SAFETY EVALUATION OF RIGHT TURNS FOLLOWED BY U-TURNS AT SIGNALIZED INTERSECTION (6 OR MORE LANE ARTERIALS) AS AN ALTERNATIVE TO DIRECT LEFT TURNS - CONFLICT ANALYSIS

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16. Abstract

This report is one of the two reports of the project evaluated safety and operational impact right turn followed by U-turn at a signalized intersection as an alternative to direct left turn from driveways and side streets. This report evaluated the safety of both alternatives by comparison of traffic conflicts. Nine types of conflicts were selected for this study. Five of the conflicts were related to RTUT movements, while the rest of them were related to DLT movements. Data was collected with the help of video recording equipment at a total of eight sites for over 300 hours. Descriptive analysis and conflict rate analysis was conducted. Two types of conflict rates, conflicts per hour and conflicts per thousand involved vehicles were used for safety comparison of the two left turning alternatives. DLT movements generated averagely 6.7 conflicts per hour, while RTUT movements generated 2.4 conflicts per hour. On the other hand, average number of conflicts per thousand vehicles involved for DLT and RTUT movements were 40.6 and 26.2 respectively. Severity of conflicts was analyzed by Risk of Collision (ROC) score. In general, when both DLT and RTUT are compared, based on the results of this study, RTUT movements reduce the number of conflicts, and the overall severity of RTUT related conflicts are significantly lower than that of DLT related conflicts.

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Abstract

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1. Introduction

1.1 Background

Every year, in the United States traffic crashes claim around forty thousand people's lives. As a consequence, traffic safety is getting more attention in the transportation area since any effort on this subject will reduce the number of crashes and severity of crashes. Traffic and transportation engineers have developed many methods to increase safety to prevent fatalities and injuries caused by traffic crashes on nation's roadways.

Access management is one of the tools that engineers and planners have used to plan and design the roads to enhance the capacity and safety of road networks. The benefits of access management include: improved safety, improved traffic flow and fuel economy, increased capacity and reduced delay and vehicle emissions. The safety benefits of access management have been clearly documented by more than four decades of research *(1)*. Many states in the nation established their own access management programs. Colorado was the first state to have a system wide access management program in 1979. Since then, other states adopted their access management programs. The State of Florida Legislature adopted the State Highway System Access Management Act in 1988. The Transportation Research Board published the first Access Management Manual in 2003 *(2)*, which was a necessary resource for transportation engineers and planners.

In the Access Management Manual, 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 *(2)*. Many metro areas in the nation have increasing population and road users while there is no space remained to make improvements on the current roadway system with conventional methods such as widening of roadways. The safety and the capacity of the roads can still be improved by applying access management techniques when conventional improvements could not be applied. Access management helps achieve the necessary balance between traffic movement and property access by careful control of the location, type, and design of driveways and street intersections while preserving the safety and the capacity of the roadway system. This is accomplished by classifying highways with respect to the level of access and mobility they are expected to provide, and then, identifying and applying the most effective techniques to preserve that function *(3)*.

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. Many studies showed that an increase on the number of access points on arterials increases crash rates. Figure 1.1 shows impacts of access management on safety based on results from NCHRP 420 report *(4)*.

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 impact on the capacity of the arterials. Driveway movements cause 10% of total crashes and 70% of intersection crashes in United States *(1)*. Researchers have been developing new methods to make the driveway movements safer. In this regard, direct left turns from driveways have been a concern as a major source of operational and safety problems. Many studies have been conducted addressing the safety and operational problems related to direct left turn (DLT) movements. Also, alternatives to direct left turn from driveways have been investigated by several studies.

Although application of access management techniques improves the capacity and safety of roadways, managing the driveway movements remains as a challenge for engineers. Geometric restrictions such as closing driveways and converting full median openings to restricted median openings bring 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, many surveys have been done to evaluate the impacts of access management on drivers and businesses *(5)*. The majority of the drivers found 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 *(6)*.

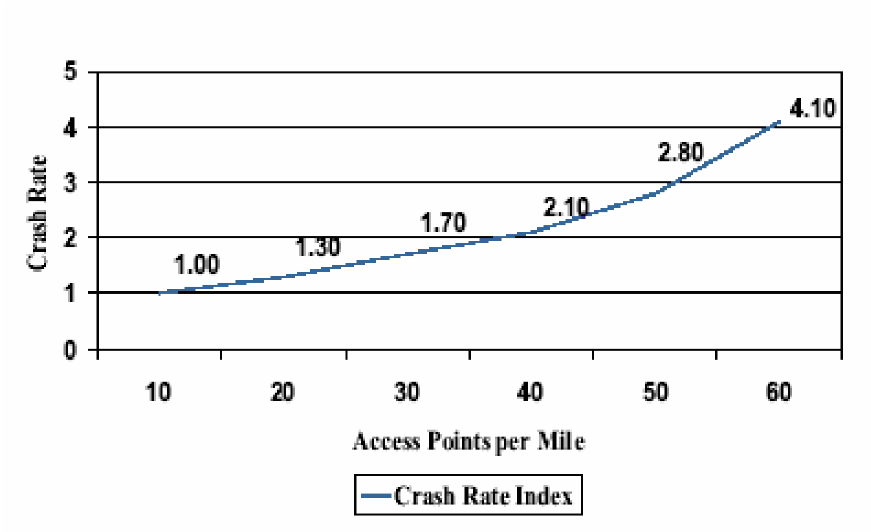

Figure 1.1 Crash Rates vs. Access Points per Mile *(4)*

1.2 Research Subject.

In 1999, a research project sponsored by Florida Department of Transportation (FDOT) was performed by Dr. John Lu and his colleagues in the University of South Florida to evaluate an access management technique: Right turn followed by U-turn at median openings as an alternative to direct left turn from driveways and side streets. The research evaluated the safety and operational impacts of such an alternative on six and eight lane arterials *(3)*. Results from that research indicated that this alternative as compared to direct left turns result in safety benefits and under certain traffic conditions result in operational benefits. On the other hand, when the state of Florida roadway system was considered, other than the right turn followed by U-turn (RTUT) at a median opening, drivers may have to make right turn followed by U-turn at a traffic signal as another alternative to direct left turn on six and lane arterials.

These direct left turn alternatives can be implemented in the roadway by treatment of median openings. 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, which is to reduce the number of conflict points. Conflict points are defined as points at which traffic movements intersect each other. The reduction of conflict points means less complex driving environment and less chance of being involved in conflicts with other vehicles from driver perspective. In theory, converting a full median opening to a directional median opening will reduce the number of conflict points at an unsignalized intersection. 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 *(2)*.

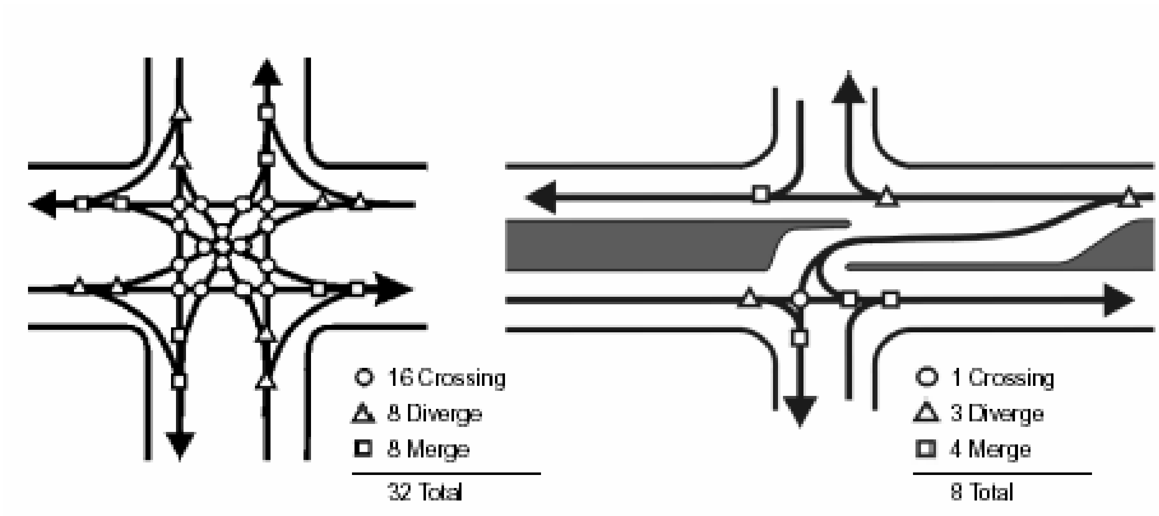

Figure 1.2 Conflict points at four-leg intersections

For better understanding of the problem with direct left turns from driveways, three possible scenarios when a driver wants to make a direct left turn from a driveway could be analyzed. In the first scenario, a driver after waiting for some time in the driveway becomes the first vehicle of the queue. If the driver is not aggressive, he/she will wait until a suitable gap is available to cross across the roadway and reach the median opening. At the median opening the same driver would wait for another suitable gap at the upstream of the roadway. At the suitable gap, he/she will join the stream of the traffic. This first scenario is the situation causing no problems from the safety perspective.

In the second scenario, the driver waits at the driveway for a suitable gap but in this case time is too long because of the heavy traffic conditions. In search of another alternative, the driver makes a right turn. Because of the fact that the driver does not have to cross the street, he/she can join the roadway traffic with ease as compare to crossing the street to reach median opening. The driver searches for a U-turn bay and makes the U-turn in order to go upstream.

In the third scenario is, similar to the second scenario the driver does not have suitable gaps to make a direct turn left turn from a driveway because of the heavy traffic conditions on the main roadway. In this case, the driver is frustrated because of the long waiting time becoming aggressive and, accepting smaller gaps than reasonable ones. When accepting smaller gaps to cross across the roadway in order to reach the median opening, the driver causes conflicts with main road users. At the median opening the same driver causes conflicts with main road users at the upstream of the roadway. Also, under heavy volume conditions of vehicles ingressing to driveway, the driver causes conflicts with vehicles ingress to driveway. Further more, direct left turning driver may cause collisions.

1.3 Problem Statement

The state of Florida has been applying access management techniques on its roadway network for more than a decade. The current design standards of FDOT, mandates that newly improved arterials with a design speed of 40 mph or higher will be constructed with raised median and restricted median openings. As mentioned before, restricted median openings forces the drivers to make RTUT movements instead of DLT. One of the options available for drivers is to make a U-turn at signalized intersections after a right a turn from a driveway or a side street. This alternative has some concerns by drivers. RTUT at a signalized intersection may increase waiting time of the drivers. Usually the drivers do not want to get into a traffic signal because left turn phases of traffic signals usually have shorter time than the through movement phase, which will increase the waiting time at the signals especially under heavy traffic conditions. Another concern related to this alternative of RTUT is the weaving. Drivers may find weaving unsafe under heavy traffic conditions. Distance between the driveway and the traffic signal has to be long enough for the drivers to safely weave to reach left turn lane of the traffic signal without any conflicts. The movements, which were studied in this research, are illustrated in the Figure 1.3. The impacts from both operational and safety perspectives for this alternative are quantified in this study.

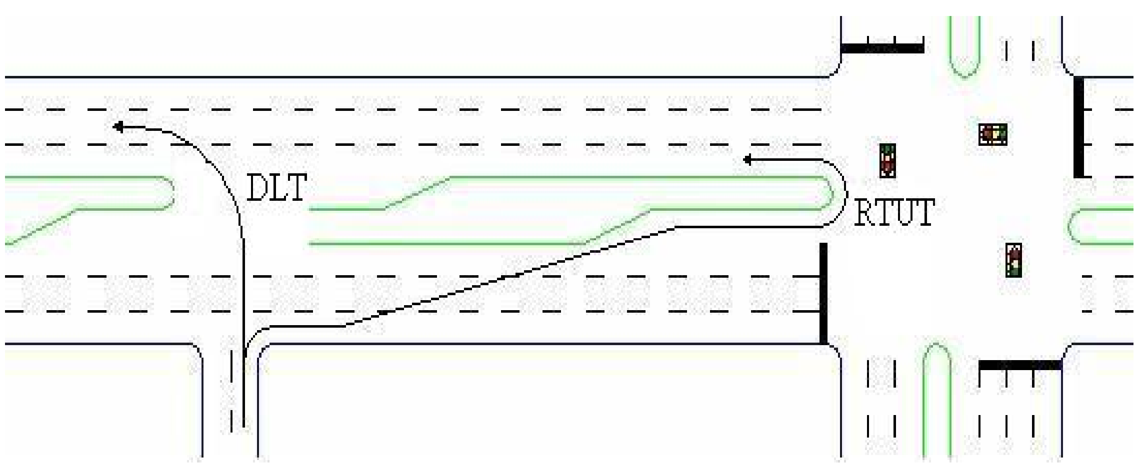

Figure 1.3 DLT and RTUT Movements Studied

1.4 Research Objectives

The main purpose of this project was to conduct a detailed safety and operational evaluation and investigation on a widely used access management technique: right-turn followed by U-turn at signalized intersection as an alternative to direct left turns from a driveway on six and eight lane arterials.

The evaluation of this specific access management technique includes an operational analysis and a conflict analysis. The safety affects of right turn followed by U-turn at signalized intersection are quantified in this report through field studies and data collection. The safety analysis includes comparisons of conflict rates and conflict severities. More specifically, the objectives of the safety aspect of this research are:

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

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 safety impacts of right turn followed by U-turns at signalized intersection or median openings considering conflicts other than the previous studies conducted at University of South Florida by Dr. John Lu and his colleagues. However, there are studies that have been conducted to evaluate the impacts of U-turn movements at signalized intersections.

One study by Thakkar, Reddy, Hadi and Vargas *(7)*developed a method to assess the prevention of median opening movement taking into consideration several factors that are important to decision-makers A model was derived based on data collected at an intersection with a right-turn overlap phase, in which the right-turn signal indication is a green arrow during opposing intersecting street left-turn/U-turn green phase. This study evaluated operational effects of U-turns at signalized intersections.
Another study conducted in 2004 by

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 *(4)*. 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.

Two study conducted at University of South Florida in 2001 evaluated right turn followed by U-turn at median opening as an alternative to direct left turn. Another study completed in 2004 and The first study's safety evalutaion included in that study used traffic conflicts to assess the impacts of right turns followed by U-turns at median openings. This study found that, right turn followed by U-turn movements generated fewer conflicts as compared to direct left turn movements. Also severity of the conflicts was less severe for right turn followed by U-turn movements *(3,4)*.

Vargas and Gautam *(8)* performed a case study regarding right turn followed by a U-turn 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.

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

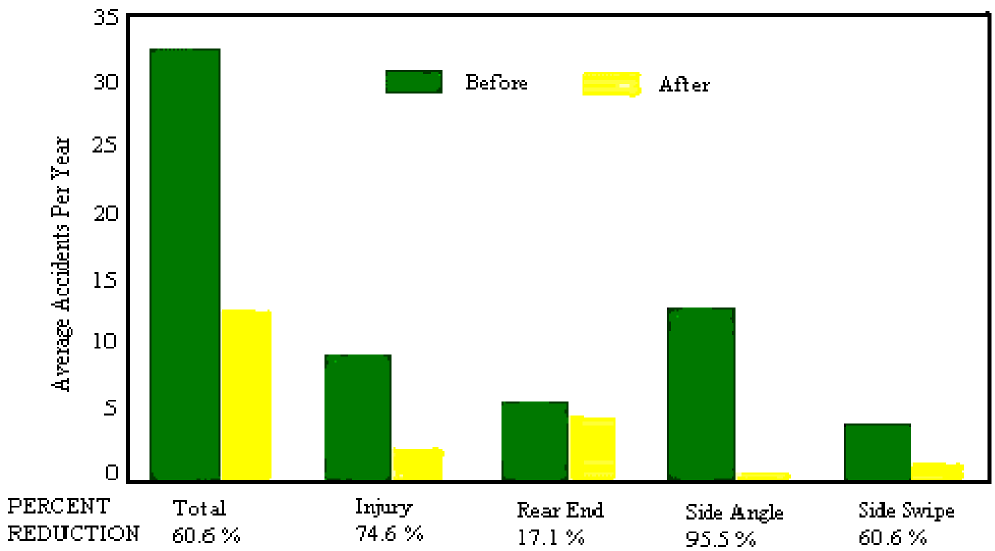

Figure 2.1 Crash Comparisons of the Michigan Study *(9)*

2.2 Florida Regulations

Florida is heavily encouraging restrictive medians on its higher designed at-grade arterial roadways *(11)*. 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 *(12)*. 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.

2.3 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 *(13,14)*. The traffic conflict technique is a methodology for field observers to identify conflict events at intersections by watching for strong braking and evasive maneuvers. The traffic conflict technique has a long history of development, including research on *(15)*:

- 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 left turn phase in signal phasing. The operational quality of service has an affect on 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 decreases as the average total delay increases *(16,17)*.

Sayed *(19)* 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 *(18)*. Another research by Sayed established frequency and severity standards for signalized intersections acquiring data from 94 conflict surveys. The study developed a intersection conflict index to compare the conflict risk at signalized intersections.

Weerasuriya and Pietrzyk *(20)* used traffic conflicts to analyze intersection 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 number and volumes were analyzed in that research. The tables resulted from this study, provided mean, variance, and 90^{th} and 95^{th} percentile conflict rates. It was proposed that those tables could be used to estimate the safety problem at different intersections.

The relationship between traffic volumes and conflicts has been another subject for researchers to investigate. Salman and Almaita *(21)* 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 conflicts and the square root of the product of volumes was higher than that of summation of volumes. Migletz. et al. *(22)* 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 *(23)* worked on 15 four leg unsignalized intersections to define the relationship between traffic volumes and the 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.

2.4 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 a required 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 *(13,14,24,25,26)*.

On the other hand, traffic conflicts have some advantages when 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 *(13,14,26)*. Second, the data collected can be used as supplementary data to crash data for analysis purposes *(13,14)*. Third, the effectiveness of a countermeasure can be evaluated in a short time and can be changed in a short time with traffic conflicts *(13,14)*. Fourth, traffic conflict provides information about volumes, frequency of different kinds of conflicts and severity of conflicts while the crash data can only give information on property damage and injury severity *(27)*. Fifth, conflict data includes human factors because the conflict data collection requires observation of the drivers at the field *(28)*.

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 *(29)* found 10% correlation between crashes and conflict. Engel *(30)* found that the relationship between the total crashes and the conflicts was not significant, but if different types of crashes and conflicts were studied the relationship would have been significant. Glauz et al *(31)* stated that the conflicts can be used to estimate the number of crashes in a particular year but it will not predict actual number. Therefore, traffic conflict can be used as a replacement of the crashes.

2.5 Conflict Severity

Obtaining the conflicts data and comparing the conflict rates are one part of the traffic conflict safety evaluation studies. The other measure is severity of conflicts that assesses 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 *(32)*. It has been defined as the time to collision of the two vehicles if they continue on the same path without any evasive maneuver such as braking or swerving. The other measures were defined as following *(15)*:

- *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 *(33,34)*. 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 *(35,36)*.

Sayed et al *(18)* 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

The data were collected at eight sites in the Tampa bay area. Six of the sites were in the city of Tampa and two of them were in the city of Saint Petersburg. Two types of sites were selected. The first type has a full median opening across the driveway, which allows driveway users to make a DLT or a RTUT at a traffic signal. The second type of site has a directional median opening across the driveway, which does not allow a DLT movement. Therefore, the driveway user has only the option of joining downstream traffic, which is RTUT at a signalized intersection. The sites were selected considering the following criteria:

1) The arterial or major road must have three or more lanes in each direction.
2) Traffic volume on the driveway should be relatively high so that the adequate number of turning vehicles could be studied.
3) The downstream signal was located at an appropriate distance away from the driveway in order to avoid the effects of possible spillbacks.
4) Posted speed on the major road is equal to or greater than 40 mph.
5) Downstream signal has protected left turn phase to prevent the conflicts with the upstream traffic with the U-turns at the signalized intersection.
6) There are no protective island and exclusive lane for right turn movements at the signalized intersection to observe the conflicts between U-turning vehicles and right turning vehicles
7) Right turn on red is allowed at the signalized intersection in order to observe the conflicts between U-turning vehicles and right turning vehicles.

