SAFETY EVALUATION OF RIGHT TURNS FOLLOWED BY U-TURNS AS AN ALTERNATIVE TO DIRECT LEFT TURNS - CONFLICT ANALYSIS

(VOLUME II OF THREE REPORTS BASED ON THE PROJECT "METHODOLOGY TO QUANTIFY THE EFFECTS OF ACCESS MANAGEMENT ON ROADWAY OPERATIONS AND SAFETY")

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ABSTRACT

This project evaluated the safety and operational impacts of two alternative left-turn treatments from driveways/side streets. The two treatments were (1) direct left turns and (2) right turns followed by U-turns. Safety analyses of the alternatives were conducted using two major approaches: traffic crash data analysis and conflict analysis. Findings related to the traffic conflict analysis are documented in this report. Two other reports document the crash data and operational analyses.

Ten sites were selected for field data collection where each site experienced one or both of the left turn alternatives from the driveway or side street. Video cameras were set up on scaffoldings to achieve enough viewing height and all the traffic movements at the selected sites were recorded. These videotapes were later reviewed and conflict data related to direct left turns or right turns followed by U-turn movements were gathered, together with corresponding traffic volumes and conflict severities.

Nine different conflict types related to the left turn movements were considered. The average number of conflicts and conflicts per thousand involved vehicles were estimated using the collected data. The average number of hourly conflicts for direct left turns was 6.35, whereas the corresponding value for right turns U-turns was 4.2. When the results were separated by time period, the differences were more significant during peak periods. The average number of conflicts per thousand involved vehicles for direct left turns and right turns followed by U-turns were 30.2 and 18.7 respectively.

A before and after comparison was also conducted at a site that underwent a median closure thereby allowing only right turns followed by U-turns. Results showed that the total average number of conflicts per hour was reduced by almost 50% by replacing direct left turns with right turns followed by U-turns. Conflict severity for the after period was also significantly lower than that for the before period.

Several different approaches to evaluating traffic conflicts resulted in the conclusion that the right turns followed by U-turn movement was safer than that of direct left turn movement.

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1. INTRODUCTION

1.1 Background

As the nation's roadway system becomes more congested and the number of vehicular crashes increases, the importance of access management is increasing. The management of access has been identified as one of the most critical elements in roadway planning and design *(1).* Access management has been defined as the process of managing access to land development while simultaneously preserving the safety and efficiency of the surrounding roadway system *(2)*. It 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. 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. The impacts of potential techniques on traffic performance and safety are important considerations when deciding which technique to implement.

Access management deals with the control and regulation of the spacing and design of medians, median openings, driveways, freeway interchanges, and traffic signals. Typical access management measures cover the type and design of medians and median openings; the location and spacing of intersections; the spacing and design of interchanges; and location, spacing, and design of driveways and street connections. The location, design, and operation of driveways play a significant role in access management. AASHTO Green Book, "A Policy on the Geometric Design of Highways and Streets", indicates that "Driveways are, in fact, at-grade intersection's and should be designed consistent with the intended use. The number of crashes is disproportionately higher at driveways than at other intersections; thus their design and location merit special consideration." *(3)*

In the "Access Management, Location, and Design, Participant Notebook", the potential access management techniques are categorized into six groups *(4)*. These categories are related to traffic operational actions, which serve to minimize the frequency and severity of traffic conflicts. The six categories are:

1) Limit number of conflict points: These techniques directly reduce the frequency of either basic conflicts or encroachment conflicts, or reduce the area of conflict at some or all driveways on the highway by limiting or preventing certain types of maneuvers.
2) Separate conflict areas: These techniques either reduce the number of driveways or directly increase the spacing between driveways and intersections. They indirectly reduce the frequency of conflicts by separating turning vehicles at adjacent access points and by increasing the decision-processing time for the through driver between successive conflicts with driveway vehicles at successive driveways.
3) Remove turning vehicles from through traffic lanes: These techniques directly reduce both the frequency and severity of conflicts by providing separate paths and storage areas for turning vehicles.
4) Reduce the number of turning movements: The provision of cross-circulation between adjacent properties and the provision of service roads allows inter-site movement without reentry to the abutting major roadway. The elimination of short distance slow movements reduces the number of conflicts along the major roadway.
5) Improve driveway operations: These techniques allow drivers to maneuver from and to the major roadway more efficiently and safely.
6) Improve roadway operations: These techniques are primarily of a policy nature, which are intended to preserve the functional integrity of the roadway. Different standards are commonly applied depending on the category of the road

In general, the benefits of access management measurements can be summarized as: improved safety, improved traffic flow and fuel economy, increased capacity, and reduced delay and vehicle emissions. Improved safety is one of the most important benefits of proper access management. The safety benefits of access management techniques have been attributed to reduction in traffic conflict points, improved access design, and larger driver response time to potential conflicts.

Various research efforts have evaluated the impacts of access management on roadway safety. The "Access Management, Location and Design, Participant Notebook" suggests that effective access management can reduce crashes by as much as 50%, increase capacity by 23-45%, and reduce travel time and delay as much as 40-60% *(4)*. In a study of the statistical relationship between vehicular crashes and highway access, conducted for the Minnesota Department of Transportation, the results from two approaches, a comparison of crash rates using a random sample of roadways from the State's highway system and a before-and-after comparison of crashes, suggested a strong and statistically sound relationship between level of access and crash rates *(5)*. It showed that crash rates reduced with improvements to median opening spacing in both rural and urban roadway categories. Bonneson and McCoy concluded that crash rates on facilities with non-traversable medians are lower than that of facilities with center two-way left-turn lanes (TWLTL) *(6)*.

These studies provide important information on various access management methods and techniques. However, questions still remain surrounding the effects of specific access management treatments on roadway safety and operations. Some of these concerns relate to the safety impacts of U-turn movements at median openings, the effect of medians on intersection capacity, the safety impacts of continuous right-turn lanes, and the effect of medians on side street operations. Other questions relate to median and driveway design practices such as right-in right-out only designs, and appropriate driveway channelization measures. Some of these questions remain unexplored either because quantification of some treatments is difficult or because not enough data are available for the evaluation of alternative treatments. Therefore, more research is needed in order to evaluate the traffic operational and safety impacts of these techniques.

1.2 Outline of the Report

This report on the conflict analysis of direct left turns versus U-turns consists of six chapters. Chapter 1 provides an overview of the research project including a summary of the past studies in this subject area. Chapter 2 describes the methodology followed in the research including a detailed description of the types of conflicts and basic concepts such as minimum required sample sizes, conflict rates, and statistical tests. Chapter 3 presents the field data collection procedure, in which the details of the sites selected for data collection, equipment used, field procedure, and data reduction procedure is provided. Chapter 4 contains the analysis of the data collected for both direct left turn and right turn followed by U-turn movements, which includes number of conflicts, conflict rates, and severity of conflicts. Chapter 5 presents the safety impacts of converting a full median opening to directional median opening based on a conflict analysis using before and after comparison. The final chapter, Chapter 6 provides the summary, conclusions and recommendations of this study.

