Bruce B. Downs Boulevard to residential areas and a Winn Dixie Supermarket parking lot. A full median opening is located opposite the driveway. Drivers can either make a direct left turn from the driveway or make a right turn followed by a U-turn at Bruce B. Downs Boulevard and Cross Creek Boulevard signalized intersection. Posted speed at this segment of Bruce B. Downs Boulevard is 45 mph.

Figure 4.4 Aerial Photograph of Site 2

Site 3 is located in the city of Tampa, on Bears Avenue and 22nd Street. Bears Avenue is a major connector road between Bruce B. Downs Boulevard and I-275 freeway with two lanes eastbound and westbound. The driveway is located on Bears Avenue and it serves a shopping plaza with a Winn Dixie Supermarket and many small businesses. A full median opening is located opposite of the driveway. Drivers can either make a direct left turn from the driveway or make a right turn followed by a U-turn at Bears Avenue and 22nd Street signalized intersection.

Site 4 is located in the city of Tampa, on Fletcher Avenue and Dale Mabry Highway. Fletcher Avenue is a major arterial with two lanes eastbound and westbound. The driveway is located on Fletcher Avenue and serves a shopping plaza with restaurants and many small businesses. A full median opening is located opposite the driveway. The drivers egressing the driveway to join eastbound Fletcher Avenue can either make a direct left turn or make a right turn to westbound Fletcher Avenue followed by U-turn at

Fletcher Avenue and Dale Mabry Highway signalized intersection. The posted speed limit on Fletcher Avenue is 45 mph.

Figure 4.5 Aerial Photograph of Site 3

Figure 4.6 Aerial Photograph of Site 4

Site 5 is located in the city of Plant City, on West Alexander Street and JI Redman Parkway. Alexander Street is a major arterial with two lanes eastbound and westbound. The driveway is located on West Alexander Street and it serves a shopping plaza with a Publix supermarket, fast food restaurants, and many small businesses. A full median opening is located opposite the driveway. The drivers egressing the driveway to join westbound West Alexander Street can either make a direct left turn or make a right turn to eastbound West Alexander Street followed by U-turn at West Alexander Street and JI Redman Parkway signalized intersection. The posted speed limit on West Alexander Street is 40 mph.

Figure 4.7 Aerial Photograph of Site 5

Site 6 is located in the city of Tampa, on Bruce B. Downs Boulevard and Tampa Palms Boulevard. This segment of Bruce B. Downs Boulevard had two lanes northbound and southbound. The driveway is located on Bruce B. Downs Boulevard and serves a shopping plaza with Olive Garden and Red Lobster restaurants, fast food restaurants and some other small businesses. A directional median opening is located opposite the driveway. Drivers who want to join northbound Bruce B. Downs Boulevard can only make a right turn to southbound followed by a U-turn at Bruce B. Downs and Tampa Palms Boulevard signalized intersection. Posted speed at this segment of Bruce B. Downs Boulevard is 45 mph.

Figure 4.8 Aerial Photograph of Site 6

Site 7 is located in the city of Citrus Park, on Gunn Highway and Sheldon Road. Gunn Highway is an arterial with two lanes eastbound and westbound. The driveway is located on Gunn Highway and it serves a shopping plaza with a Target Supermarket and many small businesses. A full median opening is located opposite the driveway. Drivers who want to join eastbound Gunn Highway can either make direct left turn or make a right turn to westbound Gunn Highway followed by a U-turn at Gunn Highway and Sheldon Road three-leg signalized intersection. The posted speed limit on Gunn Highway is 45 mph.

Site 8 is located in the city of Tampa, on 56th Street and Fowler Avenue. 56th Street is a major connector road between Fletcher Avenue and Fowler Avenue at this segment with two lanes southbound and northbound. The driveway is located on 56th Street and it serves an Eckerd Pharmacy and a Taco Bell fast food restaurant. There is no median opening located opposite the driveway. Drivers only have the choice of a right turn to southbound 56th Street followed by a U-turn at 56th Street and Fowler Avenue signalized intersection to join northbound 56th Street. The posted speed on this segment of 56th Street is 50mph.

Figure 4.9 Aerial Photograph of Site 7

Figure 4.10 Aerial Photograph of Site 8

4.1.2 Median Opening Site Descriptions

Site 9 is located in the city of Tampa, on Bruce B. Downs Boulevard and Pebble Creek. Bruce B. Downs Boulevard has two lanes southbound and northbound at this segment. The driveway, Pebble Creek Boulevard connects big residential areas and some small businesses' parking lots to Bruce B. Downs Boulevard. The driveway has one lane for the egress of vehicles and the median restricts DLT movements. One important geometric condition of the site is that an exclusive left turn lane was not present at the U-turn bay. The drivers had to slow down to turn to the U-turn bay from the major road. All other sites of this study included exclusive left turn lanes at U-turn bays. The conflicts with the slow vehicles turning to the U-turn bay and the major road vehicles are not considered as a RTUT conflict. The posted speed limit at this segment of Bruce B. Downs Boulevards is 45 mph.

Figure 4.11 Aerial Photograph of Site 9

Site 10 is located in the city of Plant City, on Thonotosassa Road and Goldfinch Drive. Thonotosassa Road is one of the major connectors between I-4 freeway and Plant City and has two lanes in each direction. Driveway is located on Thonotosassa Road and it serves a shopping plaza with a Publix supermarket and many small businesses. A directional median opening is located opposite the driveway. Right turn followed by a U-turn is the only choice for the drivers who want to join northbound traffic of Thonotosassa Road. The posted speed limit is 50 mph.

Site 11 is located in the city of Brandon, on US 301 Highway and State Road 60. US 301 Highway had two lanes southbound and northbound. The driveway is located on US 301 Highway and it serves a plaza and a major parking lot. A directional median opening is located opposite of the driveway. The posted speed limit on this segment of the US 301 highway is 50 mph.

Figure 4.12 Aerial Photograph of Site 10

Figure 4.13 Aerial Photograph of Site 11

Site 12 is located in the city of Brandon, on US 301 Highway and Brittany Road. US 301 Highway, at this segment, still had two lanes going each direction. The driveway is a connector street between US 301 Highway and a major business area. A full median opening located opposite the driveway allows drivers to make both direct left turn and right turn followed by a U-turn. The posted speed limit is 50 mph.

Site 13 is located in the city of Tampa, on Ehrlich Road and Dale Mabry Highway. Ehrlich is a major divided arterial oriented in the east-west direction with two lanes in each direction. The driveway is located on Ehrlich Road and it serves a shopping plaza with many restaurants, chain stores and small businesses. A full median is located opposite the driveway. The posted speed limit on Ehrlich Road is 45 mph.

Site 14 is located in the city of Tampa, on Gunn Highway and Henderson Road. Gunn Highway is a major divided arterial with two lanes eastbound and westbound. The driveway is located on Gunn Highway and it serves a shopping plaza with a Wal-Mart Supermarket, fast food restaurants, and some small businesses. A full median opening is located of opposite the driveway. The posted speed limit is 45 mph.

Figure 4.14 Aerial Photograph of Site 12

Figure 4.15 Aerial Photograph of Site 13

Figure 4.16 Aerial Photograph of Site 14

Site 15 is located in the city of Tampa on Gunn Highway and Anderson Road. At this segment, Gunn Highway still has two lanes at each direction. The driveway is located on Gunn Highway and it serves a shopping plaza with a Winn Dixie Supermarket, Burger King fast food restaurant, and some small businesses. A full median opening is located opposite the driveway. The posted speed limit at this segment of Gunn Highway is 45 mph.

Site 16 is located in the city of Plant City, on Thonotosassa Road and Goldfinch Drive. Thonotosassa Road is one of the major connector roads between I-4 freeway and Plant City and has two lanes in each direction. The driveway is Goldfinch Drive, which is a connector street between Thonotosassa Road and residential areas. A full median opening is located opposite the driveway. In this segment of Thonotosassa Road, the posted speed limit is 45 mph.

Figure 4.17 Aerial Photograph of Site 15

Figure 4.18 Aerial Photograph of Site 16

4.2 Data Collection Equipment

Data is collected by the use of video cameras. In the previous project, the time for transferring the data from 8mm tapes to VHS tapes was a concern. To avoid this time loss and increase the efficiency of the data collection, a system was developed as illustrated in Figure 4.19. In this system, data was recorded to the VHS tapes directly from video cameras. Eight mm tapes could only last two hours and were changed every two hours, which brought the issue of loosing the image, zoom and angle of cameras for needed data. On the other hand, VHS tapes allow six hours of continuous data collection without changing tapes. Also, using this system, the problem of changing the video camera batteries during the time of data collection was eliminated. After the initial setup of the system, responsible staff did not have to bother with the camera anymore for changing the tape or the battery. The power needed for the system was another concern. This issue was solved by using marine batteries and inverters that could last up to twenty hours (2 days of data collection) with a single charge. Those batteries supplied power to the VCRs, TVs and Video cameras. TV's are used to control the collected data simultaneously during the recording to prevent any data loss. Also, staff did not have to climb the scaffoldings, which the video cameras were placed on, to check the image of the video. Scaffoldings were necessary to use for the reason of getting the needed image. If the cameras were not placed at the suitable height from ground level, the movements of vehicles could be covered by the larger vehicles. Another concern was synchronization of the cameras because the vehicles were observed from several cameras at the same time. The video cameras had to have the same time in second's accuracy.

Traffic volumes were also needed for analysis purposes. During the data collection periods, Hi-Star device, an automatic volume and speed recorder, was installed on the pavement to collect the speed and volumes of the vehicles on major roadways. Other minor volume requirements were obtained from videos by manual counts.

Figure 4.19 Data Collection System

4.3 Field Procedure

Data was collected under normal traffic conditions, good weather, daylight and dry pavement. During the time of congested traffic conditions, either data collection was stopped, or the collected data were not used for the analysis. Conflict studies consider a day of data collection, as eleven hours from 7:00 AM to 6:00 PM. Sites studied in this project were the driveways from shopping plazas and activity centers, which had few traffic movements' egress of the driveways during early hours. Traffic volumes from the driveways had reached the desired values around the noon peak hours. Data collection started usually prior to noontime and continued until the end of the data collection day. Another reason to start the data collection at those times is that the set up of the data collection equipment takes two to three hours of time.

A typical data collection day starts with the set up of equipment. At a typical site, two scaffoldings were used. Before setting up any necessary electronic equipment, scaffoldings were assembled and placed at suitable locations. The reason for starting with the scaffoldings is that the procedure requires all the manpower available before assigning any of the staff to any camera locations. After the setup of scaffoldings, all the equipment was set up and made ready for the start of the data collection day. Placement of the video cameras requires experienced personnel because if the data needed were not collected (correct image), it would be a waste of resources and reliability so the data collected would dramatically be reduced. Another issue is synchronization of the video camera times, which is implemented before the placement of the cameras. After synchronization and placement of the video cameras, data collection started with all the cameras at the same time. Assigned staff stayed with the video cameras and all the equipment was to be checked frequently so that recording was continued to avoid any loss of data.

5. Data Analysis

This chapter includes two subchapters. The first subchapter describes the number of conflicts and the conflict rates for DLT and RTUT movements at signalized intersection sites. On the other hand, the second subchapter describes the number of conflicts and the conflict rates for DLT and RTUT movements at median opening sites. Also, conflict severities related to these movements are presented and compared in both subchapters.

5.1 Data Analysis of RTUT vs. DLT at Signalized Intersection Sites

5.1.1 Descriptive Analysis

Prior to data analysis and investigation of data, verification of sample sizes was necessary. In this study, it was not possible to estimate the necessary sample size prior to data collection because there were no past studies that used the same methodology and geometric conditions. As it was mentioned previously in the Chapter 3, verification of sample size can only be performed after data collection and data reduction processes. The sample size calculation process primarily requires the total number of DLT and RTUT movements observed. These numbers are obtained for DLT and RTUT movements for each signalized intersection site. The total number of 2240 DLT movements and 1260 RTUT movements were observed at signalized intersection sites. Another required component for the sample size calculation was the number of conflicts observed for each conflict type at signalized intersection sites. After obtaining all of the required data, the total number of movements was divided by the number of conflicts for each type of conflict to acquire the necessary proportions. These proportions were used in the formula previously explained in the Chapter 3. 95 percent level of confidence and 5 percent permitted level of error were used for sample size estimation. The results for sample size verification of RTUT movements are presented in Table 5.1. The sample size was satisfactory for all types of RTUT related conflicts. In addition, the results for DLT movements are presented in Table 5.2. Also, the sample size was satisfactory for all DLT related conflicts.

Table 5.1 Sample Size Verification for RTUT Movements, Signalized Intersection

Conflict (1)	Average Number of Conflicts (2)	RTUT Vehicles (3)	P_{RTUT} (4)=(2)/(3)	n (5)	Sample Size Satisfied
C1	73	1260	0.06	84	Yes
C2	32	1260	0.03	38	Yes
C3	24	1260	0.02	29	Yes
C4	53	1260	0.04	62	Yes
C5	54	1260	0.04	63	Yes

P_{RTUT} : Percentage of RTUT vehicles involved in a conflict.
n : Number of vehicles estimated for sample size

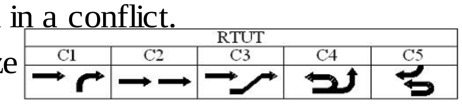
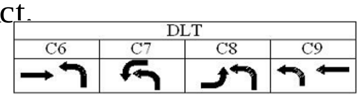


Table 5.2 Sample Size Verification for DLT Movements, Signalized Intersection

Conflict (1)	Average Number of Conflicts (2)	DLT Vehicles (3)	P_{DLT} (4)=(2)/(3)	n (5)	Sample Size Satisfied
C6	171	2240	0.08	108	Yes
C7	50	2240	0.02	34	Yes
C8	13	2240	0.01	9	Yes
C9	101	2240	0.05	66	Yes

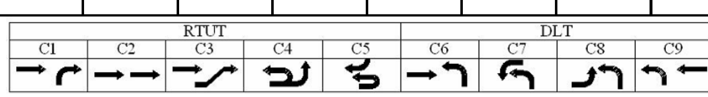
P_{DLT} : Percentage of DLT vehicles involved in a conflict.
n : Number of vehicles estimated for sample size



The errors were checked after the data reduction process. A typical error for this type of field study may be the recording of the same conflict(s) more than once. That type of error can be possible because every camera at the site records each movement at the same time and data reduction was performed by viewing those videos recorded by the cameras more than once. In case of recording a conflict more than once, the videos were reexamined and the errors were corrected. In addition, technical problems, such as broken down equipment during the data collection process, are considered as an error. If technical problems existed during the data collection process, the collected data at the time frame of the technical problem were discarded because all of the conflicts are required to be video taped at the same time. After the initial process of checking errors and data reduction, the total numbers of conflicts observed at each site for each type of conflict were obtained and are presented in Table 5.3.

Table 5.3 Summary of the Total Number of Conflicts Observed, Signalized Intersection

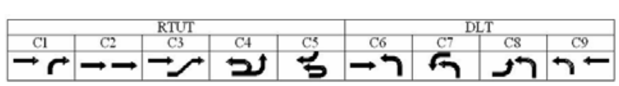
Site	Conflicts	Conflict Type									Total
		C1	C2	C3	C4	C5	C6	C7	C8	C9	
1	No.	22.0	15.0	7.0	25.0	16.0	N/A	N/A	N/A	N/A	85
	(%)	25.9	17.6	8.2	29.4	18.8	-	-	-	-	100
2	No.	3.0	1.0	2.0	1.0	1.0	38.0	14.0	5.0	28.0	93
	(%)	3.2	1.1	2.2	1.1	1.1	40.9	15.1	5.4	30.1	100
3	No.	2.0	1.0	1.0	1.0	1.0	17.0	5.0	1.0	10.0	39
	(%)	5.1	2.6	2.6	2.6	2.6	43.6	12.8	2.6	25.6	100
4	No.	4.0	1.0	1.0	3.0	4.0	44.0	12.0	4.0	25.0	98
	(%)	4.1	1.0	1.0	3.1	4.1	44.9	12.2	4.1	25.5	100
5	No.	1.0	1.0	0.0	0.0	2.0	30.0	11.0	1.0	6.0	52
	(%)	1.9	1.9	0.0	0.0	3.8	57.7	21.2	1.9	11.5	100
6	No.	18.0	10.0	9.0	12.0	13.0	N/A	N/A	N/A	N/A	62
	(%)	29.0	16.1	14.5	19.4	21.0	-	-	-	-	100
7	No.	2.0	1.0	2.0	2.0	2.0	42.0	8.0	2.0	32.0	93
	(%)	2.2	1.1	2.2	2.2	2.2	45.2	8.6	2.2	34.4	100
8	No.	21.0	2.0	2.0	9.0	15.0	N/A	N/A	N/A	N/A	49
	(%)	42.9	4.1	4.1	18.4	30.6	-	-	-	-	100
Total		73.0	32.0	24.0	53.0	54.0	171.0	50.0	13.0	101.0	*571*



During regular data collection day eleven-hour data collection was recommended. (7:00 AM-6:00 PM). However, it was not possible to start data collection as early as it was recommended in the *Traffic Conflict Technique for safety and Operation’s - Engineer’s Guide*. In case of data collection time being shorter than eleven hours, it was recommended that the data should be adjusted as it was explained in Chapter 3. The data were adjusted by using the formula explained in Chapter 3 to be used in data analysis. Table 5.4 presents the summary of the total number of conflicts adjusted for each site for each conflict type.

Table 5.4 Summary of the Total Number of Conflicts Used for Analysis, Signalized Intersection

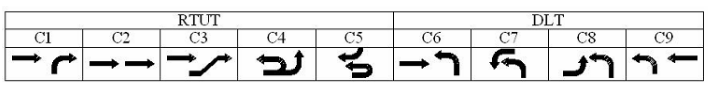
Site	Conflicts	Conflict Type									Total
		C1	C2	C3	C4	C5	C6	C7	C8	C9	
1	No.	33.5	22.7	10.7	38.1	34.3	N/A	N/A	N/A	N/A	139.3
	(%)	24.0	16.3	7.7	27.4	24.6	-	-	-	-	100.0
2	No.	12.8	3.7	9.2	5.5	3.7	74.8	22.4	5.7	50.8	188.6
	(%)	6.8	2.0	4.9	2.9	2.0	39.7	11.9	3.0	26.9	100.0
3	No.	3.7	2.8	3.7	2.8	2.8	34.6	11.6	2.2	21.0	85.2
	(%)	4.3	3.3	4.3	3.3	3.3	40.6	13.6	2.6	24.6	100.0
4	No.	9.9	2.8	2.2	7.7	34.7	109.5	29.5	9.4	62.2	267.9
	(%)	3.7	1.0	0.8	2.9	13.0	40.9	11.0	3.5	23.2	100.0
5	No.	2.8	1.8	0.0	0.0	4.6	94.8	41.7	2.0	23.0	170.7
	(%)	1.6	1.1	0.0	0.0	2.7	55.5	24.4	1.2	13.5	100
6	No.	38.5	22.0	20.2	27.5	27.5	N/A	N/A	N/A	N/A	135.7
	(%)	28.4	16.2	14.9	20.3	20.3	-	-	-	-	100
7	No.	3.7	2.8	7.3	6.4	6.4	115.0	22.0	5.5	88.0	257.1
	(%)	1.4	1.1	2.8	2.5	2.5	44.7	8.6	2.1	34.2	100
8	No.	35.6	3.5	3.5	15.3	25.7	N/A	N/A	N/A	N/A	83.6
	(%)	42.6	4.2	4.2	18.3	30.7	-	-	-	-	100
Total		141	62.1	56.8	103	140	429	127	24.8	245	*1328*



The average number of conflicts that occurred per data collection day were calculated and presented in Table 5.5. Also, the average number of conflicts for each site and each type of conflict are illustrated in Figures 5.1 through 5.8.

Table 5.5 Average Daily Number of Conflicts, Signalized Intersection

Site	Conflict Type									Total
	C1	C2	C3	C4	C5	C6	C7	C8	C9	
1	16.8	11.4	5.4	19.1	12.2	N/A	N/A	N/A	N/A	64.9
2	6.4	1.9	4.6	2.8	1.9	24.9	7.5	1.9	16.9	68.8
3	1.9	1.4	1.9	1.4	1.4	8.7	2.9	0.6	5.3	25.5
4	5.0	1.4	1.1	3.9	5.3	54.8	14.9	4.7	31.1	122.2
5	1.4	0.9	0.0	0.0	2.3	19	8.3	0.4	4.6	36.9
6	19.3	11.0	10.1	13.8	13.8	N/A	N/A	N/A	N/A	68.0
7	1.9	1.4	3.7	3.2	5.1	57.8	11.0	2.8	44.0	130.9
8	17.8	1.8	1.8	7.7	12.9	N/A	N/A	N/A	N/A	42.0



The following paragraphs discuss the conflicts at each site:

Site 1 This site has a directional median opening opposite the driveway, which restricts DLT movements. As a result, no DLT conflict data was available at this site. Conflicts related to weaving maneuvers were 52 percent of all the conflicts where as U-turn related conflicts corresponded to 48 percent. Although weaving related conflicts involved with main road vehicles running at high speed, U-turn related conflicts occurred almost equally to the number of weaving conflicts because of the high left turn and right turn traffic volumes at the signalized intersection of the site. When each conflict type considered, conflict type C4 occurred most often approximately 29 percent. Weaving conflicts C1, C2, and C3 were 26, 18, and 8 percent of RTUT related conflicts, respectively, where U-turn related conflict C5 was 19 percent. The number of daily conflicts for Site 1 is shown in Figure 5.1.

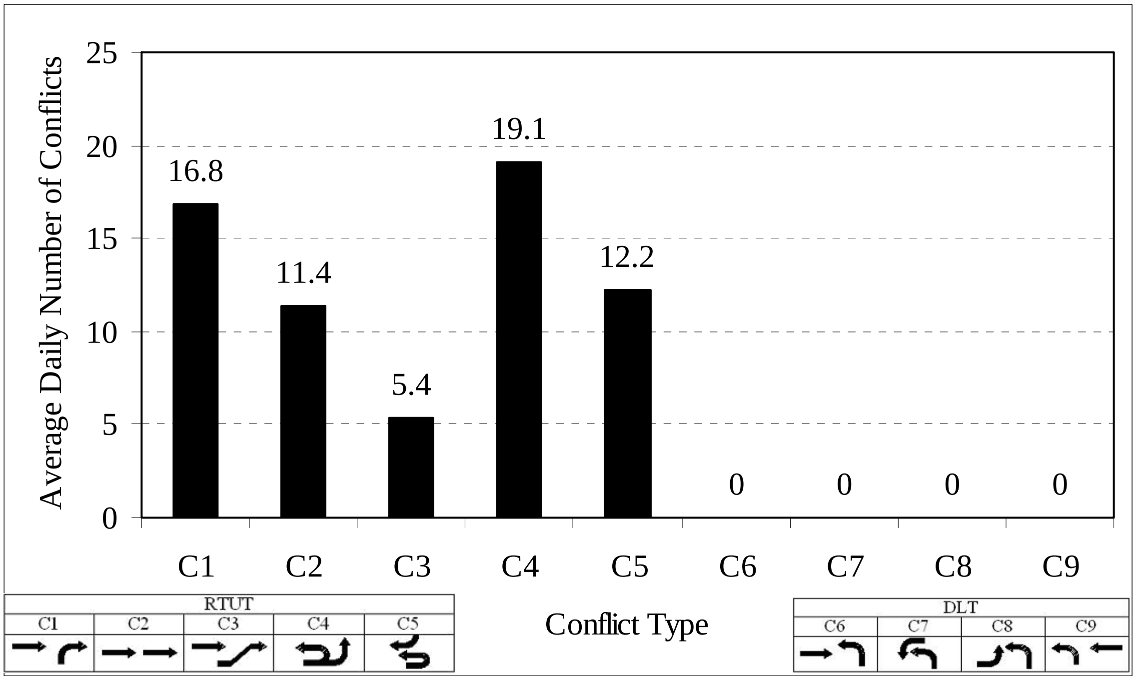


Figure 5.1 Number of Daily Conflicts by Type, Site 1, Signalized Intersection

Site 2 DLT movements generated 74 percent of all conflicts while RTUT related conflicts were 26 percent. Conflicts types C6 and C9, which occurred between DLT vehicles and main road vehicles, were 61 percent of all conflicts. When each conflict type is considered, DLT related conflicts C6, C7, C8 and C9 were 36, 11, 3, and 25 percent of all conflicts, respectively. RTUT related conflicts C1, C2, C3, C4, and C5 were 9,3,7,4, and 3 percent of all conflicts, respectively. The number of daily conflicts for Site 2 is illustrated in Figure 5.2.

Site 3 Similar to Site 2, this site had low volume of RTUT movements that generated only 31 percent of the conflicts that occurred at the site. 69 percent of all conflicts were related to DLT maneuvers. DLT related conflicts C6 and C9 were the majority of all conflicts and were 34 and 21 percent, respectively. The other DLT related conflicts C7 and C8 were 11 and 2 percent, respectively, because of the low speed of vehicles involved in these conflicts. RTUT related conflicts C1, C2, C3, C4 and C5 distributed almost equally numbers of conflicts and were 7, 6, 7, 6, and 6 percent, respectively. Daily conflict distributions for Site 3 are represented in Figure 5.3.