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 *(37)*.

The first procedure is based on the conflict per unit time as shown in Equation 3.1. The outcome for this procedure is the minimum number of hours that the data need be collected at the field. This procedure requires error of the mean and variance from previous studies, level of significance and level of error.

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

where,

n = number of hours of observation needed,

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

p = error of the hourly mean,

σ_e^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, 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 are used. In this case, ITE Manual of Engineering Studies *(14)* recommends using the advantageous procedure. For the first procedure, mean and variance values were unknown from previous studies. Although, Parker and Zeeger *(14)* established tables that include the mean and variance values for signalized and non-signalized intersections, those values were not given for the movements studied in this project . For the second procedure, conflicting rate is not known but with a conservative assumption, result of 384 vehicles was calculated. After the data collection, sample size values can be verified.

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

3.3 Types of Conflicts Studied

In this study, nine types of conflicts are used for evaluation. Five of them were related to RTUT movements at signalized intersection movements and four of them were related to DLT movements. Descriptions of these conflicts are as follows:

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. Figure 3.1 shows this type of conflict.

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. This type of conflict is illustrated in Figure 3.2.

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 left turn lane at signalized intersection. This maneuver may place through-traffic vehicles with increased potential of rear-end and sideswipe collisions. Figure 3.3 presents this type of conflict.

4) U-turn Conflict (C4), occurs when a vehicle making a U-turn at a signalized intersection, and the vehicle behind the U-turning vehicle accelerates to make a left turn. This maneuver may place left turn vehicle with increased potential of a rear end collision. Figure 3.4 demonstrates this type of conflict.

5) U-turn and right turn across the street (C5), occurs when a vehicle making a U-turn at a signalized intersection, and another vehicle across the street makes a right turn into the same direction with an increased potential of sideswipe or angle collision. Figure 3.5 shows this type of conflict.

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. This type of conflict is illustrated in Figure 3.6.

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. Figure 3.7 presents this type of conflict.

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. Figure 3.8 demonstrates this type of conflict.

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 3.9 shows this type of conflict.

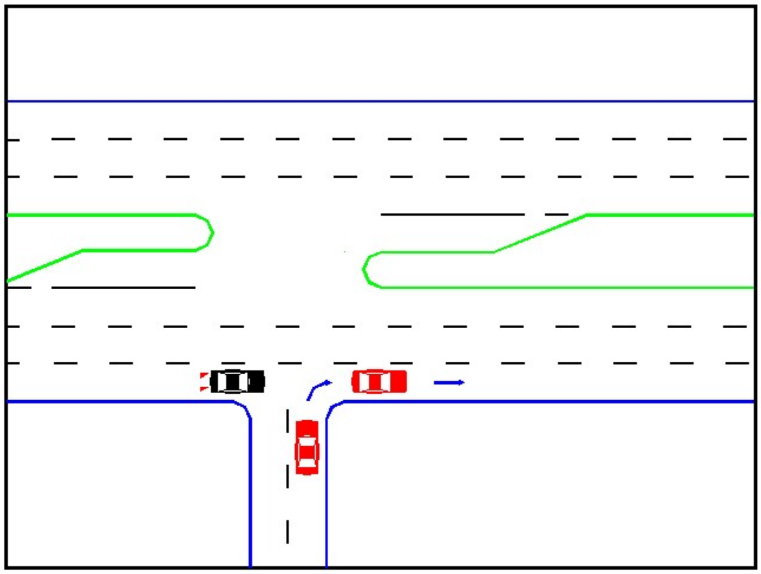

Figure 3.1 Right-Turn Out of the Driveway (C1)

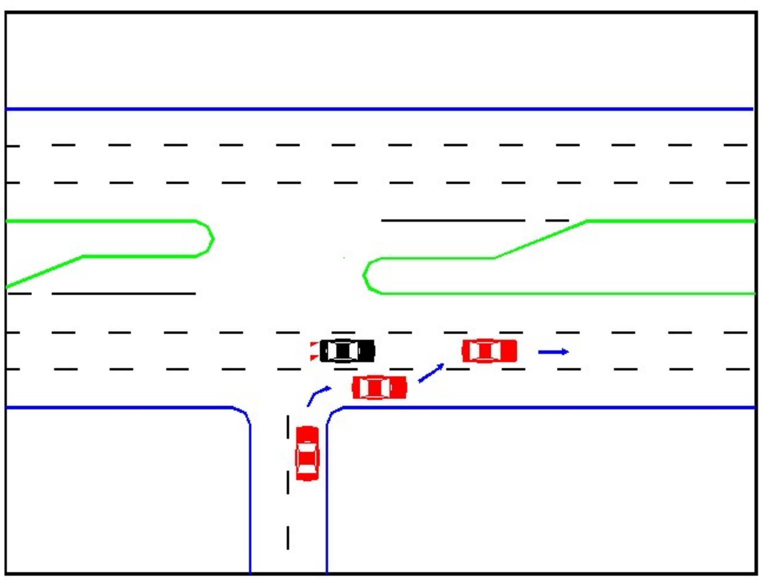

Figure 3.2 Slow-Vehicle, Same-Direction Conflict (C2)

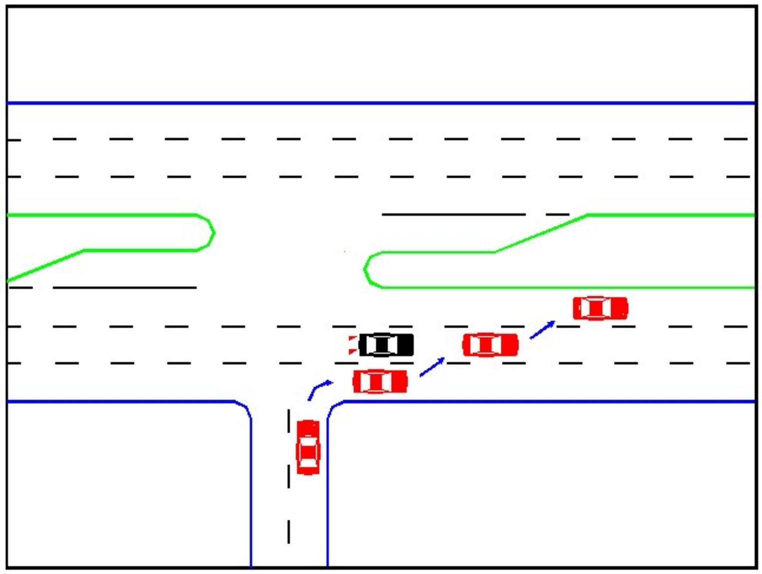

Figure 3.3 Lane Change Conflict (C3)

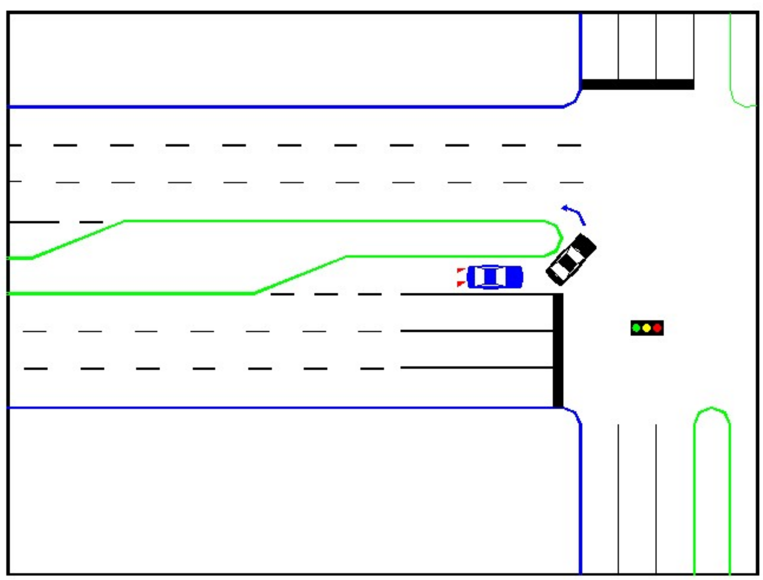

Figure 3.4 U-turn Conflict (C4)

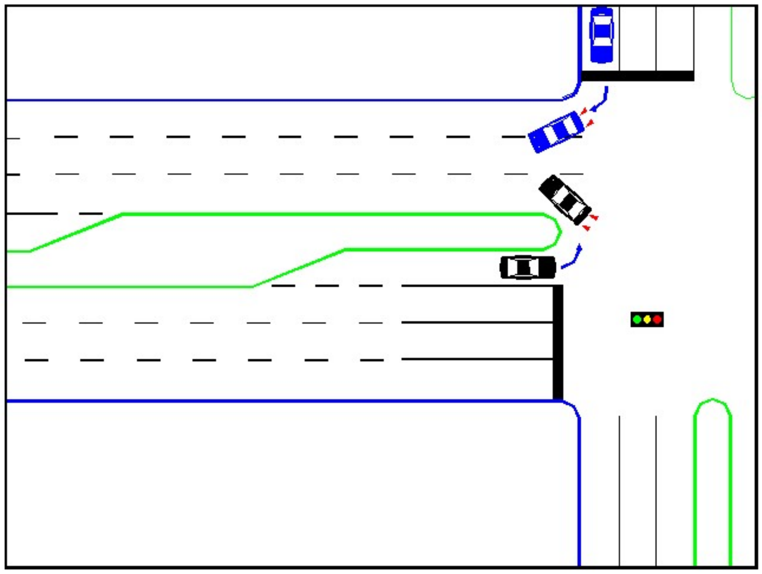

Figure 3.5 U-turn and right turn across the street (C5)

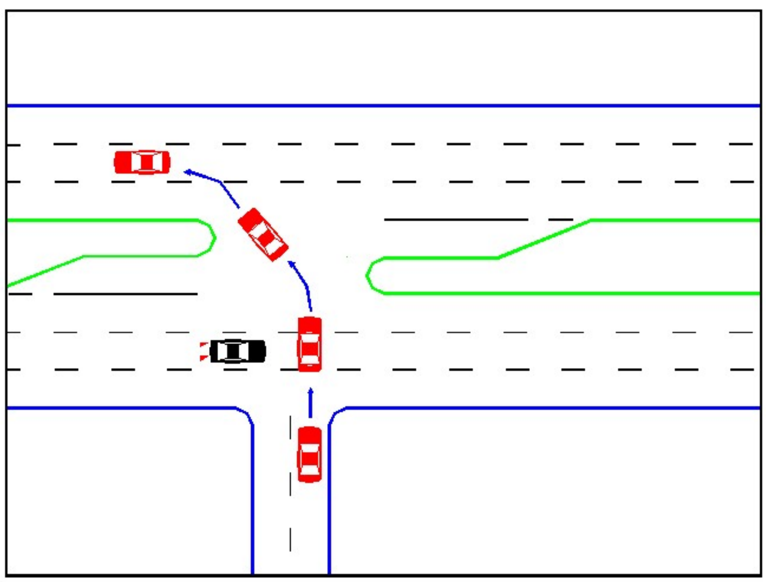

Figure 3.6 Left-Turn Out of Driveway: Conflict From Right (C6)

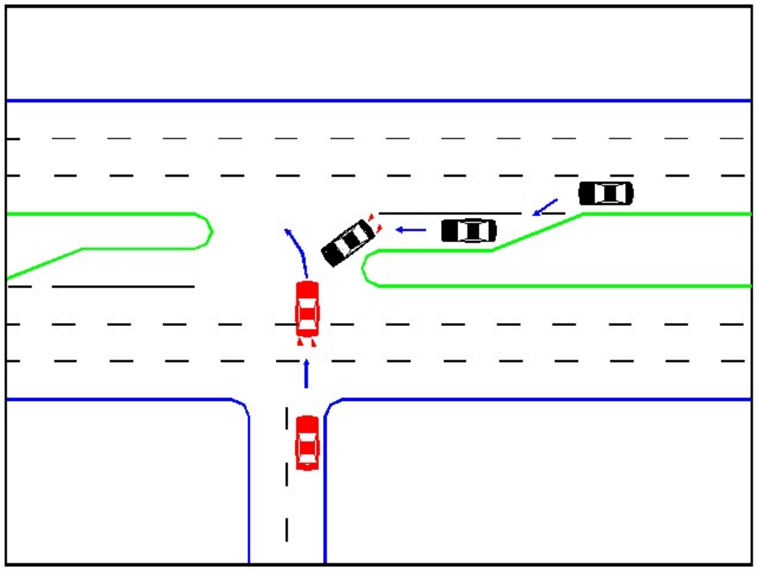

Figure 3.7 Direct-Left Turn and Left-Turn in From-Right Conflict (C7)

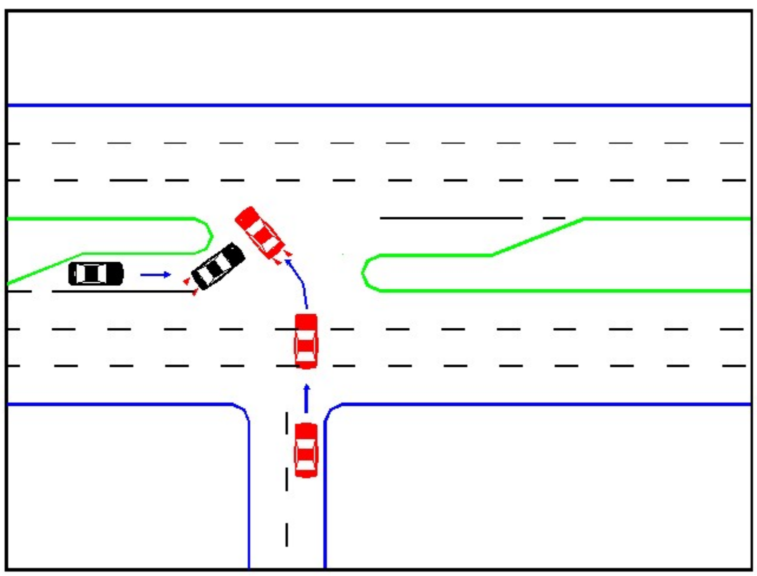

Figure 3.8 Direct-Left-Turn and Left-Turn in From-Left Conflict (C8)

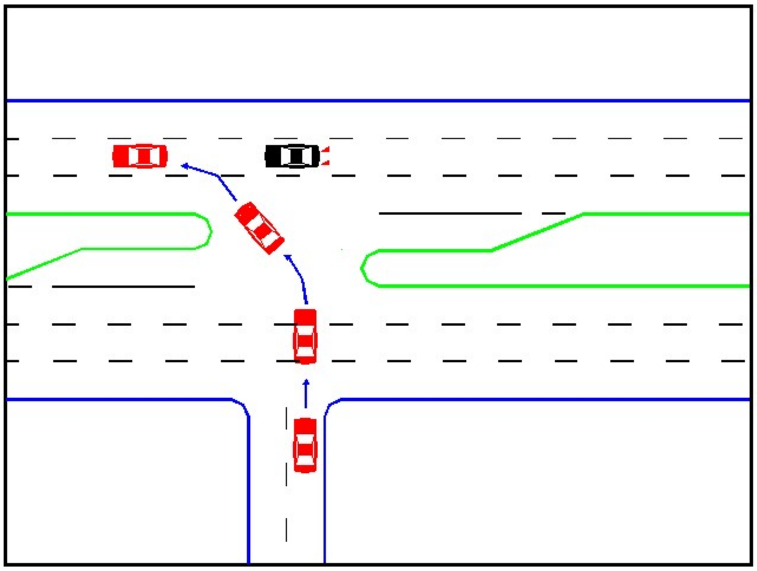

Figure 3.9 Left-Turn Out of Driveway: Conflict From Left (C9)

3.4 Identification of Conflicts

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

Brake applications are frequently used to identify conflicts. In order to identify a conflict observers should not only be aware of the vehicle's braking lights, but also the speed of the vehicles and conditions. Hence, there are situations where drivers may apply brakes for several different reasons other than a conflict situation. Especially in this study, a signalized intersection is present following the downstream of a driveway. The vehicles, which travel on major roadways, apply brakes to slow down as they approach to the signalized traffic intersection. This precautionary brake application may be interpreted as a traffic conflict; although, there is not a conflict occurring between vehicles.

Furthermore, condition is that drivers may apply brakes cautiously even when a conflict is not present in a situation *(41)*.

Swerving is another indicator of a traffic conflict. Drivers may change the direction of the vehicle or the lane instead of applying brakes to avoid collision. Swerving does not occur as frequent as brake applications because by swerving drivers might put their selves into another conflict situation. 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 *(21)*.

A third indicator of a conflict is a noticeable deceleration, which 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 are more subjective and harder to identify compared to applying brakes *(20,21)*.

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 videotapes, 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 conflicts is a time consuming process. A systematic and efficient procedure was developed in the previous study *(3)*. For this procedure the algorithm shown in Figure 3.10 is used to identify the conflicts. Once the conflict was identified it was recorded. The Traffic Conflict Technique: Observer's Guide includes a standard form for conflict studies but the conflicts studied in this research were slightly different from the conflicts explained in that guide *(14)*. As a result, some modifications had to be made to the conflict form in order to be used in this study. The conflict form that was used in this research is illustrated in Figure 3.11

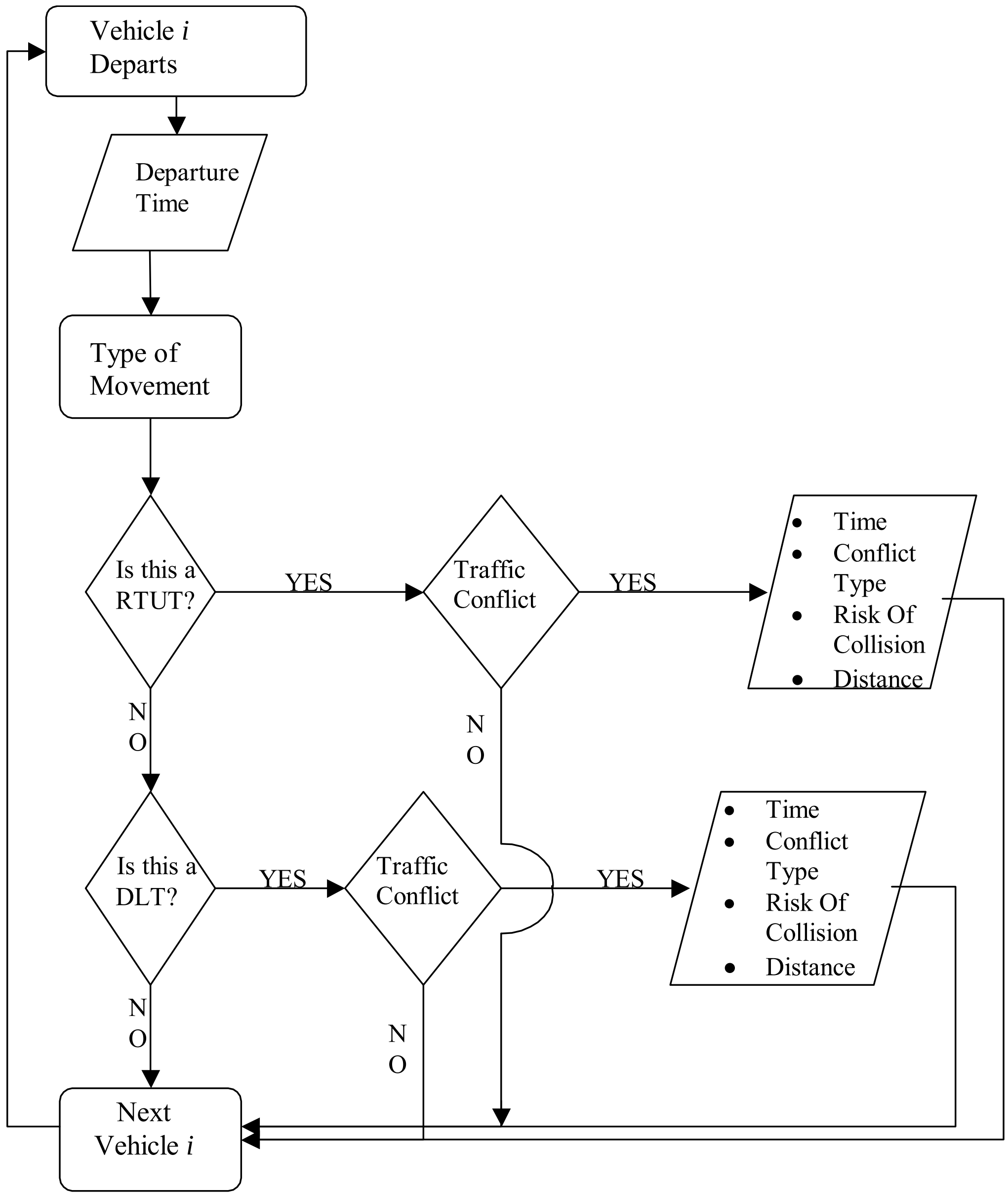

Figure 3.10 Flow Chart Describing Conflict Identification and Data Required by Observers.