1.3 Selection of the Study Subject

With the intention of identifying the technique that most needed evaluation, a number of previous studies regarding access management techniques were reviewed. Current state and national literature reviewed included but not limited to Transportation Research Board (TRB) publications, proceedings of the TRB National Access Management Conferences, reports from the National Cooperative Highway Research Program (NCHRP), publications by AASHTO, Institute of Transportation Engineers (ITE) recommended practices, and the ASCE Journal of Transportation Engineering. In addition, current rules, regulations, standards, and practices in Florida were reviewed.

Based on the literature review, the project team's experiences, and FDOT review, the subject selected for analysis was the right turn followed by U-turn as an alternative to a direct left turn from a driveway or side street. The main reasons for selecting this subject were:

1) Little documentation of quantified results and conclusions regarding this subject are available although the impact of U-turns on safety and operations has been identified as one of the important issues in access management.
2) It is feasible to quantify the safety and operational impacts of these alternatives. Both crash data and potential sites for case studies are available.
3) The results of the traffic operational and safety analysis can assist agencies like FDOT with decisions relative to installing medians or closing median openings.

1.4 The Selected Research Subject

The safety impacts of right turns followed by U-turns as an alternative to direct left turns from driveways or side streets could be explained in relation to their effect on the number of conflict points. A conflict point is defined as the point at which two traffic movements intersect each other. For example, Figure 1.1 illustrates that there are 32 conflict points at a four-leg intersection with a full median opening, whereas a directional median opening experiences only 8 conflict points.

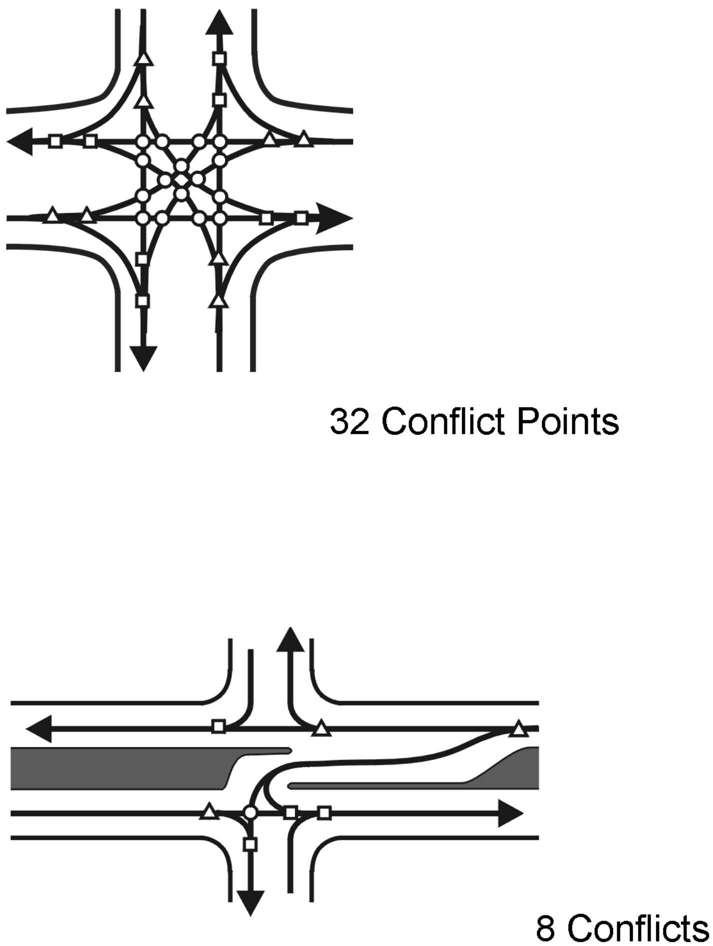

Figure 1.1 Conflict Points at Four-leg Intersections

Also, it can be seen that left-turning movements either from a cross-street or left-turn bay generate most of the conflict points. Thus, left-turn maneuvers are of special consideration when evaluating either signalized or unsignalized intersections. This is supported by the fact that approximately ten and eleven percent of the total number of crashes that occurred in 1998 and 1999, respectively, involved drivers turning to the left, as shown in Table 1.1. Despite several research studies conducted regarding left turn movements, problems with left turn movements still remain. However, little research has been performed on the effect of left turn maneuvers from driveways or side streets. Crash rates at driveways are higher than that of other intersections *(3)*. Furthermore, more than two thirds of all driveway-related crashes involve left turning vehicles *(7)*.

Table 1.1 Vehicles Involved in Single and Two-Vehicle Crashes by Vehicle Maneuver

Vehicle Maneuver	1998		1999	
	Number (Thousands)	%	Number (Thousands)	%
Going Straight	5,783	57.50	5,131	51.60
Turning Left	1,030	10.20	1,071	10.80
Stopped in Traffic Lane	991	9.80	1,096	11.00
Turning Right	365	3.60	360	3.60
Slowed in Traffic Lane	462	4.60	495	5.00
Merging/Changing	314	3.10	375	3.80
Negotiating Curve	139	1.40	374	3.80
Backing Up	133	1.30	235	2.40
Passing Other Vehicle	134	1.30	142	1.40
Starting in Traffic Lane	130	1.30	264	2.70
Leaving Parking Space	55	0.50	66	0.70
Making U-Turn	56	0.60	54	0.50
Entering Parking Space	23	0.20	25	0.30
Disabled in Traffic	12	0.10	15	0.20
Other Maneuver	439	4.40	241	2.40
Total**	10,065	100	9,942	100.00

Source: National Highway Traffic Safety Administration (2001).

For a better understanding of the safety problems related to left-turning movements from a driveway or a side street, a brief description is provided here. Figure 1.2 illustrates a driver who wants to turn to the left from a driveway that is located between two signalized intersections. According to the behavior of the driver there are three scenarios that might occur. First, if the drivers that are not aggressive will wait for a suitable gap before crossing the arterial, which in most cases would be selected after the platoon of the upstream signal clears. The second scenario occurs when a driver exposed to a long delay while waiting for an acceptable gap decides to turn right and make a U-turn at the next median opening. The third scenario occurs when a driver experiences a long delay in turning left, in which case the driver behavior becomes impatient and aggressive, tending to accept shorter gaps than are advisable. In such situations, the driver is willing to take "the risk" of crossing the street, which could result in a conflict or even a collision. This is due to the fact that overly short gaps can cause high-speed differentials and turbulence in the through traffic stream because the vehicles in the through traffic stream may be required to decelerate or attempt to change lanes *(8).* Once the driver proceeds with the direct left turn movement, he/she must be aware of other vehicles interacting at the same time. Full median openings allow several movements at the same time, therefore traffic conflicts can be created not only because of through traffic vehicles, but also because of vehicles turning into and out of the same driveway. If other vehicles do not interfere with the egress of the vehicle, then the driver crosses the arterial and enters into the median storage area. There again, the driver must find a suitable gap in order to merge into the inner lane and accelerate to the mean speed of the oncoming through traffic.