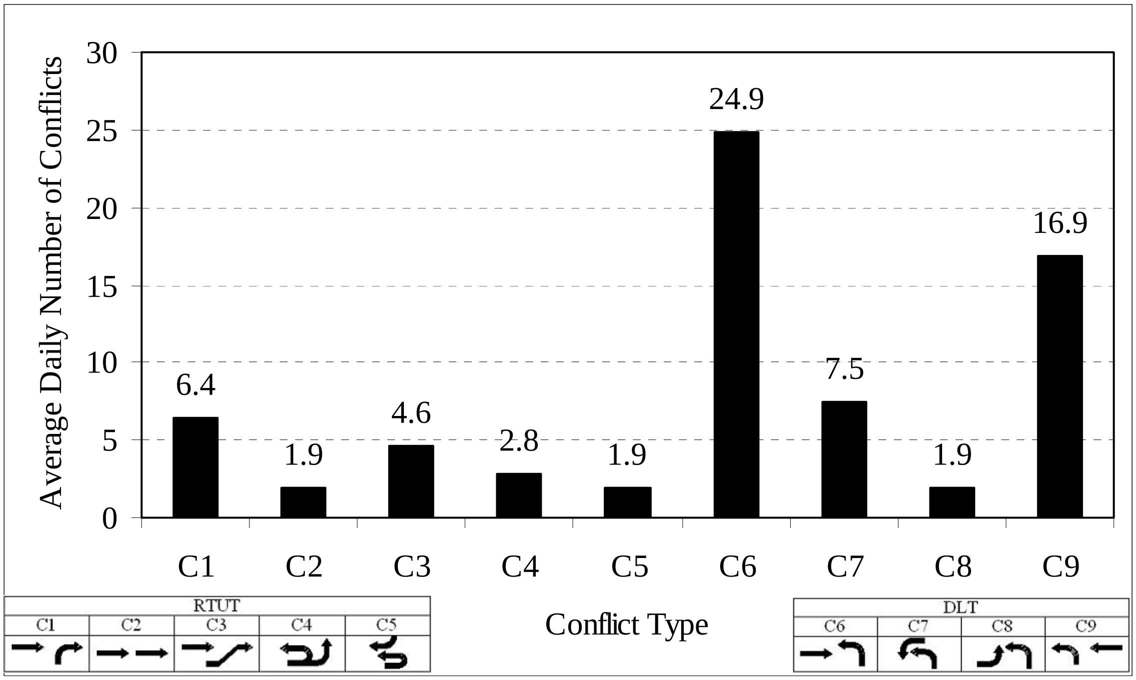


Figure 5.2 Number of Daily Conflicts by Type, Site 2, Signalized Intersection

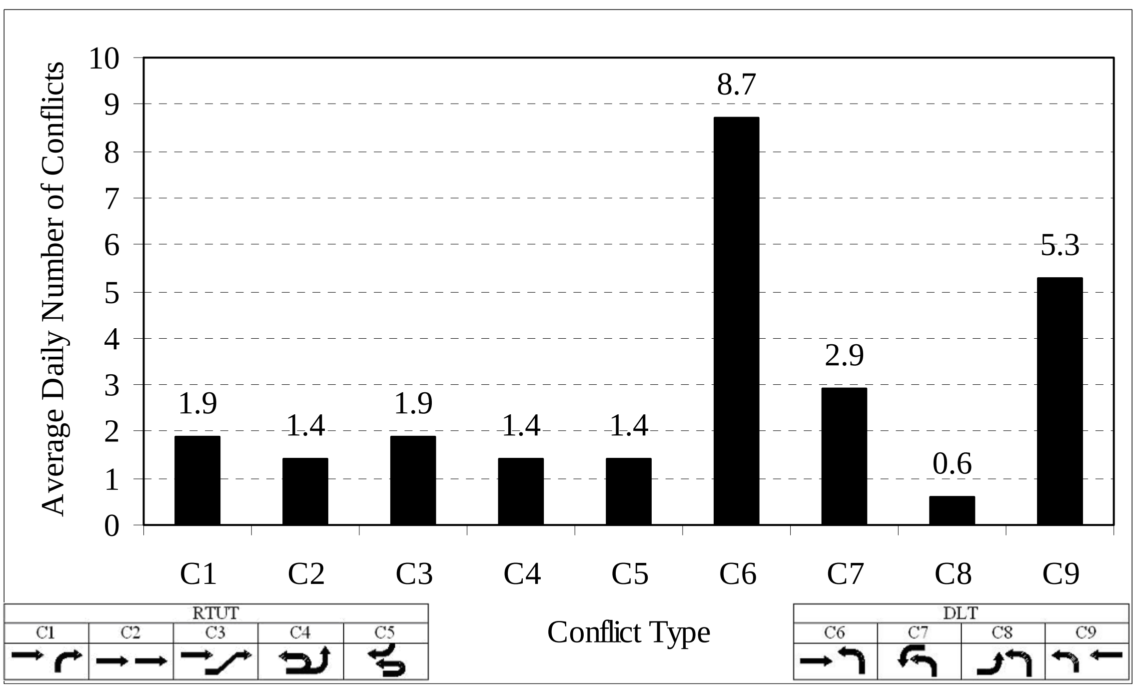


Figure 5.3 Number of Daily Conflicts by Type, Site 3, Signalized Intersection

Site 4 This site had low volume of RTUT movements, which was the main factor for the difference between DLT and RTUT conflicts. At this site, 14 percent of the conflicts were related to RTUT movements while 86 percent of the conflicts were related to DLT movements. As it is expected, DLT related conflicts C6 and C9 were observed most often and were 45 and 26 percent, respectively. The other DLT conflicts C7 and C8 were 12 and 4 percent of all conflicts, respectively. On the other hand, RTUT related conflicts had very low numbers such as C1, C2, C3, C4, and C5 were 4, 1, 1, 3 and 4 percent of all conflicts at this site, respectively. The number of daily conflicts for Site 4 is shown in Figure 5.4.

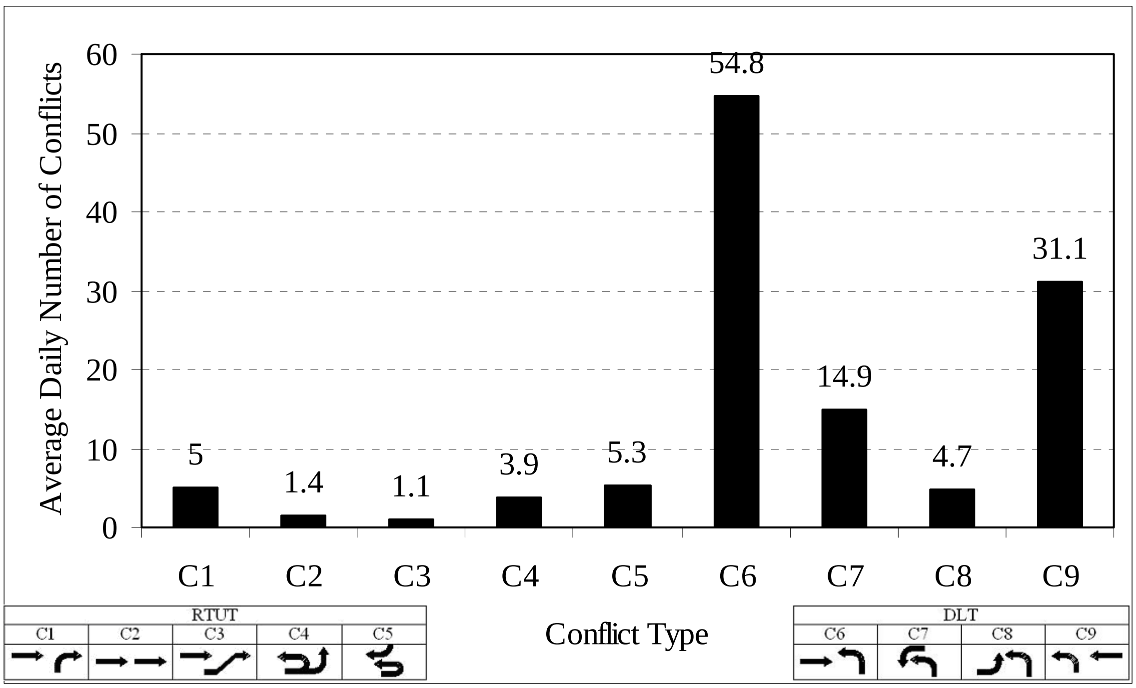


Figure 5.4 Number of Daily Conflicts by Type, Site 4, Signalized Intersection

Site 5 This site is a typical full median opening site. RTUT related conflicts were 13 percent of all conflicts while DLT related conflicts were 87 percent of all conflicts. Especially at this site, the short distances between the driveway, upstream and downstream signals made DLT maneuvers more convenient for the drivers. The DLT conflict C6 was 52 percent of all conflicts at this site. Interestingly, conflict type C7 occurs between two slow vehicles that were 23 percent and was higher than conflict C9 (13%), which is between major road vehicles and DLT vehicles. Another DLT related conflict C8 was 1 percent of all conflicts. Conflict types C3 and C4 were not observed at this site during the data collection period. The other RTUT conflicts C1, C2, and C5 were

4, 2, and 6 percent of all conflicts at this site. The number of daily conflicts for Site 5 is shown in Figure 5.5.

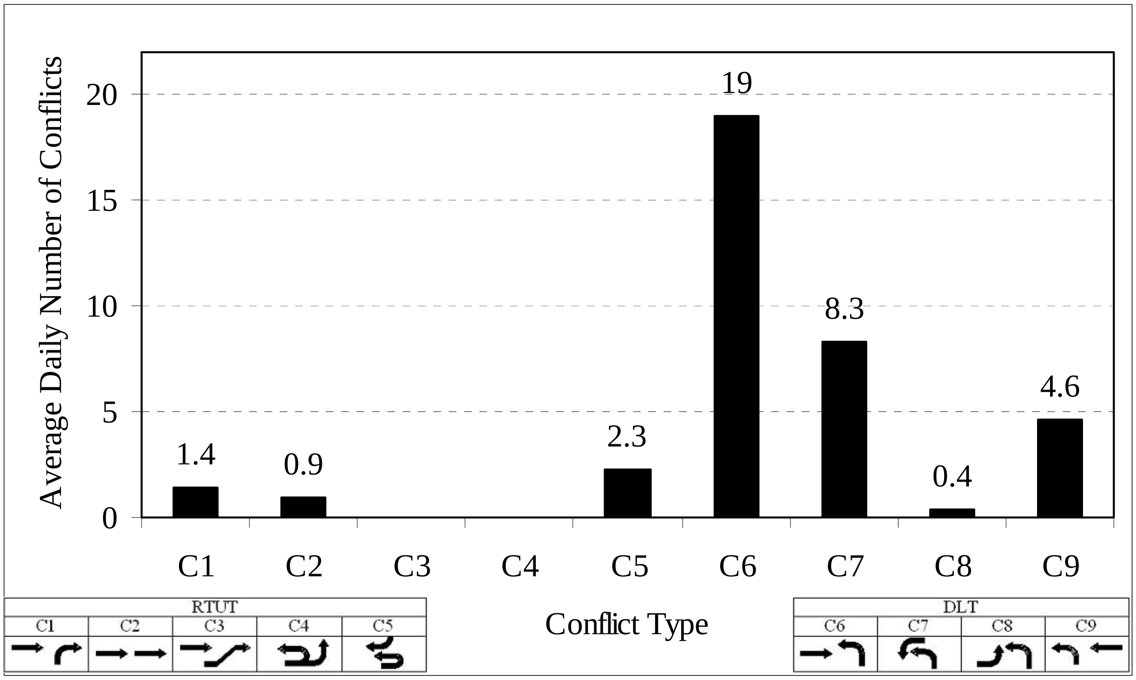


Figure 5.5 Number of Daily Conflicts by Type, Site 5, Signalized Intersection

Site 6 This site has a directional median opening opposite the driveway that prevents DLT movements at the site. U-turn movements generated 41 percent of RTUT related conflicts where weaving related conflicts were 59 percent. Weaving conflict C1 was 28 percent, which was the highest, of all conflicts. The other weaving related conflicts C2 and C3 were 16 and 15 percent, respectively. U-turn related conflicts C4 and C5 distributed equally and they were 20 and 21 percent, respectively. Figure 5.6 shows the number of daily conflicts for Site 6.

Site 7 This site has a full median opening opposite the driveway with lower major road traffic volume as compared to other sites. DLT related conflicts were 83 percent of all conflicts where RTUT related conflicts were 17 percent of all conflicts. DLT conflicts C6 and C9, which were with major road vehicles, were 38 and 33 percent, respectively, even though major road traffic volume was low. On the other hand, RTUT conflicts C1, C2, C3, C4 and C5 were 2, 2, 4, 4, and 6 percent, respectively. Figure 5.7 shows the number of daily conflicts for Site 7.

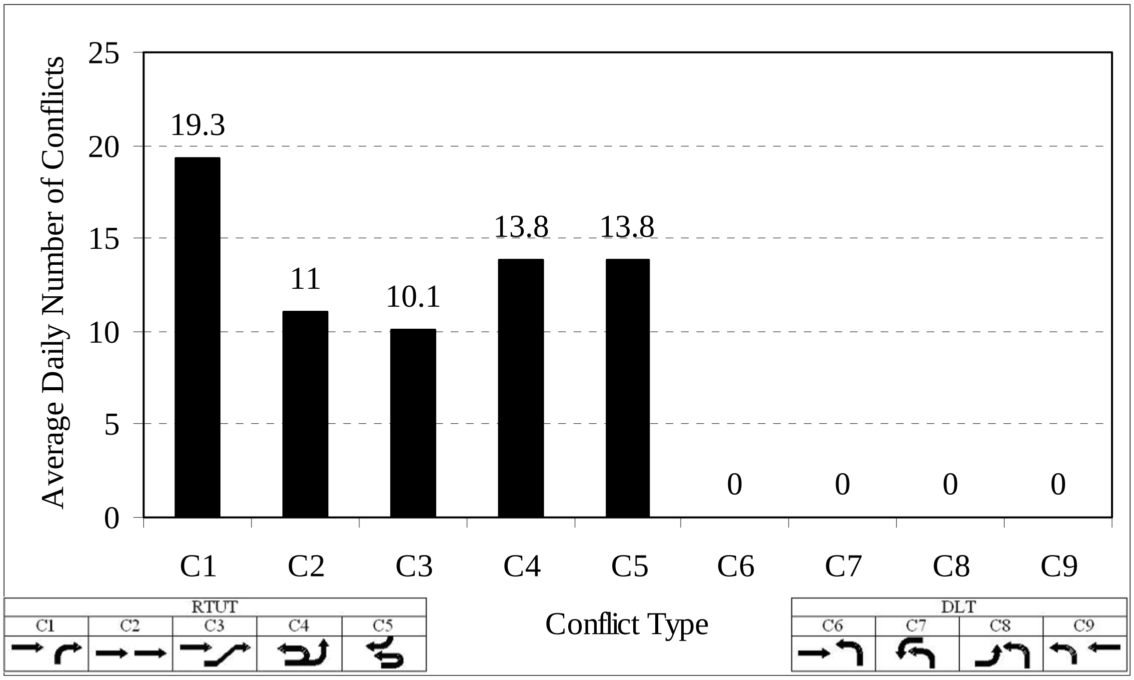


Figure 5.6 Number of Daily Conflicts by Type, Site 6, Signalized Intersection

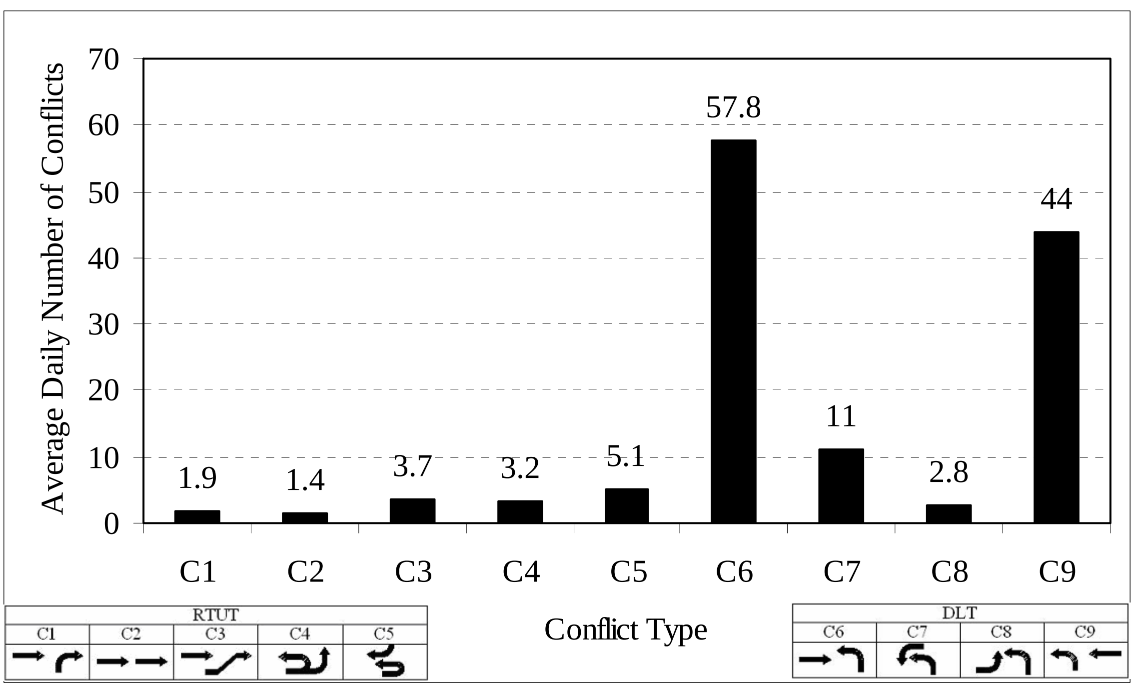


Figure 5.7 Number of Daily Conflicts by Type, Site 7, Signalized intersection

Site 8 This site did not have a median opening opposite the driveway and also the weaving distance was shorter as compared to the other sites. The short weaving distance caused a higher number of conflict type C1, because the drivers usually turn right onto the inner lane of the major road. Weaving related conflicts C1, C2, and C3 were 42, 4, and 4 percent, respectively. On the other hand, U-turn conflicts C4 and C5 were 18 and 31 percent, respectively. The high traffic volume of left turns and right turns from the cross road at the signalized intersection caused higher numbers of U-turn related conflicts. Figure 5.8 illustrates the number of daily conflicts for Site 8.

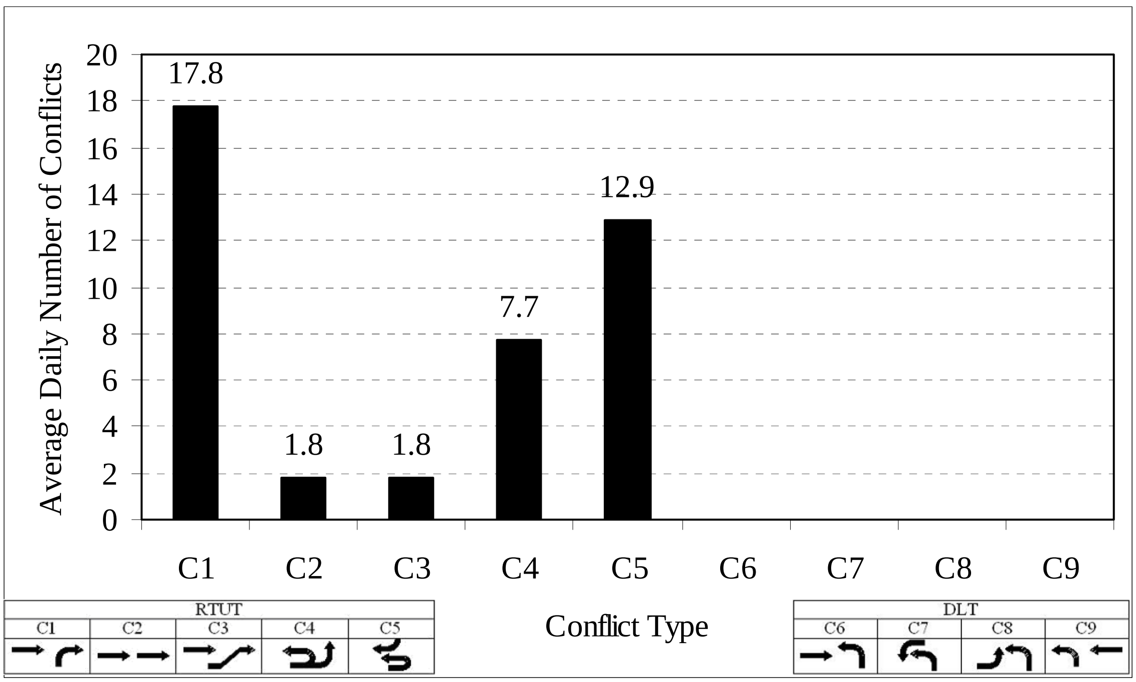


Figure 5.8 Number of Daily Conflicts by Type, Site 8, Signalized intersection.

To illustrate a more general perspective of DLT and RTUT movements' number of daily conflicts, the data for all signalized intersection sites were combined and the average daily number of conflicts for both movements were calculated by the conflict type. Figures 5.9 and 5.10 graphically illustrate the average daily number of conflicts for each conflict type related to RTUT and DLT movements respectively.

The RTUT movements generated an average of 29.8 conflicts per day. Conflicts caused by U-turn maneuvers corresponded to 45 percent of RTUT related conflicts. Although U-turns maneuvers took place at signalized intersections and conflicting vehicle volumes were very low as compared to other conflict types, the number of conflict movements can be considered fairly high because the drivers do not expect the U-turn until the last moment; therefore, they approach the U-turn vehicles without caution which causes conflicts. On the other hand, weaving maneuvers generated 55 percent of RTUT related conflicts. When we consider each conflict type separately: conflict C1 was 30 percent of all RTUT related conflicts, and conflict types C2 and C3 corresponded to 13 and 12 percent, respectively. The reason for conflict C1 to occur more than conflict C2 is that the drivers usually preferred to make a right turn onto the inner lane of the major road in this study. U-turn maneuver conflicts C4 and C5 were 22 and 23 percent of RTUT conflicts respectively.

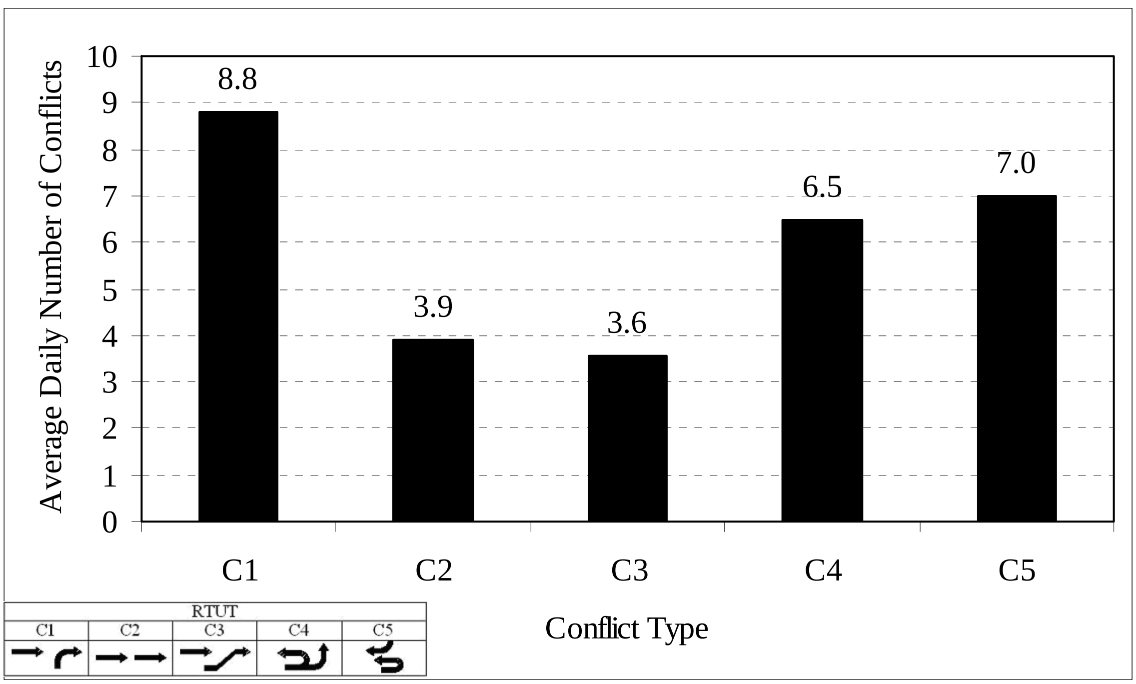


Figure 5.9 Average Number of Daily Conflicts by Type, RTUT Movement, Signalized Intersection.

The DLT movements generated approximately 56.4 conflicts per day. The conflicts with the major road vehicles were 81 percent of DLT related conflicts. The conflicts, which took place within the median opening, were 19 percent of all DLT related conflicts. These results seem to be logical because the conflicts with the major road vehicles had higher conflicting volumes than the conflicts that occurred within the median opening. When each DLT conflict type was considered, conflict C6 occurred most often and was 50 percent of all DLT related conflicts. For the other conflict types; C9, C7, and C8 were 31, 15, and 4 percent, respectively.

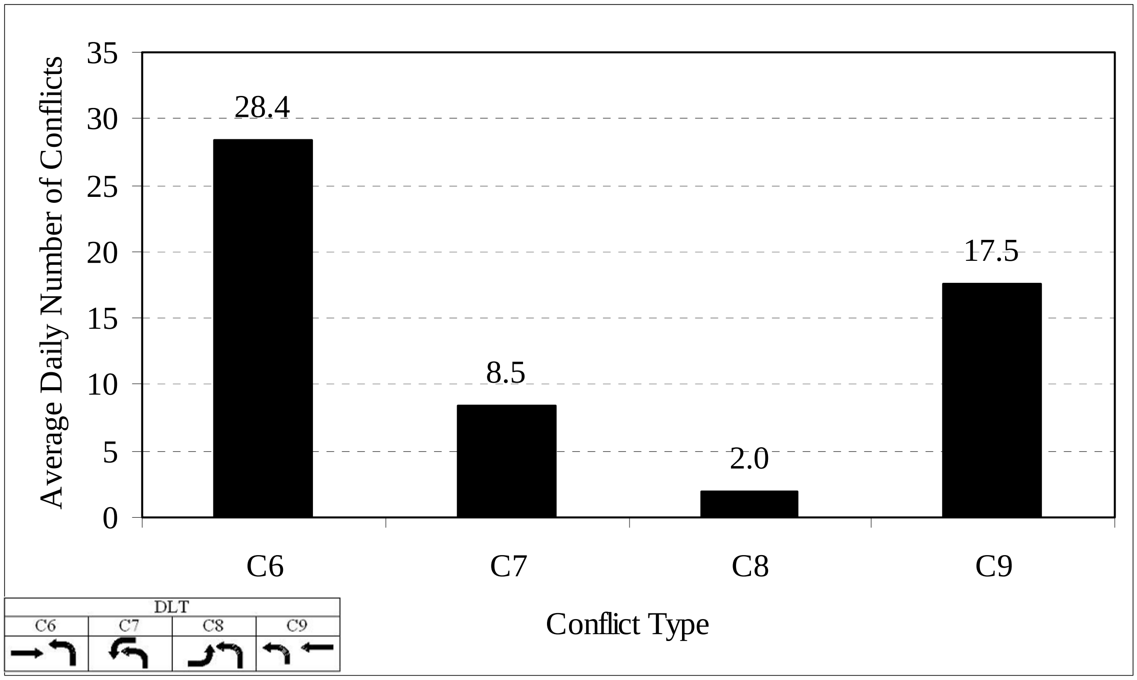


Figure 5.10 Average Number of Daily Conflicts by Type, DLT Movement, Signalized Intersection

When DLT and RTUT conflicts were compared, DLT movements had approximately two times more conflicts than the RTUT movements on an average daily basis. These results are calculated without the effects of volume and other factors. Especially, for full median opening sites drivers' choice of DLT movements over RTUT movements resulted in lower volumes of RTUT movements compared to DLT movements volumes. The purpose of the descriptive analysis was to describe and explore the data for better understanding of the data collected at the field. The conflict rates would provide a better description of safety for both of the movements. Also, the use of conflict rates will provide a more accurate comparison of both alternatives.

5.1.2 Conflict Rates

In this study, for the safety comparison of DLT and RTUT movements, two types of conflict rates were utilized. The conflicts per hour for each type of conflict were calculated and the results were presented for each site for each type of conflict. Another conflict rate, the number of conflicts per thousand vehicles involved, was calculated for each site. The average of the conflict rate for both alternatives was also calculated. Results are presented and discussed in the following subsections.

5.1.2.1 Conflicts per hour

The conflict rate, conflicts per hour, is acquired by utilizing the formula explained in Chapter 3. Figure 5.11 illustrates the average conflicts per hour for RTUT related conflicts. The average of RTUT related conflicts was not affected by peak hour and non-peak hour change, but the conflict types were affected in negative and positive ways by peak and non-peak hours. Conflict C1 decreased 26 percent during the peak hours and, because of heavy traffic conditions, drivers had to make right turns with a narrow radius to the outer lane of the roadway and continue with weaving maneuvers. Because of this reason, conflict types C2 and C3 increased by 24 and 62 percent, respectively. In addition, the U-turn maneuver related conflict C4 reduced by 14 percent while conflict C5 increased by 23 percent. Figure 5.12 illustrates the average conflicts per hour for DLT related conflicts. All of the direct left turn related conflicts were increased during peak-hour periods except for conflict C8. The conflicts C6 and C9 were with major road vehicles and increased by 34 and 24 percent, respectively. This fairly high increase can be explained by the increase in the traffic volume of DLT maneuvers and the major roads. Also conflict C7, which occurred within the median opening, increased by 52 percent during peak-hour periods because of higher traffic volumes of left turn ingress and egress off the driveways.

Figure 5.13 presents the average number of conflicts per hour for RTUT and DLT movements. When both peak and non-peak periods were compared, both movements had higher conflict rates during the peak hours. When conflicts per hour for both alternatives were compared, DLT movements generated approximately two times more average conflicts per hour than RTUT movements.