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																						
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C : Conflict

SC : Secondary Conflict

Figure 3.11 Form Used for Recording Traffic Conflicts

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 was initially checked for accuracy and quality purposes at the end of every data collection day. Data reduction process started with identifying the vehicles making RTUT and DLT movements. The tapes that covered the study area were watched and all vehicles egressing from the driveway observed. If a vehicle made a DLT, the times for the specific vehicle was recorded. The same procedure was applied to the vehicles making RTUT as well. The times for vehicles making DLT and RTUT are shown in Table 3.1. The times noted for each vehicle were required with accuracy in seconds in order to identify vehicles in different tapes according to the analysis performed. By identifying RTUT and DLT vehicles, traffic volumes for these two movements were obtained without extra work.

Table 3.1 Data Reduction Recording Times

	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 traffic signal
Time 3	Vehicle leaves the median opening	Vehicle makes the U-turn

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

Conflict studies usually considered eleven hours as one day, starting at 7:00 AM and ending at 6:00 PM *(14)*. The Traffic Conflict Technique for safety and Operation’s -

Engineer's Guide recommends *(14)* adjusting the data for the periods for 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 number of conflicts was obtained by adding all observed and non-observed conflict. Application of this procedure made the data ready for calculation of several types of conflicts rates. Table 3.2 presents two types of conflict rates used in this study. The first one is conflicts per hour and the second conflict rate conflicts per thousand vehicles involved

Table 3.2 Definition of Different Conflict Rates

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

All the eight sites are listed below with a brief description followed by an aerial photograph. These sites were selected based criteria previously addressed at Section 2.1. Figure 4.1 shows the study locations in a map and illustrates the sites considered for data collection. Table 4.1 presents the descriptions of sites studied in this project.

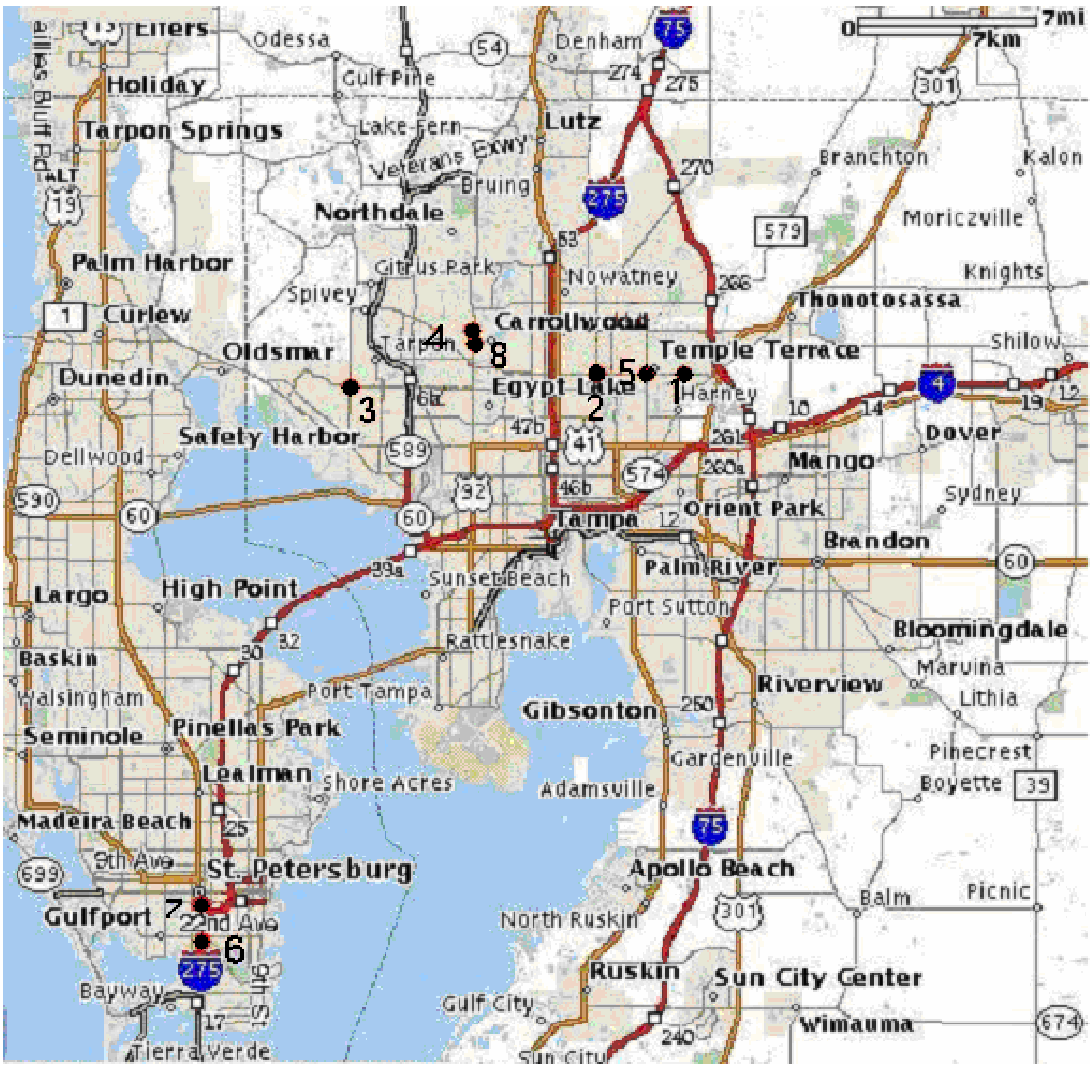


Figure 4.1 Map of Selected Sites

Table 4.1 Description of Selected Sites

Intersection		Number of Lanes		Maneuver allowed by median	
		Arterial	Driveway	DLT	RTUT
1	Fowler Ave. & 56th St.	3	1	No	Yes
2	Fowler Ave. & 22nd St.	3	2	Yes	Yes
3	Hillsborough Ave. & Webb Ave.	3	1	Yes	Yes
4	Dale Mabry Hwy.. & North Dale St.	3	1	No	Yes
5	Bruce B. Downs Blvd & Fletcher Ave.	3	2	Yes	Yes
6	54th S. & 34th St. (St. Petersburg)	3	1	Yes	Yes
7	54th S. & 22nd N. St. (St. Petersburg)	3	1	Yes	Yes
8	Dale Mabry Hwy.. & Maple Dale St.	3	1	No	Yes

Site 1 is located in the city of Tampa, at Fowler Avenue and 56th Street. Fowler Avenue is a major arterial with three lanes for eastbound and westbound traffic. It is divided by a raised median. The studied driveway is located on Fowler Avenue and it serves a shopping plaza with a Publix Supermarket and many small businesses. The median opening across the driveway is a directional median opening, which restricts DLT movements. Drivers, who want to go west on Fowler Avenue, after the right turn from the driveway, have to make a U-turn at the Fowler Avenue and 56th Street signalized intersection. The posted speed on Fowler Avenue is 50 mph. The aerial photograph of site 1 is illustrated in Figure 4.2

Site 2 is located in the city of Tampa, at Fowler Avenue and 22nd Street. Fowler Avenue is divided by a raised median at this segment with three lanes in eastbound and four lanes in westbound. The studied driveway is located on Fowler Avenue and it is one of the driveways that serve the University Mall. The driveway has two lanes for egress of vehicles with one lane dedicated to DLT vehicles and one lane is dedicated to right turning vehicles. The median opening across the driveway is a full median opening. Drivers who want to make a RTUT movement to go eastbound on Fowler Avenue, they need to make their U-turn at the Fowler Avenue and 22nd Street signalized intersection after the right turn from the driveway. The posted speed on this segment of Fowler Avenue is 45mph. The aerial photograph of site 2 is illustrated in Figure 4.3

Figure 4.2 Site 1, Fowler Avenue and 56th Street

Figure 4.3 Site 2, Fowler Avenue and 22nd Street

Site 3 is located in the city of Tampa, at Hillsborough Avenue and Webb Avenue. Hillsborough Avenue is a major arterial and state road. This segment of the arterial is divided by a raised median and has three lanes for both eastbound and westbound. The driveway that was studied is located on Hillsborough Avenue. The driveway serves a parking lot for a plaza that includes a major bank and some small businesses and it is located on Hillsborough Avenue. The median opening across the driveway is a full median opening. The drivers who want to make a RTUT movement to westbound of Hillsborough Avenue, need to make their U-turn at the Hillsborough Avenue and Webb Avenue signalized intersection after the right turn from the driveway. The posted speed on Hillsborough Avenue is 45mph. The aerial photograph of site 3 is illustrated in Figure 4.4

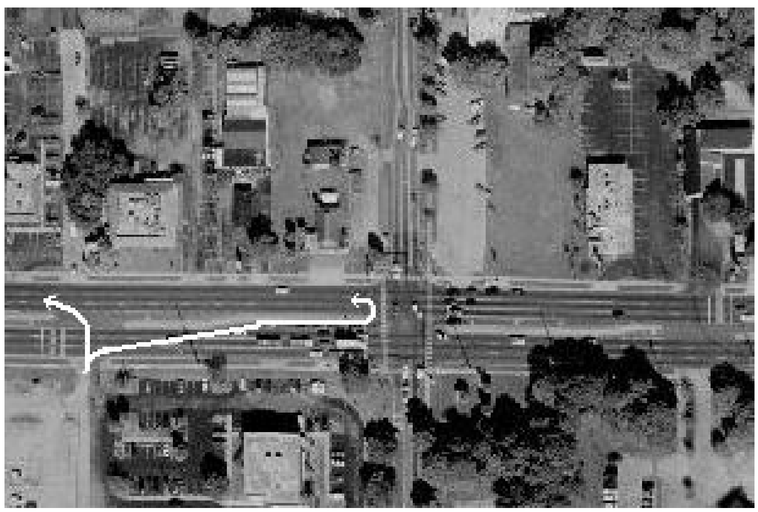


Figure 4.4 Site 3, Hillsborough Avenue and Webb Street

Site 4 is located in the city of Tampa at Dale Mabry Highway and North Dale Street. Dale Mabry Highway is a major highway divided by a raised median. This highway has three lanes for northbound and southbound traffic. The driveway is on Dale Mabry Highway and it is one of the driveways that serve a major shopping plaza that includes many small businesses and retail stores. The median opening across the driveway is a directional median opening, which restricts DLT movements from the driveway. The drivers, who use the studied driveway and want to go north on Dale Mabry Highway, has to make a RTUT. RTUT vehicles turn right to southbound of highway and make the U-turns at the Dale Mabry Highway and North Dale Street signalized intersection. The posted speed on Dale Mabry Hwy is 45 mph. The aerial photograph of site 4 is illustrated in Figure 4.5

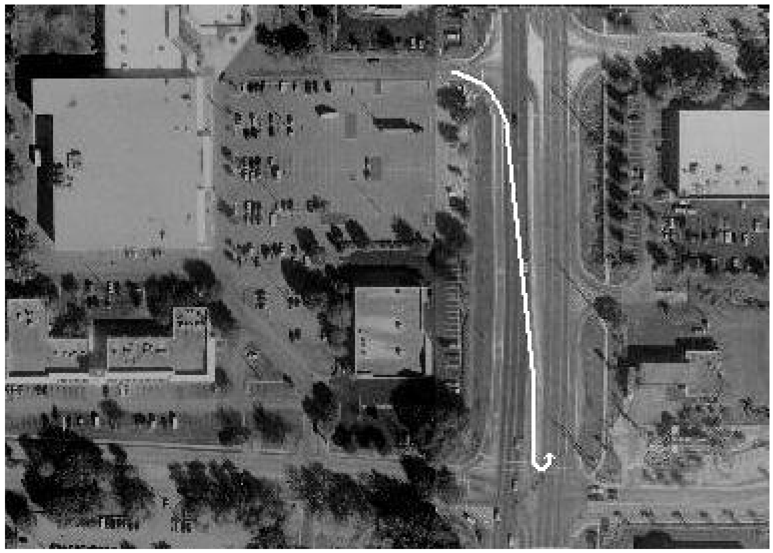


Figure 4.5 Site 4, Dale Mabry Highway and North Dale Street

Site 5 is located in the city of Tampa at Bruce B. Downs Boulevard and Fletcher Avenue. Bruce B. Downs Boulevard is a major arterial, which connects New Tampa Area to the University Area. The studied segment of the arterial is divided by a raised median and has three lanes for northbound and southbound traffic. The driveway is one of the driveways that serve Target Plaza that consists of; Target, Eckerd and U Save supermarkets, fast food restaurants and many small businesses. The driveway is on Bruce B. Downs Boulevard and has two separate lanes for DLT and right-turn movements. There is a full median opening located across the driveway. The drivers, who want to make a RTUT to go northbound, after right turn from the driveway, need to complete their movements with a U-turn at the Bruce B. Downs Boulevard and Fletcher Avenue signalized intersection. The posted speed on Bruce B. Downs Boulevard is 45 mph. The aerial photograph of site 5 is illustrated in Figure 4.6

Figure 4.6 Site 5, Bruce B. Downs Boulevard and Fletcher Avenue

Site 6 is located in the city of Saint Petersburg at 34th Street and 54th Street. 34th Street is major arterial with three lanes for northbound and southbound traffic. It is divided by a raised median. The driveway studied is one of the driveways that serve a major shopping plaza that consists of a Publix Supermarket, some retail stores and many small businesses and it is located on 34th Street. The median across the driveway has a full median opening. The vehicles which make a RTUT to go northbound of 34th Street, after the right-turn from the driveway; need to complete the movement with a U-turn at the 34th Street and 54th Street signalized intersection. The posted speed on 34th Street is 45 mph. The aerial photograph of site 6 is illustrated in Figure 4.7

Site 7 is located in the city of Saint Petersburg at 34th Street and 22nd N. Street. 34th Street is a major arterial with three lanes for northbound and southbound traffic. It is divided by a raised median. The driveway studied is one of the driveways that serve a major shopping plaza consisting of a Kash N Karry Supermarket, some retail stores and many small businesses and it is located on 34th Street. The median across the driveway has a full median opening. The RTUT movements are completed with a U-turn at the 34th

Street and 22nd N. Street signalized intersection. The posted speed on this segment of 34th Street is 45 mph. The aerial photograph of site 7 is illustrated in Figure 4.8

Figure 4.7 Site 6, 34th Street and 54th Street

Site 8 is located in the city of Tampa at Dale Mabry Highway and Maple Dale Street. At this segment, Dale Mabry Highway is divided by a raised median with three lanes for northbound and southbound traffic. The driveway is on Dale Mabry Highway and it serves the parking lot for Sam's Club Retail Store. The median opening across the driveway is a directional median opening, which restricts DLT movements from the driveway. The drivers, who uses the studied driveway and want to go south on Dale Mabry Highway, has to make a RTUT. The RTUT vehicles turn northbound of the highway and make the U-turns at the Dale Mabry Highway and Maple Dale Street signalized intersection. The posted speed on Dale Mabry Highway is 45 mph. The aerial photograph of site 8 is illustrated in Figure 4.9

Figure 4.8 Site 7, 54th Street and 22nd N. Street

Figure 4.9 Site 8, Dale Mabry Highway and Maple Dale Street

4.2 Data Collection Equipment

In this project, data were collected by using video cameras. As a result, scaffoldings were necessary to use in order to set the needed image for video cameras. If the cameras were not placed at the suitable height from the ground level, movements of the vehicles could not be fully covered by cameras. In the previous project, there were some concerns about the data collection equipment. In this project, to prevent those problems and increase the efficiency of data collection, a system was developed as illustrated in Figure 4.10. In the previous project, the time for transferring the data from 8mm tapes to VHS tapes was a concern. In the new system data were recorded to the VHS tapes directly from video cameras. 8-mm tapes could only last two hours and had to be 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 of the video camera batteries during the time of data collection has been eliminated. After the initial setup of the system, responsible staff did not have to bother with the camera anymore to change the tapes or the batteries. The power needed for the system was another concern. This issue was solved by using marine batteries and inverters which 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. In addition, staff did not have to climb the scaffoldings, which the video cameras were placed on, to check the image of the video. Another concern was synchronization of the cameras because the vehicles were observed from several cameras at the same time. The video cameras were set to have the same time in second’s accuracy.

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

Figure 4.10 Data Collection System

4.3 Field Procedure

Data were 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 data collected was 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 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 noon peak hours. For this project, data collection was 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 started 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 was 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 video cameras requires experienced personnel because if the data needed were not collected (correct image), it would be a waste of resources and reliability of the data would dramatically be reduced. Another issue was synchronization of the video camera times, which was implemented before the placement of cameras. Once, all video cameras were synchronized and placed, data collection was 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

5.1 Descriptive Analysis

Before the analysis of the data, it was necessary to verify that the data collected reached the required sample size. This process was conducted as explained previously in the methodology chapter. For this process, the expected proportion of vehicles observed that were involved in a conflict was calculated by dividing the total number of vehicles observed for RTUT and DLT movements to various kinds of conflicts related to those movements. Finally, the required sample sizes were calculated using the different proportions for each type of conflict. The confidence level of 95 percent and a 5 percent permitted level of error were used for sample size estimation. The sample sizes collected and estimated for RTUT and DLT movements are presented in Tables 5.1 and 5.2 respectively. When comparing the sample size values, it was found that the collected sample sizes satisfied the required values.

Table 5.1 Sample Size Verification for RTUT Movements

Conflict (1)	Average Number of Conflicts (2)	RTUT Vehicles (3)	P_{RTUT} (4)=(2)/(3)	n (5)	Sample Size Satisfied
C1	55	1280	0.04	63	Yes
C2	50	1280	0.04	58	Yes
C3	52	1280	0.04	60	Yes
C4	74	1280	0.06	84	Yes
C5	222	1280	0.17	220	Yes

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

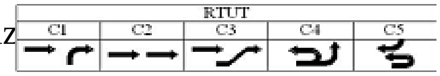
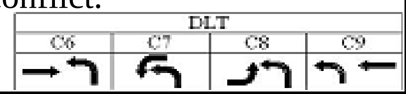


Table 5.2 Sample Size Verification for DLT Movements.

Conflict (1)	Average Number of Conflicts (2)	DLT Vehicles (3)	P_{DLT} (4)=(2)/(3)	n (5)	Sample Size Satisfied
C6	354	2530	0.14	185	Yes
C7	116	2530	0.05	67	Yes
C8	66	2530	0.03	39	Yes
C9	230	2530	0.09	127	Yes

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



Once sample sizes were verified, the collected data were evaluated. Data are presented in different tables and graphical illustrations to facilitate a descriptive analysis of the information.

After data were collected at the field and reduction is processed, the raw data were checked for errors. Also, data were not useful because of the technical problems during the data collection, was discarded. Different types of conflicts observed for DLT and RTUT movements at each site after these explained processes was presented in Table 5.3

As it was mentioned in methodology chapter a typical data collection day was considered as eleven hours (7:00 AM – 6:00 PM). Data were not collected for eleven hours, so it was adjusted with the process explained earlier. Table 5.4 presents the data adjusted and used for analysis purposes.

The average daily number of conflicts for each site and conflict type were obtained based on the average number of conflicts and these values are given in Table 5.5, and Figures 5.1 through 5.8 graphically illustrate the individual data at each site for all conflict types.