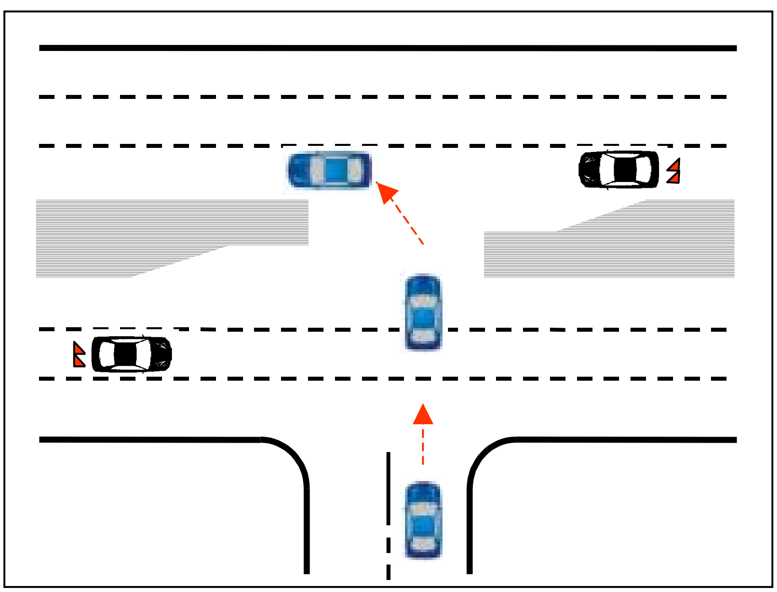

Figure 1.2 Direct Left-turn Movement.

The major problems that could be encountered during the direct left turn movement are illustrated in Figure 1.3. First (a), a vehicle departing from a driveway at a very low speed creates a speed differential problem with oncoming through traffic. Second, several cars may sometimes be observed in a median storage area making it possible to find left turning vehicles waiting for a gap with part of the vehicle encroaching on the inner lane of oncoming through traffic, as shown in Figure 1.3 (b). Another problem is that drivers waiting for a gap on the storage area may have sight obstructions. Sight obstructions could be due to the left turn-in volume or due to other vehicles located in the storage area, as shown in Figure 1.3 (c). The lack of sight distance is dangerous because drivers cannot clearly see approaching vehicles so that they may merge onto the arterial by "trial and error" or by waiting until the sight is completely clear as shown in Figure 1.3 (d).

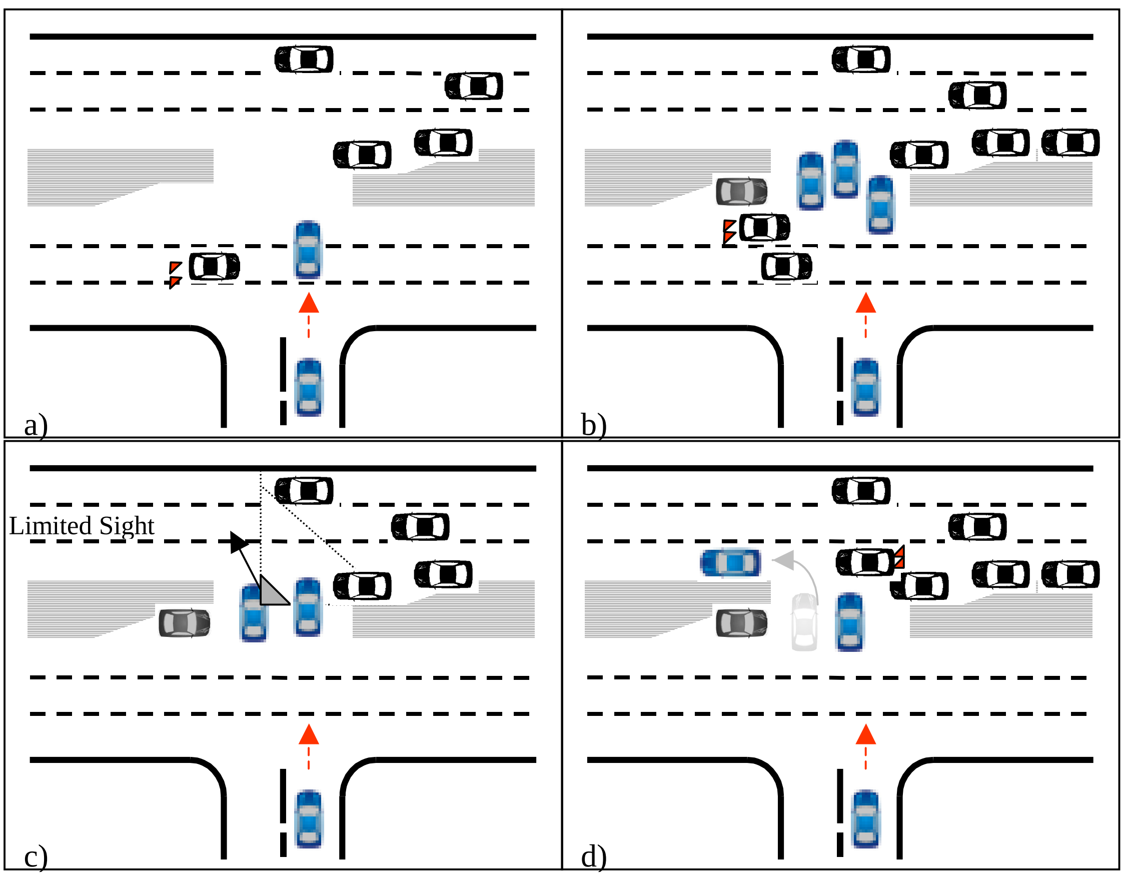

Figure 1.3 Safety Concerns Related to Direct Left Turn Movements.

To overcome the safety problems generated by left turn vehicles, different treatments have been proposed, such as median U-turns, jug handles, and recently by NCHRP Report 420, *"Impacts of Access Management Techniques"* the right turn followed by U-turn as alternatives for direct left turns from a driveway *(9)*. The latter consists of vehicles turning to the right and then changing lanes until they get to the next median opening, where they can make a U–turn. This alternative is attractive since it does not require a major financial investment such as roadway reconstruction or right of way acquisition. Another advantage is that the effect of U-turn movements on left turn lanes at signalized intersections could be avoided when proper intermediate turn lanes are provided. Preliminary results from a study performed by the North Carolina State University suggested that the reduction in saturation flow of left turn lanes is 10 percent when U-turns are between 65 and 85 percent of the volume in the left-turn lane, and the corresponding reduction is 20 percent when U-turns exceed 85% *(10).*

The procedure followed by vehicles turning to the right and then making a U-turn at a median opening is illustrated in Figure 1.4. It shows a driver waiting at a driveway until there is a suitable gap for turning to the right and merge onto the arterial. Once the driver enters the arterial, available gaps are evaluated so that he/she can change lanes until the median opening is reached. If there is proper coordination with the signal located upstream of the driveway, it is sometimes, possible for the arriving vehicle to find an adequate gap to make the U-turn without waiting. Otherwise, the driver has to wait at the U-turn bay.