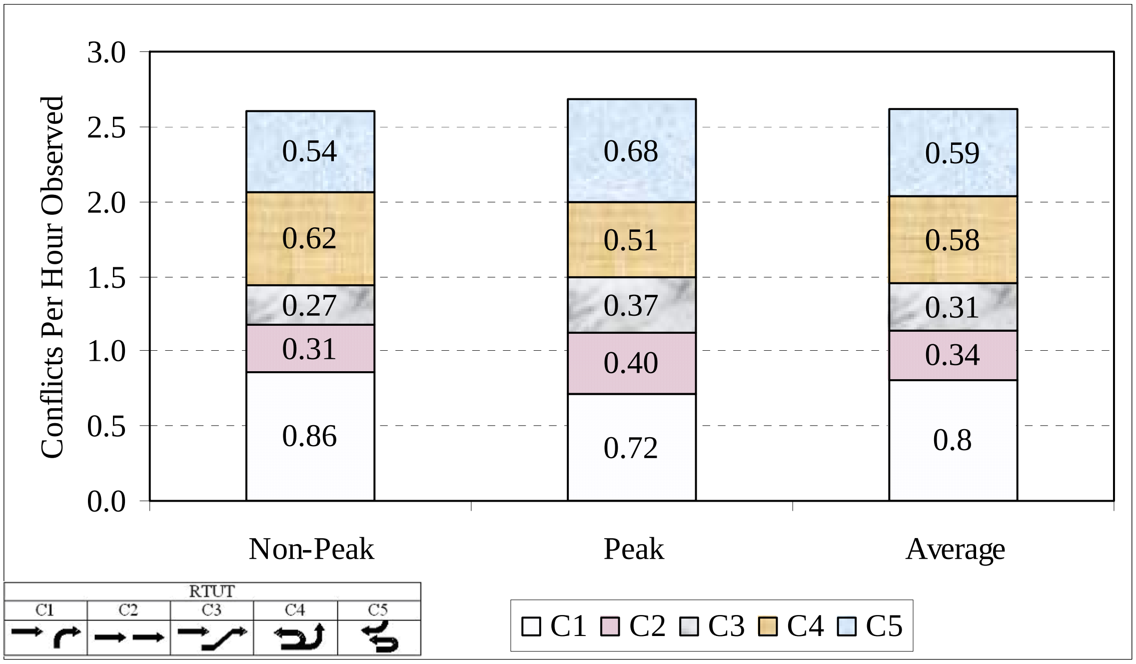


Figure 5.11 Conflicts by time Period, RTUT Movement, Signalized Intersection

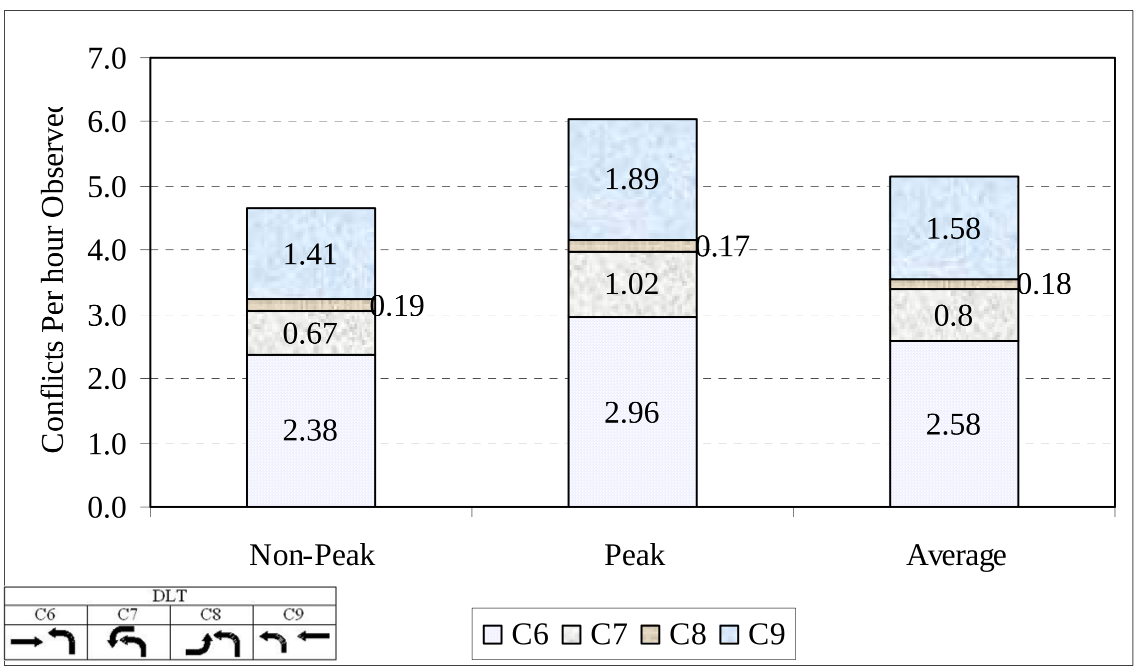


Figure 5.12 Conflicts by time Period, DLT Movement, Signalized Intersection

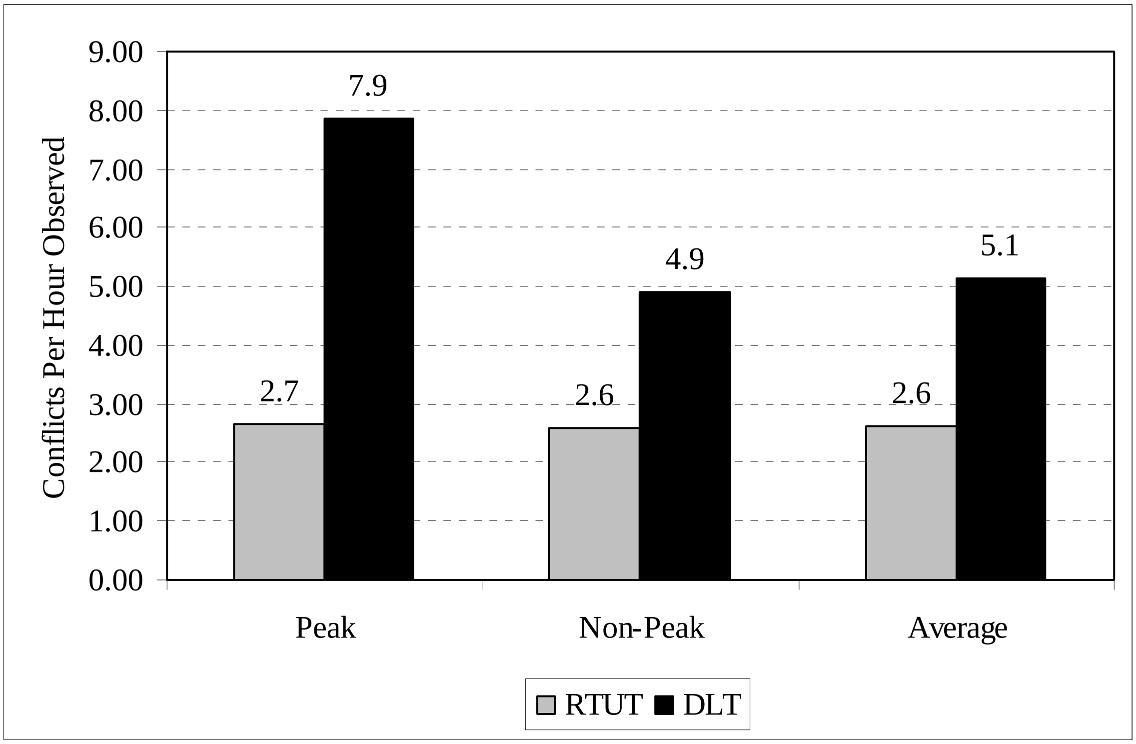


Figure 5.13 Conflicts by time Period, DLT and RTUT Movements Comparison, Signalized Intersection

5.1.2.2 Conflicts per Thousand Involved Vehicles

The second conflict rate that takes traffic volumes effect into consideration was the conflicts per thousand vehicles involved. Based on the results of previous studies, the square root of the product of the volumes involved in conflicts was considered as the best option when calculating the conflict rate. The total number of conflicts, through traffic vehicles, maneuvering vehicles, and conflict rates were obtained for each site. Table 5.6 presents the number of conflicts per thousand involved vehicles at each site. RTUT movements had higher conflict rates at all sites with the exception of Site 3 and Site 7. In addition, when the average conflict rate of all sites were considered, RTUT movements average conflict rate was 5.4 percent more than DLT movements. The reason for the higher RTUT conflict rate is due to the very low conflicting volume of U-turn maneuvers while the high number of conflicts related to these maneuvers occurred at signalized intersections. Table 5.6 and Figure 5.14 show the results of conflicts per thousand vehicles involved.

Table 5.6 Number of Conflicts per Thousand Vehicles Involved, Signalized Intersection

Site	DLT	RTUT
Site 1	N/A	53.86
Site 2	45.72	52.36
Site 3	43.77	42.85
Site 4	52.4	52.68
Site 5	53.62	46.13
Site 6	N/A	50.94
Site 7	48.7	38.4
Site 8	N/A	74.5
Average	48.84	51.47

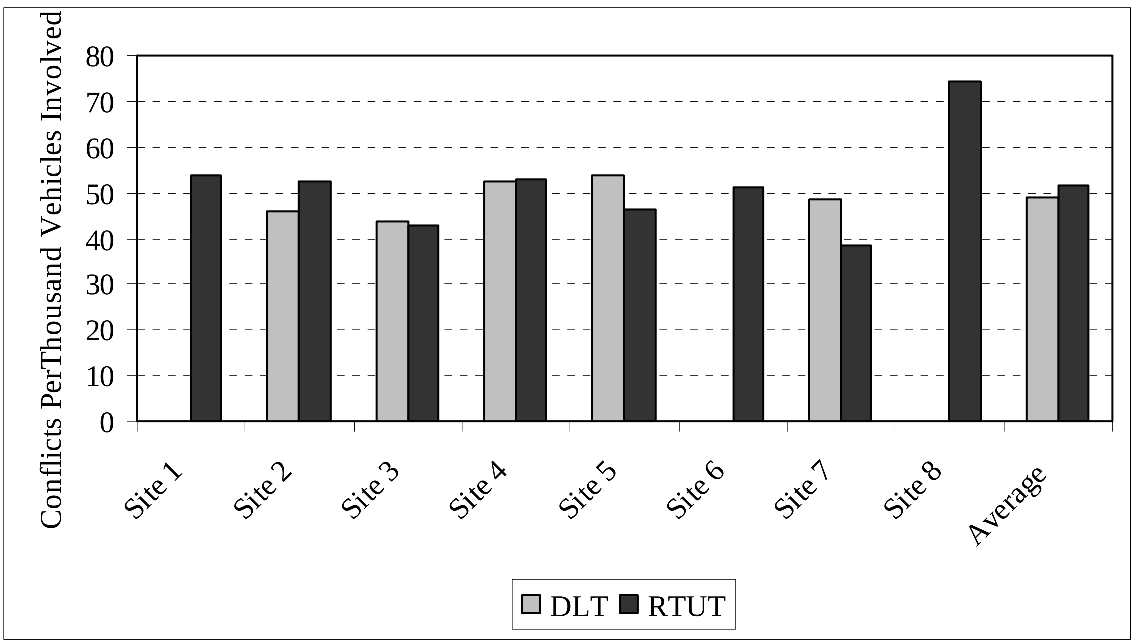


Figure 5.14 Conflicts per Thousand Involved Vehicles, Signalized Intersection

5.1.3 Severity Analysis

The severity of conflicts was analyzed by considering a subjective score that was based on the Risk of Collision (ROC) of the maneuver. An objective score, that was based on the concept of Time to Collision (TTC) was considered as well but conflict types C4 and

C5 which are RTUT related conflicts and conflict types C7 and C8 which are DLT related conflicts were not possible to define by an objective method (TTC) because the maneuvers do not occupy the same path and the speed data were not available for those maneuvers. Also, the lane change conflict (C3) cannot be defined by TTC when there was little or no speed difference between vehicles that were involved in a conflict. The ROC score is subjective because it depends on the observer but it can still be used for comparison purposes. The conflict score ranged from 1 through 3 as it is presented in Table 5.7.

Table 5.7 Risk of Collision (ROC) Scores

TTC and ROC Scores	ROC
1	Low Risk
2	Medium Risk
3	High Risk

The frequency of the severity for each conflict type with ROC score were calculated and are illustrated in Figures 5.15 through 5.23. Based on these figures, average ROC score values were calculated for all conflicts.