Table 5.3 Summary of the Total Number of Conflicts Observed

Site	Conflicts	Conflict Type									Total
		C1	C2	C3	C4	C5	C6	C7	C8	C9	
1	No.	10.0	4.0	7.0	21.0	35.0	N/A	N/A	N/A	N/A	77
	(%)	13.0	5.2	9.1	27.3	45.5	-	-	-	-	100
2	No.	3.0	2.0	2.0	0.0	15.0	75.0	26.0	14.0	67.0	204
	(%)	1.5	1.0	1.0	0.0	7.4	36.8	12.7	6.9	32.8	100
3	No.	1.0	1.0	0.0	0.0	2.0	9.0	4.0	0.0	8.0	25
	(%)	4.0	4.0	0.0	0.0	8.0	36.0	16.0	0.0	32.0	100
4	No.	7.0	8.0	10.0	2.0	18.0	N/A	N/A	N/A	N/A	45
	(%)	15.6	17.8	22.2	4.4	40.0	-	-	-	-	100
5	No.	19.0	21.0	27.0	42.0	80.0	192.0	58.0	32.0	123.0	594
	(%)	3.2	3.5	4.5	7.1	13.5	32.3	9.8	5.4	20.7	100
6	No.	1.0	1.0	0.0	1.0	2.0	35.0	16.0	9.0	21.0	86
	(%)	1.2	1.2	0.0	1.2	2.3	40.7	18.6	10.5	24.4	100
7	No.	2.0	2.0	1.0	0.0	10.0	43.0	12.0	11.0	11.0	92
	(%)	2.2	2.2	1.1	0.0	10.9	46.7	13.0	12.0	12.0	100
8	No.	12.0	11.0	5.0	8.0	60.0	N/A	N/A	N/A	N/A	96
	(%)	12.5	11.5	5.2	8.3	62.5	-	-	-	-	100
Total		55.0	50.0	52.0	74.0	222.0	354.0	116.0	66.0	230.0	*1219*

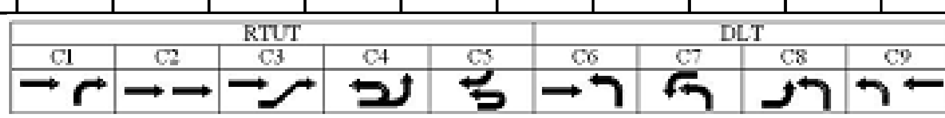


Table 5.4 Summary of the Total Number of Conflicts Used for Analysis

Site	Conflicts	Conflict Type									Total
		C1	C2	C3	C4	C5	C6	C7	C8	C9	
1	No.	17.4	7.7	11.7	39.0	65.3	N/A	N/A	N/A	N/A	141.1
	(%)	12.3	5.5	8.3	27.6	46.3	-	-	-	-	100.0
2	No.	3.6	2.6	3.2	0.0	20.2	103.4	34.9	18.6	90.2	276.7
	(%)	1.3	0.9	1.2	0.0	7.3	37.4	12.6	6.7	32.6	100.0
3	No.	1.8	1.8	0.0	0.0	1.0	15.8	7.0	0.0	14.1	41.5
	(%)	4.3	4.3	0.0	0.0	2.4	38.1	16.9	0.0	34.0	100.0
4	No.	12.7	16.1	19.9	4.3	34.7	N/A	N/A	N/A	N/A	87.7
	(%)	14.5	18.4	22.7	4.9	39.6	-	-	-	-	100.0
5	No.	23.7	26.2	33.6	52.3	99.6	239.1	72.2	39.8	153.2	739.7
	(%)	3.2	3.5	4.5	7.1	13.5	32.3	9.8	5.4	20.7	100
6	No.	1.4	1.3	0.0	1.4	2.7	53.2	22.4	12.2	31.5	126.1
	(%)	1.1	1.0	0.0	1.1	2.1	42.2	17.8	9.7	25.0	100
7	No.	3.7	2.5	1.3	0.0	13.8	69.3	17.4	16.2	18.4	142.6
	(%)	2.6	1.8	0.9	0.0	9.7	48.6	12.2	11.4	12.9	100
8	No.	19.1	17.5	9.3	12.8	80.6	N/A	N/A	N/A	N/A	139.3
	(%)	13.7	12.6	6.7	9.2	57.9	-	-	-	-	100
Total		83.4	75.7	79	110	318	481	154	86.8	307	*1695*

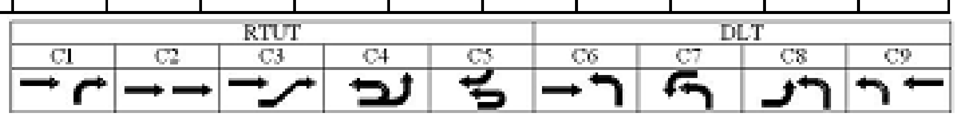


Table 5.5 Average Daily Number of Conflicts

Site	Conflict Type									Total
	C1	C2	C3	C4	C5	C6	C7	C8	C9	
1	5.8	2.6	3.9	13.0	22.0	N/A	N/A	N/A	N/A	47.3
2	0.9	0.7	0.8	0.0	5.0	25.8	8.7	4.6	22.5	69.0
3	0.9	0.9	0.0	0.0	0.5	7.9	3.5	0.0	7.0	20.7
4	3.2	4.0	5.0	1.1	8.7	N/A	N/A	N/A	N/A	22.0
5	7.9	8.7	11.2	17.4	33.2	79	24.1	13.3	51.1	246.3
6	0.5	0.4	0.0	0.5	0.9	17.7	7.5	4.0	10.5	42.1
7	1.2	0.9	0.4	0.0	4.6	23.1	5.8	5.4	6.2	47.6
8	6.4	5.8	3.1	4.3	26.9	N/A	N/A	N/A	N/A	46.5

Site 1, which was a directional median opening site where no DLT conflict data were available. 74 percent of total conflicts were related to U-turn maneuvers at the traffic signal (conflicts C4 and C5). Conflict C5 that is the conflict between U-turning vehicles and left turning vehicles was approximately 46 of total conflicts for this site because of the high volume of left turns at traffic signal. Conflict C4 that is between the U-turning vehicles and right turning vehicles across the intersection was around 28 percent of total conflicts. The other RTUT conflict types C1, C2, and C3 were 12, 5, and 8 percent of total conflicts respectively. Number of daily conflicts for Site 1 is shown in Figure 5.1

Site 2, the conflicts generated by DLT movements (89%) were remarkably high when compared to the conflicts generated by RTUT movements (11%). Conflict C6 was 37 percent of all conflicts occurred at this site. Also, this conflict type was 42 percent of the DLT movement conflicts. The high volume on main roadway and high volume of DLT movements would cause high percentage of C6 type conflicts. Conflict type C9 between main road vehicles and DLT vehicles, another type of conflict like C6, was 33 percent of the total conflicts. The other DLT conflict types C7 and C8 were 13 and 7 percent of total conflicts, respectively. On the other hand, for RTUT movements; C5 was the conflict type that mostly occurred for all the RTUT conflicts. This conflict was 7 percent of all conflicts occurred at this site. Also another interesting point is that no C4 type conflicts occurred during the observation period. The other types of conflicts related to RTUT conflict occurred very rare, which were C1, C2, and C3 1.3, 0.9 and 1.2 percent of total conflicts. Number of daily conflicts for Site 2 is illustrated in Figure 5.2.

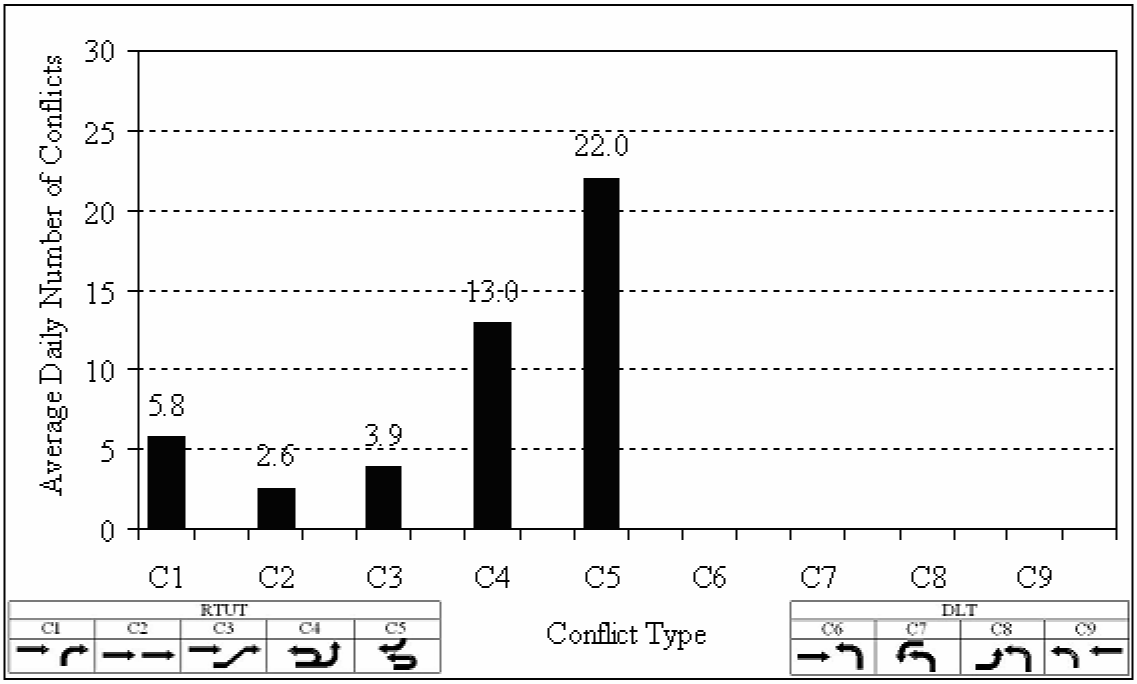


Figure 5.1 Number of Daily Conflicts by Type, Site 1

Site 3 had less number of conflicts when compared to the other sites studied. The reason for this situation would be a relatively lower volume of the driveway studied. Interestingly distribution of conflicts for DLT and RTUT movements were similar to Site 2, where DLT movement related conflicts were 89 percent of the total conflicts and RTUT movements generated 11 percent of total conflicts. At this site conflict types C3 and C4 which were RTUT related conflicts, and C8 which was DLT related conflict, were not observed. Conflict C6 was 38 percent of all conflicts occurred at this site. The other DLT conflict types C7 and C9 were 17 and 34 percent of the total conflicts, respectively. RTUT movement conflicts had very low average daily number of conflicts. The both conflicts types C1 and C2 were 4 percent of the total conflicts, while Conflict type C5 was 2.4 percent of all conflicts. Number of daily conflicts for Site 3 is presented in Figure 5.3

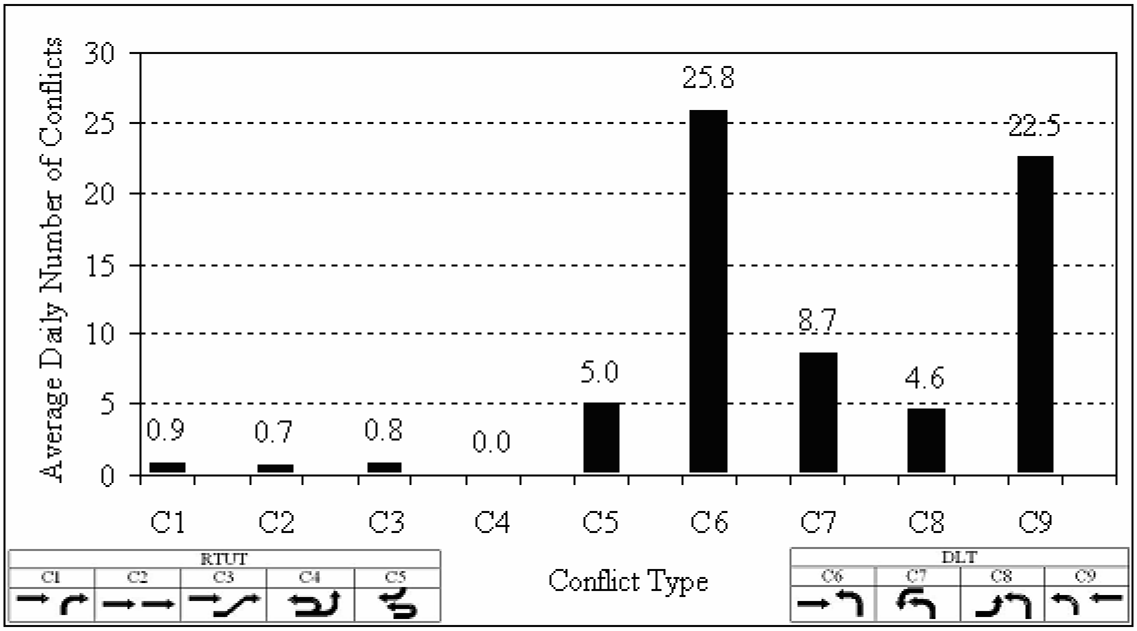


Figure 5.2 Number of Daily Conflicts by Type, Site 2

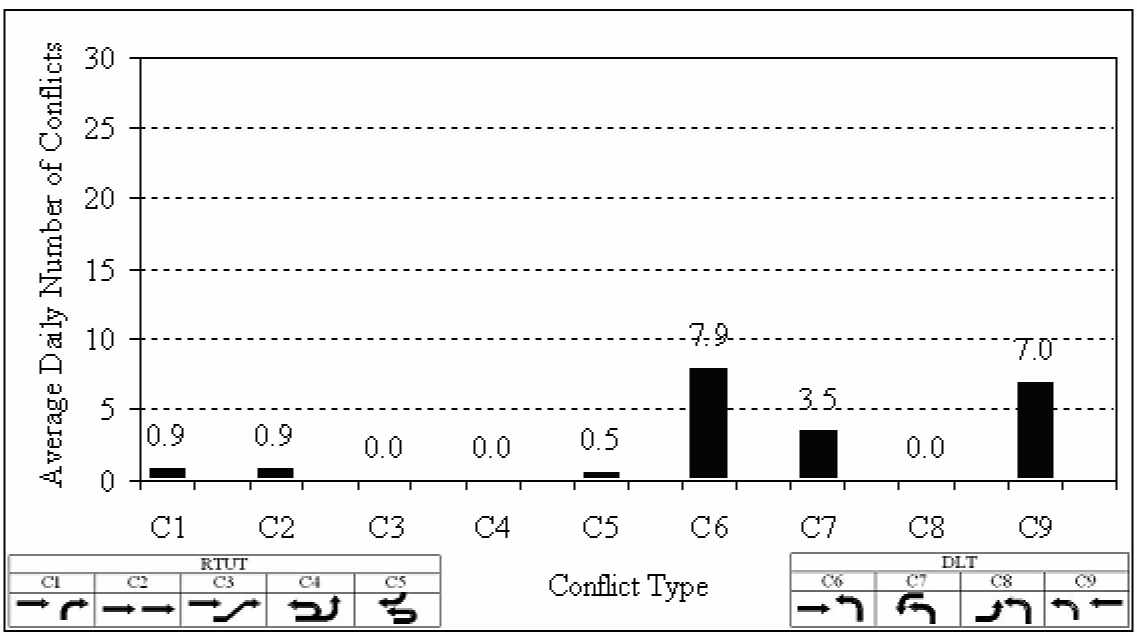


Figure 5.3 Number of Daily Conflicts by Type, Site 3

Site 4 was another directional median opening site. Approximately 45 percent of all conflicts were related to the U-turn maneuvers at the traffic signal. As it was at the other directional median opening sites, Conflict type C5 occurred most out of all conflicts observed. 40 percent of all conflicts were C5 type of conflict. Conflict type C4, that is another U-turn maneuver related conflict occurred least with percentage of 5. The other RTUT related conflict types C1, C2, and C3 which occurred between right turning and weaving vehicles, and main road vehicles, were 15, 18, and 23 percent of all conflict observed at this site. Number of daily conflicts for Site 4 is shown in Figure 5.4

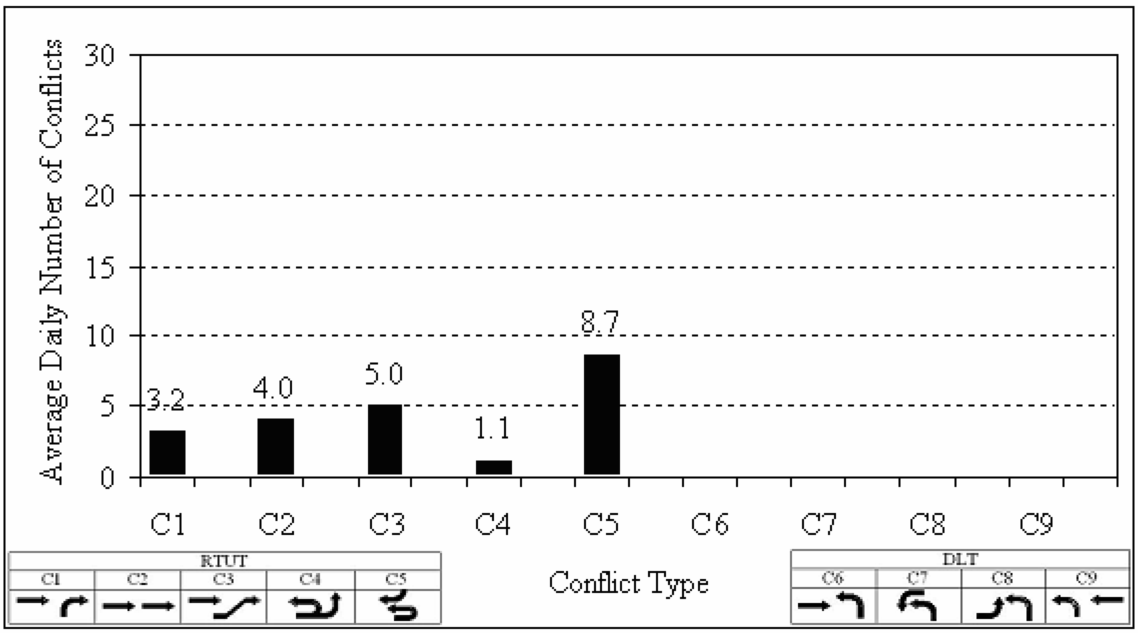


Figure 5.4 Number of Daily Conflicts by Type, Site 4

Site 5, out of all the sites, had the highest driveway volume. Figure 5.5 shows, the average daily numbers of all conflicts were higher than other sites. The DLT related conflicts were 68 percent of total conflicts while the RTUT related conflicts were 32 percent of total conflicts occurred. Conflict type C6 occurred the most with a percentage of 32 of total conflicts, and 47 percent of DLT related conflicts. Conflict type C9 was 21 percent of total conflicts. The reason for high percentages of conflict types C5 and C9 was high volumes of both DLT and main road vehicles. Conflict types C7 and C8, which were slow vehicles' conflicts at the median openings, were 9.8 and 5.4 percent of total conflicts. The RTUT related conflicts were spread through various conflict types except conflict type C5. Conflict type C5 was approximately 14 of all conflicts and 42 percent of the RTUT related conflicts. The other RTUT related conflict types C1, C2, C3, and C4 were 3, 4, 5, and 7 percent of all conflicts respectively and 10, 11, 14 and 22 percent of RTUT related conflicts respectively.