1.5 Problem Statement

Current regulations of the Florida Department of Transportation (FDOT) require all highways with a design speed greater than 40 mph to have restrictive medians. FDOT also designs and constructs some new unsignalized median openings as directional openings. In addition, FDOT may close an existing unsignalized median opening or convert it to left-turn or U-turn only. Hence, the purpose of this project is to evaluate the safety and operational impacts of U-turns on the State highway system.

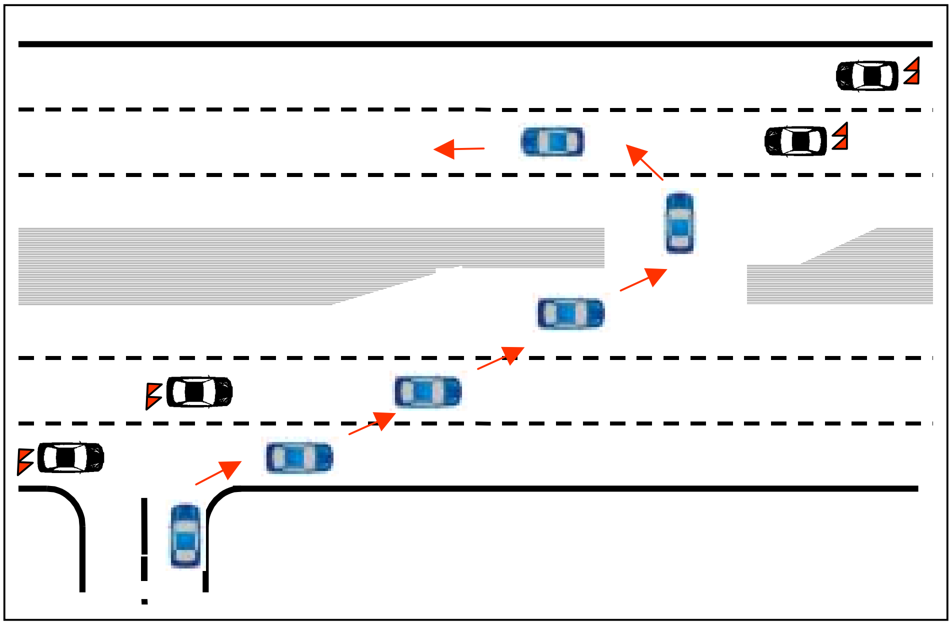

Figure 1.4 Description of Right Turn Followed by U-turn at a Median Opening.

Because right-turn followed by U-Turn movements require drivers to weave a certain distance and then evaluate available gaps for making a U-turn maneuver, some drivers view this procedure as “unsafe”. A survey conducted by TEI Engineers and Planners found that one of the most common complaints was that U-turn movements would result in safety problems *(11).* On the other hand, the same survey found that 57 percent of the respondents did not feel inconvenienced by U-turns. Therefore, it is necessary to examine the relative safety of right turn/U-turns compared to direct left-turns.

Although, theoretical reduction of conflict points from 32 to 8 suggests a decrease of approximately 70 percent, this value does not really quantify the reduction in the actual number of conflicts or its effect on traffic safety. Moreover, there is little information on the safety and operational effects of median closures and few guidelines for practitioners relative to closing median openings. The National Highway Institute Course No. 15255 has general descriptions suggesting when to implement a conflict reduction technique *(4).* For example, installing a non-traversable median is recommended when undivided highways have a pattern of left-turn crashes. However, more detailed and quantified results regarding the safety implications of left turn alternatives should be available to transportation engineers and planners to assist them in the decision making process.

Better information and methods for evaluating safety and operational impacts of median changes are also important when interacting with the general public. Gwynn noted that a frequent public complaint was that the agencies do not have adequate supporting reasons for implementing median changes *(11).* The general public has a "show me" attitude that is difficult to satisfy unless there is sufficient documentation, especially quantifiable documentation, of the basis for the median changes.

1.6 Research Objectives

The goal of this study was to quantify the safety impact of vehicles making right turns followed by U-turns, and compare it to that of direct left turn movements from driveways. The safety evaluation was divided into two parts. The first part consisted of a cross comparison of crash rates for several Florida sites. The second part consisted of conducting a traffic conflict study to evaluate and compare the implications of these maneuvers. The latter is described in this report. Accordingly, the objectives of this study were:

1) To estimate the average number of traffic conflicts for both direct left turn and right turn followed by U-turn maneuvers,
2) To estimate the average conflict rates for each of the two left turning alternatives from driveways and to compare these values,
3) To evaluate the severity of conflicts generated by direct left turn and right turn followed by U-turn maneuvers and to compare the severities.
4) To compare the safety effects of replacing direct left turns with right turn followed by U-turn movements by conducting a case study using before and after analysis.

1.7 Past Studies

1.7.1 General

There were no previous reports or articles regarding the safety evaluation of left turn alternatives from driveways or side streets by using a traffic conflict study. However, there have been several past studies that used traffic conflicts at signalized and unsignalized intersections as a tool for evaluating the relationship between crashes and conflicts, the relationship between conflicts and volumes, and ranking of hazardous intersections. Some of them are briefly mentioned here.

Traffic conflict studies began with Perkins and General Motors in 1967, when they were analyzing the involvement of GM cars in crashes. In their study, they defined typical incidents that could be related to a specific crash type at intersections. A traffic conflict was defined as an evasive action taken by a driver in order to avoid a collision *(12).* The procedure followed in that research was known as the Traffic Conflict Technique *(13, 14).* Several studies followed the General Motor's study but it was only in 1977 that an accepted definition of a traffic conflict was given. This definition was "A conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged" *(15).* A more general definition was found in Parker et al, which defined a traffic conflict as "an event involving two or more road users, in which the action of one user causes the other to make an evasive maneuver to avoid a collision" *(13, 14)*. Traffic conflict studies have been used for various purposes, as stated by Hauer: "Traffic conflicts technique is applicable to a variety of situations. It can be used to measure the effectiveness of devices, layouts, design, and procedures" *(16).*

1.7.2 Conflicts and Crashes

Traditionally, most traffic safety problems are detected by collecting and analyzing the history of crashes at a particular site. However, several problems have been documented with analyzing sites based upon crash records *(17, 18, 19).* The first problem is with the reliability of police reported crash records because the number of crashes tends to be under-reported. Second, crash databases are subject to human error during the input of data. Therefore, code errors, reporting errors and even interpretation errors may appear *(20).* Third, the waiting time for obtaining an adequate sample size may be too long *(19).* This waiting time could have serious implications because several collisions may occur before any correction could be made to treat or correct a deficiency *(21, 22).* Other concerns are the randomness of crashes and the human factors associated with them.