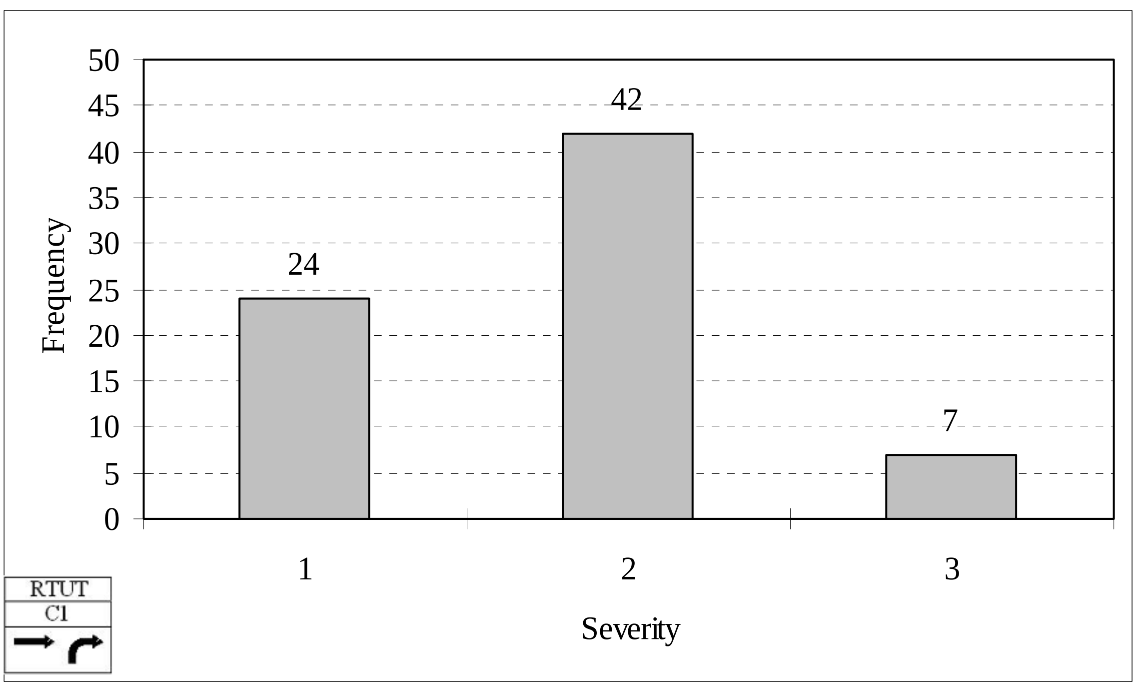


Figure 5.15 Distribution of Severity Conflict Type C1, Signalized Intersection

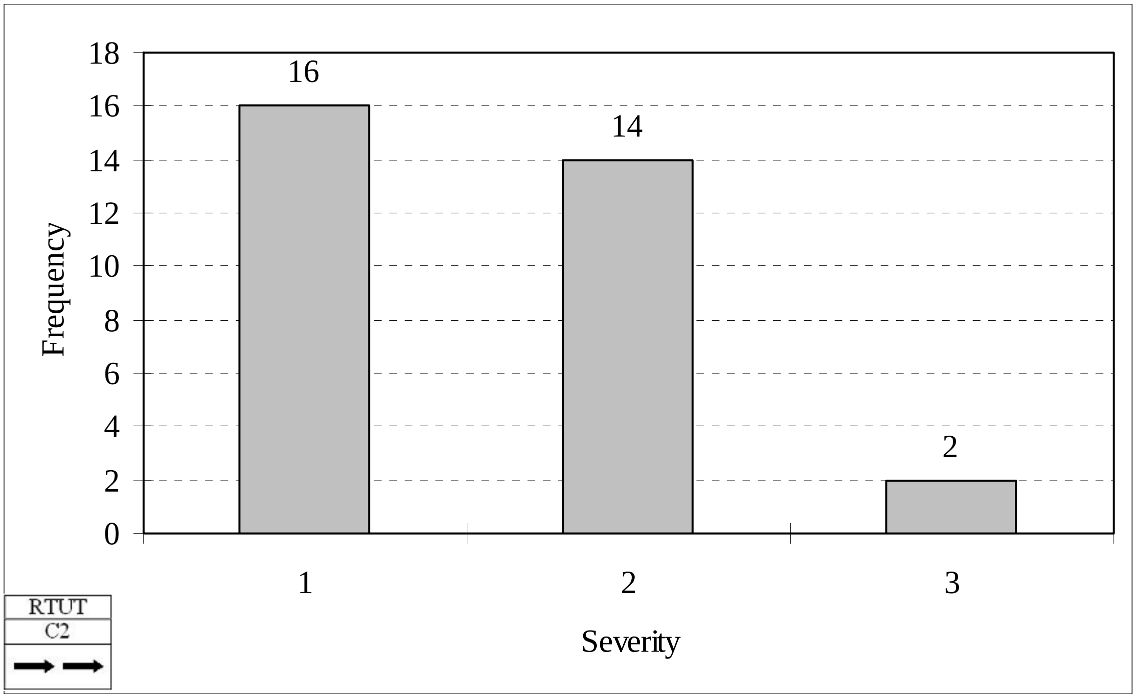


Figure 5.16 Distribution of Severity Conflict Type C2, Signalized Intersection

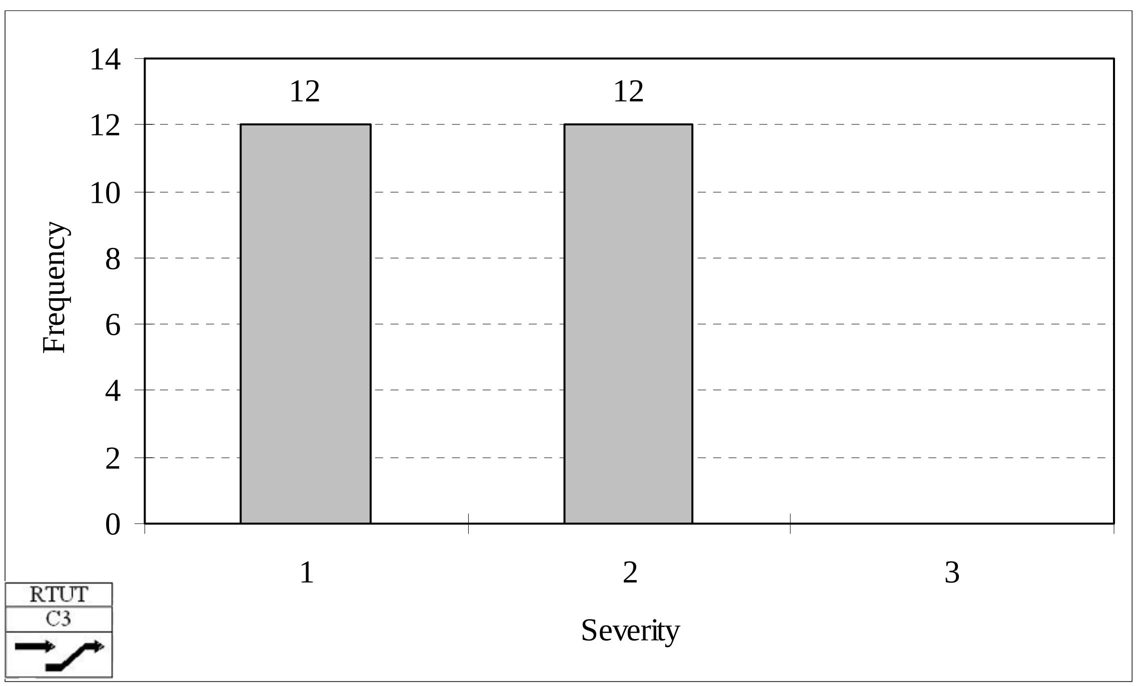


Figure 5.17 Distribution of Severity Conflict Type C3, Signalized Intersection

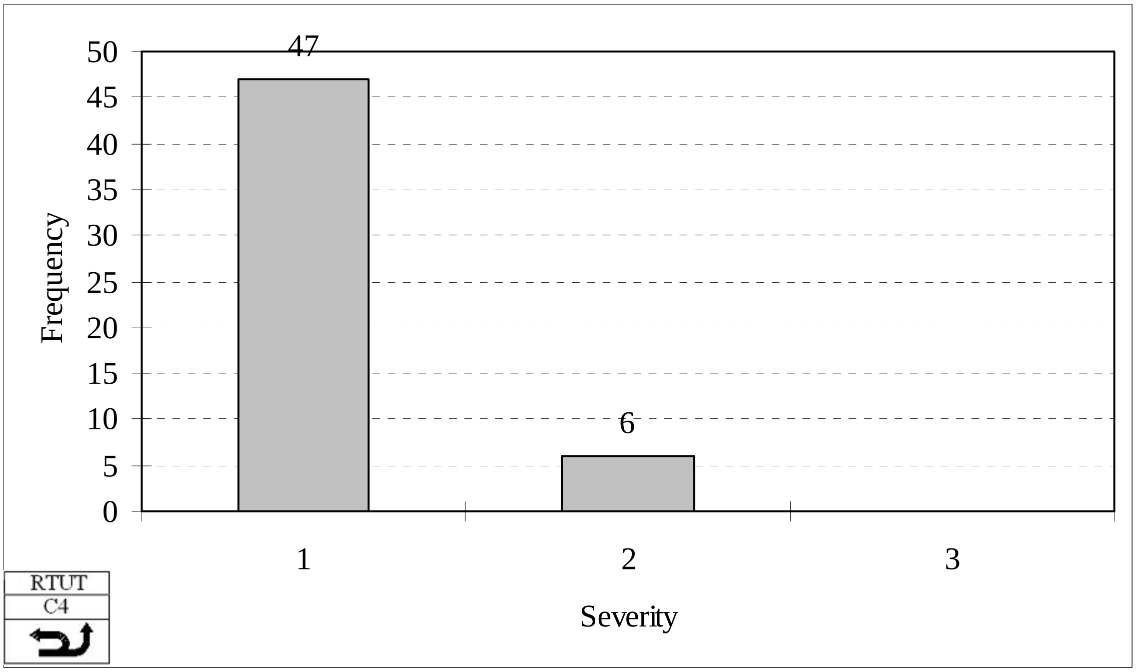


Figure 5.18 Distribution of Severity Conflict Type C4, Signalized Intersection

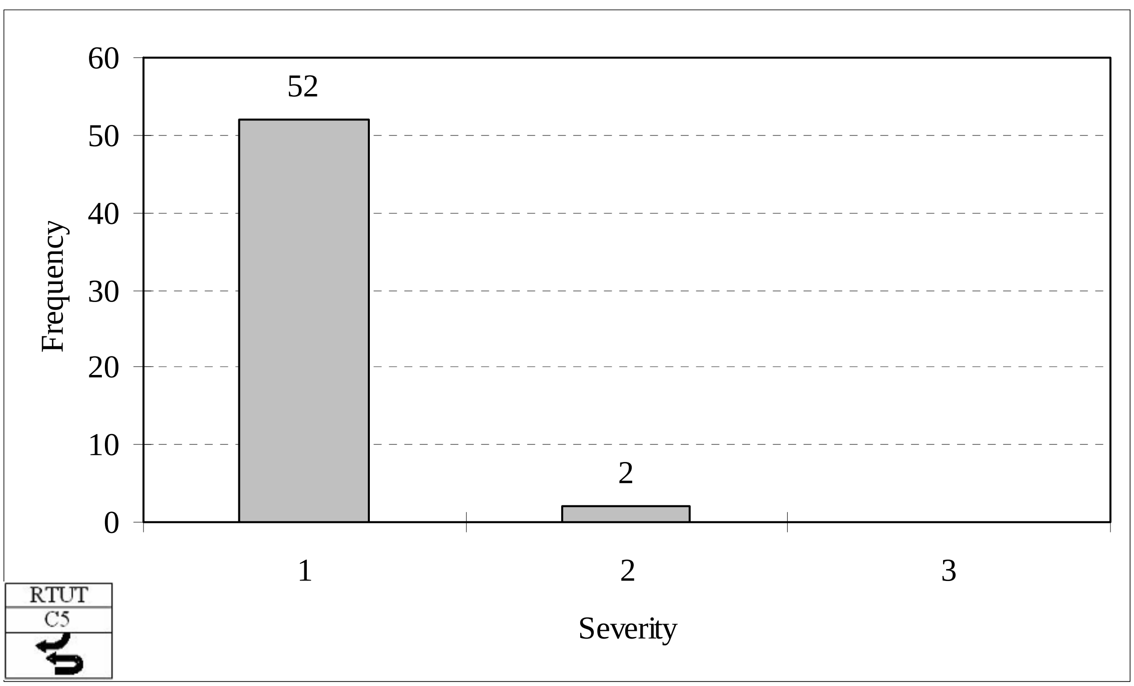


Figure 5.19 Distribution of Severity Conflict Type C5, Signalized Intersection

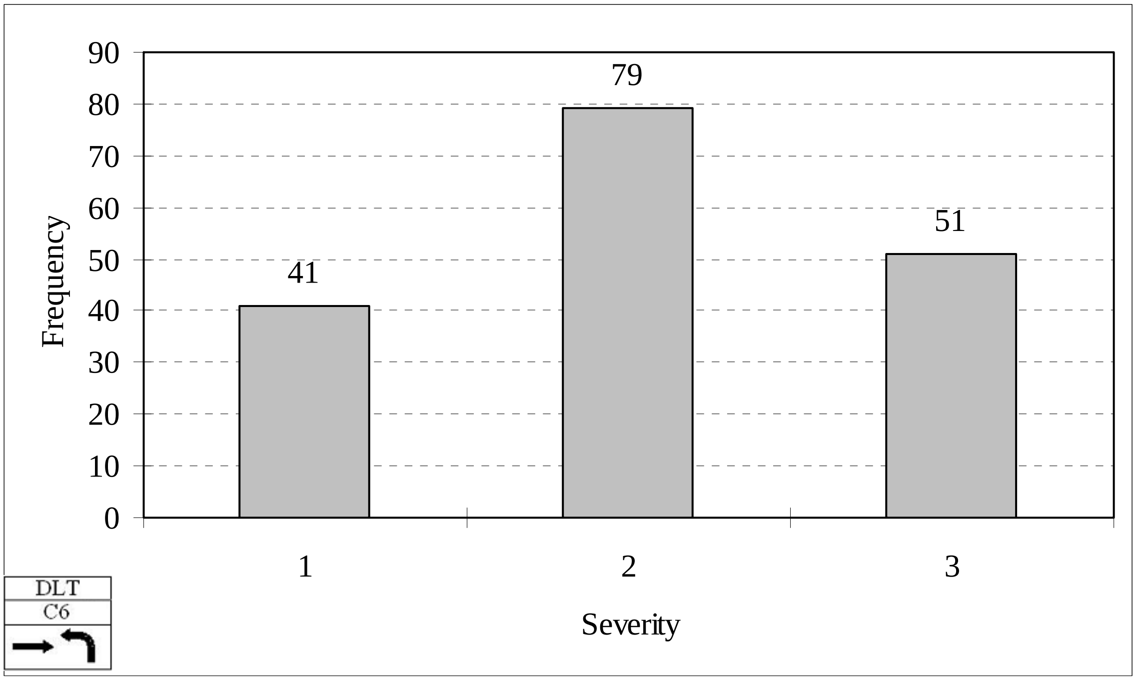


Figure 5.20 Distribution of Severity Conflict Type C6, Signalized Intersection

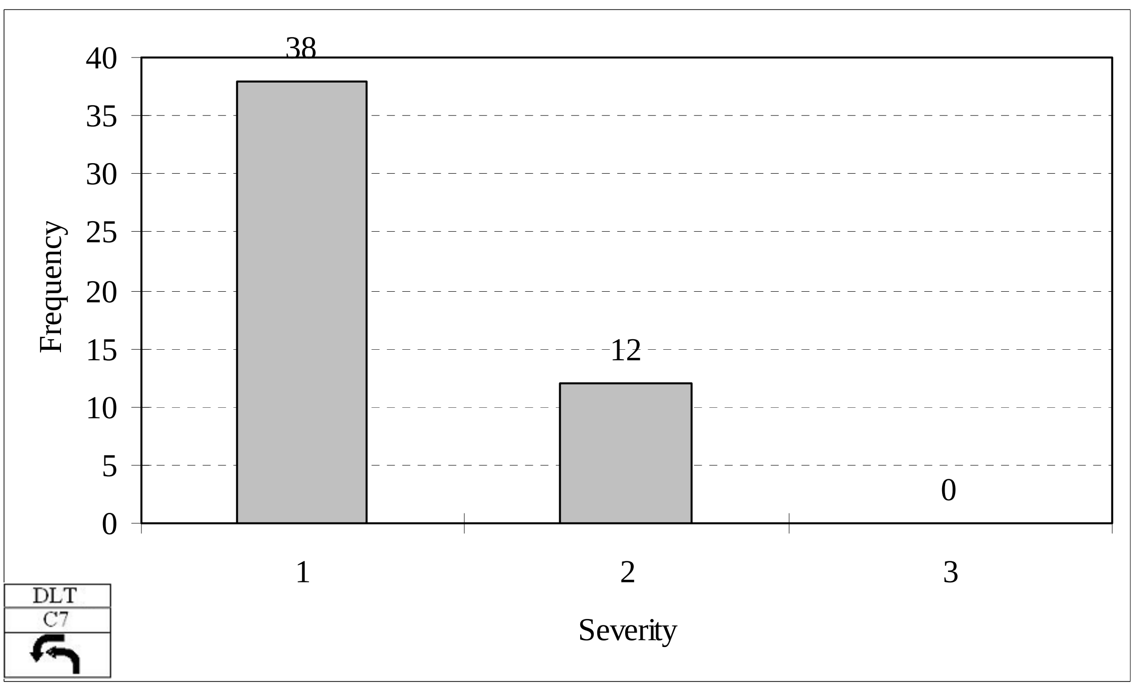


Figure 5.21 Distribution of Severity Conflict Type C7, Signalized Intersection

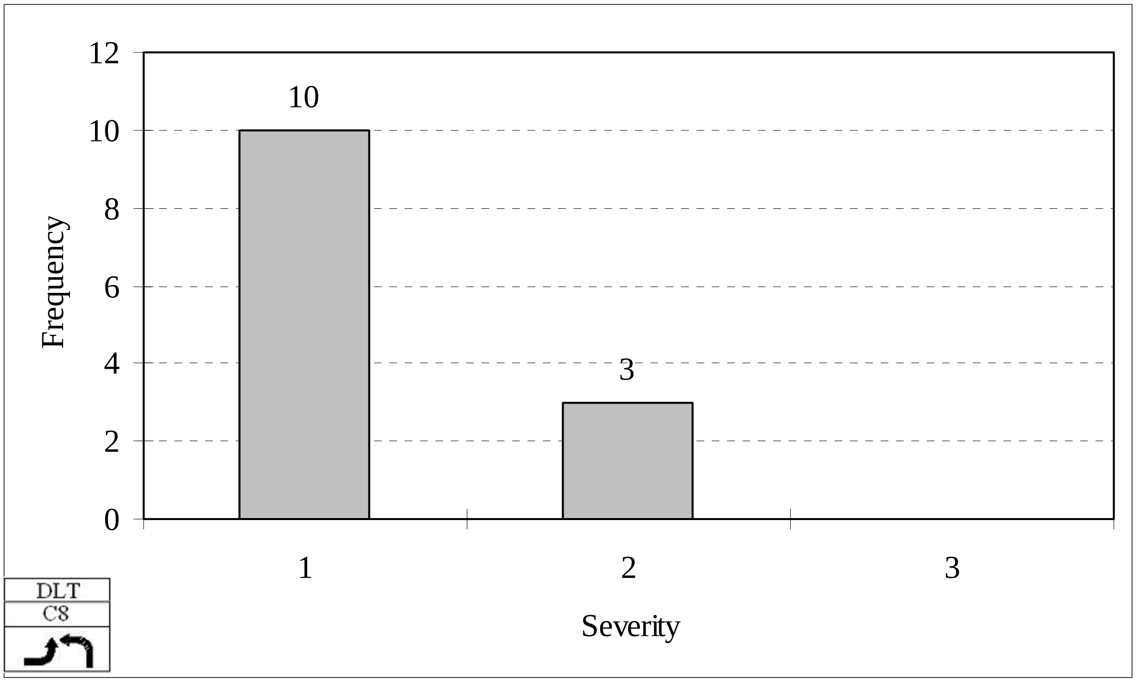


Figure 5.22 Distribution of Severity Conflict Type C8, Signalized Intersection

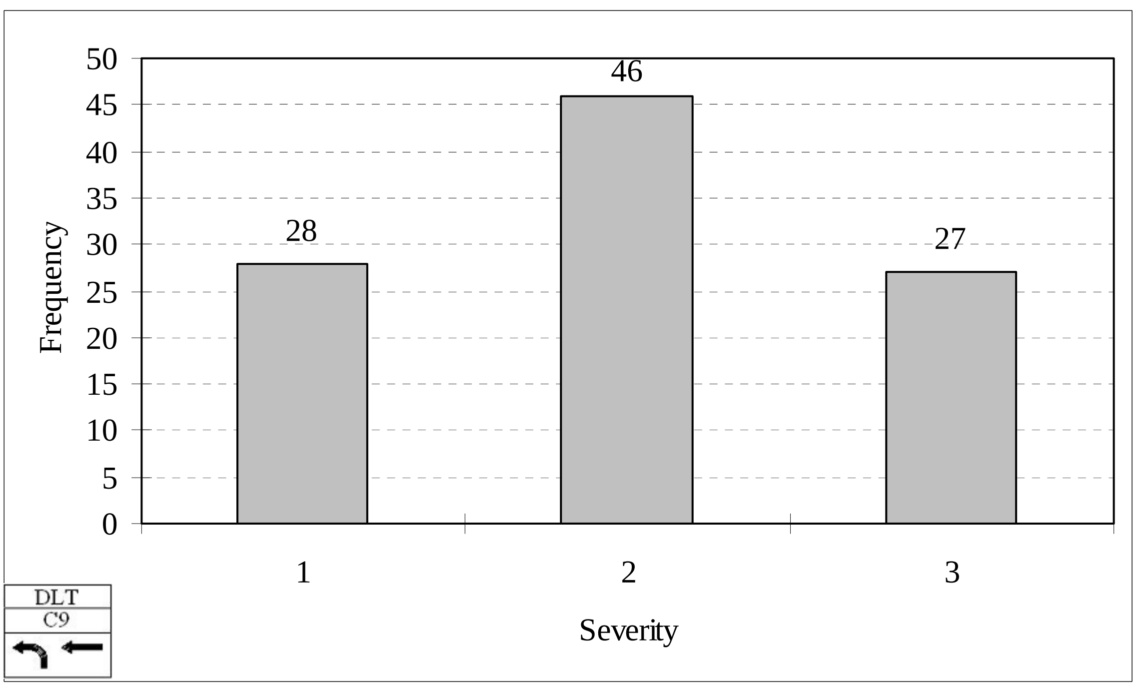


Figure 5.23 Distribution of Severity Conflict Type C9, Signalized Intersection

Figure 5.24 illustrates the average ROC scores for RTUT movements. Conflict types C1, C2, and C3 have higher severity scores as compared to conflict types C4 and C5. Conflict types C1, C2 and C3 have higher severity scores because of higher speed differences between main road vehicles and right turning vehicles from the driveway. On the other hand, conflict types C4 and C5 occurred at signalized intersections where speed differences between vehicles were relatively low. Figure 5.25 illustrates the average ROC scores for DLT movements. Conflict types C6 and C9 have higher severity as compared to conflict types C7 and C8. These results were expected because higher severity conflicts occur more frequently with the main road vehicles running at high speed than the other conflicting vehicles. Median opening related conflicts C7 and C8 have lower severities because of low speeds and low speed differences of vehicles involved in the conflicts. The average severity of RTUT and DLT movements are illustrated in Figure 5.26. The RTUT movements had an average severity score of 1.40 while the average severity score for DLT movements was 1.88.

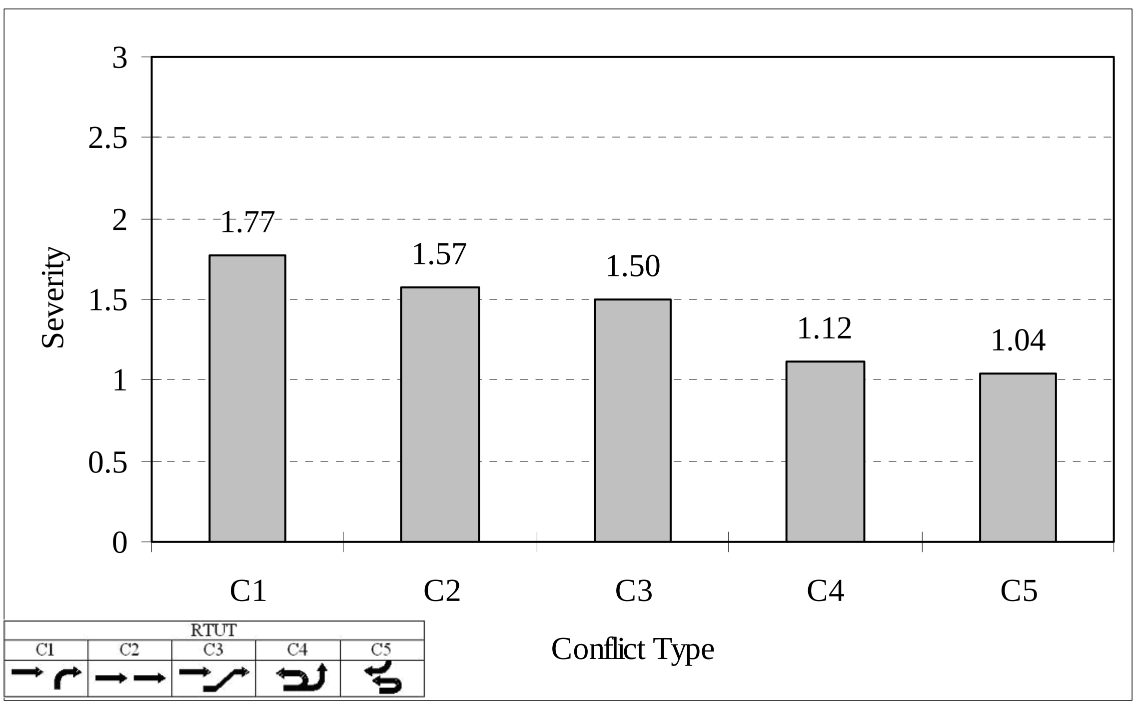


Figure 5.24 Average ROC Scores for RTUT Movements, Signalized Intersection

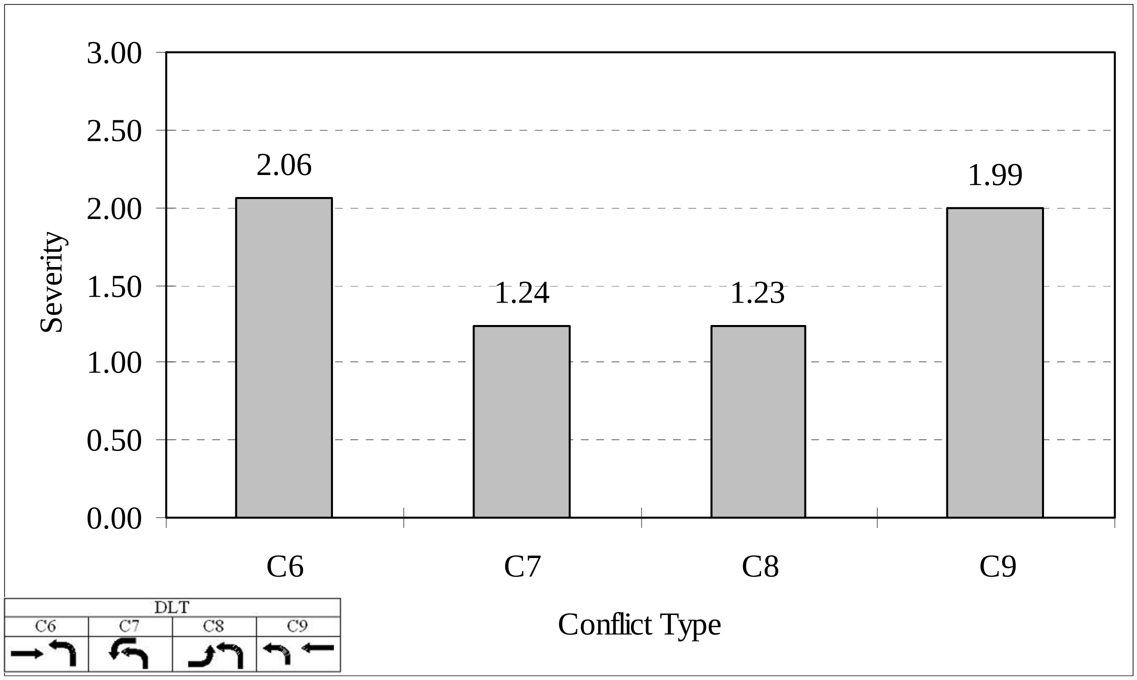


Figure 5.25 Average ROC Scores for DLT Movements, Signalized Intersection

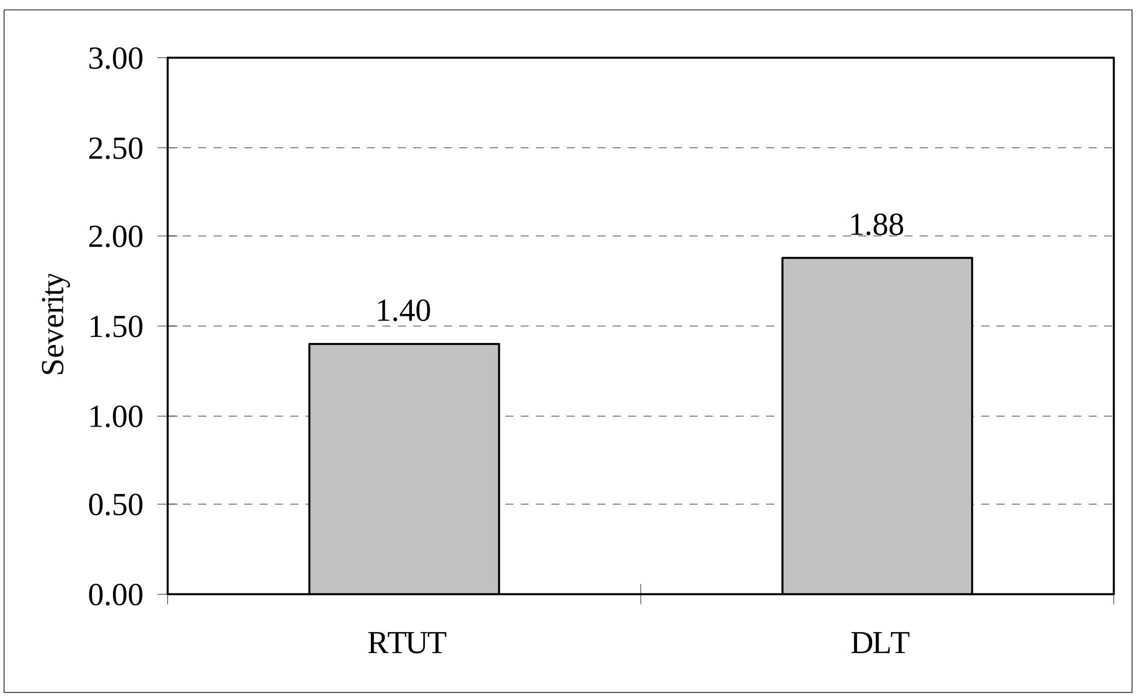


Figure 5.26 Severity Comparison for DLT and RTUT Movements by ROC, Signalized Intersection

5.2 Data Analysis of RTUT vs. DLT at Median Opening Sites

5.2.1 Descriptive Analysis

Sample size verification details were discussed previously in the subchapter of data analysis of signalized intersection sites. The total number of 2350 DLT movements and 1770 RTUT movements were observed at median opening sites. The results for sample size verification of RTUT and DLT movements are presented in Table 5.8 and 5.9, respectively. Sample size for RTUT and DLT movements were satisfactory for all types of conflicts.

Table 5.8 Sample Size Verification for RTUT Movements, Median Opening

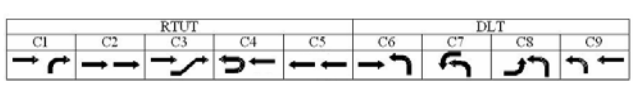
Conflict (1)	Average Number of Conflicts (2)	RTUT Vehicles (3)	P_{RTUT} (4)=(2)/(3)	n (5)	Sample Size Satisfied
C1	63	1770	0.04	53	Yes
C2	62	1770	0.04	52	Yes
C3	31	1770	0.02	26	Yes
C4	61	1770	0.03	51	Yes
C5	75	1770	0.04	62	Yes

P_{RTUT} : Percentage of RTUT vehicles involved in a conflict.
n : Number of vehicles estimated for sample size

Table 5.9 Sample Size Verification for DLT Movements, Median Opening

Conflict (1)	Average Number of Conflicts (2)	DLT Vehicles (3)	P_{DLT} (4)=(2)/(3)	n (5)	Sample Size Satisfied
C6	188	2620	0.07	72	Yes
C7	80	2620	0.03	32	Yes
C8	16	2620	0.01	7	Yes
C9	135	2620	0.05	53	Yes

P_{DLT} : Percentage of DLT vehicles involved in a conflict.
n : Number of vehicels estimated for sample size



The data for median opening sites are presented in two tables. The number of conflicts observed, for each type of conflict at each site are presented in Table 5.10. Furthermore, the number of conflicts used for analysis are presented in Table 5.11. In this table the data were adjusted for non-observed times.

Table 5.10 Summary of the Total Number of Conflicts Observed, Median Opening

Site	Conflicts	Conflict Type									Total
		C1	C2	C3	C4	C5	C6	C7	C8	C9	
9	No.	26.0	20.0	11.0	31.0	26.0	N/A	N/A	N/A	N/A	114
	(%)	22.8	17.5	9.6	27.2	22.8	-	-	-	-	100
10	No.	16.0	17.0	6.0	12.0	17.0	N/A	N/A	N/A	N/A	68
	(%)	23.5	25.0	8.8	17.6	25.0	-	-	-	-	100
11	No.	16.0	18.0	12.0	13.0	24.0	N/A	N/A	N/A	N/A	83
	(%)	19.3	21.7	14.5	15.7	28.9	-	-	-	-	100
12	No.	1.0	1.0	0.0	1.0	2.0	39.0	19.0	4.0	30.0	97
	(%)	1.0	1.0	0.0	1.0	2.1	40.2	19.6	4.1	30.9	100
13	No.	2.0	3.0	1.0	1.0	2.0	26.0	12.0	2.0	15.0	64
	(%)	3.1	4.7	1.6	1.6	3.1	40.6	18.8	3.1	23.4	100
14	No.	1.0	2.0	1.0	2.0	2.0	35.0	22.0	3.0	28.0	96
	(%)	1.0	2.1	1.0	2.1	2.1	36.5	22.9	3.1	29.2	100
15	No.	1.0	1.0	0.0	1.0	2.0	42.0	14.0	5.0	27.0	93
	(%)	1.1	1.1	0.0	1.1	2.2	45.2	15.1	5.4	29.0	100
16	No.	0.0	0.0	0.0	0.0	0.0	46.0	15.0	2.0	35.0	98
	(%)	0.0	0.0	0.0	0.0	0.0	46.9	15.3	2.0	35.7	100
Total		63.0	62.0	31.0	61.0	75.0	188.0	82.0	16.0	135.0	*713*

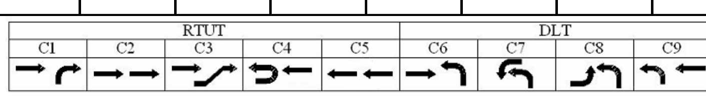
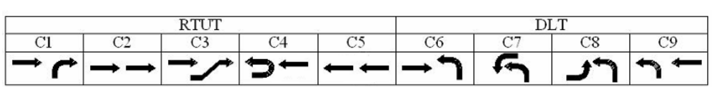


Table 5.11 Summary of the Total Number of Conflicts Used for Analysis, Median Opening

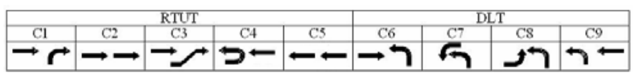
Site	Conflicts	Conflict Type									Total
		C1	C2	C3	C4	C5	C6	C7	C8	C9	
9	No.	52.7	35.1	23.2	48.2	55.3	N/A	N/A	N/A	N/A	214.5
	(%)	24.6	16.4	10.8	22.5	25.8	-	-	-	-	100.0
10	No.	43.3	41.5	13.6	35.5	49.4	N/A	N/A	N/A	N/A	183.3
	(%)	23.6	22.6	7.4	19.4	23.5	-	-	-	-	96.5
11	No.	28.1	30.0	18.5	21.5	38.5	N/A	N/A	N/A	N/A	136.6
	(%)	20.6	22.0	13.5	15.7	28.2	-	-	-	-	100.0
12	No.	3.1	3.1	0.0	2.2	4.4	57.2	25.1	5.7	43.8	144.6
	(%)	2.1	2.1	0.0	1.5	3.0	39.6	17.7	3.9	30.3	100.3
13	No.	5.6	8.7	2.4	3.1	5.6	38.1	14.7	2.9	22.0	103.1
	(%)	5.4	8.4	2.3	3.0	5.4	37.0	14.3	2.8	21.3	100
14	No.	3.7	5.9	2.4	4.9	5.9	51.9	32.2	4.5	40.9	152.3
	(%)	2.4	3.9	1.6	3.2	3.9	34.1	21.1	3.0	26.9	100
15	No.	2.2	1.7	0.0	1.7	3.9	71.5	23.8	8.4	46.1	159.3
	(%)	1.4	1.1	0.0	1.1	2.4	44.9	14.9	5.3	28.9	100
16	No.	0.0	0.0	0.0	0.0	0.0	57.8	37.4	5.0	86.4	186.6
	(%)	0.0	0.0	0.0	0.0	0.0	31.0	20.0	2.7	46.3	100
Total		139	126	60.1	117	163	277	133	26.5	239	*1280*



The average daily number of conflicts for each median opening site and conflict type were obtained and these values are presented in Table 5.12.

Table 5.12 Average Daily Number of Conflicts, Median Opening

Site	Conflict Type									Total
	C1	C2	C3	C4	C5	C6	C7	C8	C9	
9	17.6	11.7	7.7	16.1	18.4	N/A	N/A	N/A	N/A	71.5
10	14.4	13.8	4.5	11.8	16.5	N/A	N/A	N/A	N/A	61.0
11	9.4	10.0	6.2	7.2	12.8	N/A	N/A	N/A	N/A	45.6
12	1.6	1.6	0.0	1.1	2.2	28.6	12.6	2.9	21.9	72.5
13	2.8	4.4	1.2	1.6	2.8	19.1	8.9	1.5	11.0	53.3
14	1.9	3.0	1.2	2.5	3.0	26.0	16.1	2.3	20.5	76.5
15	1.1	0.9	0.0	0.9	2.1	17.9	6.0	2.1	11.5	42.5
16	0.0	0.0	0.0	0.0	0.0	56.4	18.7	2.5	43.2	120.8



The following paragraphs discuss the conflicts at each site:

Site 9 This site has a directional median opening with high major road and RTUT traffic volume. Particularly, this site has the highest volume of RTUT movements. Approximately, 48 percent of all the conflicts were related to U-turn maneuvers and the conflicts related to weaving maneuvers corresponded to 52 percent, respectively. The conflicts C4 and C5 related to U-turn maneuvers were 23 and 26 percent of all the conflicts. In addition, the conflicts C1, C2, and C3 related to weaving maneuvers corresponded to 25, 16, and 11 percent of all the conflicts, respectively. The number of daily conflicts for Site 9 is illustrated in Figure 5.27.

Site 10 This site is another directional median opening site. Roughly, 54 percent of all conflicts were related to weaving maneuvers whereas 46 percent of all conflicts were related to U-turn maneuvers. The weaving maneuver conflicts C1, C2, and C3 were 24, 23, and 7 percent while the U-turn maneuver conflicts C4 and C5 were 19 and 27 percent, respectively. The number of daily conflicts for Site 10 is illustrated in Figure 5.28.

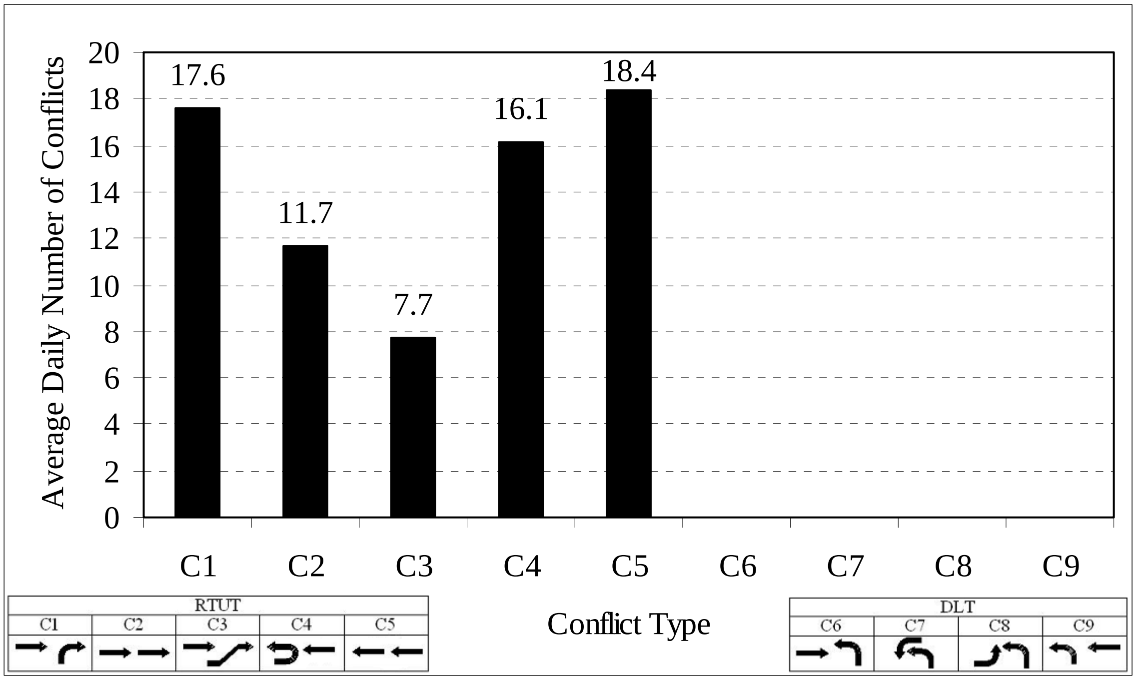


Figure 5.27 Number of Daily Conflicts by Type, Site 9, Median Opening

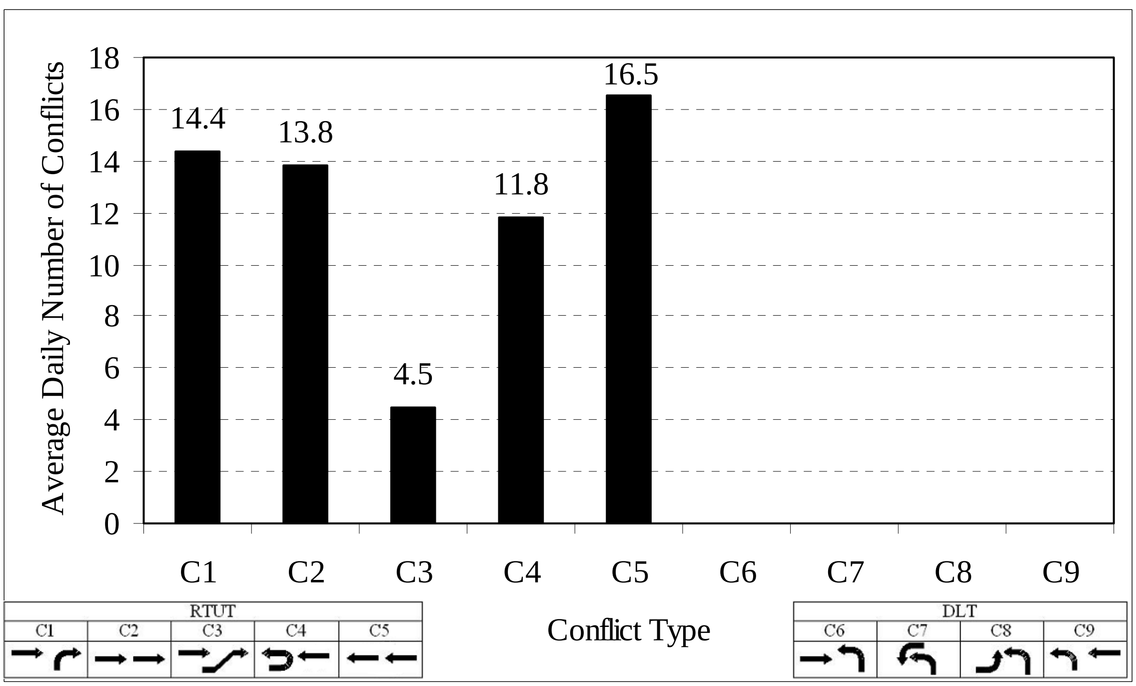


Figure 5.28 Number of Daily Conflicts by Type, Site 10, Median Opening

*Site 11*This site i*s* a directional median opening site. The weaving maneuver conflicts C1, C2, C3 were 20, 22, and 14 percent while the U-turn maneuver conflicts C4 and C5 were 16 and 28 percent respectively. The numbers represent the approximate total percentage of weaving movements in all conflicts is 56 whereas U-turn movements were approximately 44 percent of all conflicts. The number of daily conflicts for Site 11 is illustrated in Figure 5.29.