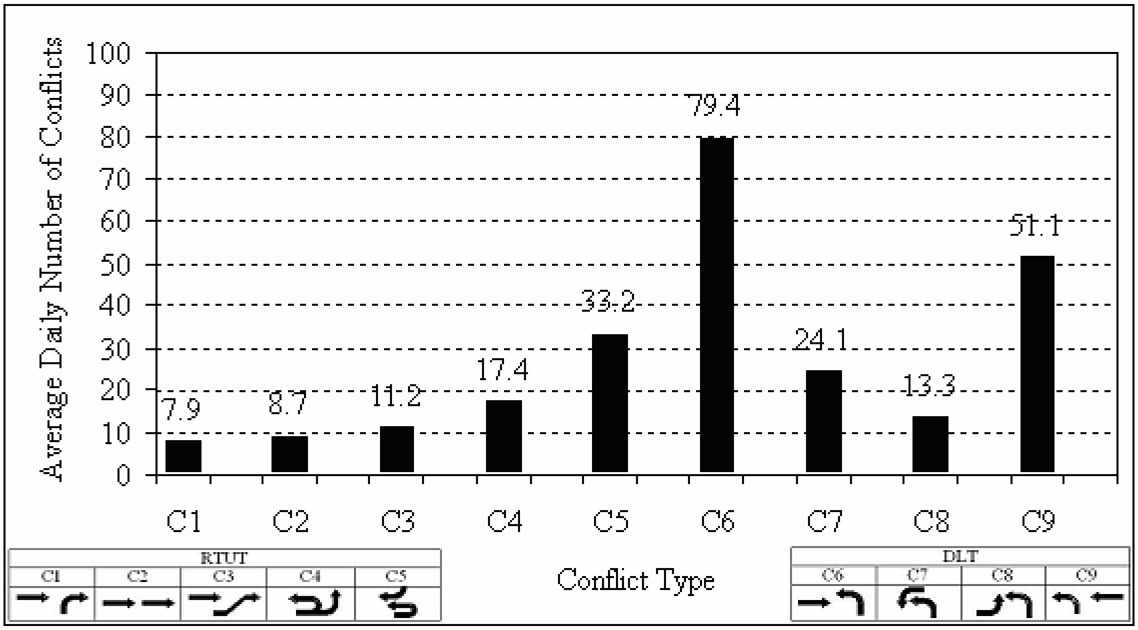


Figure 5.5 Number of Daily Conflicts by Type, Site 5

Site 6 had the largest difference between DLT and RTUT average daily number of conflicts. The DLT movements generated 95 percent of all conflicts while RTUT movements generated only 5 percent of conflicts. Conflict type C6 was 42 percent of conflicts and 45 percent of DLT related conflicts. At this site because of the high volume of the median opening movements, median opening related conflict types C7 and C8 had high percentages, which were around 18 and 10 percent respectively. Also, another factor median width was an important factor for higher percentage of median opening related conflicts. Conflict type C9 was 25 percent of total conflicts. The RTUT related conflicts had the lowest percentages of all the sites. Conflict types C1, C2, C4, and C5 were 1.1, 1, 1.1 and 2.1 percent of total conflicts, respectively. Conflict type C3 was not observed at this site. Figure 5.6 shows number of daily conflicts for Site 6.

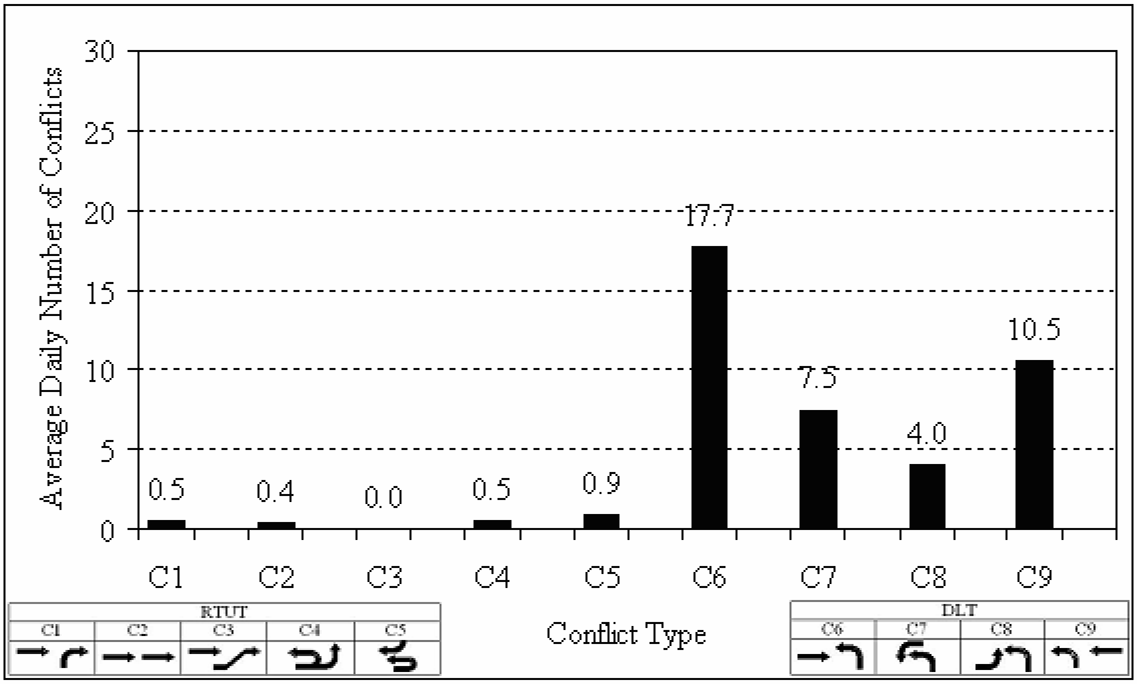


Figure 5.6 Number of Daily Conflicts by Type, Site 6

For Site 7, DLT related conflicts were 85 percent of the total conflicts. On the other hand the RTUT related conflicts were 15 percent of all conflicts. Conflicts type C6 had the highest percentage as compared to other sites, which was 49 percent of all conflicts and 57 percent of DLT related conflicts. The other DLT related conflicts C7, C8, and C9 were 12, 11, and 13 percent of the total conflicts respectively. For RTUT movements, conflict type C5 was 9.6 percent of all conflicts and 95 percent of the RTUT related conflicts. Because 22nd street connects 34th street to I-275, left turn volume at the signalized intersection was relatively high. This factor caused high percentages of conflict type C5 at this site. Conflict type C4 was not observed at this site. The other RTUT related conflicts, C1, C2, and C3 were 3, 2 , 1 percent of all conflicts respectively. Figure 5.7 illustrates number of daily conflicts for Site 7.

Site 8 U-turn maneuvers generated 67 percent of all conflicts at this directional median opening site. Conflict type C5 was 58 percent of all conflicts, which was remarkably higher when compared to the directional median opening sites. The other conflict types, C1, C2, C3, and, C4 were 14, 13, 7 and 9 percent of total conflicts that were observed at this site. Figure 5.8 presents number of daily conflicts for Site 8.

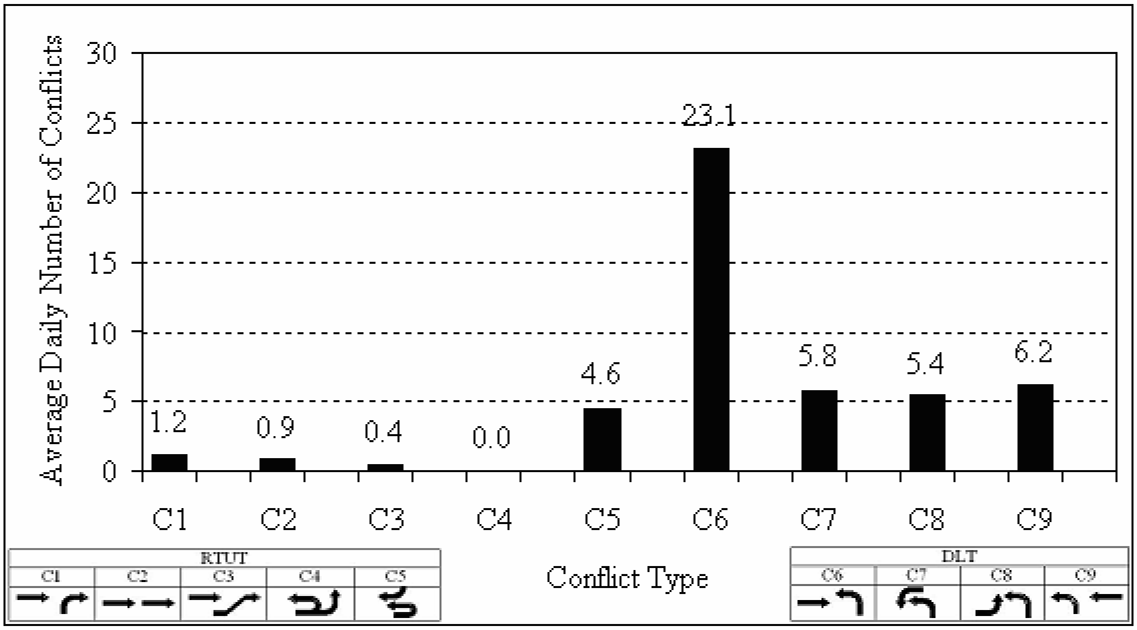


Figure 5.7 Number of Daily Conflicts by Type, Site 7

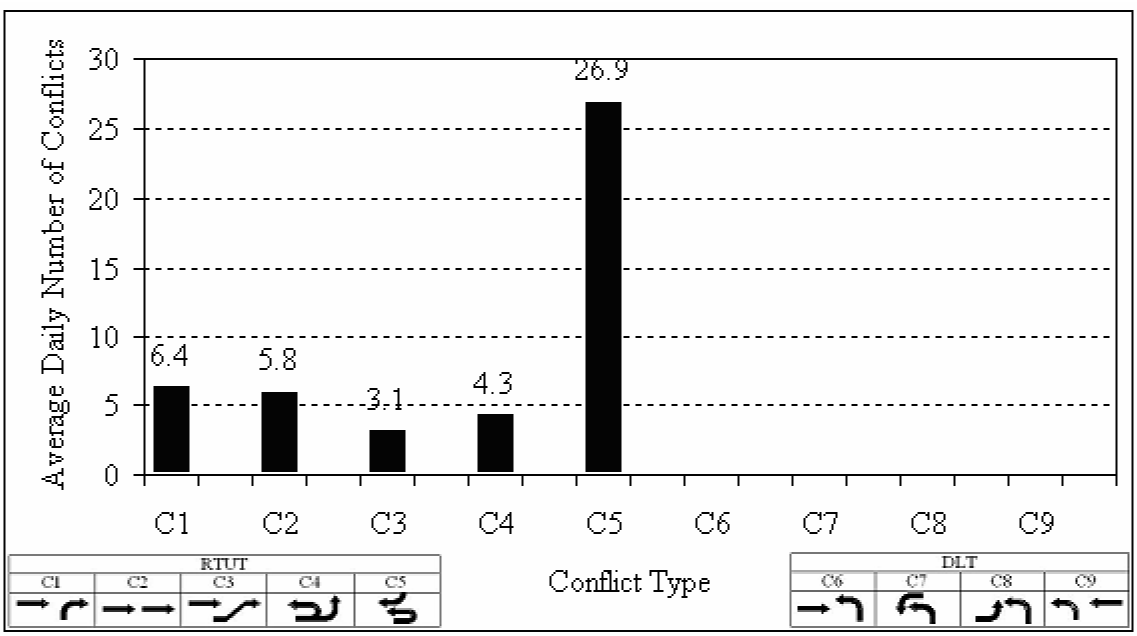


Figure 5.8 Number of Daily Conflicts by Type, Site 8.

The conflict data for all sites were aggregated for the purpose of calculating the average daily number of conflicts related to RTUT and DLT movements by each conflict type, which are presented in Figures 5.9 and 5.10, respectively.

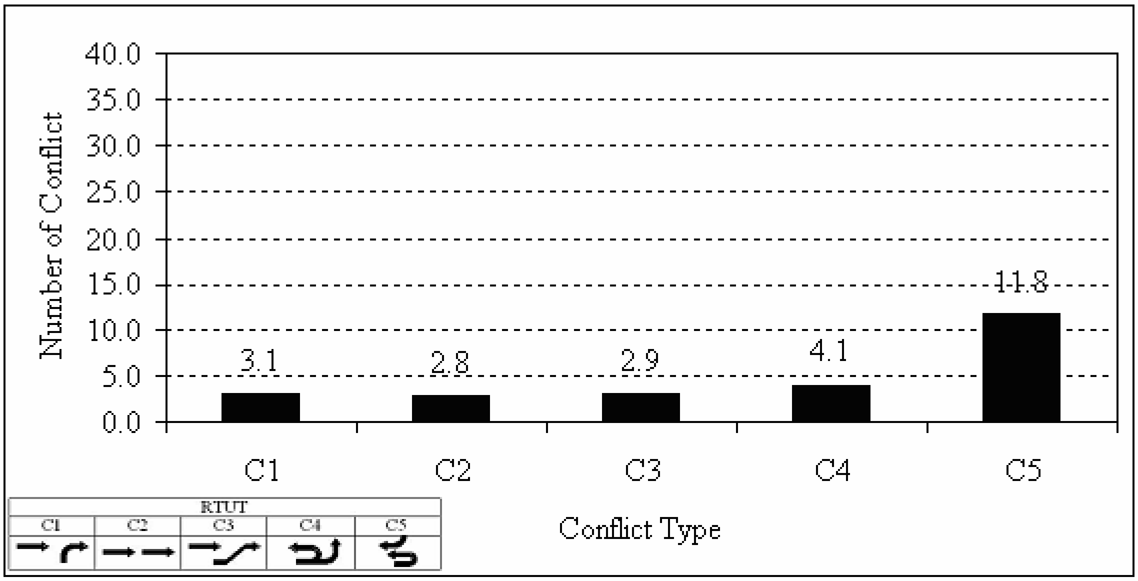


Figure 5.9 Average Number of Daily Conflicts by Type, RTUT Movement.

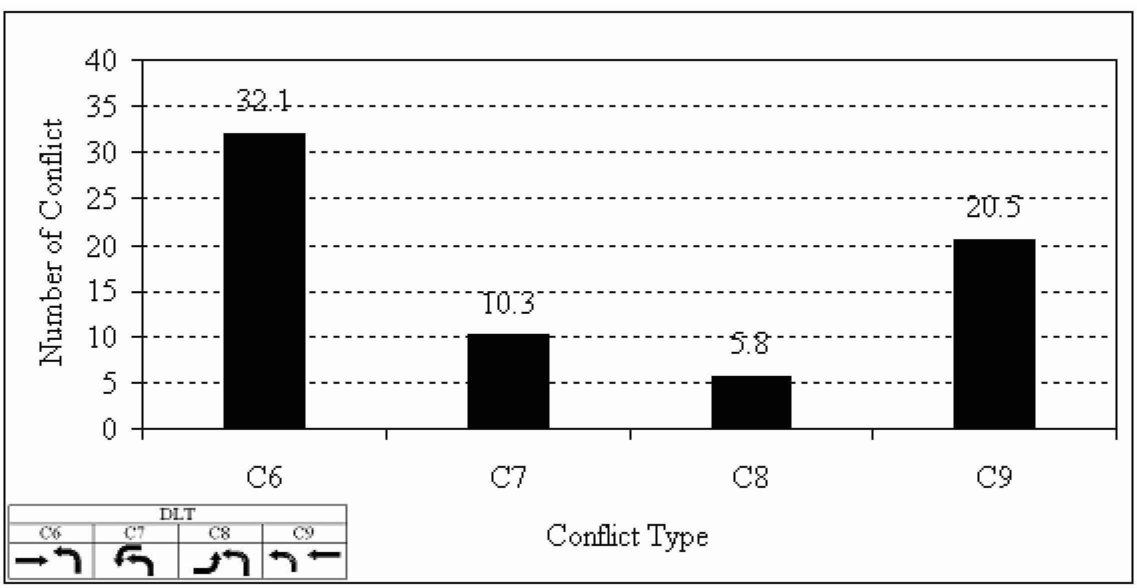


Figure 5.10 Average Number of Daily Conflicts by Type, DLT Movement.

The RTUT movements generated an average of 26.6 conflicts per day. 48 percent of the RTUT related conflicts were conflict type C5. Although this conflict occurred between two slow vehicles, it occurred the most. The other conflict types; C1, C2, C3, and C4 were 13, 11, 11, and 17 percent of all RTUT related conflicts, respectively. U-turn maneuvers at the traffic signal generated 65 percent of all RTUT related conflicts, which was interesting because those conflicts occurred at the intersection where the vehicles have less speed difference as compared to other types of RTUT related conflicts. U-turn related conflicts have higher percentages as compared to other RTUT related conflicts because the drivers at the intersection do not realize a vehicle is making a U-turn until the U-turn maneuver begins. Because the drivers do not expect the U-turn until the last moment, they approach the U-turn vehicles without caution which causes conflicts.

An average of 65.7 conflicts was observed for DLT movements. The data show that conflict type C6 occurred the most, with a 47 percent of the all DLT related conflicts. For the other conflict types; C9, C7, and C8 were 30, 15, and 8 percent respectively. Conflict types C6 and C9 are the conflicts with main road vehicles; therefore, it was expected for these type of conflicts to occur more frequent than the other types. As expected, conflict types C7 and C8 have lower frequency because the volumes involved in these conflicts were lower when compared to C6 and C7.

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

5.2 Conflict Rates

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

5.2.1 Conflicts per hour

Conflicts per hour were calculated for each conflict type at each site. Figures 5.11 through 5.18 present conflicts per hour for each site. When conflicts per hour for both alternatives when considering all sites were compared, DLT movements generated more average conflicts per hour than RTUT movements. Figure 5.19 illustrates average conflicts per hour for RTUT related conflicts. In general, RTUT movement conflicts were not affected by peak hour traffic significantly. Changes during the peak hours were in a positive or a negative way for different conflict types. Conflict type C1 had higher rate during the peak hour period when compared to non-peak hour. When other types of conflicts were compared; conflict type C2 decreased by 5 percent during peak hours. This decrease can be explained by the volume increase entering downstream signal causing speed reduction of the vehicles while they were approaching the signal. Although vehicles have lower speeds because of the heavier traffic during peak hours lane changes causes more conflicts. The lane change conflict C3 increased by 68 percent. U-turn related conflicts; C4 decreased by 14 percent where conflict type C5 increased by 14 percent during peak hours. On the other hand, all DLT related conflicts except conflict type C8 increased during peak hours as it is illustrated in Figure 5.20. Median opening related conflict type C8 was decreased by 48 percent while conflict types C6 and C7 increased 10 percent and 6 percent, respectively. Finally, conflict type C9 increased by 11 percent during peak hours. These changes were lower than expected, this can be explained by the downstream signal which provided available gaps and reduced the approaching vehicle speeds.