Crashes that involve human factors may not provide enough details on geometric conditions that might have caused the crash *(12).*

Alternatively, traffic conflict studies have been accepted for several reasons. First, data can be collected within a short period of time so that an engineer does not have to wait for the occurrence of several crashes to improve the conditions of a site *(13, 14, 21, 23, 24).* Second, the effectiveness of a treatment can be evaluated within a short period and if this fails to correct the problem then the countermeasure can be changed again in a very short time *(13, 14).* Third, traffic conflicts include human factors because the behavior of drivers can directly be observed in the field *(12).* Fourth, traffic conflict studies can be used with or without crash data since each type of conflict is associated with a particular type of crash *(13, 14).* Finally, traffic conflict data provides information about traffic volumes, routine conflicts, moderate conflicts, erratic maneuvers, severe conflicts or near-miss crashes, and other minor crashes, while crash data can only give information on property damage and injury severity *(19).*

Although the traffic conflict technique has been used widely, it has also created controversy especially when determining the relationship between conflicts and crashes. Some researchers have found a significant relationship between conflicts and crashes. Migletz et al found that crashes and conflicts were significant at the 10 percent level of significance and Salman and Almaita found that the relationship was linear and statistically significant *(18, 25)*. In contrast, other researchers have found that the relationship is not very strong. Engel found that the correlation between conflicts and crashes was poor, although he found that by separating types of conflicts and their corresponding crashes the correlation could be increased *(26)*. Brown concluded that the relationship between total crashes and conflicts was poor, but if data were segregated by types of conflicts and crashes, the relationship would have been significant *(12)*. Although former research is contradictory, Glauz et al stated, “the proper use of conflicts is to estimate an expected rate of crashes as opposed to predicting the actual number that might occur in a particular year” *(26)*. Hence, traffic conflicts can be used as a surrogate of crashes.

1.7.3 Conflicts and Traffic Volume

The relationship between traffic volumes and conflicts has also been controversial. In a study conducted by Migletz et al., different types of volumes were defined according to the type of conflict being studied *(26)*. 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.

Salman and Almaita worked on the determination of the relationship between conflicts and volumes at three-leg unsignalized intersections in which the number of conflicts per hour was compared with two types of volumes *(18)*. One volume was defined as the summation of all the volumes entering the intersection, and the other one was defined as the square root of the product of the volumes that generated conflicts. Linear regression models were used for correlating same direction, left turn, right turn, and same direction conflicts with volumes. It was found that the correlation factor between conflicts and the square root of the product between volumes was larger than that of summation of volumes.

Katamine studied different volume definitions for conflicts at unsignalized intersections using data collected at 15 four leg unsignalized intersections *(23)*. Traffic volumes consisted of through traffic, right turn, left turn, and U-turn volumes. These volumes were then combined into thirteen different definitions and related with eleven types of conflicts. It was found that the total entering volume, which corresponds to the summation of all the volumes at the intersection, was significantly correlated to most of the conflict types, although using the total volume may not explain why different conflicts occur at the same intersection.

Sayed et al. developed a traffic conflict simulation for unsignalized intersections by using a microscopic model in which only data corresponding to vehicles involved in severe conflicts were recorded for further evaluation *(20)*. It also involved the concept of gap acceptance in order to evaluate the behavior of different types of drivers. This model randomly generated vehicles with different characteristics, and the driver assigned to that vehicle behaved according to a minimum gap acceptance capabilities based on the sex and age of the driver. A conflict was recorded if the distance between the involved vehicles divided by the mean speed was less than 1.5 seconds. The simulation software used data from unsignalized intersections and produced a set of curves for different types of roads. Sayed stated, “if only low traffic volumes are considered (volumes less than the warrants for a traffic signal), conflicts may appear to be proportional to the square root of the conflicting volumes. The large increase in simulated conflicts at high traffic volumes is probably the result of allowing drivers in the model to accept shorter gaps as their delay increases.” *(20)*

1.7.4 Conflict Severity

In the past studies, severity of traffic conflicts have been measured and evaluated by using both objective and subjective methods. Objective methods rely on physical properties such as time, distance, and speed while subjective measures rely on human observers to record the perceived risk at the moment in which the conflict occurred. Among the objective methods of measurement, Hayward developed the concept of Time to Collision (TTC) to differentiate severe near misses from near misses that were not severe by using physical properties such as distance and time *(28).* TTC is defined as the time required for two vehicles to collide if they continue at their present speeds on the same paths. Hayward defined the minimum TTC as the perception and reaction time of drivers because failing to react to an event would result in a collision. Near misses were recorded by using a video camera and used for determining TTC values for rear-end, lane change, cutoff, broadside, and right of way cases. It was determined that the mean TTC value was 1.46 seconds and that near misses occurred when the TTC was less than 1.0 second.

Other objective measurement methods have also been used for evaluating the severity of conflicts. Allen et al. made a complete description of other objective measurements, including the concept of Encroachment Time (ET) *(29)*. ET was defined as the time during which a left turning vehicle infringes upon the path of an oncoming through-traffic vehicle. Another method was using the gap time (GT) concept, which corresponds to the time at which the offended vehicle was expected to arrive at the conflict point minus the time at which the offending vehicle cleared the path. Another method was "zonal braking technique", in which zones where conflicts with a pre-determined TTC values could be observed. Once a conflict occurs in a given zone, its corresponding TTC was associated to the risk of the maneuver assuming that the speed did not differ greatly. A method based on the Deceleration Rate (DR) has also been used, although DR greatly differs among drivers. Another method was the Post Encroachment Time (PET), which was the difference between the time at which the offending vehicle clears the path of an oncoming vehicle, and the time at which the offended vehicle arrives at the potential point of collision.

Sayed et al considered both objective and subjective methods for evaluating the risk of conflicts because if only objective methods were used, they could overestimate the risk factor *(20)*. Thus, it was recommended to combine these two for obtaining a reasonable risk value. For objective measurements, the study defined three "ranking zones" in which TTC would vary from 0 to 1 second, 1 to 1.5 seconds, and more than 1.5 seconds. For the subjective evaluation, observers assigned a value known as Risk Of Collision (ROC), based on the severity of the risk perceived while collecting data in the field. The TTC and ROC values had equal weight for low, moderate, and high risk conflicts, as shown in Table 1.2.

Table 1.2 TTC and ROC Score Values.

TTC and ROC Scores	TTC (seconds)	ROC
1	1.51 – 2.00	Low Risk
2	1.00 – 1.50	Medium Risk
3	0.00 – 0.99	High Risk

Katamine evaluated the relationship between conflicts and secondary conflicts at 15 unsignalized intersections based upon a severity grading system created by Glauz and Migletz *(23, 27)*. The first grade corresponded to a conflict that occurs when a vehicle applies the brakes in a precautionary way when another vehicle merges onto the arterial and tries to move into another lane. The second grade occurred when drivers have enough time to apply brakes or make evasive maneuvers. A third grade conflict occurs when the conflicted vehicle experiences a rapid deceleration, changes lanes or stops in order to avoid a collision, and where the driver has no time for a controlled maneuver. The most severe grade occurs when a near miss occurs. The study found that through cross-traffic conflicts with the traffic from right and the left produced a high percentage of the conflicts with severity grade 4, as well as secondary conflicts.