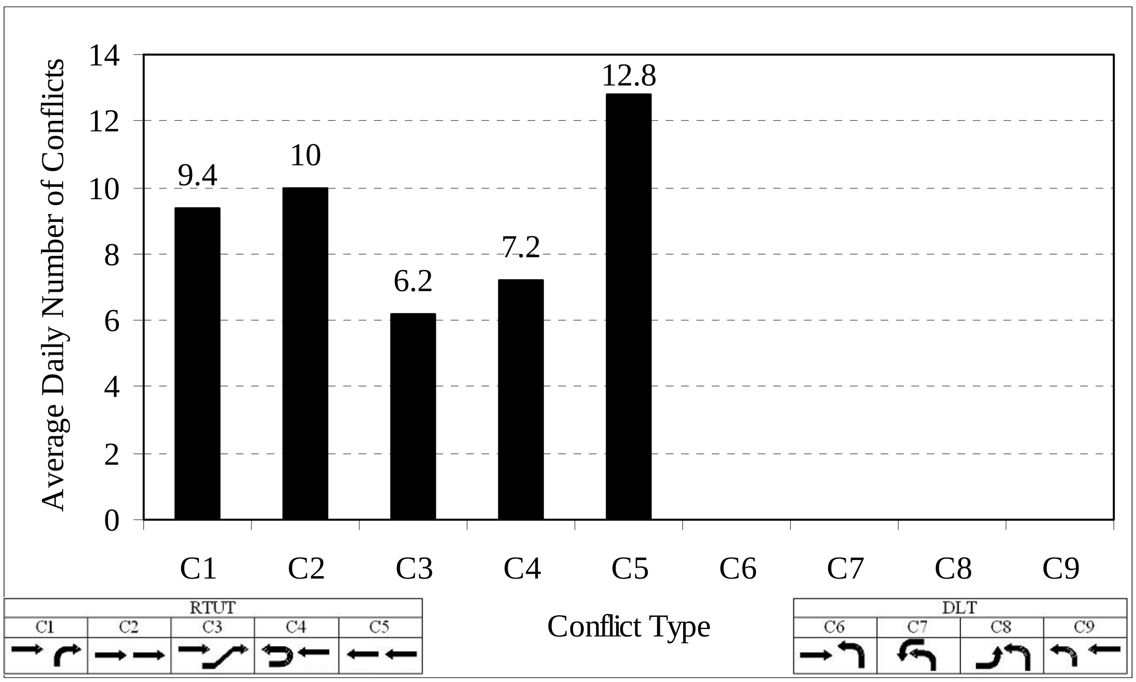


Figure 5.29 Number of Daily Conflicts by Type, Site 11, Median Opening

Site 12 This site has a full median opening opposite of the driveway. The overall percentage of RTUT conflicts is significantly lower than the overall percentage of DLT conflicts, which are 9 and 91 respectively. The weaving movement conflicts C1 and C2 were 2 and 2 percent, respectively. There were no results for the weaving movement conflict C3. The percentage of U-Turn movement conflicts C4 and C5 were 2 and 3. The percentage of DLT conflict C6 was 39.4, which is significantly the highest percentage among all of the DLT conflicts. DLT conflict C7, C8, and C9 were 17, 4, and 30. The number of daily conflicts for Site 12 is illustrated in Figure 5.30.

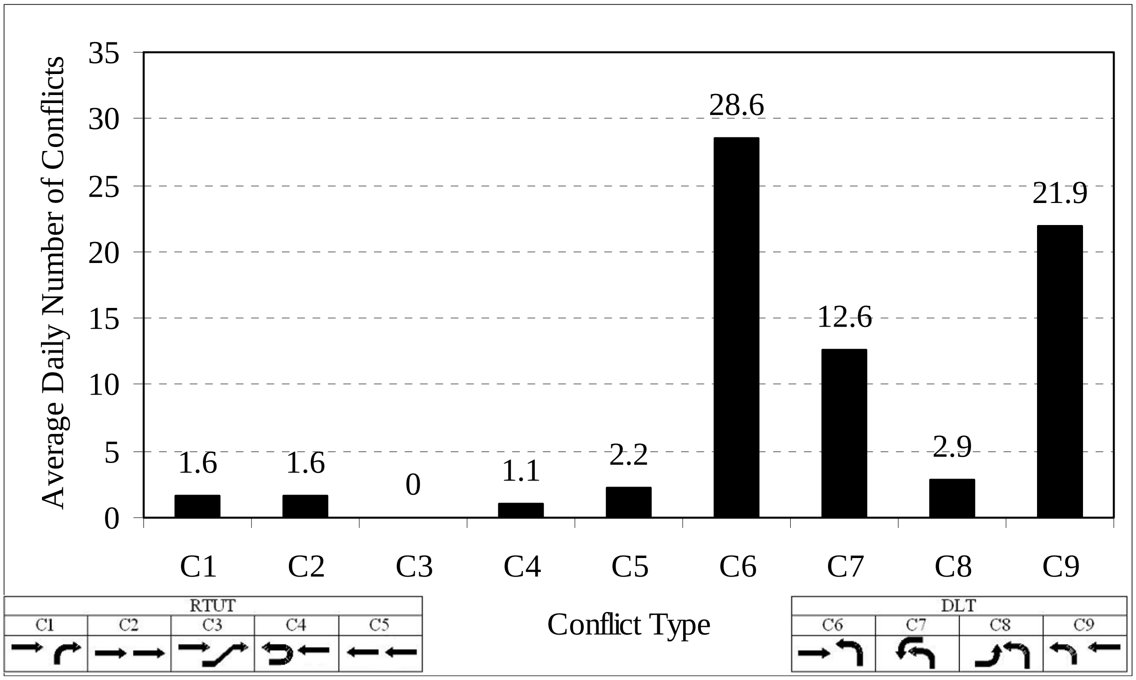


Figure 5.30 Number of Daily Conflicts by Type, Site 12, Median Opening

Site 13 This site has a full median opening opposite of the driveway. Although, the number of RTUT movements was still significantly lower than the number of DLT movements. The conflicts C1, C2, and C3 of weaving maneuvers were 5, 8, and 2 percent of all conflicts, respectively. The conflicts C4 and C5 of U-Turn maneuvers were 3 and 5 percent respectively. DLT conflicts C6, C7, C8, and C9 were 36, 17, 3, and 21 percent, respectively. Notice that the DLT conflict C6 is the highest percentage among all DLT movements. The overall percentage of RTUT conflicts was 24 as compared to the percentage of DLT at 76. The number of daily conflicts for Site 13 is illustrated in Figure 5.31.

Site 14 This site has a full median opening opposite of a driveway. The percentages for the weaving conflicts C1, C2, and C3 were 3, 4, and 2 while the U-turn conflicts C4 and C5 were 3 and 4 percent, respectively. Additionally, the DLT conflcits C6, C7, C8, and C9 were 34, 21, 3, and 27 percent, respectively. Note that 21 percent for DLT conflict C7 is increased slightly due to higher DLT volume. RTUT movements resulted in 15 percent whereas the DLT movements resulted in 85 percent of all conflicts. The number of daily conflicts for Site 14 is illustrated in Figure 5.32.

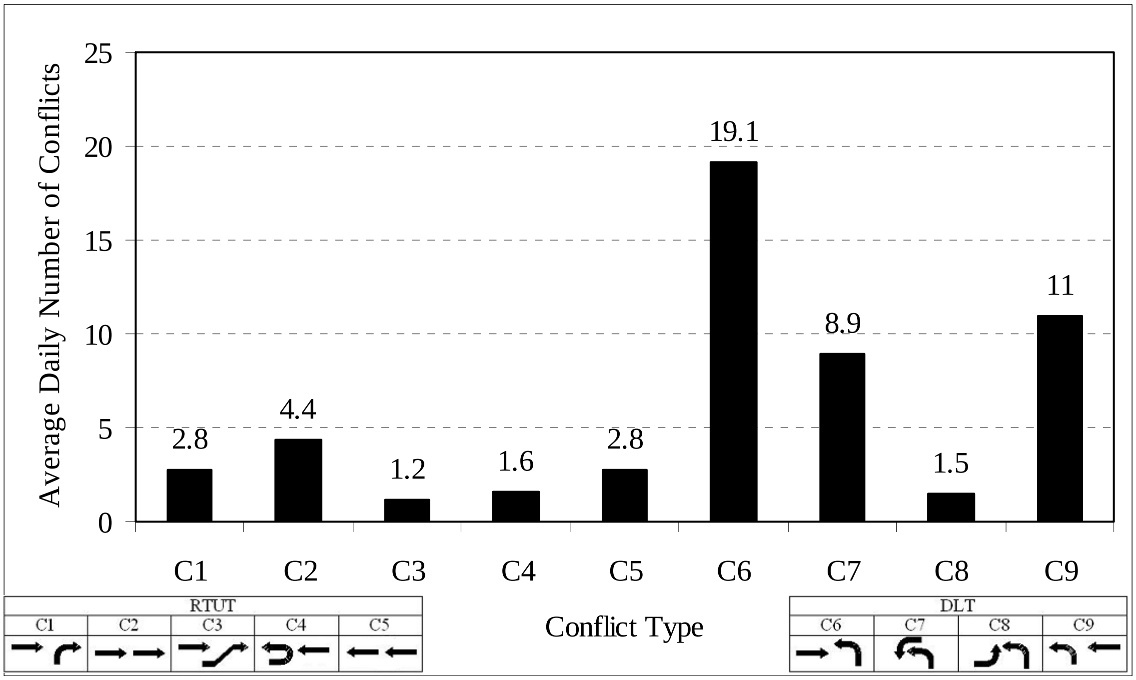


Figure 5.31 Number of Daily Conflicts by Type, Site 13, Median Opening

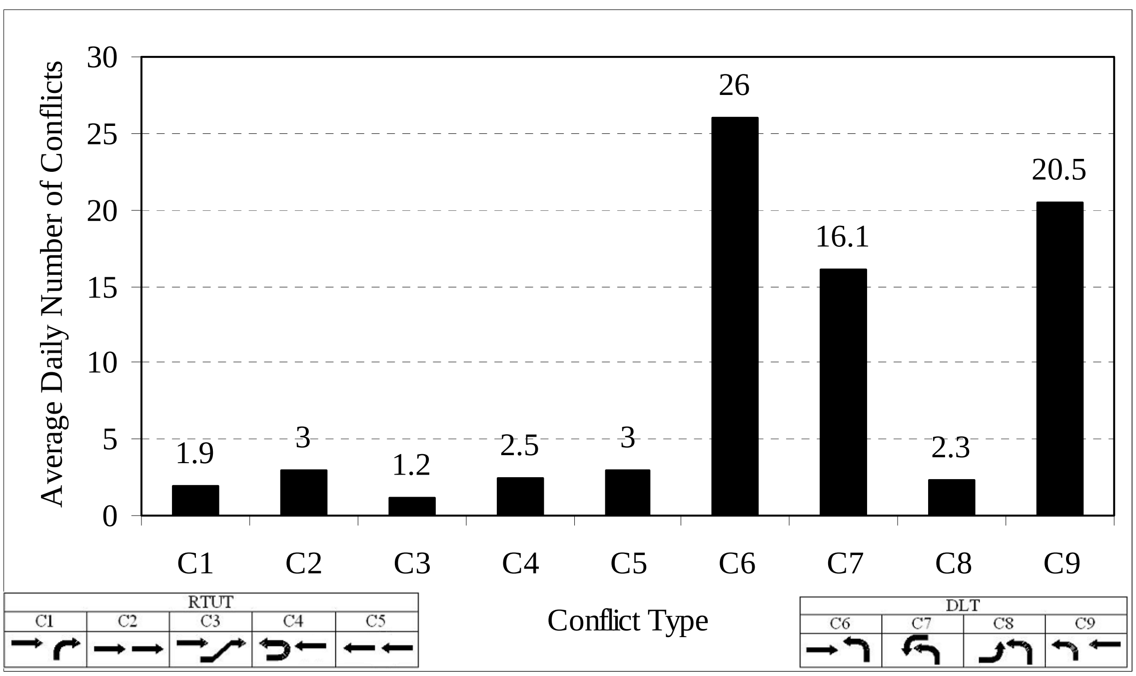


Figure 5.32 Number of Daily Conflicts by Type, Site 14, Median Opening

Site 15 This site has a full median opening opposite the driveway. The RTUT conflict percentage was 12 compared to DLT conflict percentage at 88 of all conflicts. The weaving movement related conflicts, C1 and C2, were 3 and 2 percent, while U-turn movement related conflicts C4 and C5 were 2 and 5 percent, respectively. Conflict type C3 was not observed at this site. DLT movement related conflicts C6, C7, C8, and C9 were 42, 14, 5, and 27 percent, respectively. The number of daily conflicts for Site 15 is illustrated in Figure 5.33.

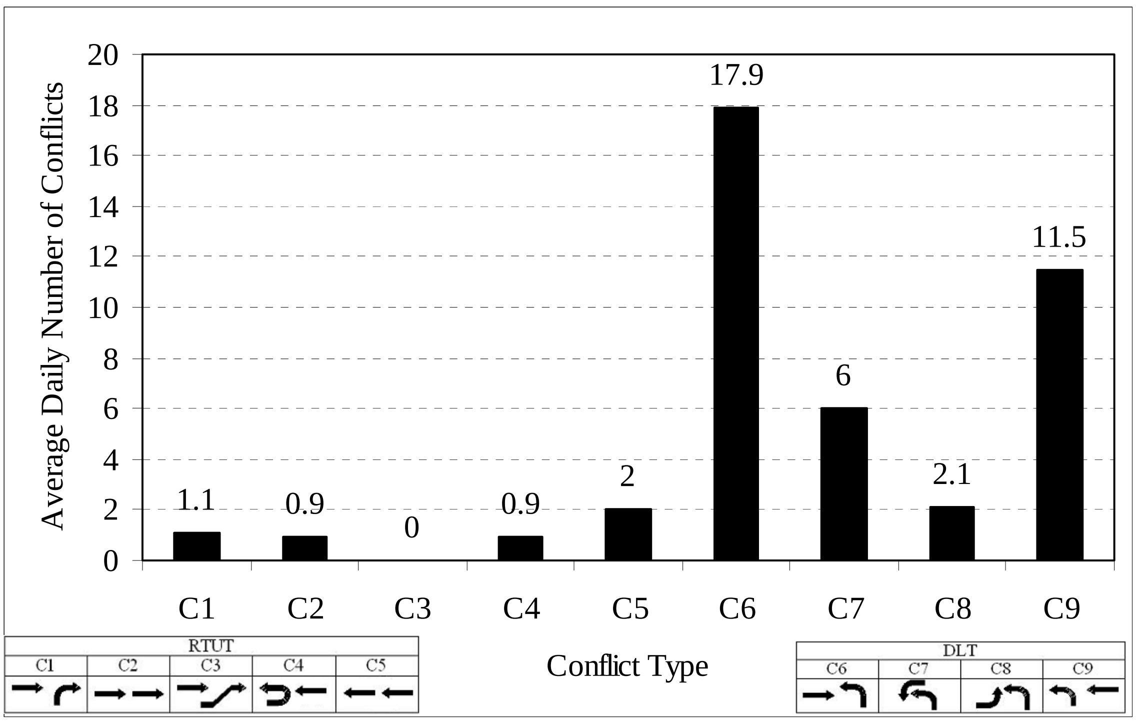


Figure 5.33 Number of Daily Conflicts by Type, Site 15, Median Opening

Site 16 At this site, there was no observation of any RTUT movement related conflicts at this site. DLT movement related conflicts C6, C7, C8, and C9 were 56, 19, 3, and 43 percent, respectively. DLT conflict type C6 had the highest percentage over all conflict types because of the main road vehicles running very high speed. The number of daily conflicts for Site 16 is illustrated in Figure 5.34.

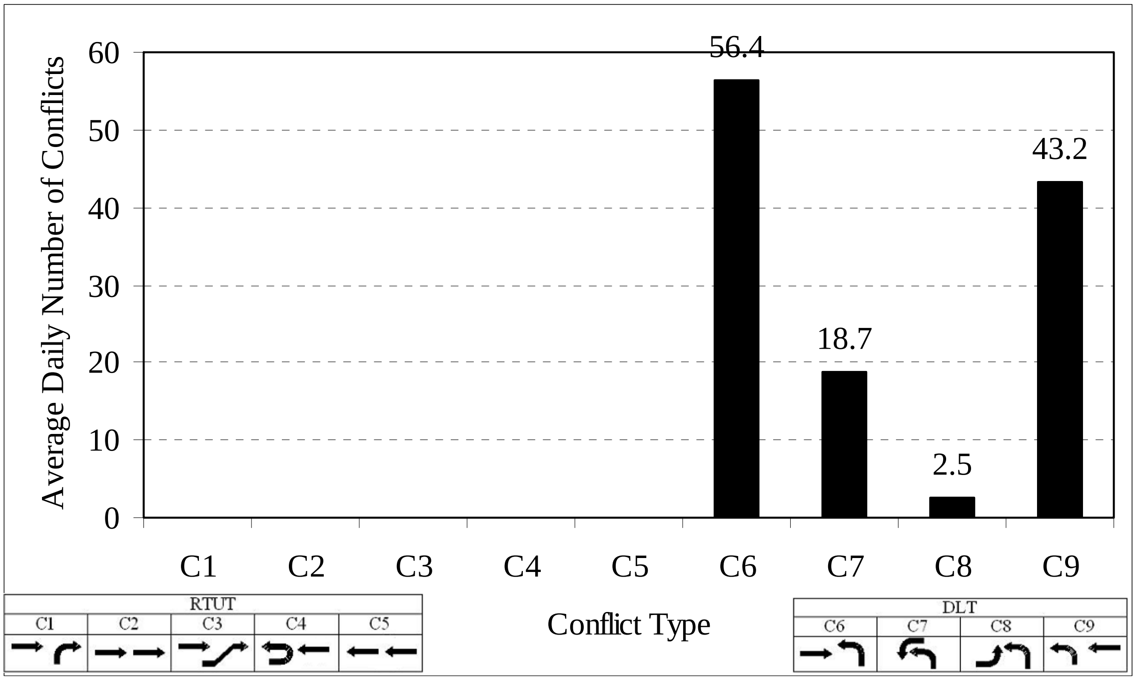


Figure 5.34 Number of Daily Conflicts by Type, Site 16, Median Opening

Figures 5.35 and 5.36 graphically illustrate the average daily number of conflicts for each conflict type related to RTUT and DLT movements respectively.

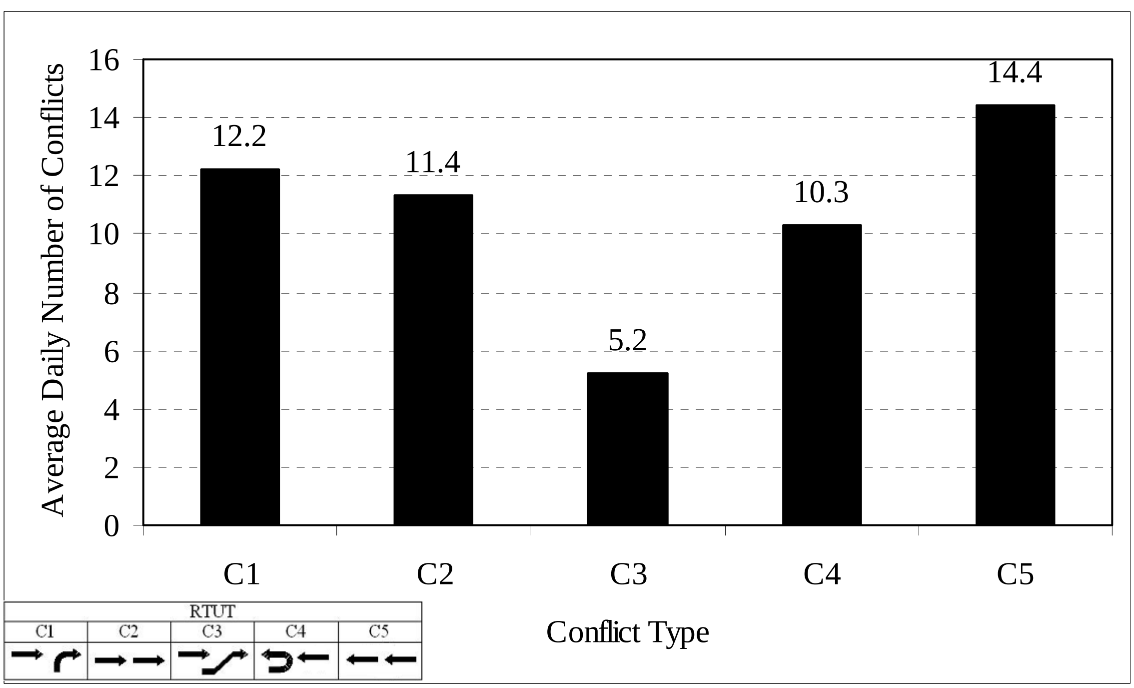


Figure 5.35 Average Number of Daily Conflicts by Type, RTUT Movement. Median O.

RTUT movements generated an average of 53.5 conflicts per day. 27 percent of the RTUT related conflicts were conflict type C5. This conflict type occurred between slow U-turn vehicles. The other conflict types: C1, C2, C3, and C4 were 23, 21, 10, and 19 percent of all RTUT related conflicts, respectively. U-turn maneuvers at the median openings generated 46 percent of all RTUT related conflicts while weaving maneuvers generated 54 percent of all RTUT related conflicts.

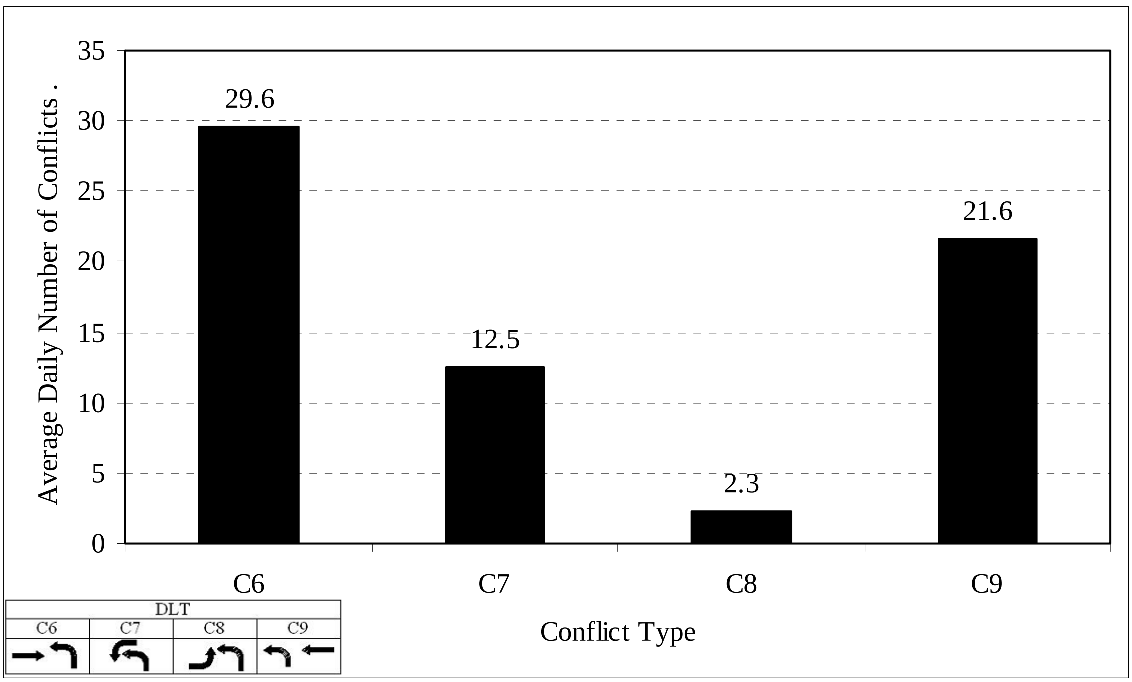


Figure 5.36 Average Number of Daily Conflicts by Type, DLT Movement, Median Opening

An average of 66 conflicts was observed for DLT movements. The data show that conflict type C6 occurred most often and were 45 percent of the all DLT related conflicts. For the other conflict types: C9, C7, and C8 were 33, 19, and 3 percent respectively. Conflict types C6 and C9 are conflicts with main road vehicles; therefore, it was expected for these types of conflicts to occur more frequently than conflict types C7 and C8,which occur within the median opening.

When DLT and RTUT conflicts were compared, DLT movements had approximately 23 percent more conflicts than RTUT movements on an average daily basis. These results are calculated without the affects of volume and other factors. Also, the use of conflict rates will provide a more accurate comparison of both alternatives.

5.2.2 Conflict Rates

5.2.2.1 Conflicts per hour

When comparing the conflict rate, conflicts per hour, DLT movements generated more conflicts per hour than RTUT movements. Figure 5.37 illustrates the average conflicts per hour for peak and non-peak periods and the average of conflicts per hour for RTUT related conflicts. In general, RTUT movement conflicts were affected by peak hour traffic significantly, the conflicts per hour increased for all the RTUT conflicts. RTUT conflict types C1, C2, C3, C4, and C5 were increased by 23, 56, 25, 20 and 15 percent during peak hour periods respectively. On the other hand, all DLT related conflicts increased during peak hours as it is illustrated in Figure 5.38. DLT conflict types C6, C7, and C8 were increased by 14, 21, 44 and 11 percent during peak hour periods.