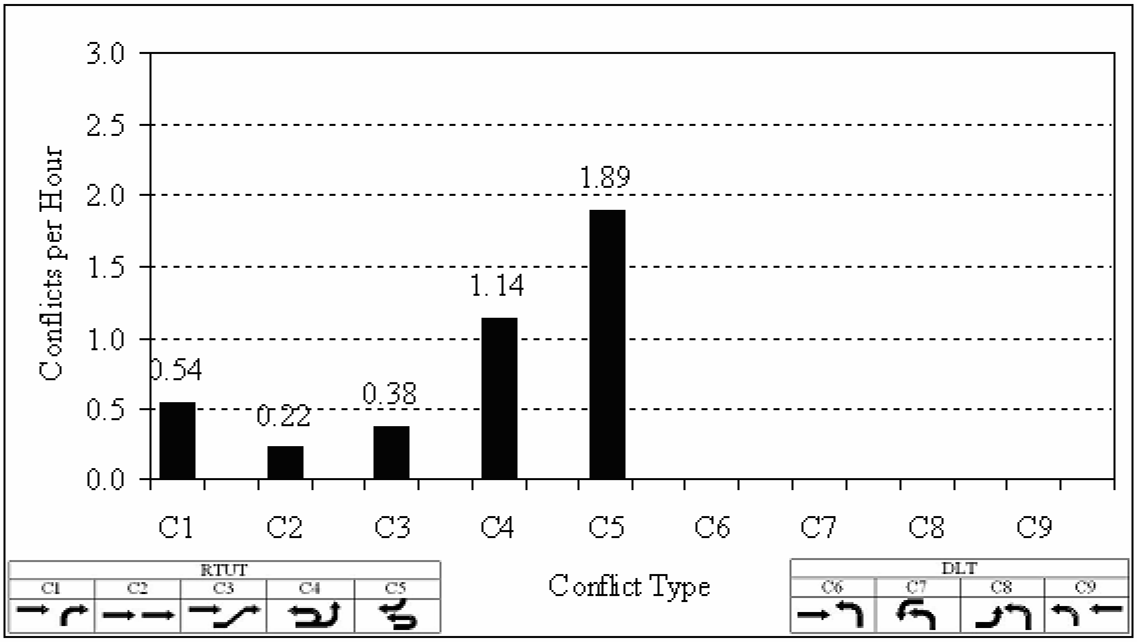


Figure 5.11 Conflicts per Hour, Site 1

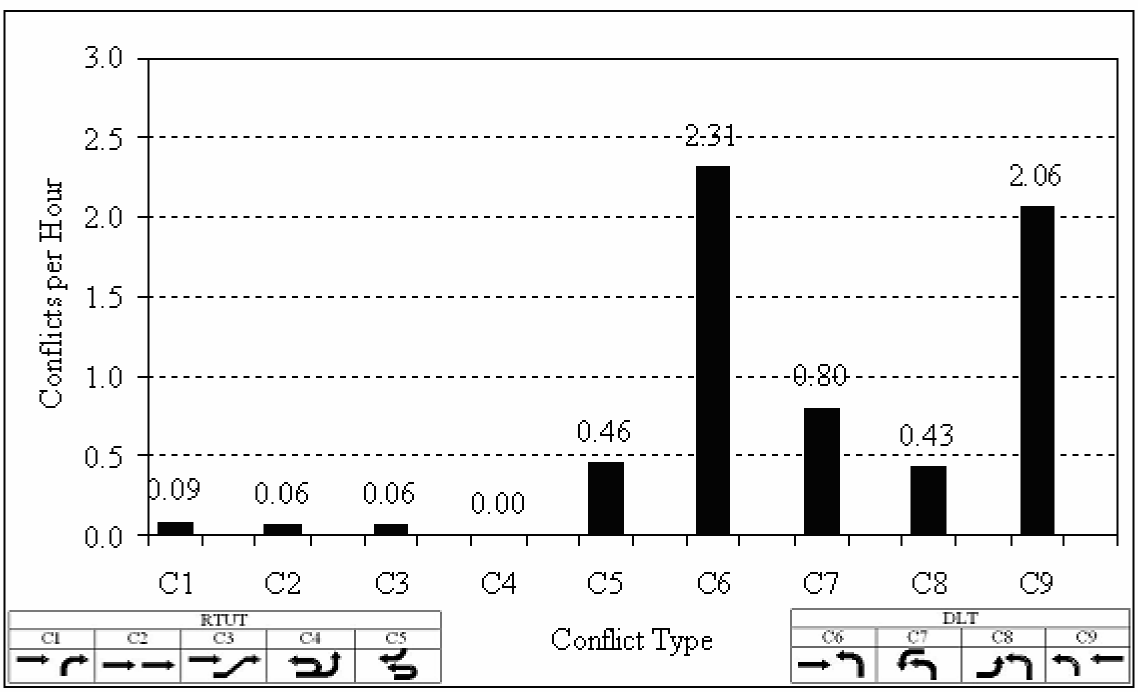


Figure 5.12 Conflicts per Hour, Site 2

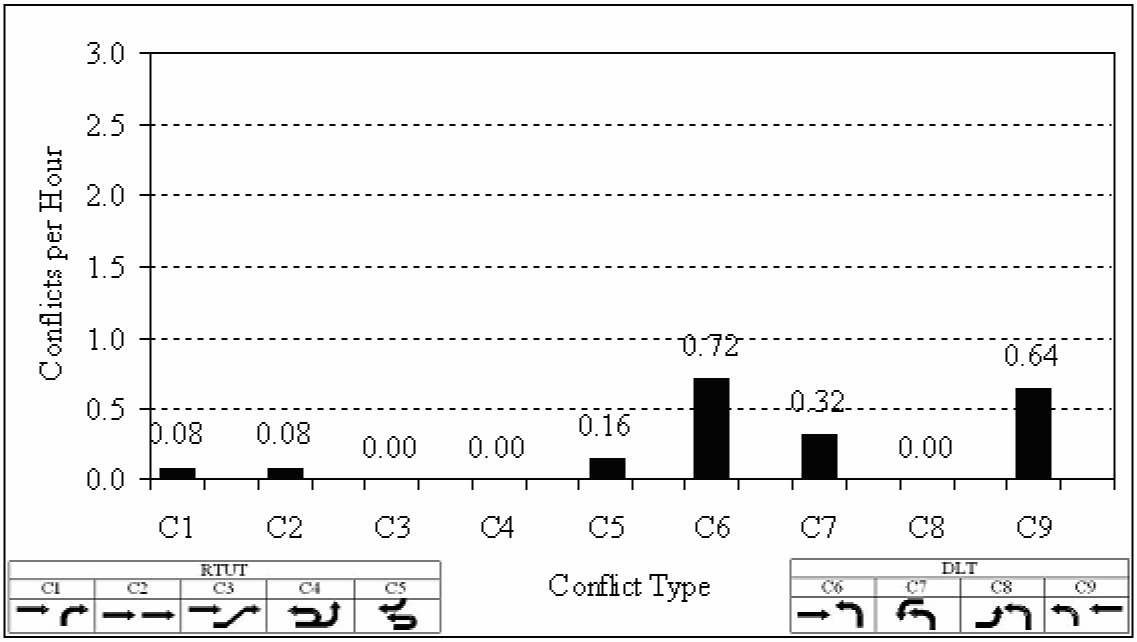


Figure 5.13 Conflicts per Hour, Site 3

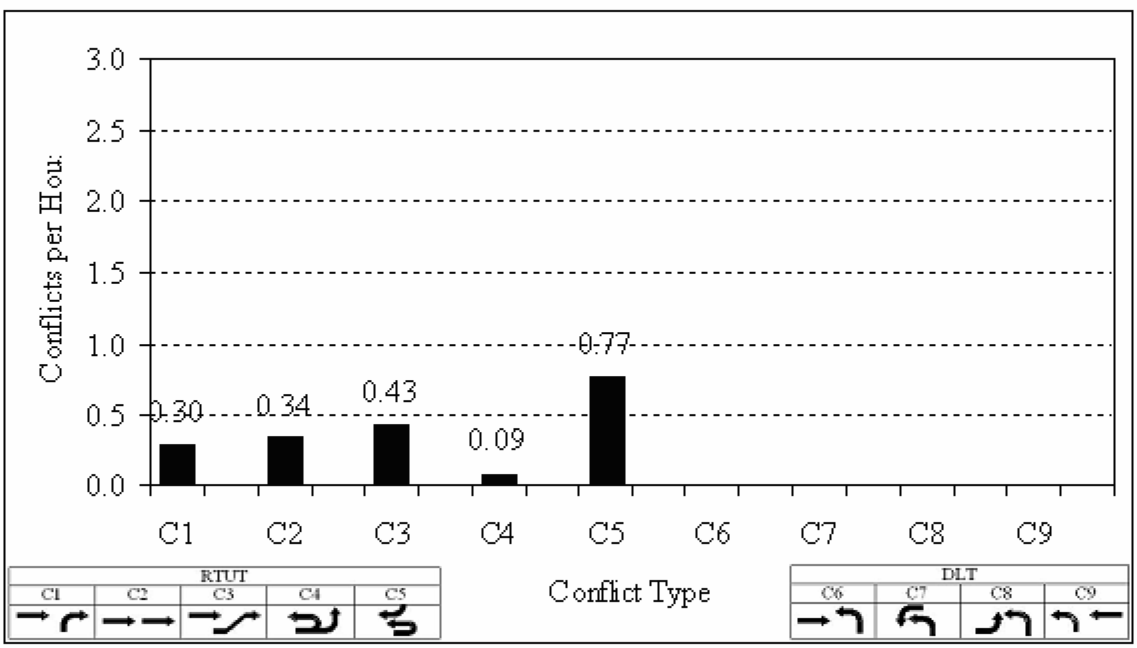


Figure 5.14 Conflicts per Hour, Site 4

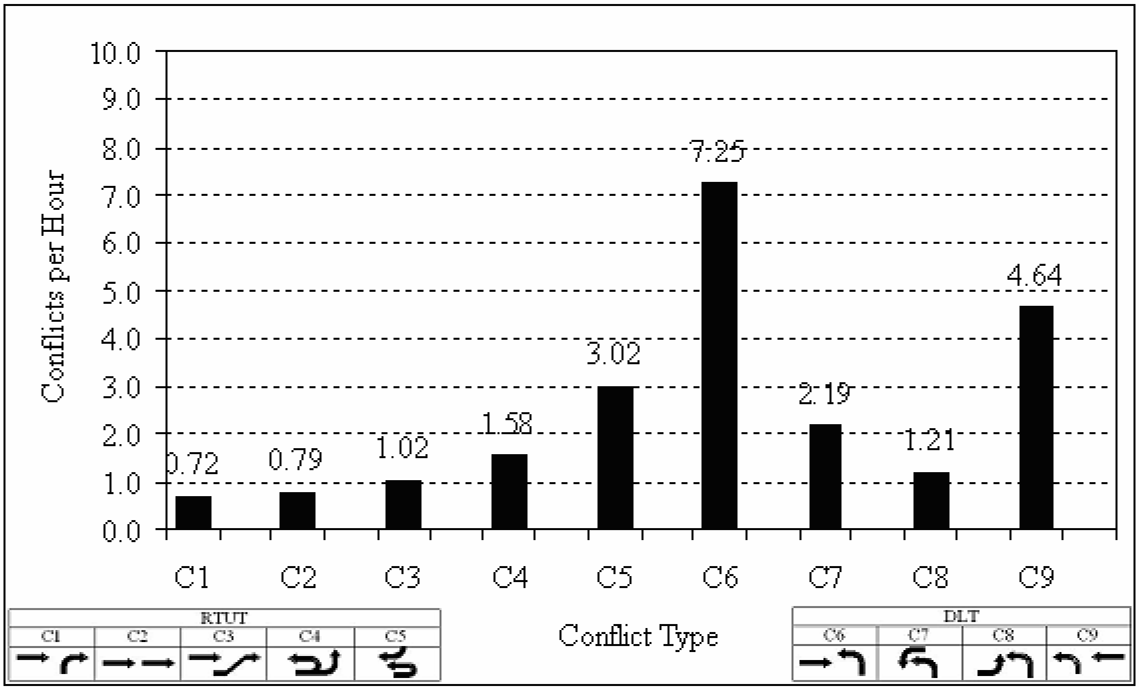


Figure 5.15 Conflicts per Hour, Site 5

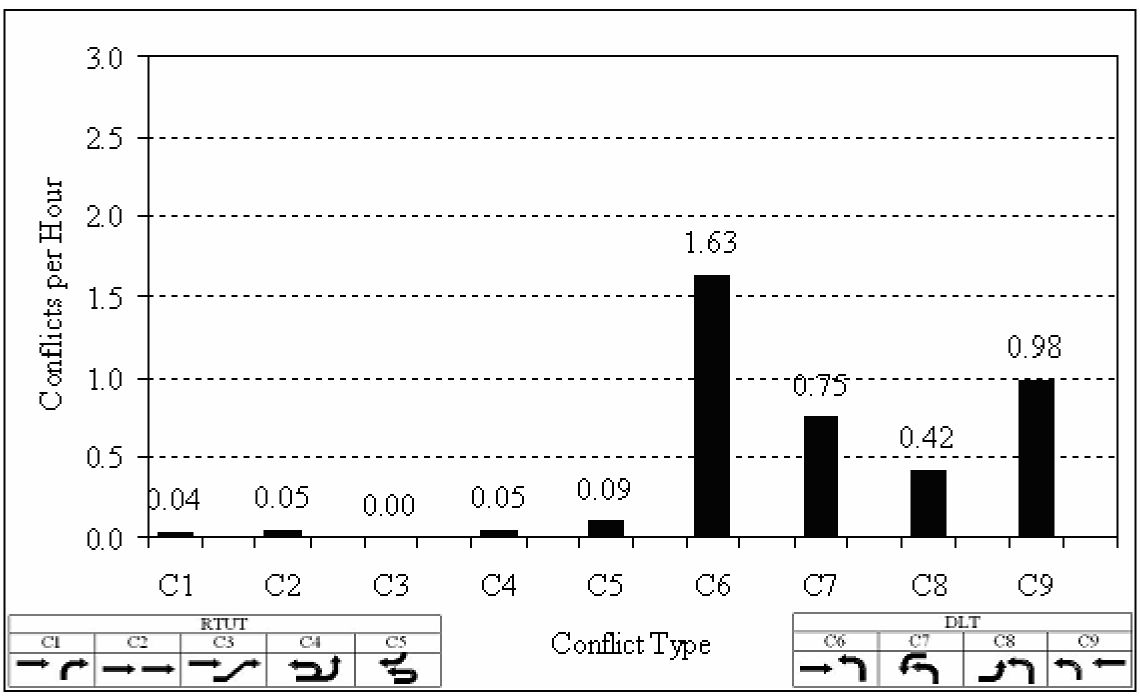


Figure 5.16 Conflicts per Hour, Site 6

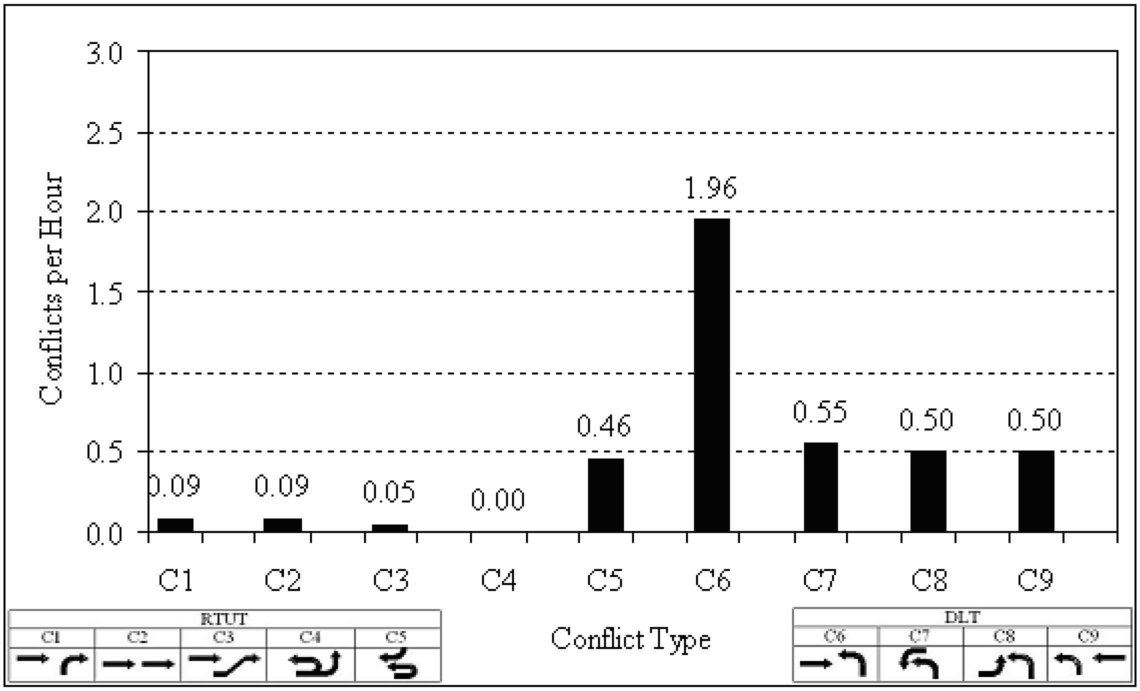


Figure 5.17 Conflicts per Hour, Site 7

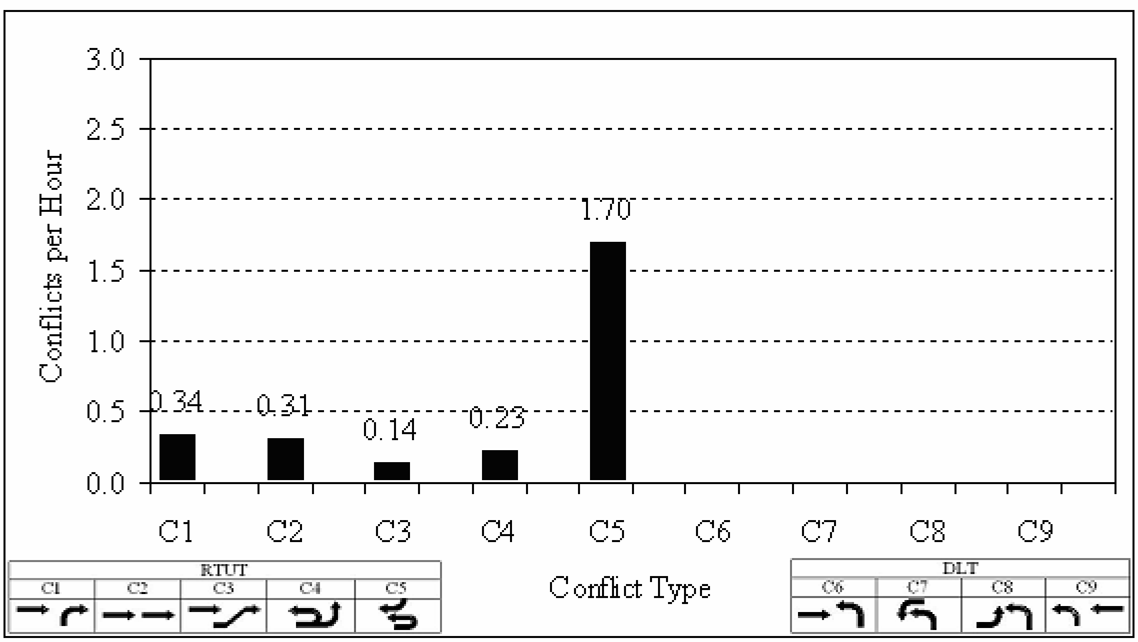


Figure 5.18 Conflicts per Hour, Site 8

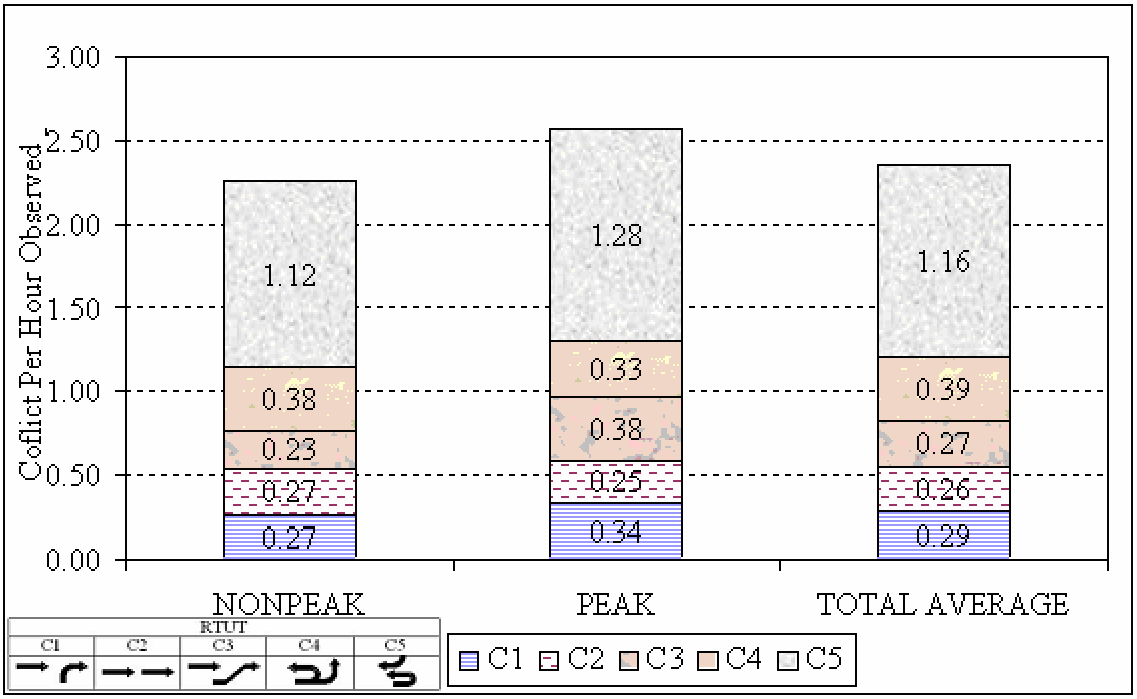


Figure 5.19 Conflicts by time Period, RTUT Movement

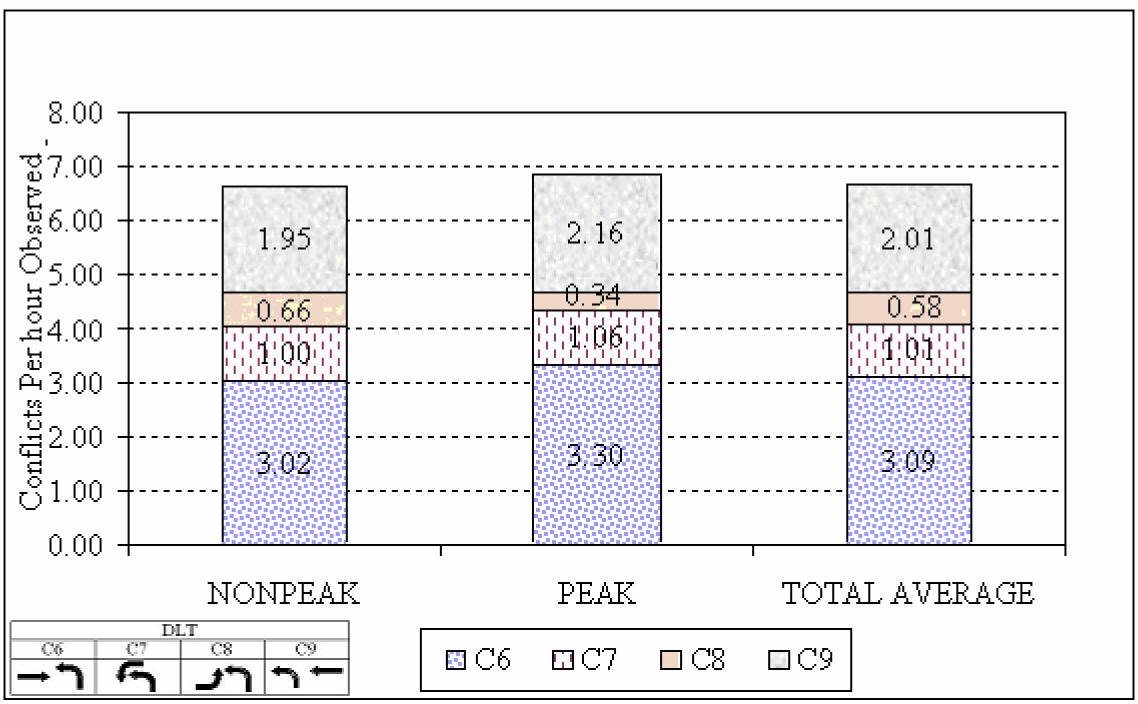


Figure 5.20 Conflicts by time Period, DLT Movement

Figure 5.21 presents average number of conflicts per hour for RTUT and DLT movements. When both peak and non-peak periods are compared, both movements have higher conflict rates during the peak hours.

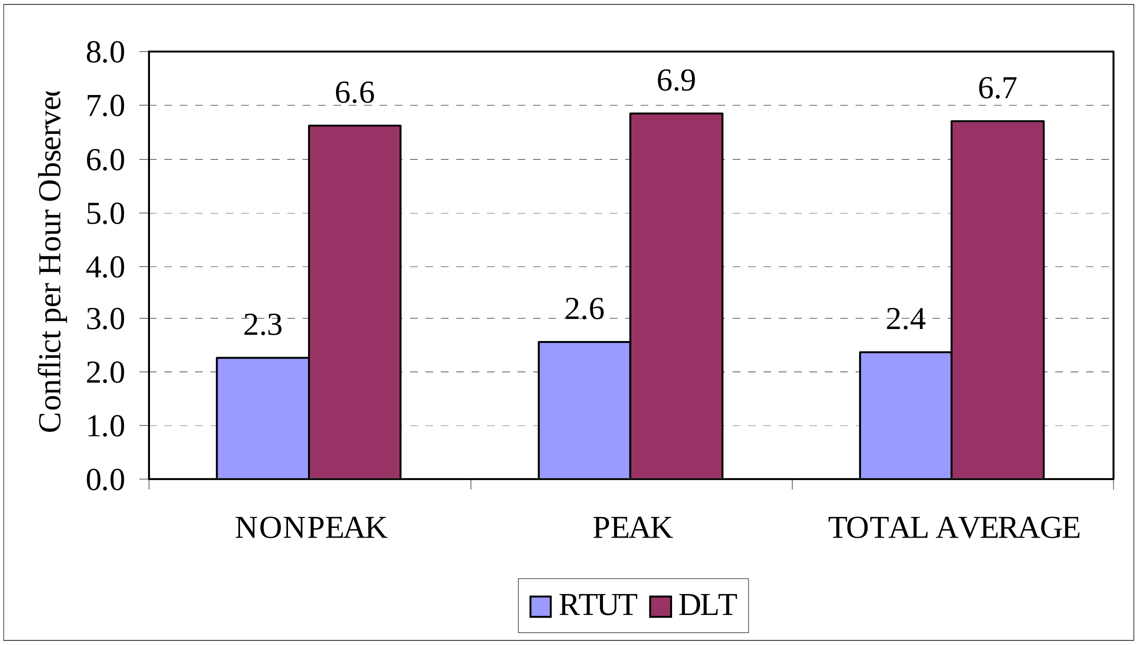


Figure 5.21 Conflicts by time Period, DLT and RTUT Movements Comparison

5.2.2 Conflicts per Thousand Involved Vehicles

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. The values given in Table 5.6 indicate that all sites had lower conflict rates for RTUT movements. Moreover, Table 5.6 indicates that the average conflict rate for RTUT was 33 percent lower than that of DLT movements.

Table 5.6 Number of Conflicts per Thousand Involved Vehicles.

Site	DLT	RTUT
Site 1	N/A	30.43
Site 2	45.43	25.45
Site 3	23.99	15.24
Site 4	N/A	28.82
Site 5	38.61	32.87
Site 6	62.99	15.46
Site 7	30.46	25.2
Site 8	N/A	36.46
Average	40.30	26.24

5.3 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, which 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) can not 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 was 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 and cumulative frequency of the severity for each conflict type with ROC score were calculated and are illustrated in Figures 5.22 through 5.30. Based on these figures, average ROC score values were calculated for all conflicts.