Salman and Almaita also used a severity grading system for evaluating the safety of three-leg unsignalized intersections *(18)*. The purpose of that study was to rank the intersections according to the amount of risk. Each conflict was assigned a risk factor and the intersections with unusually high number of conflict values were determined using a "risk index". The risk index was calculated by using following equations:

$$R.I_j = \sum_{i=1}^{n} R.I_{ij}$$

$$R.I_{ij} = K_i \times (I.V.)_{ij}$$

$$K_i = \frac{W_i}{\sum_{i=1}^{n} W_i}$$

where, $R.I_j$ = total risk index for intersection *j*.

$R.I_{ij}$ = risk index for conflict type *i* at intersection *j*.

K_i = relative weight for conflict type *i*.

W_i = weighting factor for conflict type *i*.

$(I.V.)_{ij}$ = indicator value for conflict type *i* at intersection *j*.

n = number of conflicts

The weighting factor was based on a subjective scale, which ranged from 1 to 3: 1 being the score for the least severe conflict, and 3, the score for the most severe conflict. The indicator value corresponded to the number of conflicts per thousand entering vehicles on the site. After the risk index was determined for each intersection, this value was incorporated into the conflict matrix so that the most dangerous intersections could be found.

In addition to using various methods to determine the severity of conflicts, research has also been conducted to evaluate more accurate methods. Shinar evaluated the reliability of subjective evaluations *(30)*. The methodology consisted of filming conflicts at a three-leg intersection and evaluating those conflicts according to three types of measurements. The first measurement was objectively determined by using the deceleration of the vehicle as an indicator. The other two measurements were subjective in which risk scores ranging from 0 to 100 were given and the time to collision of the maneuver was estimated and assigned a score. The study found that people seemed to have an internal concept of what constitutes a conflict or a near crash and were consistent in their evaluation of vehicle movements based on that concept.

Kruysse performed two experiments to determine the information used by observers when assessing the severity of conflicts *(31)*. The research used TTC as the objective measurement and compared its results to the risk perceived by subjects. Results showed subjects were reliable for observing traffic conflicts if they were taught to see initial stages of conflicts. The study also found that the commencement of a maneuver had more information regarding the evaluation of the severity than the other stages of the conflict. Thus, if one part of the conflict observed was considered as dangerous, the conflict would be judged dangerous, even if the rest of the information contained by the conflicts indicated it was not dangerous. Also, it could happen that the commencement of the conflict was not dangerous but the evasive action was, so that the conflict was considered dangerous.

2. METHODOLOGY

This chapter describes the methodology used in collecting, classifying, and analyzing traffic conflicts including the criteria used for selection of sites, estimation of sample sizes, definitions of the types of conflicts evaluated, identification of traffic conflicts, and data reduction.

2.1 Site Selection

According to the objectives of the study, two sets of sites were selected for direct left turns (DLT) and right turns followed by U-turns (RTUT). The first type corresponds to those sites where the driveway vehicles in need of making a left turn could either turn to the left directly or turn to the right and make a U-turn. The second type corresponds to those sites where only turning to the right was allowed, so that, only RTUT movements would be expected but not DLT movements. Each site was selected based upon the following requirements:

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 adequate turning vehicles could be studied.
3) The minimum distance between the driveway and upstream signal should be at least 200 ft, which is the median value of the distance traveled during driver perception-reaction time and the impact distance due to a right turning vehicle *(3)*.
4) The downstream signal was located at an appropriate distance away from the driveway in order to avoid the effects of possible spillbacks.
5) Posted speed on the major road is equal to or greater than 45 MPH.

2.2 Sample Sizes

The sample size for a traffic conflict study depends on the types of conflicts that are being studied, traffic volumes on both the arterial and driveway, and the level of significance required for the study. *Traffic Conflict Technique for Safety and Operation:*

Engineer's Guide provides information about the number of hours of data collection recommended for obtaining the minimum sample size for both signalized and unsignalized intersections with three or four leg approaches, low and high speeds, and for two and four lane roads *(1)*. Also, it explains the procedure for calculating the number of observation hours needed based on the level of significance, error of the hourly mean, hourly variance estimated from previous conflict studies, and the hourly mean number of conflicts of a specific type, as follows:

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

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.

This procedure requires previous knowledge of the mean and variance of the conflict numbers, σ_e^2 and Y, for calculating the sample size. Hence, application of this method was not possible since the hourly variance and mean numbers of conflicts due to the two maneuvers evaluated in this study were unknown.

Another procedure used in calculating the sample size is described in the *Manual of Transportation Engineering Studies, Chapter 12 (14).* This method estimates the number of approaching vehicles that must be counted for a specific level of significance and error. Then, the number of vehicles calculated is compared to that of the field study, so that it can be corroborated that the estimated conflict rate is between the desired errors. The equation used to calculate the sample size with this method is:

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

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.

For example, if one wants to find the sample size, with a level of significance of 5 percent, and with an absolute error of 5 percent, the number of vehicles would be

n= 0.50 * (1-0.50)*(1.96/.05)^2= 384 approach vehicles

In the example presented above, the expected proportion of vehicles observed and involved in conflicts was unknown. Thus, a conservative estimate of the sample size could be obtained by assuming p as 0.5. This method was followed to calculate the sample size of this study.

2.3 Types of Conflicts Studied

Not all the conflict types as defined in previous studies are important for the maneuvers evaluated in this study *(12).* Therefore, it was necessary to evaluate the types of conflicts that were significant to the scope of the study. This resulted in the selection and evaluation of nine relevant types of conflicts, which are briefly described as follows.

1) Right-Turn Out of the Driveway (C1), occurs when a vehicle (offending 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. See Figure 2.1.

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 shown in Figure 2.2.

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 U-turn bay.

This maneuver may place through-traffic vehicles with increased potential of rear-end and sideswipe collisions. See Figure 2.3.

4) U-turn Conflict (C4), occurs when a vehicle making a U-turn places vehicles coming from the opposite direction with increased potential of a sideswipe or angle accident. This type of conflict is illustrated in Figure 2.4.

5) Slow U-Turn Vehicle, Same-Direction Conflict (C2UT), occurs when a vehicle that completed the U-turn maneuver and accelerates; placing an oncoming major-road vehicle with increased potential of a rear-end collision. This type of conflict is similar to conflict type C2, but it was exclusively designated for vehicles making U-turn. In this type of conflict the speed differential involved could be even more dangerous than that of conflict type C2 because U-turn maneuvers are usually made at a very low speed making the stop distance greater. This type of conflict is graphically illustrated in Figure 2.5.

6) Left-Turn Out of Driveway: Conflict From Right (C5), 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, as shown in Figure 2.6.

7) Direct-Left Turn and Left-Turn in From-Right Conflict (C6), 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, as shown in Figure 2.7.

8) Direct-Left-Turn and Left-Turn in From-Left Conflict (C7), 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, as shown in Figure 2.8.

9) Left-Turn Out of Driveway: Conflict From Left (C8), 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, as shown in Figure 2.9.