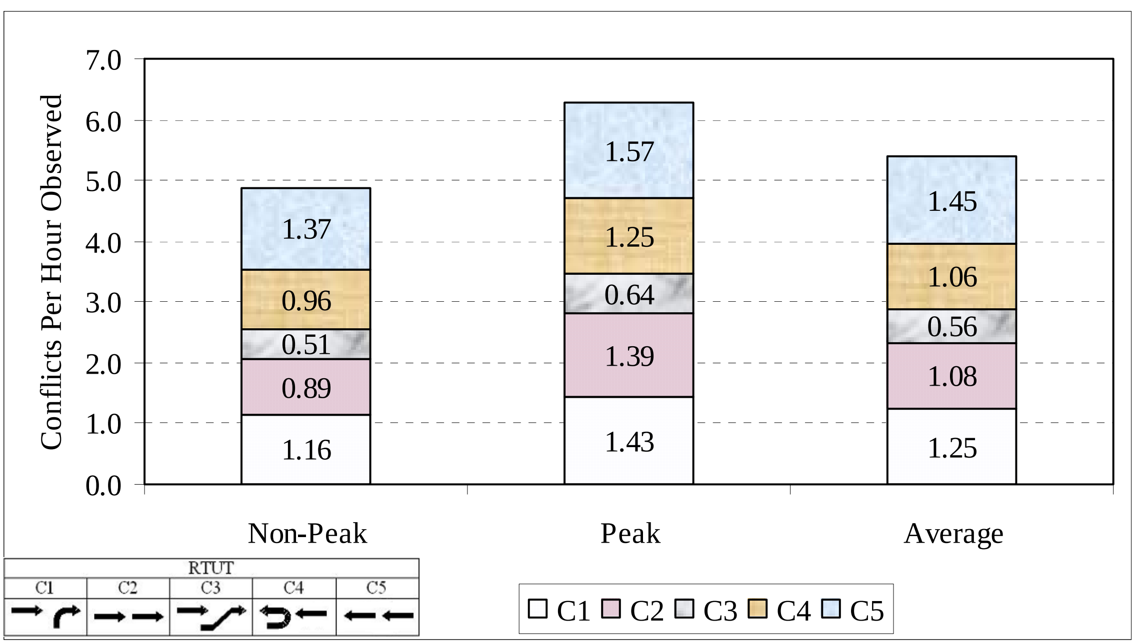


Figure 5.37 Conflicts by time Period, RTUT Movement, Median Opening

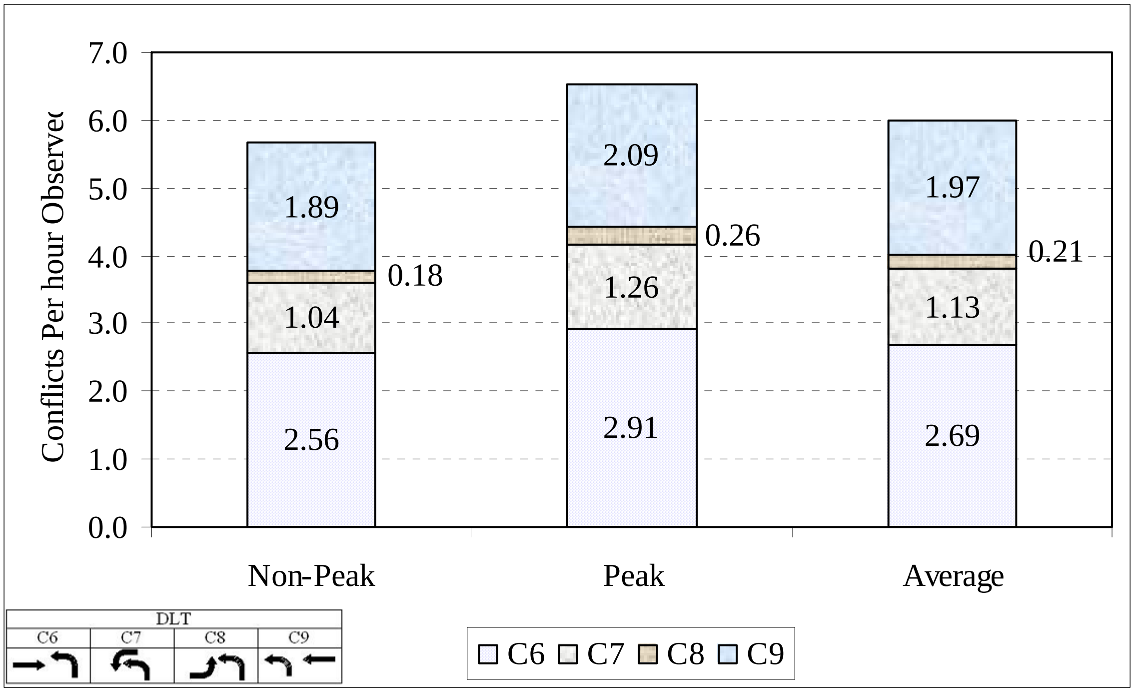


Figure 5.38 Conflicts by time Period, DLT Movement, Median Opening

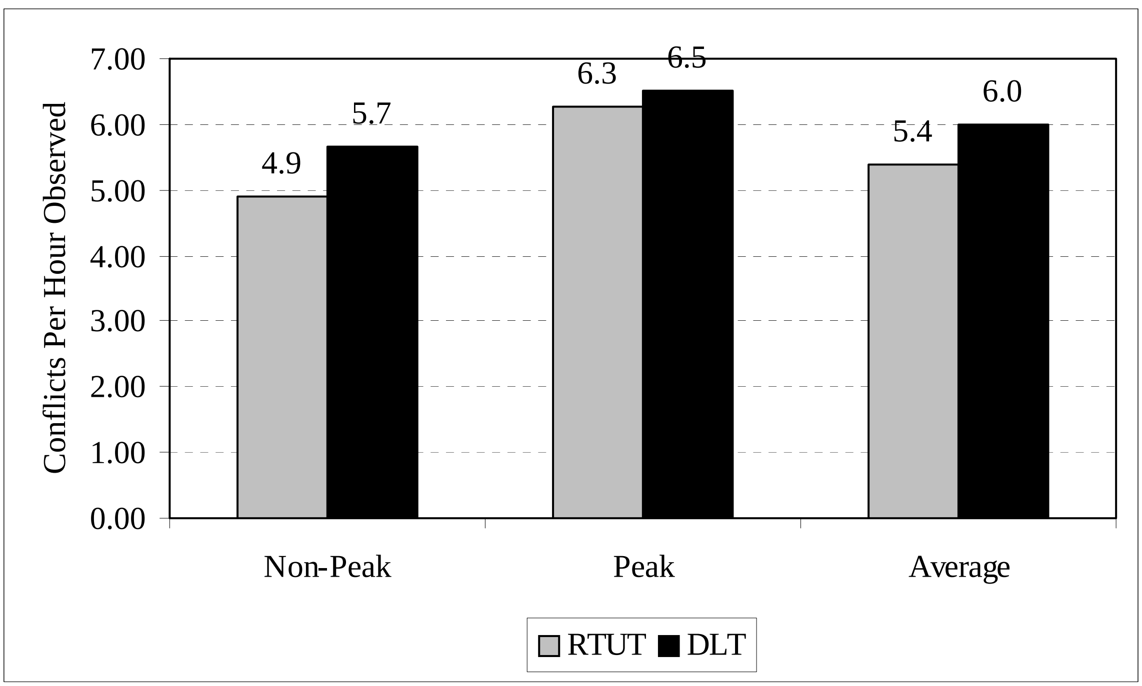


Figure 5.39 Conflicts by time Period, DLT and RTUT Movements Comparison, Median Opening

Figure 5.39 presents the average number of conflicts per hour for RTUT and DLT movements. When both peak and non-peak periods are compared, both movements have high conflict rates during the peak hours. On average, DLT movements generated 10 percent more conflicts per hour than RTUT movements.

5.2.2.2 Conflicts per Thousand Involved Vehicles

This conflict rate was utilized for median opening sites as well. The total number of conflicts, through traffic vehicles, maneuvering vehicles, and conflict rates were obtained for each site at a median opening. Table 5.13 and Figure 5.40 presents the number of conflicts per thousand vehicles involved at each median opening site. The values given in Table 5.13 indicate that all sites had low conflict rates for RTUT movements. Moreover, Table 5.13 indicates that the average conflict rate for RTUT was 39 percent lower than that of DLT movements.

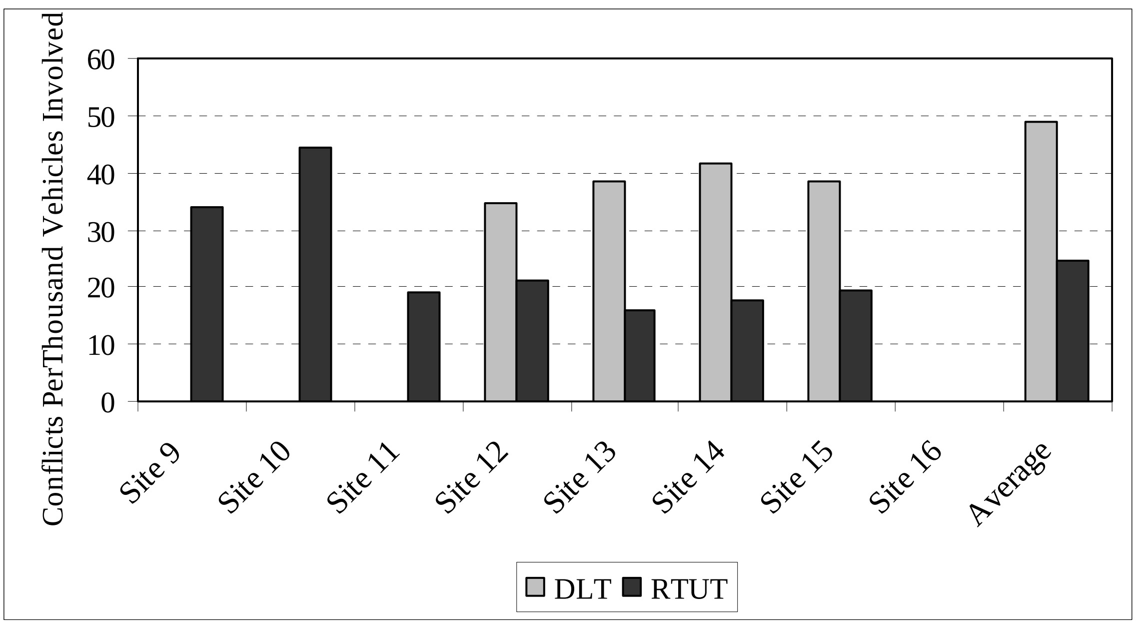


Figure 5.40 Conflicts per Thousand Involved Vehicles, Median Opening

Table 5.13 Number of Conflicts per Thousand Involved Vehicles, Median Opening

Site	DLT	RTUT
Site 9	N/A	33.93
Site 10	N/A	44.43
Site 11	N/A	18.92
Site 12	34.52	21.32
Site 13	38.61	15.83
Site 14	41.59	17.64
Site 15	38.47	19.53
Site 16	45.42	N/A
Average	39.72	24.51

5.2.3 Severity Analysis

The frequency of the severity for each conflict type with ROC score were obtained for median opening sites and are illustrated in Figures 5.41 through 5.49. Based on these figures, the average ROC scores were calculated for all conflicts.