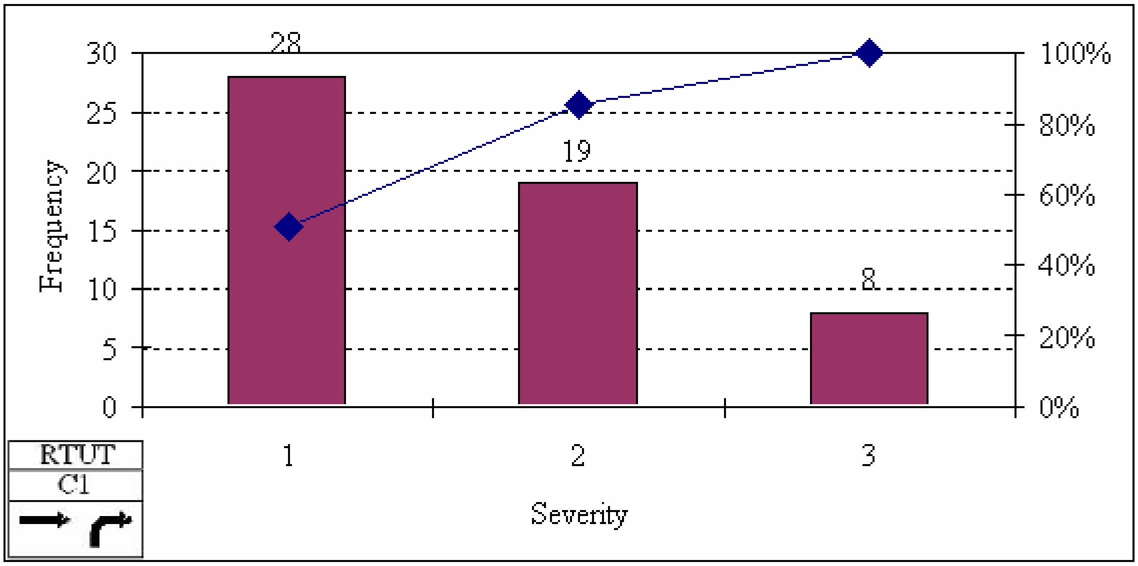


Figure 5.22 Distribution of Severity Conflict Type C1

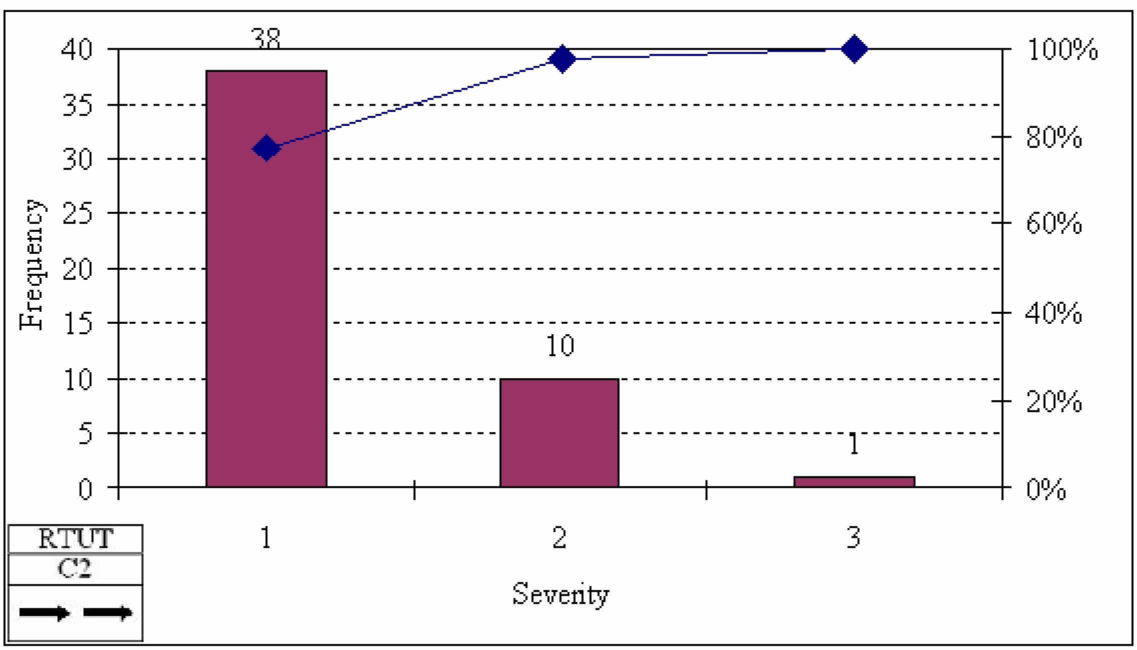


Figure 5.23 Distribution of Severity Conflict Type C2

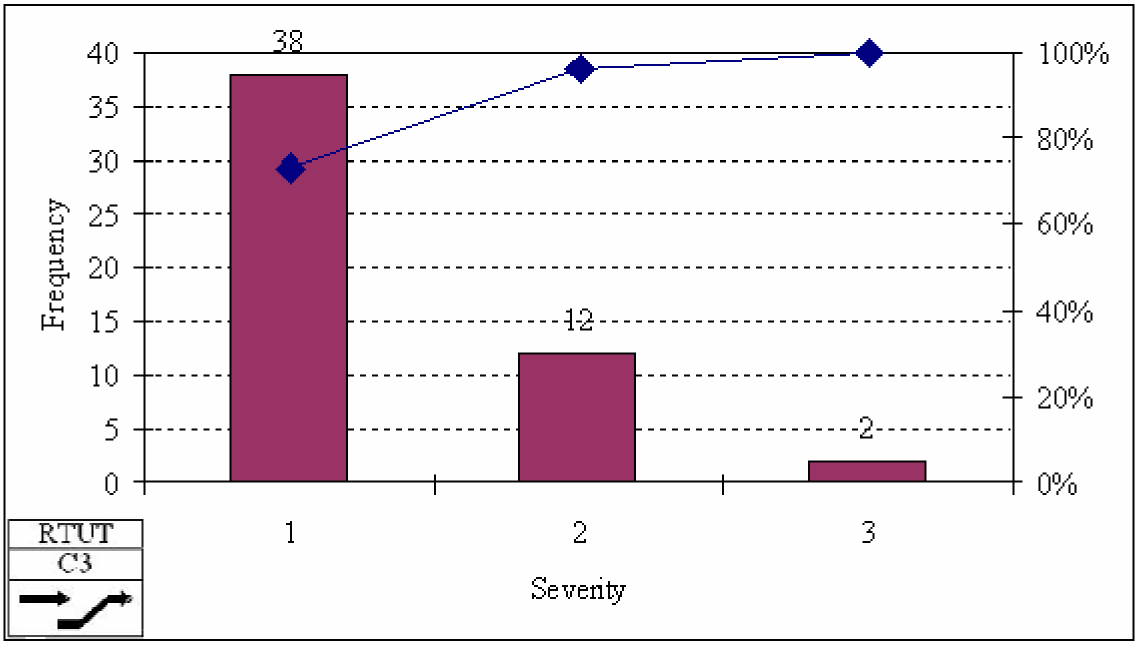


Figure 5.24 Distribution of Severity Conflict Type C3

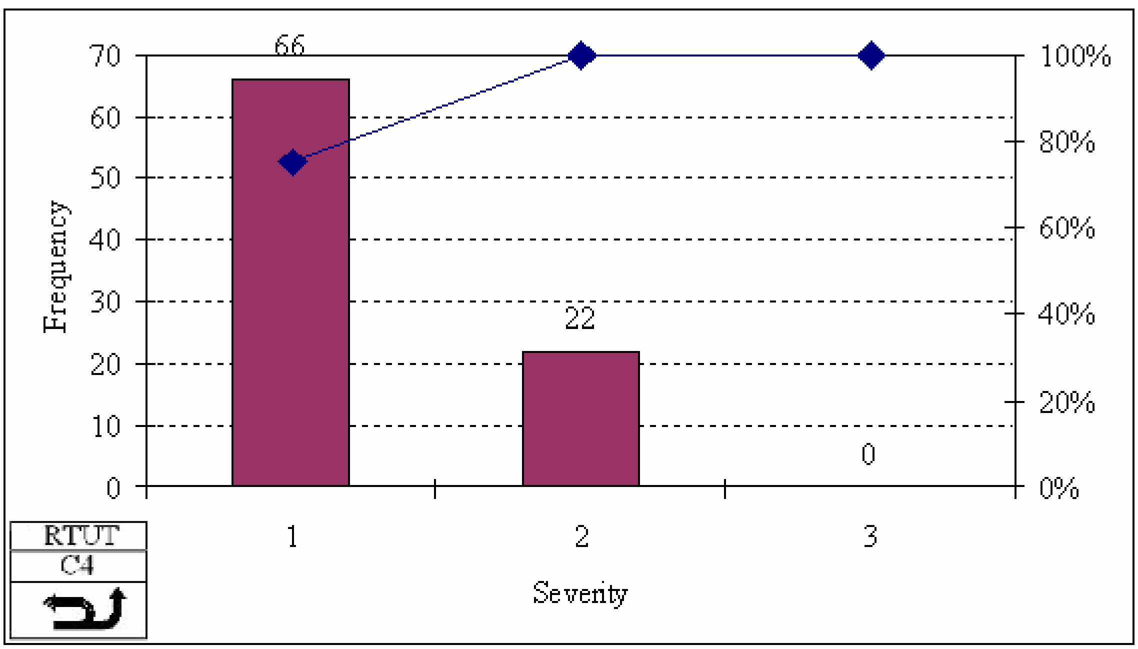


Figure 5.25 Distribution of Severity Conflict Type C4

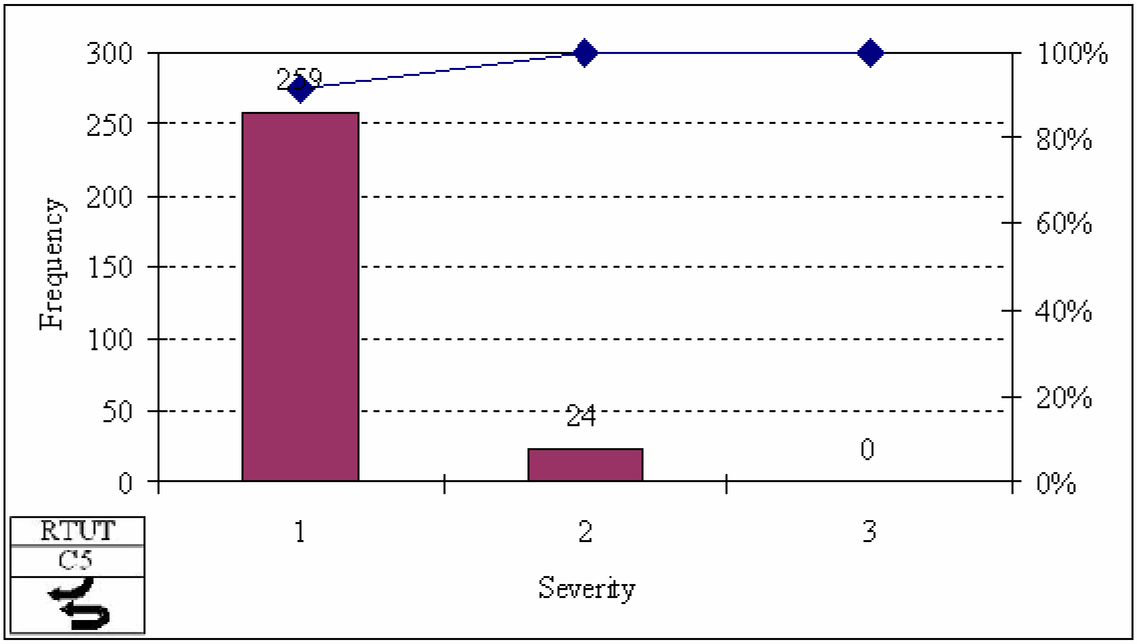


Figure 5.26 Distribution of Severity Conflict Type C5

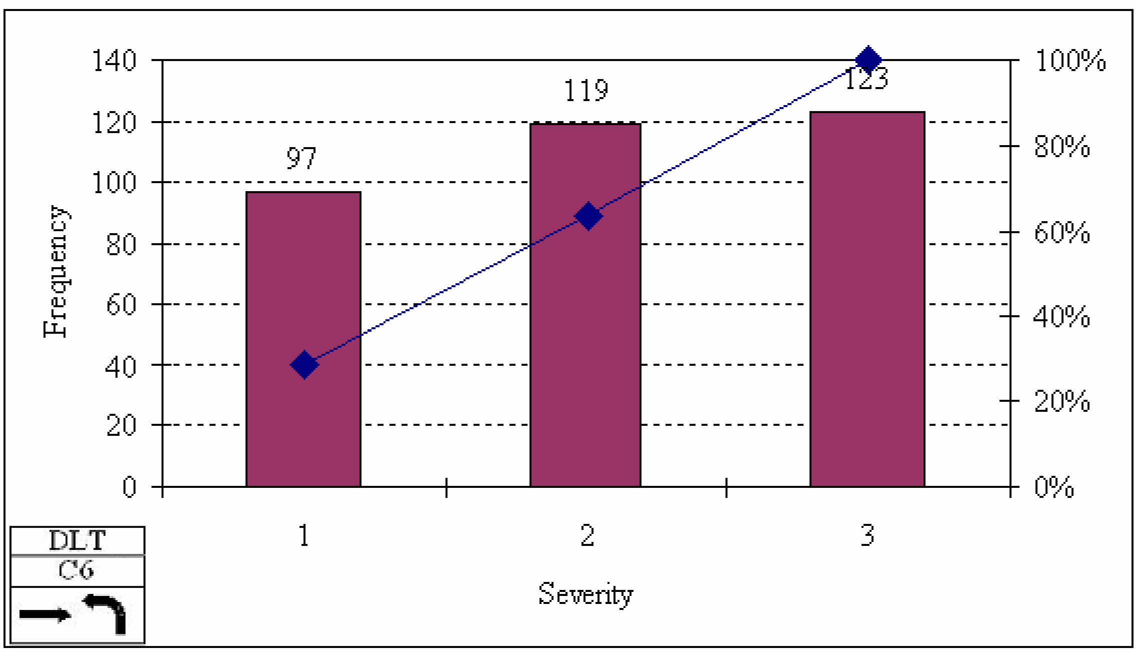


Figure 5.27 Distribution of Severity Conflict Type C6

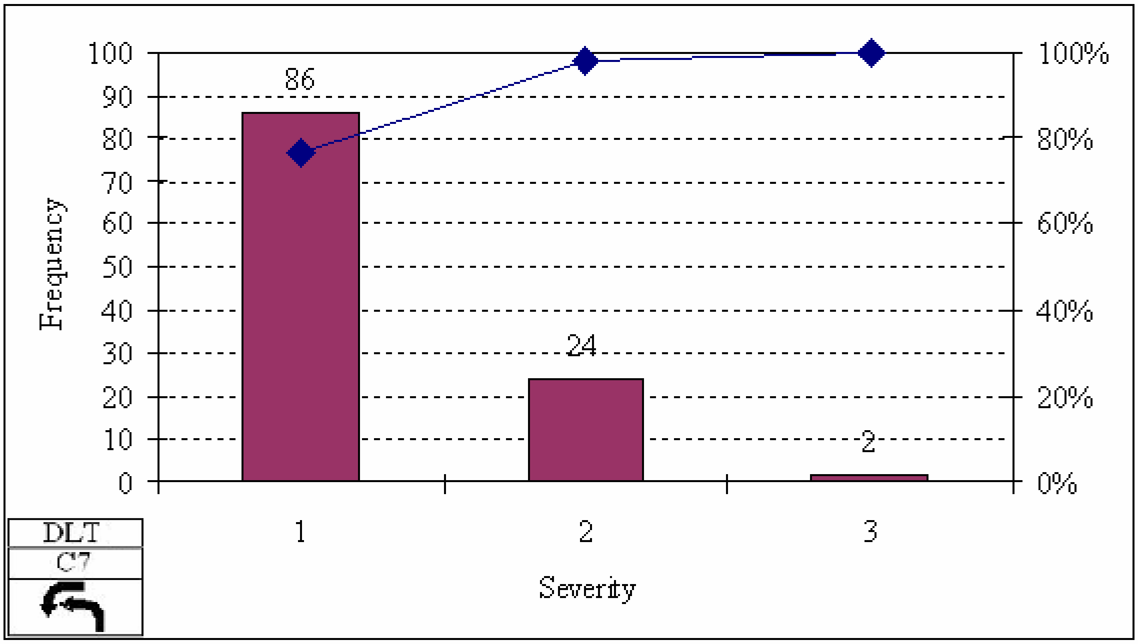


Figure 5.28 Distribution of Severity Conflict Type C7

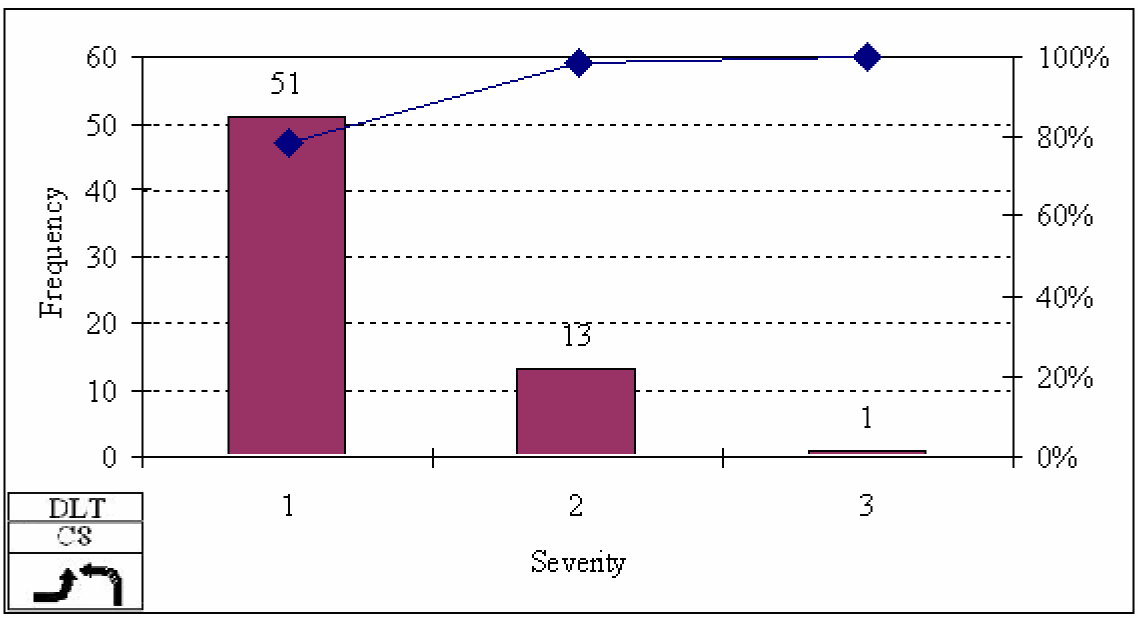


Figure 5.29 Distribution of Severity Conflict Type C8

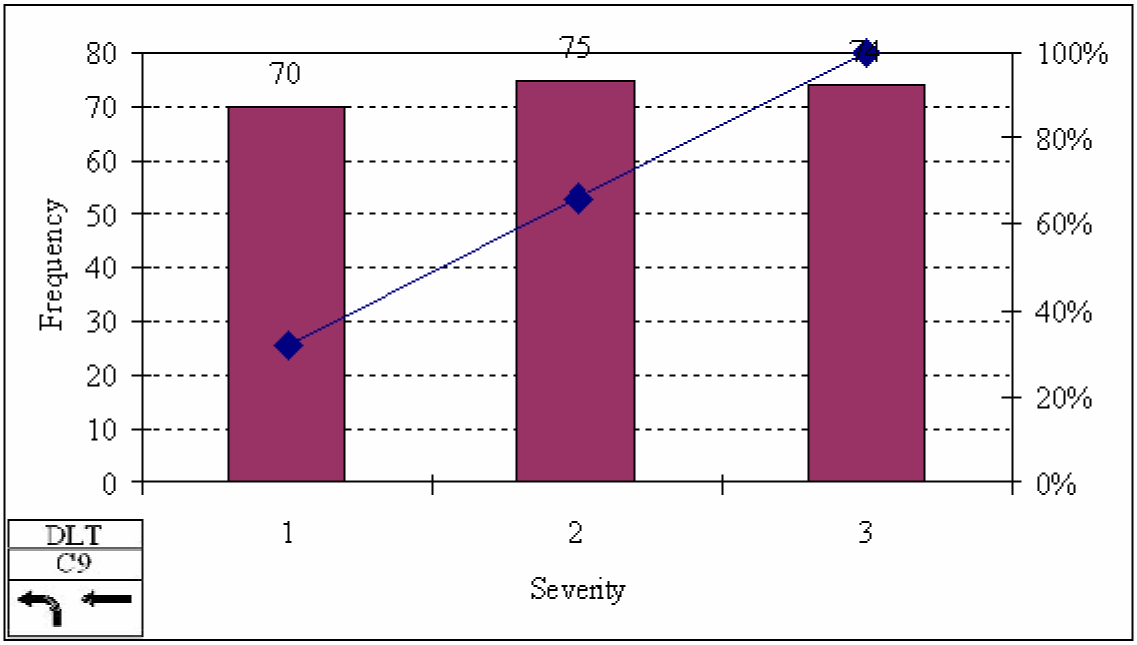


Figure 5.30 Distribution of Severity Conflict Type C9

Figure 5.31 illustrates the average ROC scores for RTUT movements. Conflict type C1, C2, and C3 have higher severity when compared to conflict types C4 and C5. Conflict types C1, C2 and C3 has higher severities 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 the signalized intersection where speed differences between vehicles are relatively lower. Figure 5.32 illustrates the average ROC scores for DLT movements. Conflict types C6 and C9 have higher severity when compared to conflict types C7 and C8. These results were expected because higher severity conflicts occur with the main road vehicles, which have higher speed values than the other conflicting vehicles. Median opening related conflicts C7 and C8 has lower severities because of low speeds and low speed differences of vehicles involved in conflicts. When comparing the severity scores of RTUT and DLT movements, DLT conflicts seem to have a higher severity as presented in Figure 5.33. It is indicated that conflicts generated by RTUT (1.17) movements have a lower severity than conflicts generated by DLT (1.86) movements.

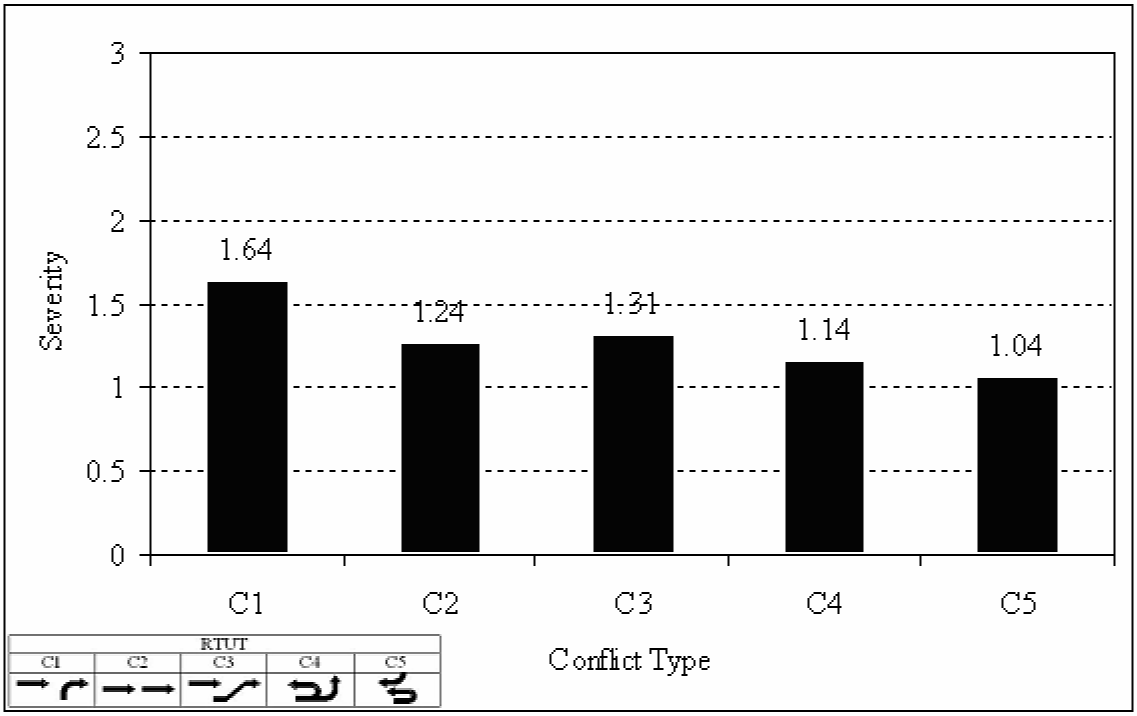


Figure 5.31 Average ROC Scores for RTUT Movements

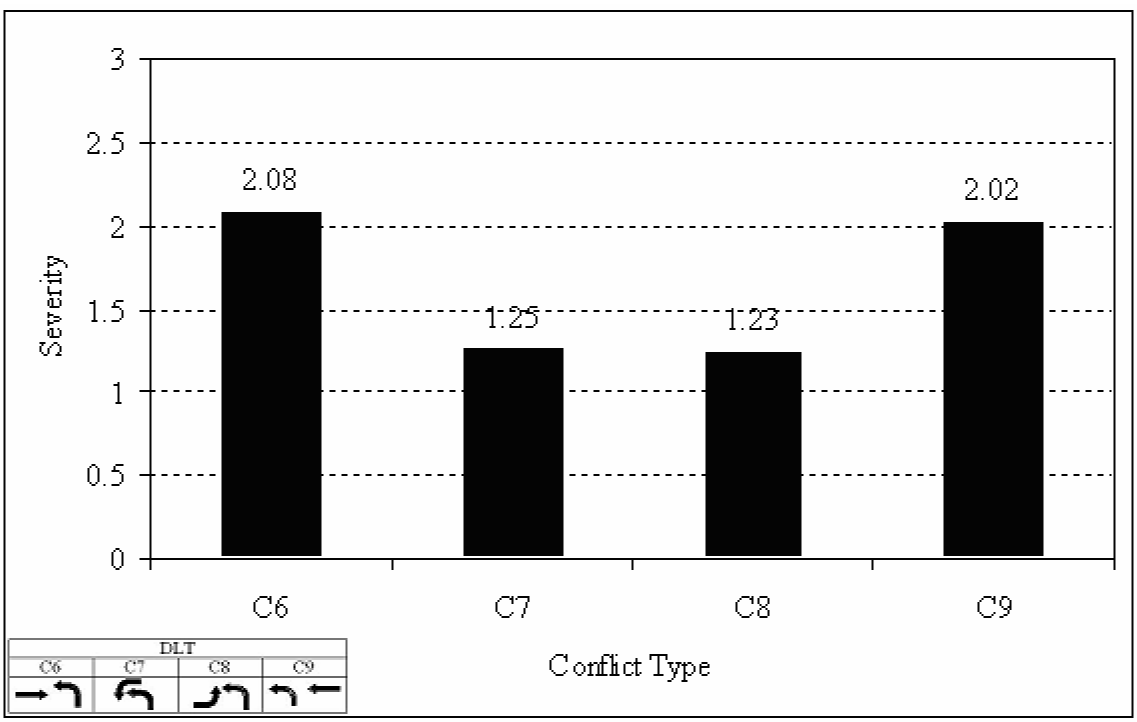


Figure 5.32 Average ROC Scores for DLT Movements

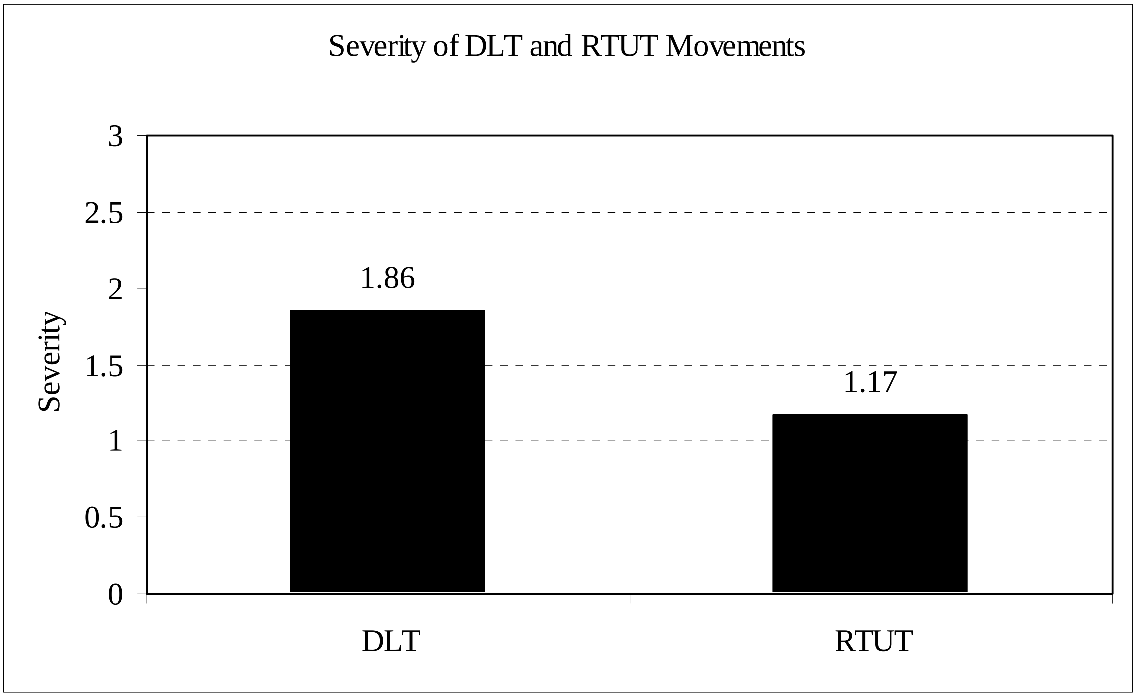


Figure 5.33 Severity Comparison for DLT and RTUT Movements by ROC

5.3 Summary

Results indicated that the RTUT technique could reduce both the number of conflicts per hour and the number of conflicts per thousand involved vehicles. Furthermore, an analysis of the severity of conflicts generated by both RTUT and DLT movements indicated that the overall severity of conflicts generated by RTUT movements was lower than that of conflicts generated by DLT movements.

6. Summary, Conclusions and Recommendations

6.1 Summary

This report is one of the reports that evaluated the safety and traffic operational effects of right turns followed by U-turns at signalized intersections as an alternative to direct left turns from driveways or side streets on six and eight lane arterials. Safety evaluation of both alternatives was conducted by traffic conflicts. Nine types of conflicts were selected for this study. Five of the conflicts were related to RTUT movements, while the rest of them were related to DLT movements. Data were collected with the help of video recording equipment at a total of eight sites for over 300 hours. Data analysis was conducted by following procedures.