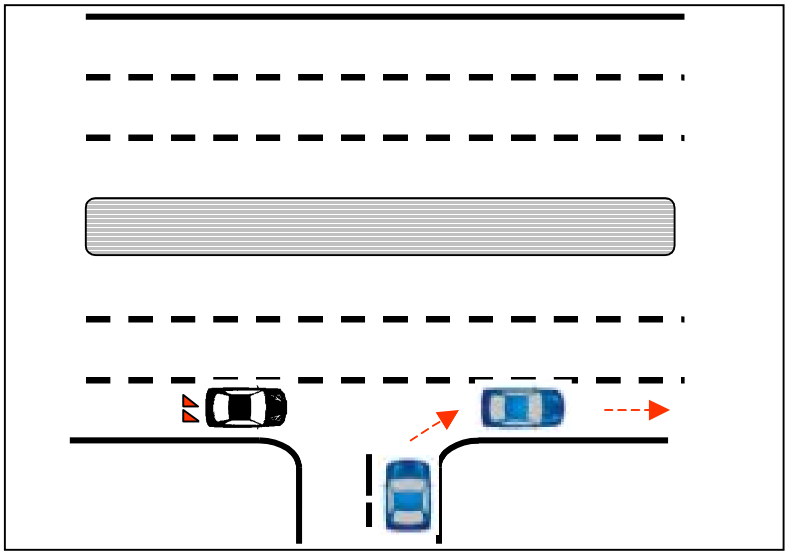

Figure 2.1 Conflict Type C1

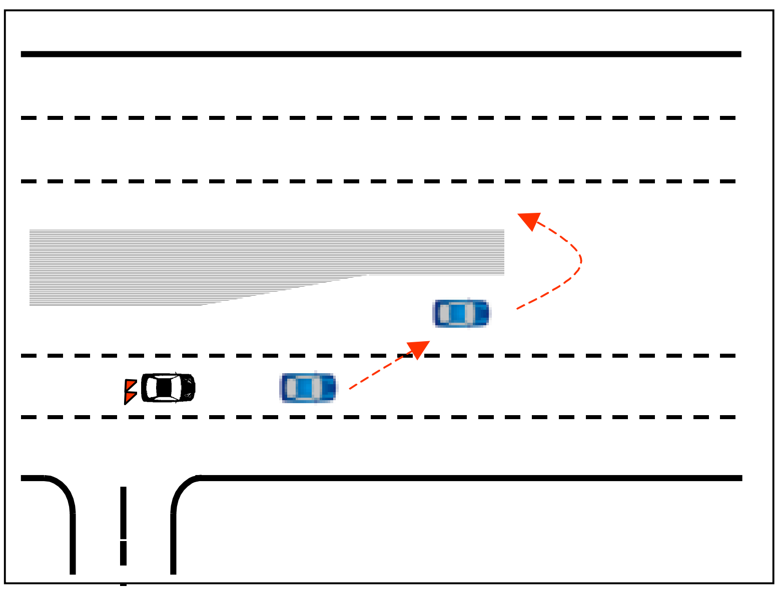

Figure 2.2 Conflict Type C2.