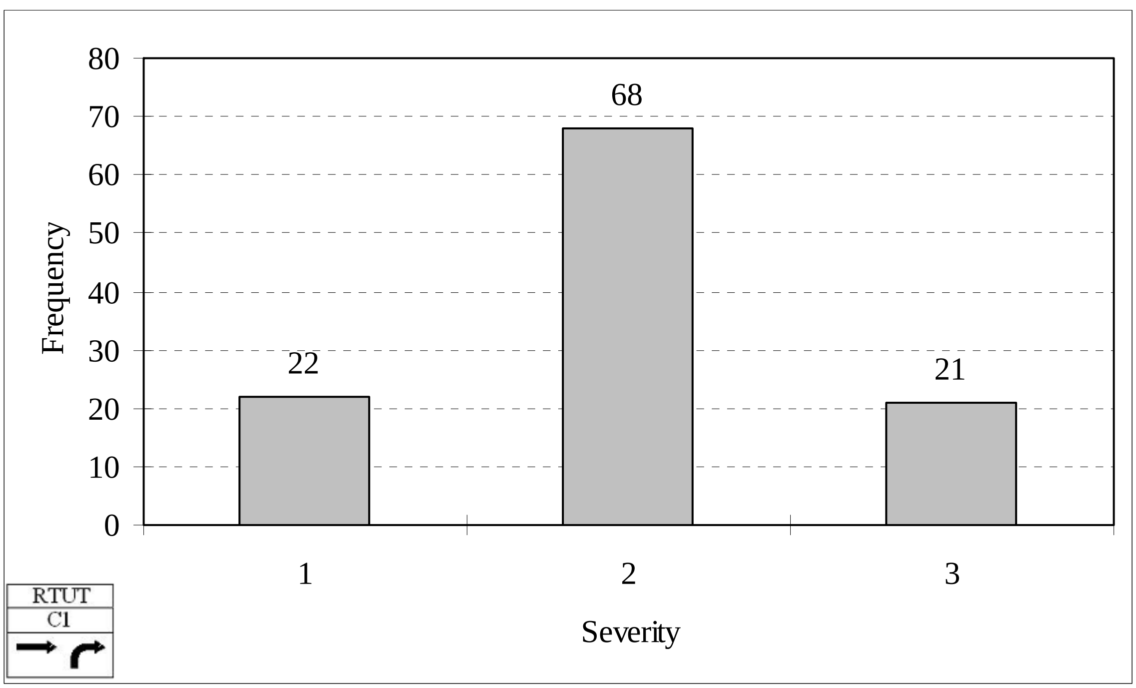


Figure 5.41 Distribution of Severity Conflict Type C1, Median Opening

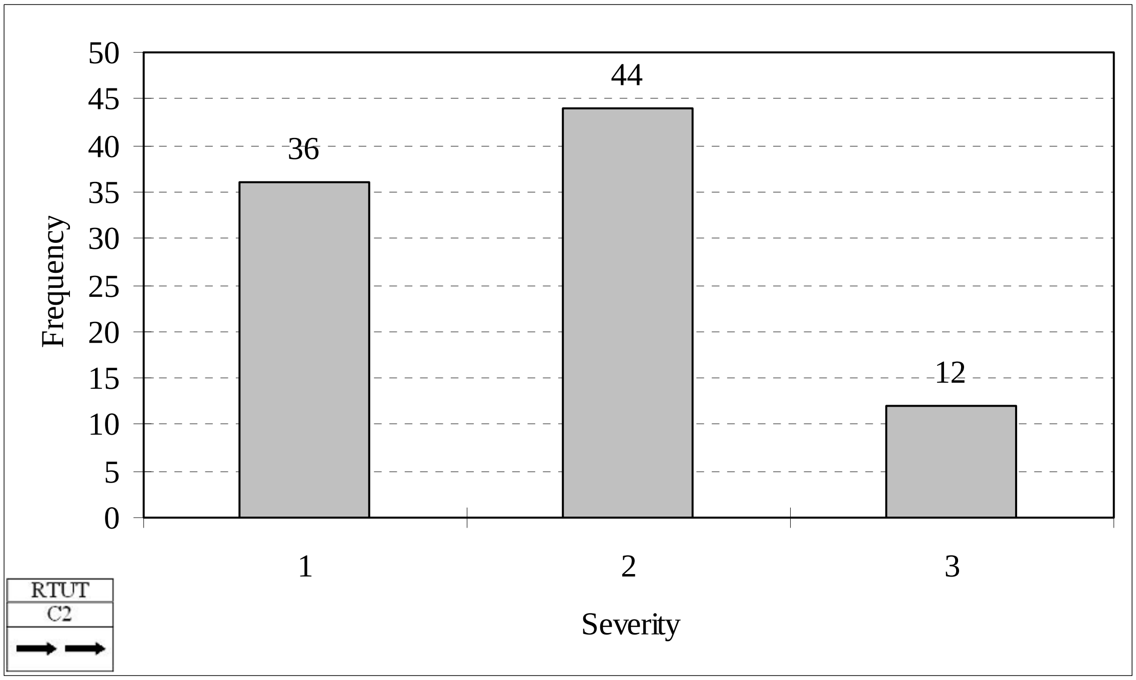


Figure 5.42 Distribution of Severity Conflict Type C2, Median Opening

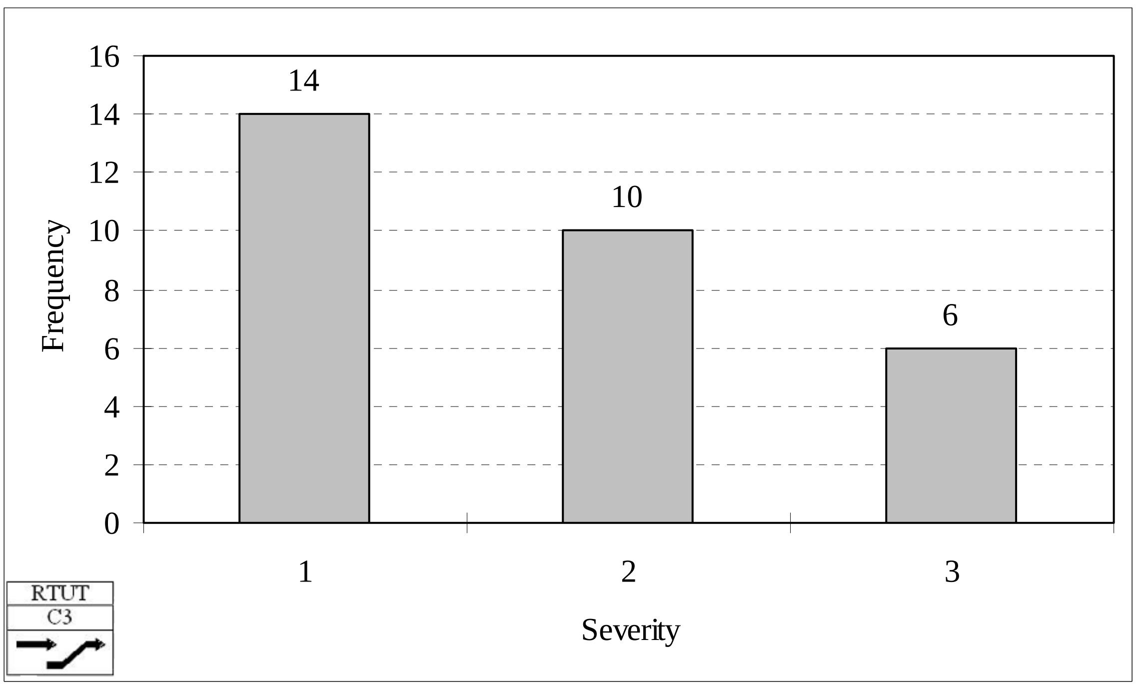


Figure 5.43 Distribution of Severity Conflict Type C3, Median Opening

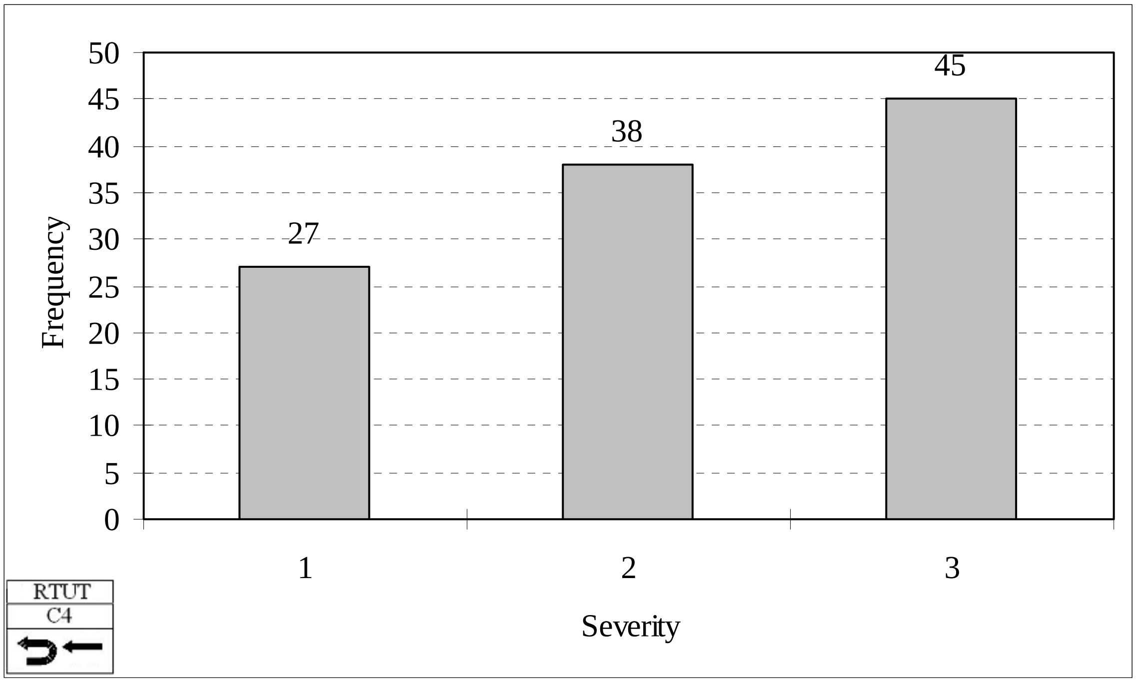


Figure 5.44 Distribution of Severity Conflict Type C4, Median Opening

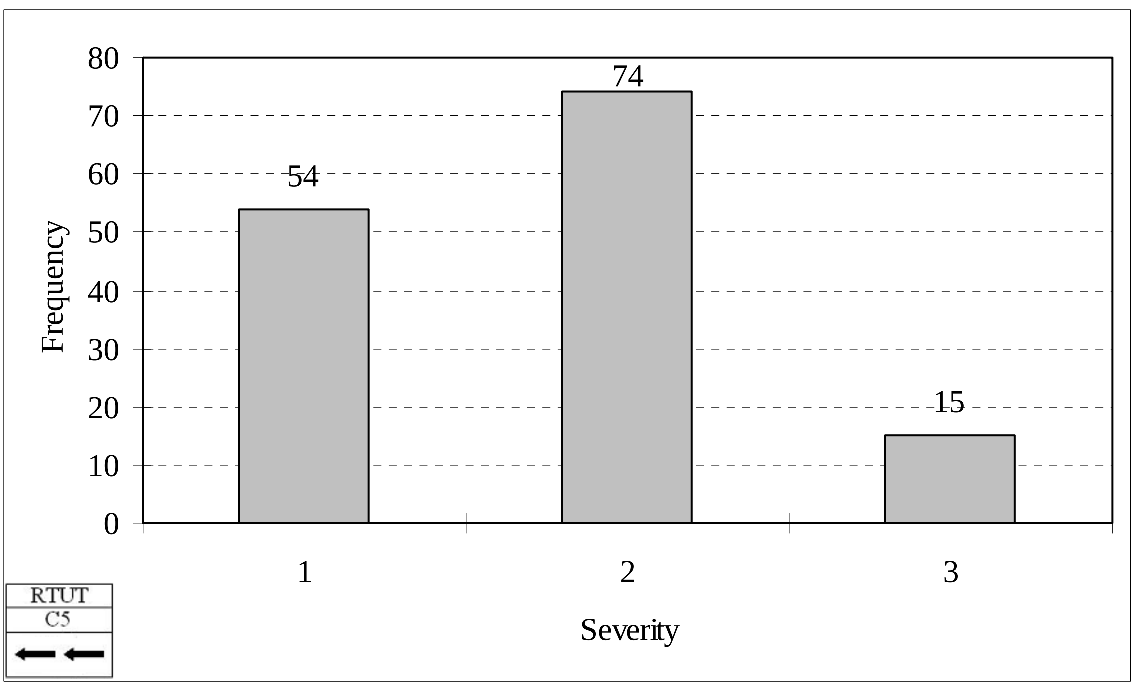


Figure 5.45 Distribution of Severity Conflict Type C5, Median Opening

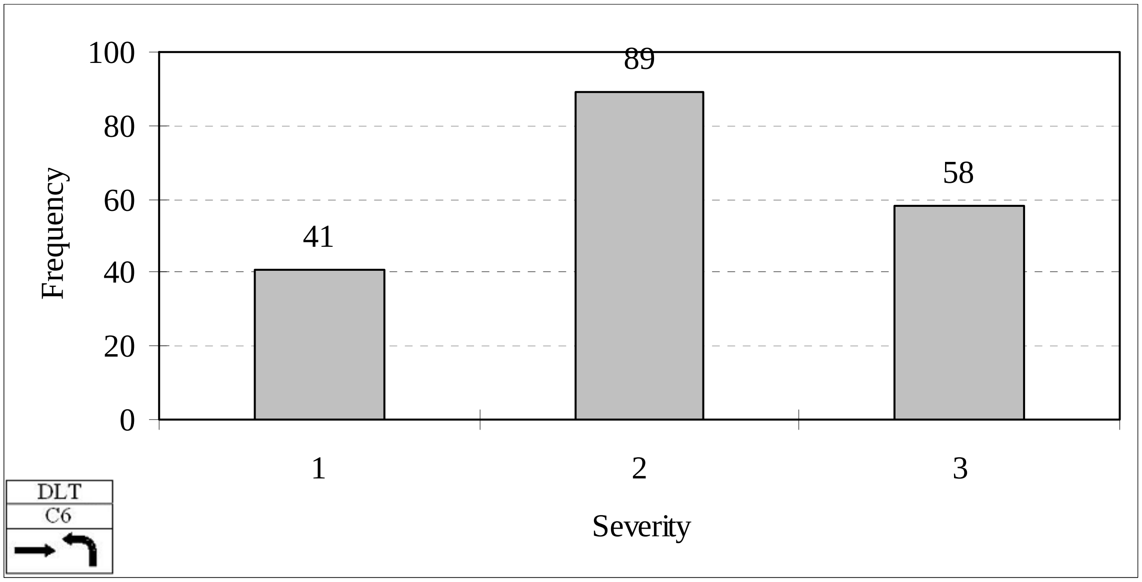


Figure 5.46 Distribution of Severity Conflict Type C6, Median Opening

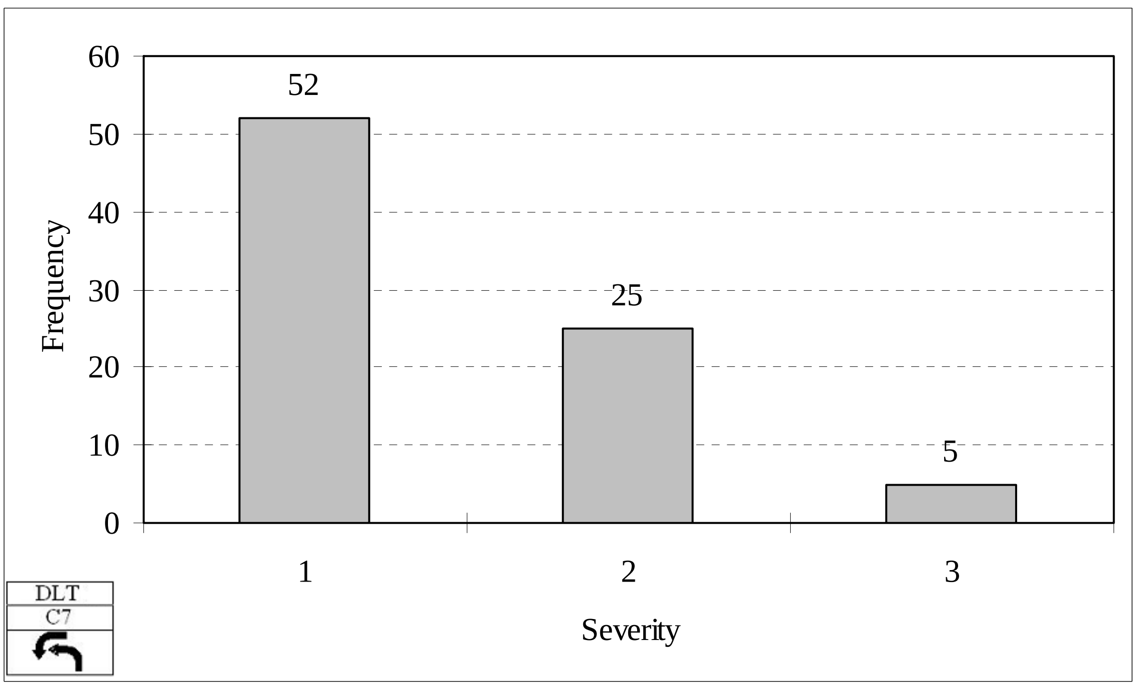


Figure 5.47 Distribution of Severity Conflict Type C7, Median Opening

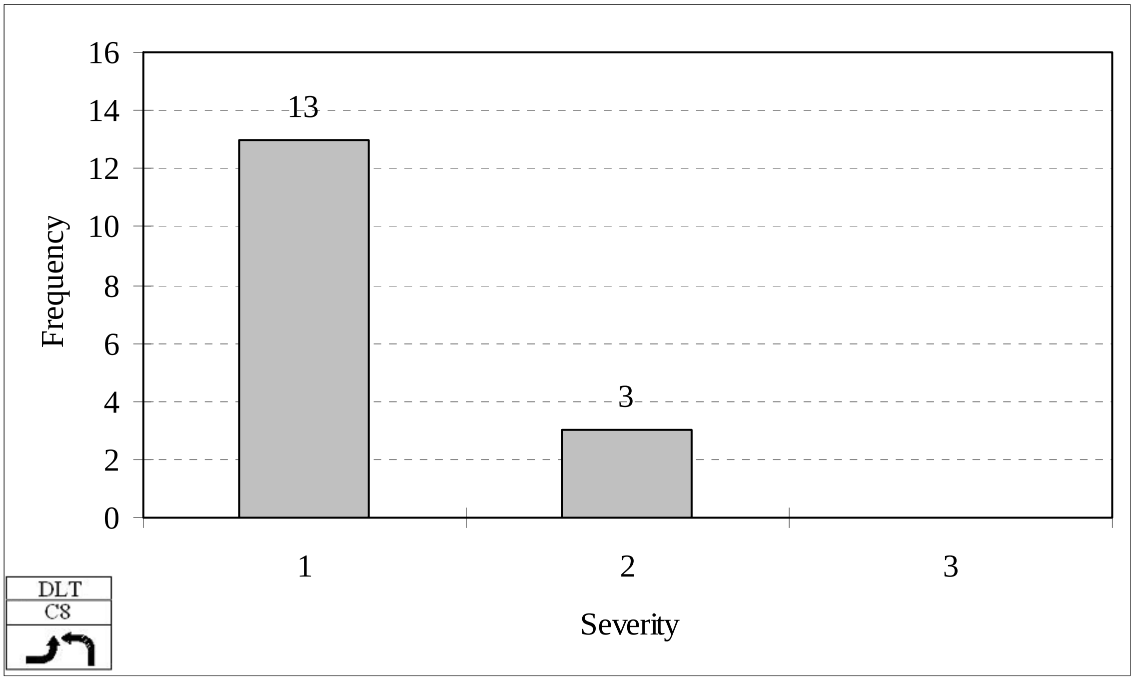


Figure 5.48 Distribution of Severity Conflict Type C8, Median Opening

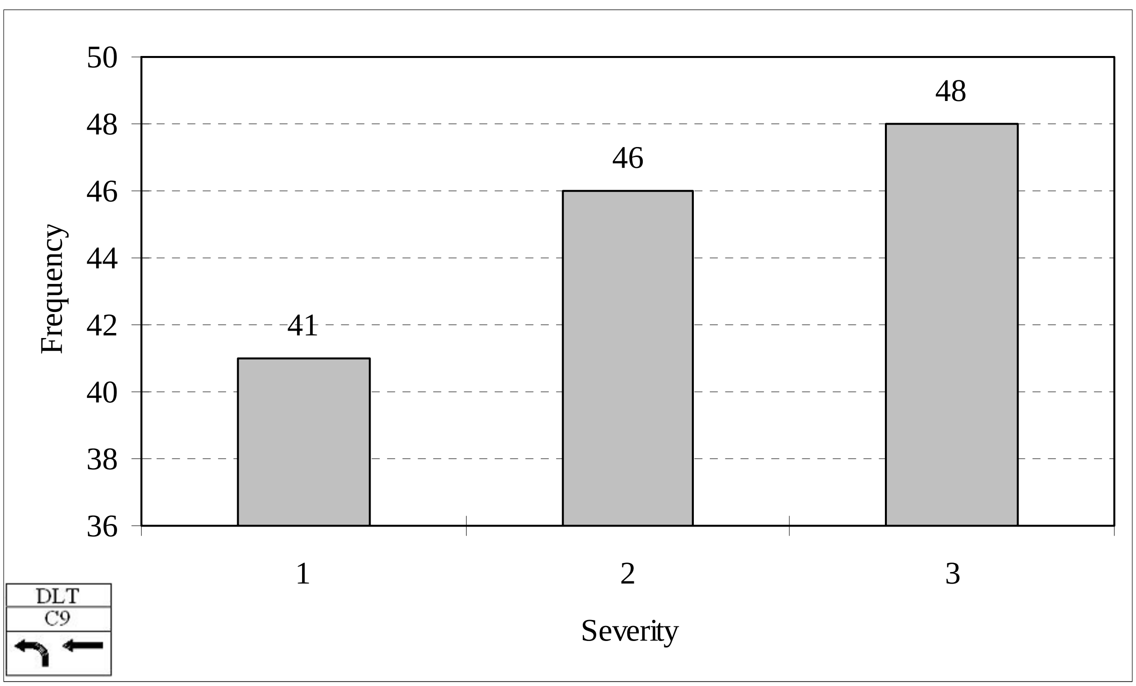


Figure 5.49 Distribution of Severity Conflict Type C9, Median Opening

Figure 5.48 illustrates the average ROC scores for RTUT movements for median opening sites. Conflict types C1 and C4 had higher severity when compared to conflict types C2, C3 and C5 because of the speed difference with the major road vehicles are higher for the conflicts C1 and C4. On the other hand, the speed difference for conflicts C2, C3 and C5 was relatively low. Figure 5.49 illustrates the average ROC scores for DLT movements. Conflict C6 and C9 have significantly higher average severity scores compared to conflicts C7 and C8. Overall comparison in the average severity scores of RTUT and DLT movements indicated that DLT movements had more severe conflicts than RTUT movements. DLT movements had an average severity score of 1.91 while RTUT movements had an average severity score of 1.60.

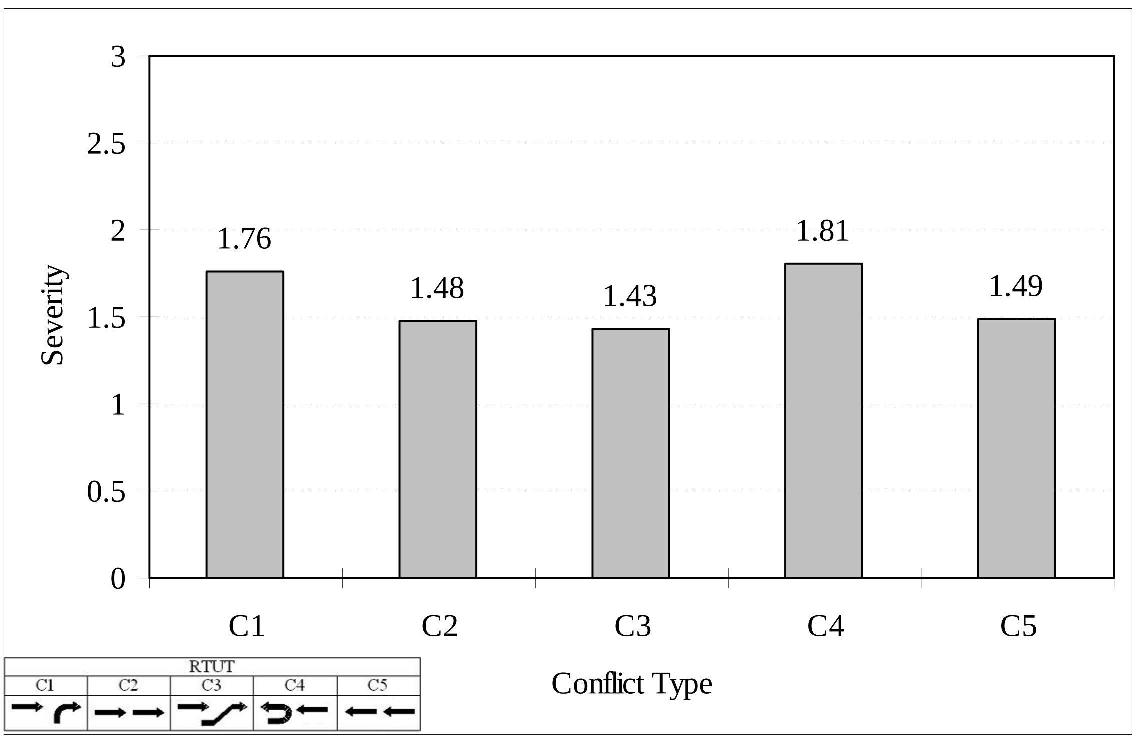


Figure 5.50 Average ROC Scores for RTUT Movements, Median Opening

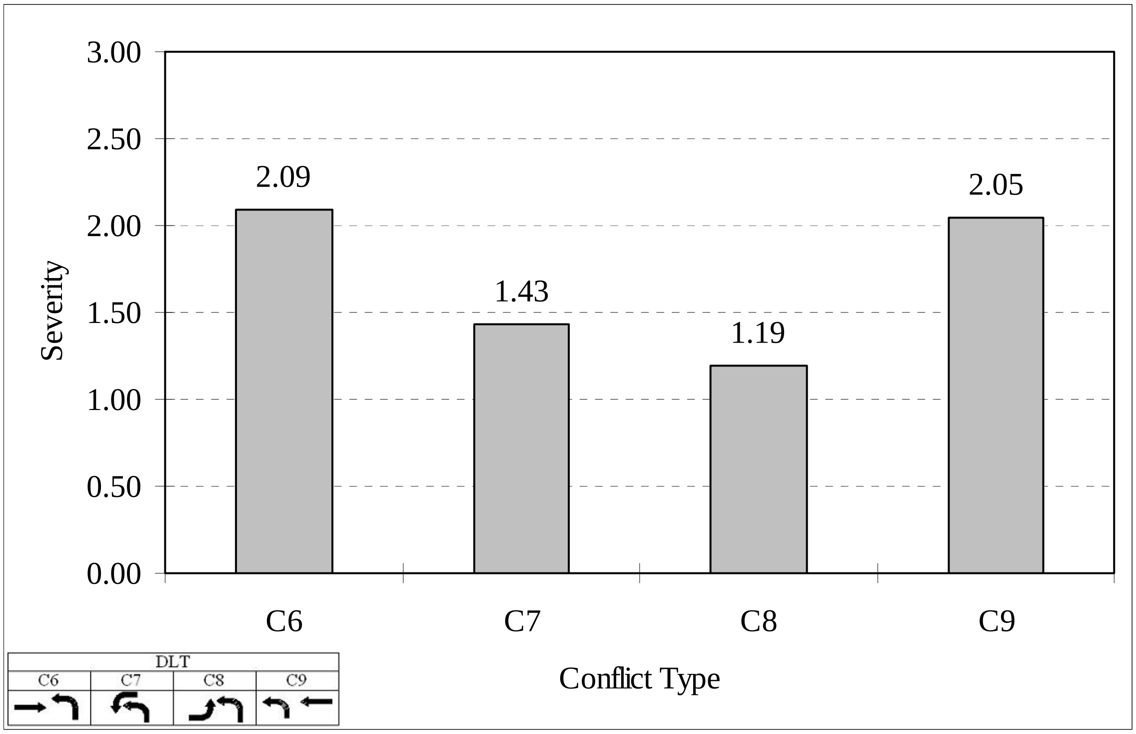


Figure 5.51 Average ROC Scores for DLT Movements, Median Opening

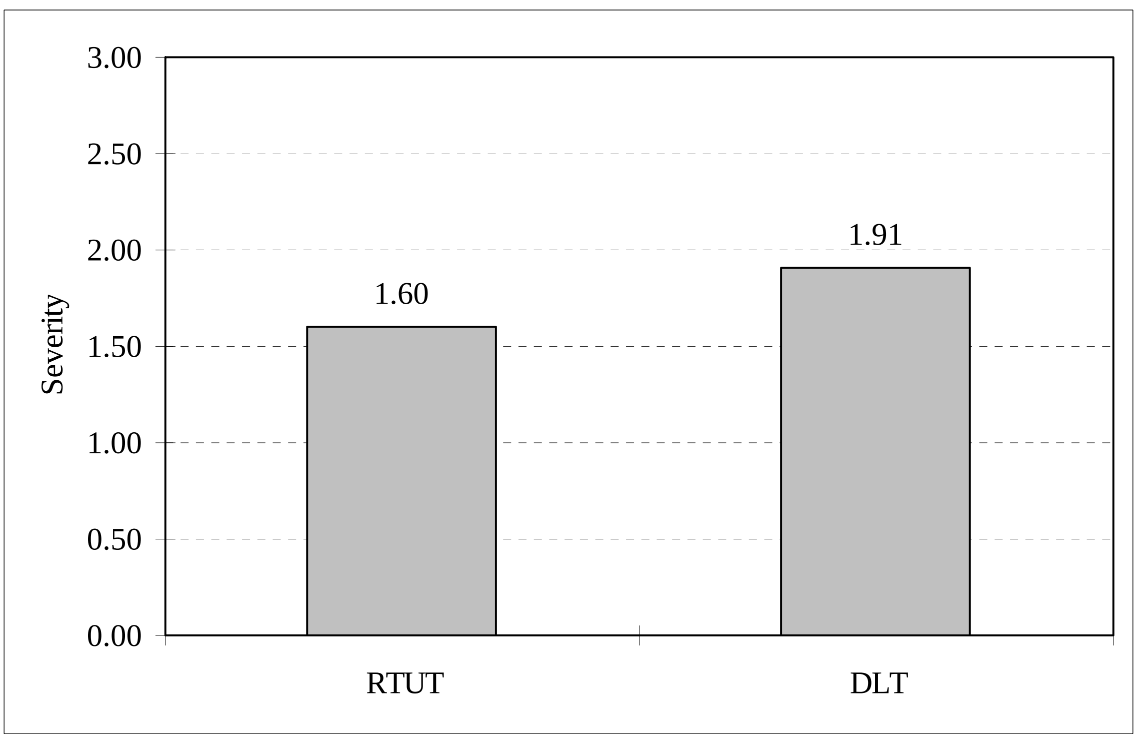


Figure 5.52 Severity Comparison for DLT and RTUT Movements by ROC, Median Opening

5.3 U-turn Analysis

5.3.1 U-turn Distribution at Median Openings

In this analysis, additional data other than the conflict data were collected at median opening sites. The data have included types of vehicles and geometric characteristics of median openings. Also, vehicles' U-turn behavior was observed to evaluate the geometric characteristics of median openings. U-turns were classified in three categories; First, vehicles made U-turn onto inner lane of main road. Second, vehicles made U-turn onto outer lane of main road. Finally, vehicles turn onto flare or encroach onto the shoulder in case a flare was not present in geometric design. Vehicles making U-turns at selected sites were classified in five categories. The criteria for classification of the vehicles were length and size of the vehicles. These categories were:

Category 1	PV:	Passenger vehicles
Category 2	MV:	Minivans, light pick-up trucks and small sport utility vehicles
Category 3	LV:	Vans, medium pick-up trucks, large sport utility vehicles
Category 4	MT:	Medium trucks and busses
Category 5	LT:	Large trucks and busses

The data were collected at six sites. The geometric characteristics of these sites were presented in Table 5.14. Also, Figure 5.53 illustrates a typical median opening with the geometric characteristics.

Table 5.14 Geometric Characteristics of Sites for U-turn Analysis

Site			R (ft)			Auxiliary Lane
Arterial		Location	R_1	R_2	R_3	
9	Bruce B. Downs Blvd.	Pepple Creek.	47	24	N/A	No
10	Thonotosassa Rd.	Goldfinch Dr.	3	24	8	Yes
11	US 301	SR 60	25	24	12	Yes
13	Bearss Ave	Dale Mabry Hwy	18	24	N/A	No
14	Gunn Hwy.	Normandie	45	25	N/A	Yes
15	Gunn Hwy.	Anderson	21	25	N/A	Yes

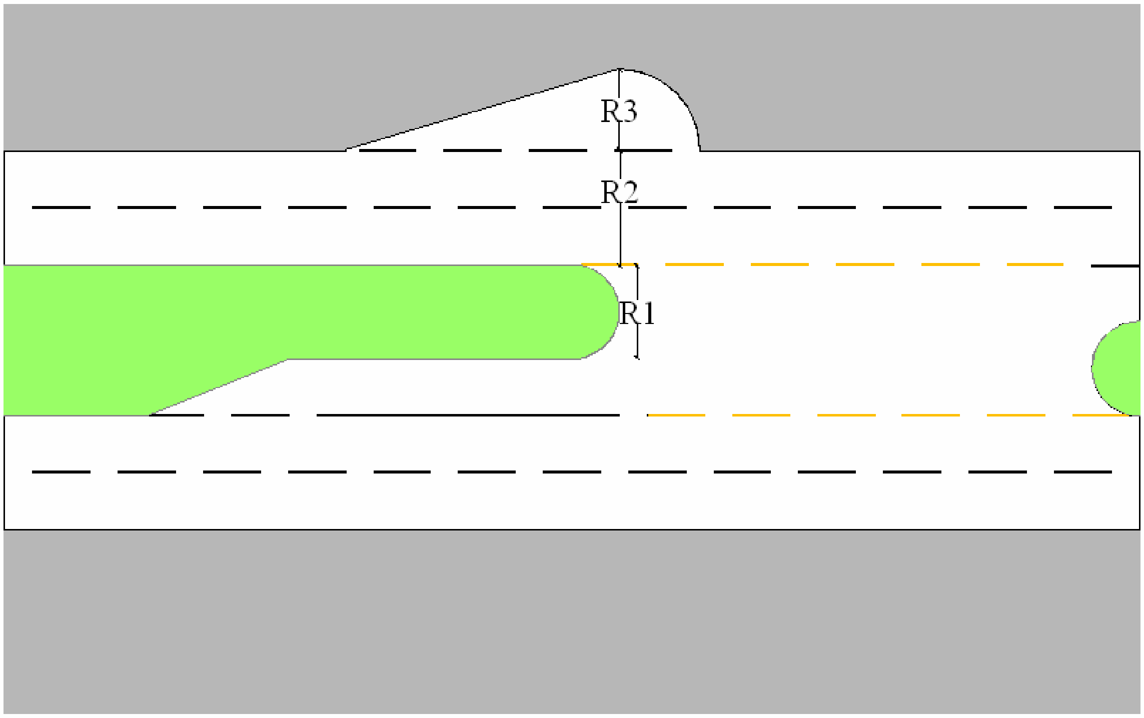


Figure 5.53 Median Opening Geometric Characteristics

Table 5.15 presents the data collected at the field for U-turn distribution at six sites. Also, Figures 5.54 through 5.59 illustrates the distribution of U-turns at each site. The geometric characteristics and U-turns distributions at each site are explained in the following paragraphs.

Site 9 This site has a wide median (47 ft.) without an auxiliary lane. All the vehicles turned on to either inner lane or outer lane of the main road. The vehicles turned on to inner lane were 46 percent of all vehicles while 54 percent of the all vehicles turn onto outer lane. At this site, construction of the auxiliary lane would be beneficial for safety and accommodation of the vehicles making a U-turn.

Site10 This site has very narrow median (3 ft.) with an auxiliary lane and flare to accommodate U-turns. All of the large vehicles used flare to make U-turns. The vehicles turning on to flare was 73 percent while vehicles turned on to inner and outer lanes were 2 and 25 percent, respectively.

Site 11 This site has 25-foot median with an auxiliary lane and flare. When this site is compared to Site 10 more vehicles turned on to inner lane to complete U-turns. At this site approximately 72 percent of the vehicles turn on to outer lane while 9 percent and 19 percent turned on to inner lane and flare, respectively.

Site 13 This site has an 18-foot median without an auxiliary lane and flare. Most of the large vehicles had to go out of road to shoulder to make U-turns. Only 4 percent of all vehicles turned on to inner lane. The vehicles which turned on to outer lane and shoulder were 47 and 49 percent, respectively. Construction of an auxiliary lane is suggested to increase safety at this site.

Site 14 This site has a wide median (45 ft.) with an auxiliary lane. At this site, road site has a curb which prevents vehicles to encroach on to the shoulder. At this site, 25 percent of vehicles turn on to inner lane while 75 percent used outer lane to make U-turns.

Site 15 This site is very similar to Site 14 except the median width is 25 feet. Also, this site has a curb along the major road. At this site, 23 percent of vehicles turn on to inner lane while 77 percent used outer lane to make U-turns.

Table 5.15 U-turn Distribution at Six Sites

Site	U-Turn	PV			MV			LV			MT			LT		
		Inner Lane	Outer Lane	Shl./ Flare	Inner Lane	Outer Lane	Shl./ Flare	Inner Lane	Outer Lane	Shl./ Flare	Inner Lane	Outer Lane	Shl./ Flare	Inner Lane	Outer Lane	Shl./ Flare
9	No.	114	126	0	60	72	0	20	28	0	4	4	0	0	4	0
	%	47.7	52.3	0.0	45.5	54.5	0.0	41.5	58.5	0.0	50.0	50.0	0.0	0.0	100	0.0
10	No.	8	88	156	0	28	108	0	0	60	0	0	12	0	0	4
	%	3.2	34.9	61.9	0.0	20.6	79.4	0.0	0.0	100	0.0	0.0	100	0.0	0.0	100
11	No.	26	198	40	7	48	11	0	24	15	0	2	5	0	0	2
	%	9.8	75.0	15.2	10.6	72.7	16.7	0.0	61.4	38.6	0.0	28.6	71.4	0.0	0.0	100
13	No.	5	53	40	1	20	22	0	5	15	0	0	4	0	0	2
	%	5.1	54.3	40.6	2.3	46.5	51.2	0.0	25.0	75.0	0.0	0.0	100	0.0	0.0	100
14	No.	69	106	0	19	114	0	3	32	0	0	21	0	0	7	0
	%	39.4	60.6	0.0	14.3	85.7	0.0	8.6	91.4	0.0	0.0	100	0.0	0.0	100	0.0
15	No.	116	80	0	37	61	0	13	64	0	0	14	0	0	2	0
	%	59.3	40.7	0.0	38.0	62.0	0.0	16.7	83.3	0.0	0.0	100	0.0	0.0	100	0.0