The average number of daily traffic conflicts was calculated for each site and evaluated by conflict type. It was found that the most common conflict type generated by DLT movements was the left-turn maneuver itself (conflict type C6), followed by conflicts of left turn vehicles departing from the median storage area (conflict type C9), then by conflicts between left-turn and left-turn in movements (conflict type C7), and finally conflicts between DLT and left turning vehicles into a driveway located on the opposite side of the driveway studied (conflict type C8). Those results showed that DLT vehicles have more interactions with the main road vehicles than the vehicles at the median openings. The conflict distribution for RTUT movements was as following: Most of the conflicts occurred because of the U-turn maneuvers (conflict types C4, C5), the other three conflict types (C1, C2, and C3) were almost equally distributed. The comparison of the total average number of conflicts per hour of the two maneuvers showed that RTUT conflicts had a conflict rate two and half times less than that of DLT movements.

The data were also analyzed by time period: peak and non-peak hours. Results of the analysis showed that RTUT related conflicts types C2 and C4 were slightly lower during the non-peak hours. The other conflicts type C1, C3, and C5 were higher during non-peak hours. On the other hand, DLT conflicts where higher during peak hours except conflict type C8.

In addition, a comparison of the number of conflicts per thousand involved vehicles was performed. Results indicated that RTUT movements generated 33 percent fewer conflicts per thousand vehicles than DLT movements.

The analysis of severity conducted was analyzed by means of subjective scores. The analysis results showed that the severity of conflicts caused by RTUT movements was lower than that of DLT conflicts.

6.2 Conclusions

The analysis of RTUT at signalized intersection and DLT from driveways on six and eight lane arterials using traffic conflicts resulted in several conclusions. These are presented in the following paragraphs.

The comparison of the number of conflicts per hour of RTUT and DLT movements shows that RTUT movements generate three times less conflicts than DLT movements per hour. Also, the conflict rate which was used to analyze the effect of volumes, results also showed the effectiveness of RTUT movements had 35 percent lower conflict rate on six or eight lane roads.

The comparison of severity for both alternatives shows that RTUT movements reduce the number of conflicts, and also the severity of them. Results of this study indicated that the overall severity of RTUT related conflicts 37 percent lower than that of DLT related conflicts.

6.3 Recommendations

During this project, FDOT has not made any modifications or median opening conversions on the sites studied so, it was not possible to conduct before and after analysis. It would be useful to do a before and after analysis with median opening closures and conversions. Furthermore, more relationships between conflicts generated by RTUT movements and other geometric characteristics should be studied such as weaving length and median width.

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