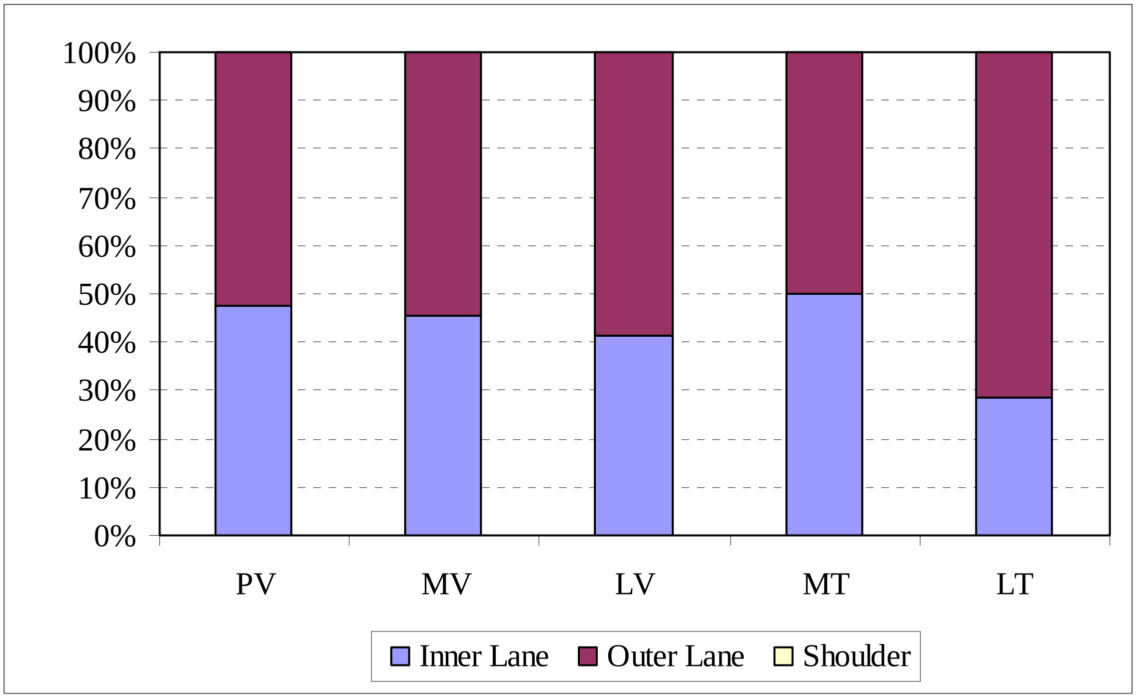


Figure 5.54 U-Turn Distribution by Vehicle Type, Site 9

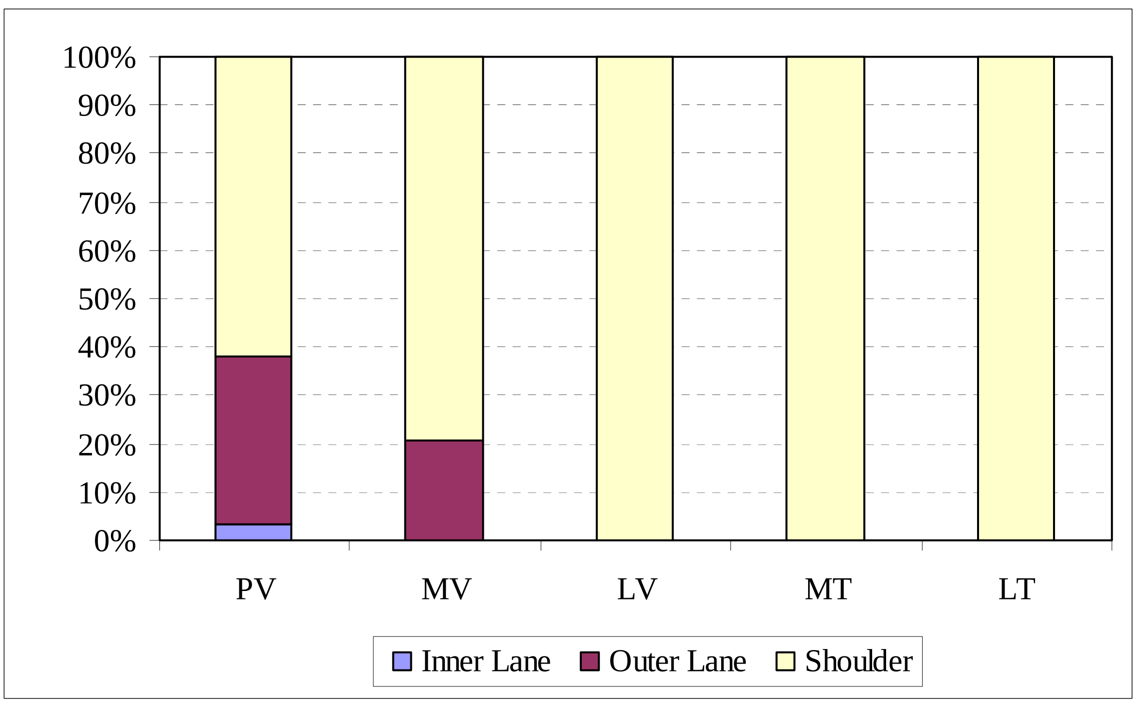


Figure 5.55 U-Turn Distribution by Vehicle Type, Site 10

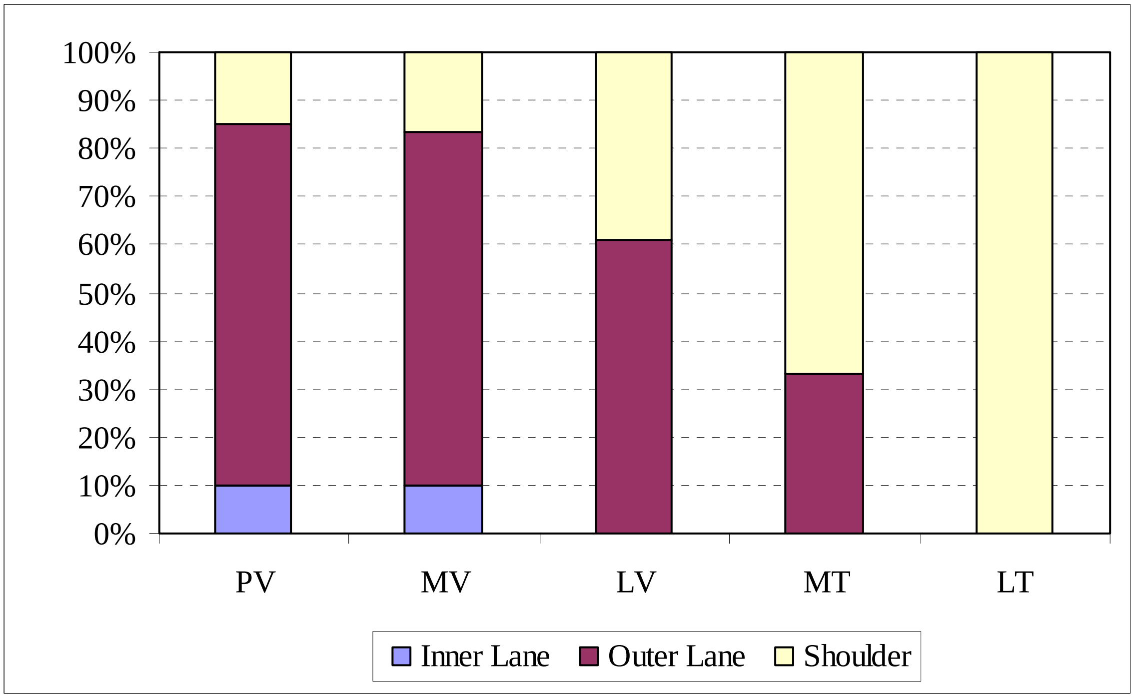


Figure 5.56 U-Turn Distribution by Vehicle Type, Site 11

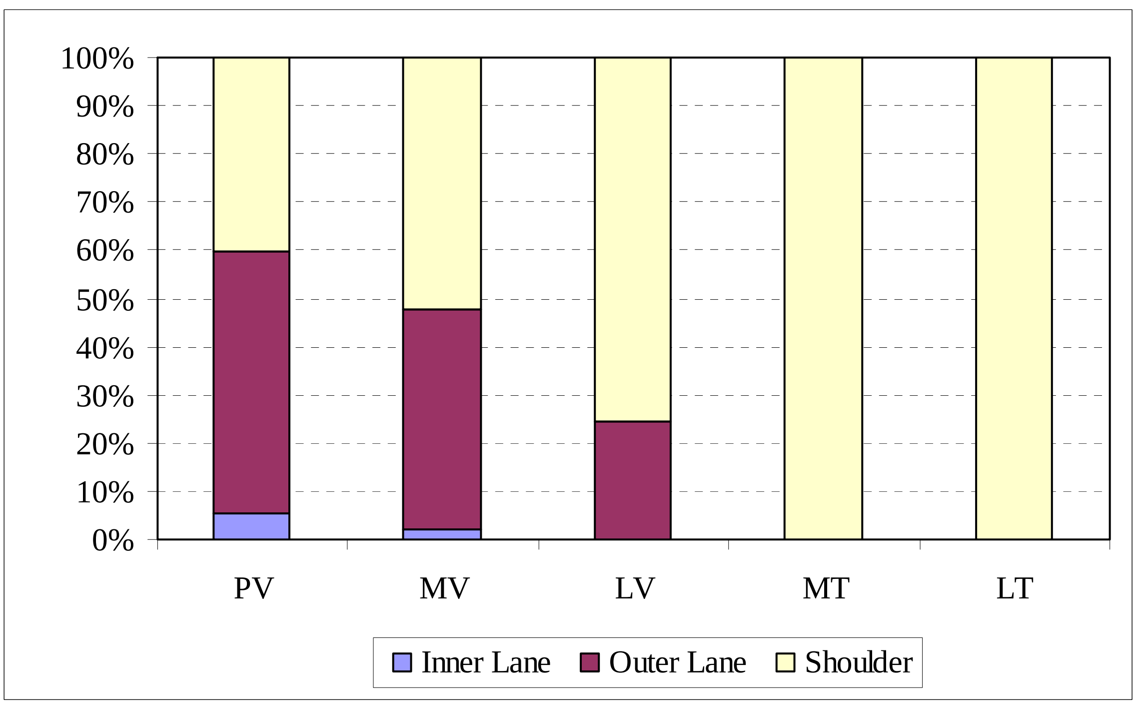


Figure 5.57 U-Turn Distribution by Vehicle Type, Site 13

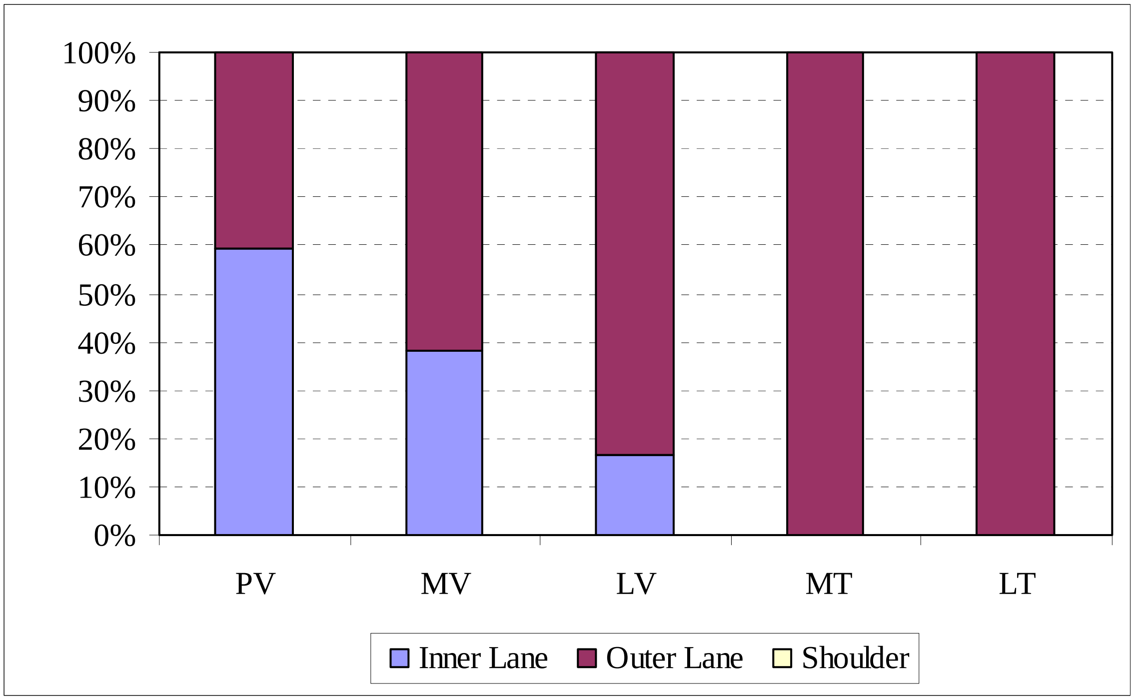


Figure 5.58 U-Turn Distribution by Vehicle Type, Site 14

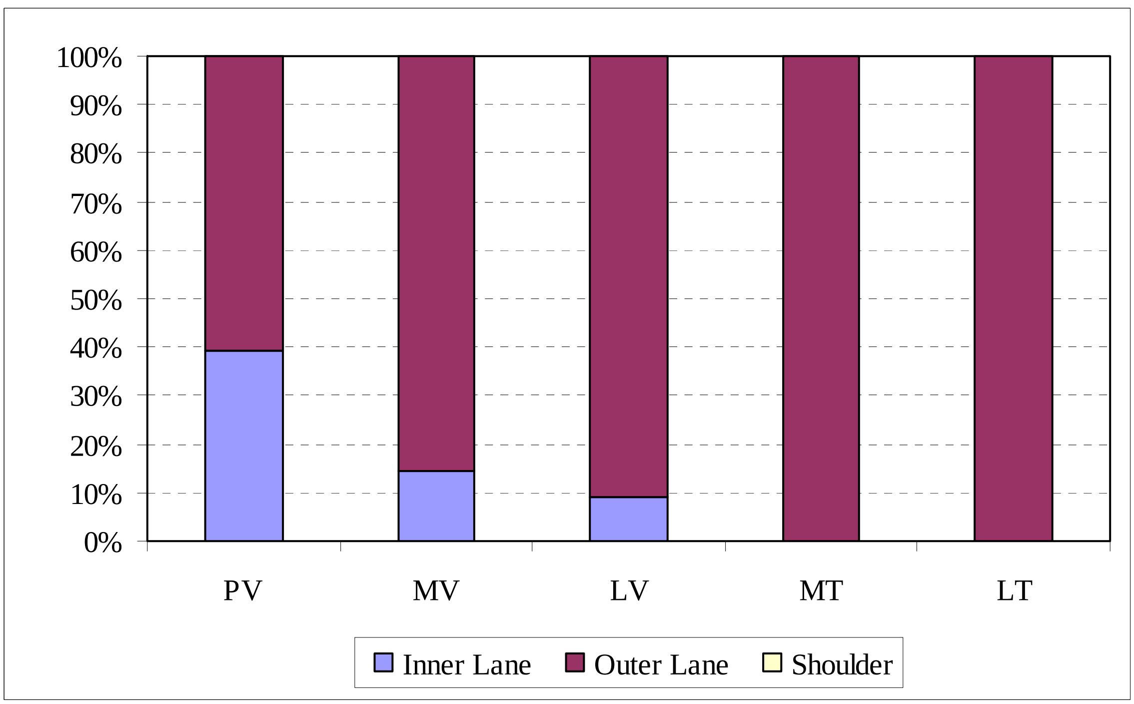


Figure 5.59 U-Turn Distribution by Vehicle Type, Site 15

The results of the analysis show at most sites, median openings accommodate U-turns without any problems for Category 1 and 2 vehicles which were 85 percent of all the vehicles observed in this analysis. Construction of flares helped the drivers where geometric characteristics of median openings are not sufficient to accommodate U-turns.

5.3.2 Right Turn and U-turn Conflict Model

The conflicts related to U-turns and right turns from cross streets were a major concern at signalized intersection sites. Especially, safety evaluation of RTUT and DLT conflicts showed that this type of conflicts has a significant effect on RTUT maneuvers safety. Figure 5.60 shows the conflict type between U-turns and right turns from the cross streets.

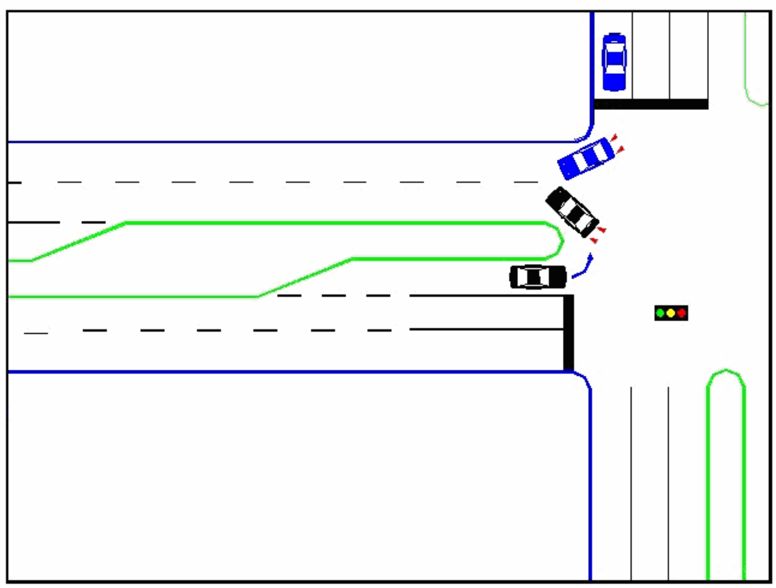


Figure 5.60 RT-UT Conflict

A linear regression model was developed to estimate the relationship between U-turn and right turn volumes, and conflicts rates. Several different regression models were tried and the linear regression model with exponential form was found to have the best goodness of fit to the field data. In the regression model, dependent variable is RT-UT conflict rate, which is the average of conflict rates for the same volume conditions of U-turns and right turns at cross streets. The residual values were plotted against each variable. A bell-shape was observed for the plot of residual values against U-turn volume variable which indicated that a quadratic form was necessary in specifying the model. Therefore, the square of U-turn volume was used instead of U-turn volume in the model. The regression results were presented in Table 5.16.

Table 5.16 Regression Model Results

Model Summary(b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.698(a)	.487	.468	.42186

a Predictors: (Constant), Uvolume2, Rtvolume
b Dependent Variable: RT-UT Conflict

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9.131	2	4.565	25.653	.000[a]
	Residual	9.610	54	.178		
	Total	18.741	56			

a. Predictors: (Constant), Uvolume2, Rtvolume
b. Dependent Variable: lnConflict

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.30144	.169		-1.779	.081
	Rtvolume	.03863	.006	.676	6.929	.000
	Uvolume2	.00089	.001	.139	1.427	.159

a. Dependent Variable: lnConflict

$$RT\text{-}UT = e^{-0.030+0.03868RTVOL+0.00089UTVOL} \quad \text{……….……………………….……………}(5.1)$$

where,

RT-UT– Average conflict rate per fifteen minute interval,

Uvolume2– The square of U-turn Volume per fifteen minute interval, RTVOL – Right turn volume of cross street under green arrow time in subject approach per fifteen minute interval.

The model shows that the RT-UT conflict rate increases with the increase of U-turn volume and right turn at cross streets. The adjusted R square value is 0.468, which implies that the selected independent variables can explain 46.8% of variations in dependent variable. T-stat indicated that right turn volume is significant at a 95 percent level of confidence, while the U-turn volume was significant at an 80 percent level of confidence. The coefficients of variables were showed that right turn volume at cross streets had higher effect on the RT-UT conflict rate than U-turn volume.

Based on Equation 5.1, curves for the average RT-UT conflict were developed. Figure 5.61 shows a group of curves for average RT-UT conflict rate for the volume values of right turns at cross streets during the green arrow time of subject approach ranges from 10 to 50 vehicles per fifteen minute intervals. The y-axis represents the U-turn volume at signalized intersection. The x-axis represents the average RT-UT conflict rate per fifteen minute interval.

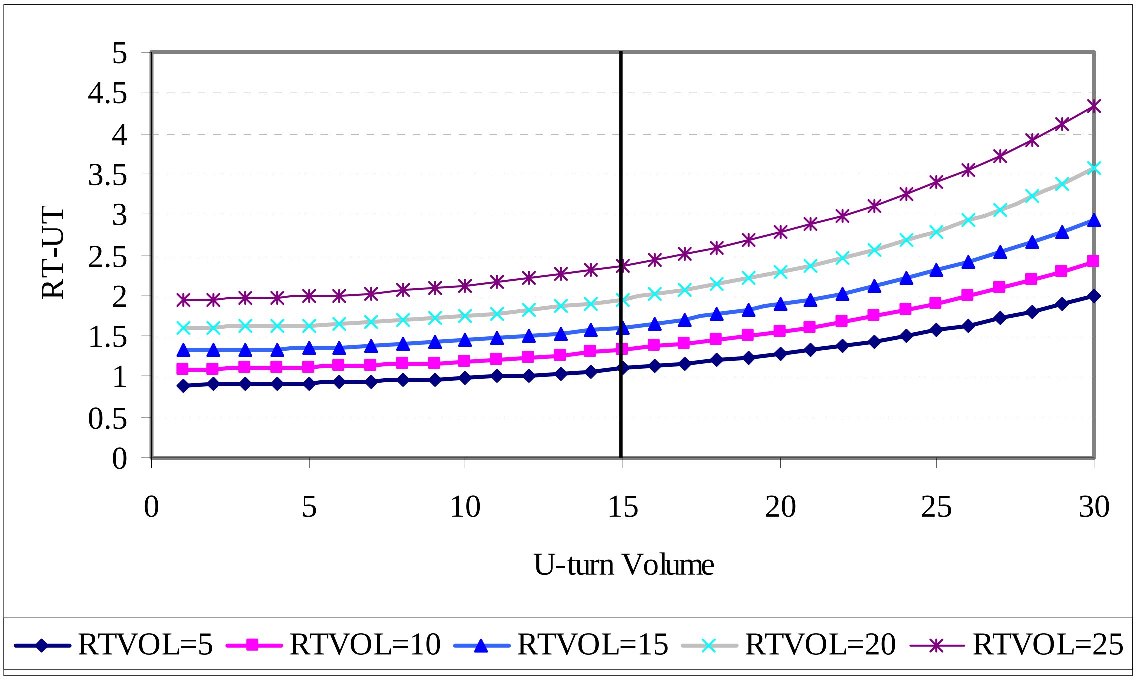


Figure 5.61 RT-UT Conflict Rate Curves Based on the Model

According to the curves plotted in Figure 5.61, when U-turn volume and right turn volume at cross street reaches to 30 vehicles per fifteen minute interval, conflict rate is approximately 4.3. Higher rates of RT-UT conflict will cause safety and operational problems at signalized intersections. Median opening closures or conversions in advance of signalized intersections will force the drivers to make right turn followed by a U-turn at signalized intersection. This kind of changes will result in an increase of U-turn volume at signalized intersection and also increase in conflicts between U-turn and right turn vehicles. From the author's point of view when the volumes of U-turns at signalized intersections exceed 15 vehicles per fifteen minute interval, RT-UT conflict rate will increase significantly. The designers and planners can use the curves plotted in Figure 5.61 as a guideline for median closures and conversions in advance of signalized intersection.

5.4 Summary

This chapter focused on the analysis of two left turn alternatives, DLT and RTUT movements at signalized intersections and at median opening sites. The number of conflicts were presented and compared for DLT and RTUT movements. Two types of conflicts rates were utilized for the safety comparison of these movements. Also, these conflict rates were presented and compared. Furthermore, severity distribution of each conflict type of RTUT and DLT movements were presented and compared. Additionally, U-turn analysis for signalized intersection and median opening sites were conducted and results were presented.

6. Summary, Conclusions and Recommendations

6.1 Summary

This report summarizes a research project that evaluated the safety effects of right turns followed by U-turns (RTUT) at signalized intersections and at median openings as an alternative to direct left turns (DLT) from driveways or side streets on four lane arterials. Safety of both alternatives was evaluated based on traffic conflict analysis. Conflict analysis was chosen over crash analysis because advantages of conflict analysis are shorter data collection time than crash data and the effectiveness of countermeasures can be evaluated in a shorter time. Nine types of conflicts were utilized for this study. Five of the conflict types were related to RTUT movements, while the rest of them were related to DLT movements.

Sixteen sites were selected for data collection in the Tampa Bay Area and Plant City. Data collection sites were divided into two sets by geometric criteria. At the first set of sites, the drivers had to complete U-turn movement of RTUT at a signalized intersection. On the other hand, at the second set of sites the U-turns were at median openings. Data were collected with the help of video recording equipment at selected sites during peak and non-peak hour periods. Over 500 hours of data were collected.

Data analysis was conducted by describing the number of conflicts and the comparison of two types of conflict rates. The numbers of daily conflicts for each site and each conflict type were obtained. These numbers were compared for RTUT and DLT movements for median opening sites and signalized intersection sites. Two types of conflict rates were utilized which were conflicts per hour and conflicts per thousand vehicles involved. These conflict rates were compared for RTUT and DLT movements for signalized intersection and median opening sites.

Another important safety evaluation measure for conflict studies is the severity of conflicts, which is acquired by the use of risk of collision (ROC) scores. The average severity of each conflict type was calculated for RTUT and DLT movements at signalized intersections and median opening sites. Furthermore, average severity scores for DLT and RTUT movements were calculated and compared.

6.2 Conclusions

The safety evaluation of RTUT and DLT from driveways or side streets on four lane arterials using traffic conflicts resulted in several conclusions. They are explained in the following paragraphs.

At traffic signal sites, DLT movements generated two times more conflicts per hour than RTUT movements. When the effects of traffic volumes have been taken into consideration, RTUT movements had a 5 percent higher conflict rate than DLT movements. U-turn movements at signalized intersections caused a higher conflict rate of RTUT movements. Severity comparison of DLT and RTUT movements indicated that RTUT related conflicts were less severe than DLT related conflicts.

At median opening sites, DLT movements generated 10 percent more conflicts per hour than RTUT movements. Furthermore, the other conflict rate, which takes the effect of traffic volumes into consideration, was 62 percent higher for DLT movements as compared to RTUT movements. Severity analysis results indicated that DLT movements had higher average severity scores than RTUT movements.

6.3 Recommendations

It would be useful to do a before and after analysis of median closures and median opening conversions which would point out the safety and operational effects such changes.

Geometric conditions of U-turn areas may have impacts on the safety performance of RTUT movements. Median openings without exclusive turn lanes may affect the safety and capacity of the roadways and RTUT movements. Also, the effects of geometric conditions such as narrow medians, median openings with insufficient storage space, and U-turn areas with low turning radius should be considered for safety evaluation of RTUT movements. Another research project should be conducted to fully evaluate the impacts of these geometric conditions.

7. References

1. Access Management Manual, Transportation Research Board, 2003
2. Koepke, F., and Levinson H. (1992). NCHRP 348: Acess Management Guidelines for Activity Center. Transportation Research Board, National Research Council, Washington D.C.
3. Gluck, J., Levinson, H.S. and Stover, V.G. (1999). Impacts of Access Management Techniques, National Cooperative Highway Research Program Report 420, Transportation Research Board, National Research Council, Washington, DC.
4. Lu, J., Dissanayake, S, Castillo, N., and Williams, K. Safety Evaluation Of Right Turns Followed By U-Turns as an Alternative to Direct Left Turns - Conflict Analysis, USF 2001
5. Lu, J., Pirinccioglu, F, Pernia, J.C. Safety Evaluation Of Right Turns Followed By U-Turns at Signalized Intersections as an Alternative to Direct Left Turns - Conflict Analysis, USF 2004
6. Opinion survey following Oakland Park Boulevard median reconstruction. Florida Department of Transportation, District 4, Traffic Operations.
7. Ivey, Harris and Walls, “Districtwide Median Evaluation Technical Memorandum: Corridor Land Use, Development & Driver/Business Survey Analysis,” prepared for FDOT District 5, 1995
8. Vargas, F.A. and Gautam, Y. (1989), Problem: Roadway Safety vs. Commercial Development Access. Compendium of technical papers, ITE, 59th annual meeting San Diego California
9. Maki, R.E., “Directional Crossovers: Michigan’s Preferred Left-Turn Strategy,” Presented at the 1996 Annual Meeting of the Transportation Research Board.
10. Kach, B., “The Comparative Accident Experience of Directional and Bi Directional Signalized Intersections,” Michigan Department of Transportation (April 15, 1992).
11. Potts, I.B., Levinson, H.S., Harwood, D.W., and Gluck J.(2004) Safety of U-Turns at Unsignalized Median Openings, National Cooperative Highway

Research Program Report 17-21, Transportation Research Board, National Research Council, Washington, DC.

12. Townes, M.S., Boardman, J.H. and Skinner, R.E.(2004). Safety of U-turns at Unsignalized Median Openings, National Cooperative Highway Research Program Report 524, Transportation Research Board, National Research Council, Washington, DC.
13. Carter, D., Hummer, J., Foyle, R., and Philips, S.(2004)"Operational and Safety Effects of U-turns at Signalized Intersections" Transportation Research Board 84th Annual Meeting Proceedings.
14. *Rule Chapter 14-97: State Highway System Access Management Classification System and Standards,* Florida Department of Transportation.
15. Gary H. Sokolow. (1993).*Practical Consideration for Beginning a Comprehensive Access Management Program.* Florida Department of Transportation. The first national access management conference.
16. Parker, M.R., and Zegeer, C.V. (1989). "Traffic Conflict Technique for Safety and Operations-Observer's Manual", FHWA-IP-88-27, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. Parker,
17. M.R., and Zegeer, C.V. (1989). "Traffic Conflict Technique for Safety and Operations-Engineer's Guide", FHWA-IP-88-26, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. Website FHWA
18. Gettman D. and Head L., (2003) Surrogate Safety Measures From Traffic Simulation Models, Final Report, FHWA-RD-03-050, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. Website FHWA
19. Recommended Warrants for the Use of Protected/Permissive Left-Turn Phasing. Technical Committee Project 4A-30, Institute of Transportation Engineers, Washington, DC, 1994.
20. Torbic D., Borkowski J., Elefteriadou L., McFadden J., (1998) "Relationships Between Traffic Operations and Safety at Signalized Intersections" Third International Symposium on Highway Capacity, Copenhagen, Denmark

21. Sayed, T; Brown, G; and Navin, F. (1994). "Simulation of Traffic Conflicts at Unsignalized Intersections with TSC-Sim". *Accident Analysis and Prevention*, Vol.26, No.5, 1994, pp.593-607.
22. Sayed, T., and Zein, S. (1999). "Traffic Conflict Standards for Intersections", Transportation Planning and Technology, Vol. 22, No.4, pp 309-323
23. Weerasuriya SA, Pietrzyk MC (1998) "Development of Expected Conflict Value Tables for Unsignalized Three-Legged Intersections", Transportation Research Board Issue 1635, pp 121-126
24. Salman, N.K., and Al-Maita, K.J. (1995). "Safety Evaluation at the Three-leg, Unsignalized Intersections by Traffic Conflict Technique", Transportation Research Record 1485, Transportation Research Board, National Research Council, Washington, D.C., pp. 177-185previous 26
25. Migletz, D. J. Glauz, W. D. and Bauer, K.M. (1985). "Relationships Between Traffic Conflicts and Accidents", Report No. FHWA/RD-84/042, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.
26. Katamine, N.M. (2000). "Nature and Frequency of Secondary Conflicts at Unsignalized Intersections". Journal of Transportation Engineering, Vol. 126, No. 2, pp. 129-132.
27. Hauer, E., (1978). "Design Considerations on Traffic Conflict Surveys", *Transportation Research Record 667*, Transportation Research Board, National Research Council, Washington, D.C., pp.57-66.
28. Chin, H.C., and Quek, S. T. (1997). "Measurement of Traffic Conflicts", Accident Analysis and Prevention, Vol.26, No.3, pp.169-185.
29. Torbic, D., Borkowski, J., Elefteriadou, L., and McFadden, J. (1998). "Relationships Between Traffic Operations and Safety at Signalized Intersections", Proceedings of the Third International Symposium on Highway Capacity, Copenhagen, Denmark.

30. Zegeer, C.V., Deen, R.C. (1978). “Traffic Conflicts as a Diagnostic Tool in Highway Safety”. *Transportation Research Record 667*, Transportation Research Board, National Research Council, Washington, D.C., pp. 48-55.

31. Brown, G.R. (1994). “Traffic Conflicts for Road Safety Studies”. Canadian Journal of Civil Engineering, Vol. 21, No.1, pp.1-15.

32. Migletz, D. J. Glauz, W. D. and Bauer, K.M. (1985). “Relationships Between Traffic Conflicts and Accidents”, Report No. FHWA/RD-84/042, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

33. Engel, U. (1985). “To What Extent Do Conflict Studies Replace Accident Analysis: Validation of Conflict Studies - An International Review. In Organisme National De Securite Routiere. Proceedings “Evaluation 85”, Paris, France. Vol.2, pp. 324-343.

34. Glauz, W. D., Bauer, B. M., and Migletz, D. J. (1985). “Expected Traffic Conflict Rates and Their Use in Predicting Accidents”, *Transportation Research Record 1026*, Transportation Research Board, National Research Council, Washington, D.C., pp. 1-12.

35. Hayward, J.C. (1972). “Near-Miss Determination Through Use of a Scale of Danger”. *Highway Research Board Record No. 384*, Washington D.C., Highway Research Board, pp. 24-33.

36. H. Kruysse, 1991. "The subjective evaluation of traffic conflicts based on an internal concept of dangerousness, "Accident Analysis and Prevention, Vol. 23, No. 1.

37. G. Tiwari, et al., 1995. "Conflict analysis for prediction of fatal crash locations in mixed traffic streams," Proceedings of the 29th Annual Association for the Advancement of Automotive Medicine, Oct 17-18. Chicago, IL.web site

38. D. Cooper and N. Ferguson, 1976. "A conflict simulation model," Traffic Engineering and Control, Vol. 17, pp. 306-309

39. J. Darzentas, et al., 1980. "Minimum acceptance gaps and conflict involvement in a single crossing maneuver," Traffic Engineering and Control, Vol. 21, pp. 58-62.

40. Robertson, H.D., Hummer, J. E., and Nelson D. C. (1994). “Manual of Transportation Engineering Studies, Chapter 12” Institute of Transportation Engineers. Prentice Hall, NJ.