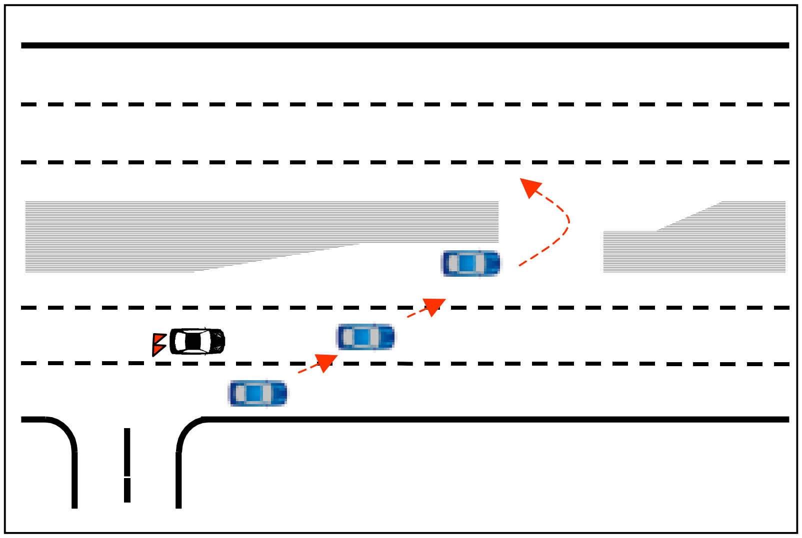

Figure 2.3 Conflict Type C3

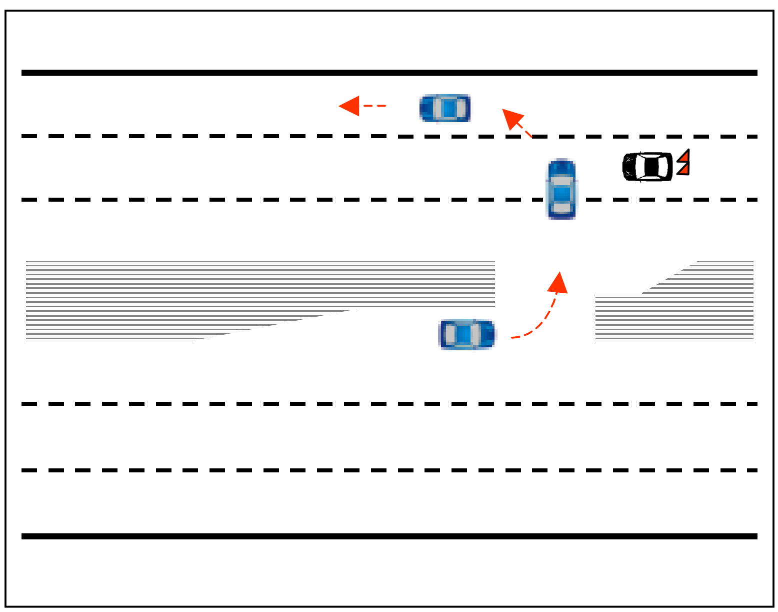

Figure 2.4 Conflict Type C4

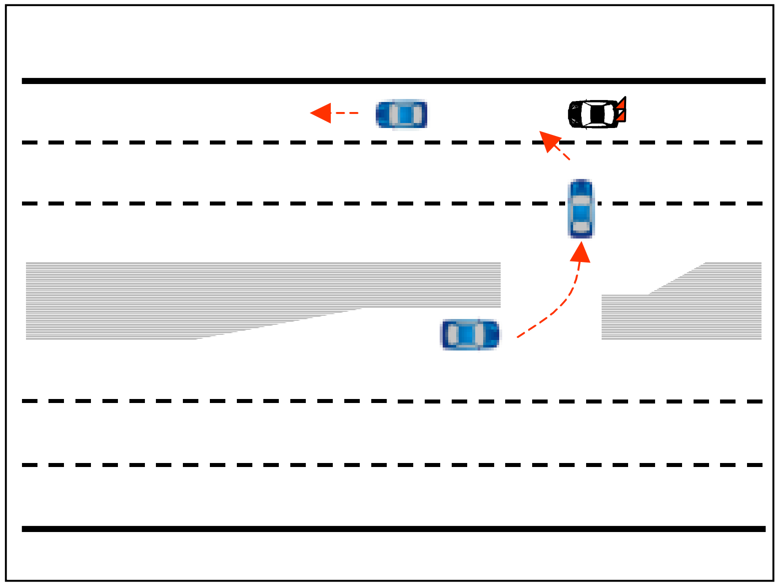

Figure 2.5 Conflict Type C2U-T

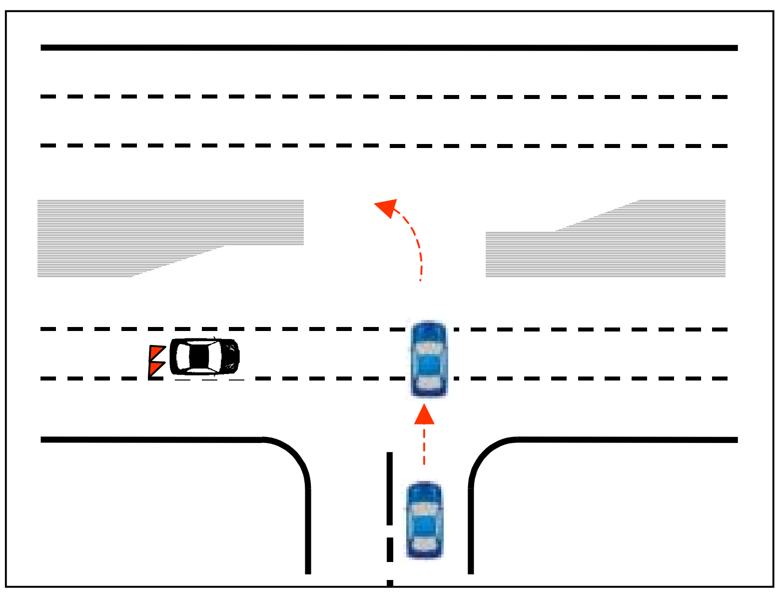

Figure 2.6 Conflict Type C5

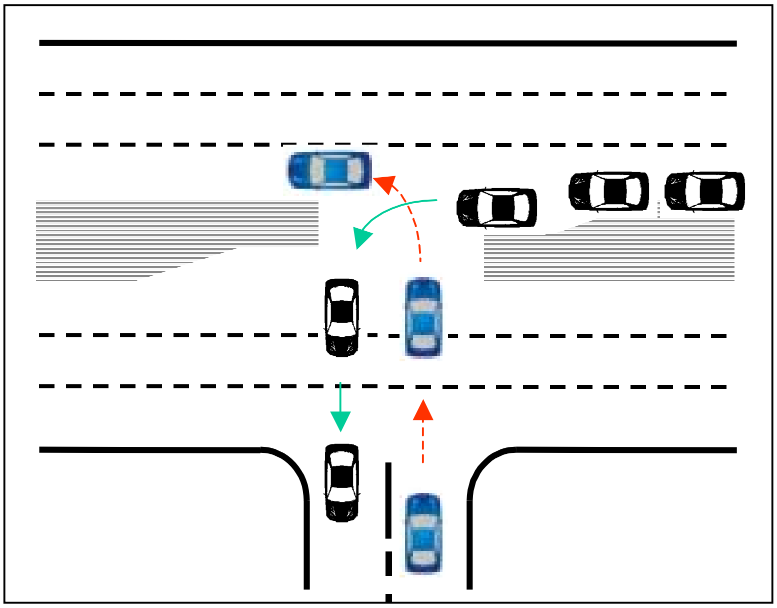

Figure 2.7 Conflict Type C6

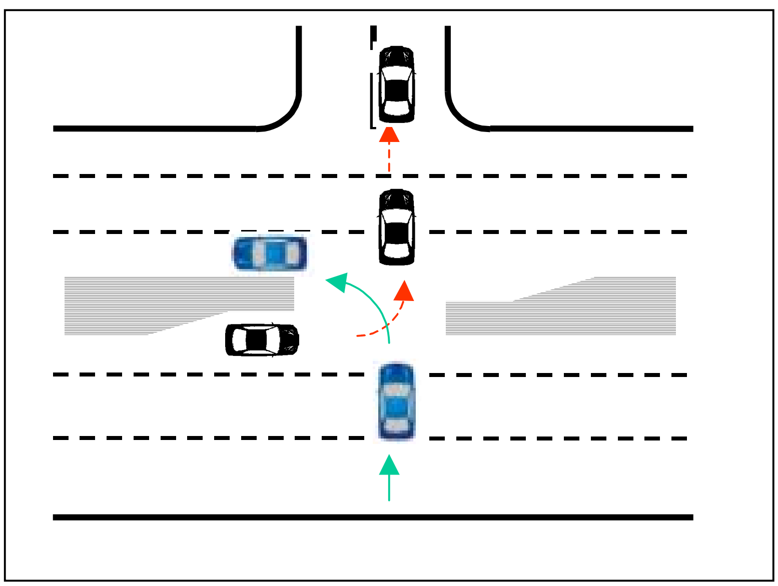

Figure 2.8 Conflict Type C7

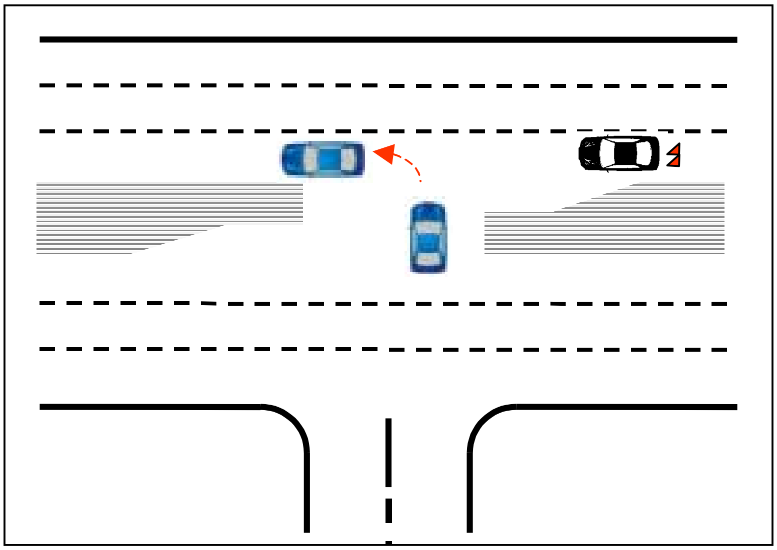

Figure 2.9 Conflict Type C8

2.4 Identification of Traffic Conflicts

This study considered evasive maneuvers such as applying brakes, swerving, or noticeably decelerating in order to avoid a collision, as conflicts. Brake applications have been used in several studies as indicators of the occurrence of a conflict, even though this might pose some problems in some cases *(18, 23, 24, 28, 33, 34, 35)*. For example, brake applications could be made as a precautionary action which could be misunderstood as a conflict, they may not provide information regarding the severity of the conflict, in some cases collisions may occur when vehicles accelerate to avoid a collision instead of applying brakes, and brake lights could have mechanical failures *(29)*. Swerving is also used as an indicator of the occurrence of a conflict, although it may not sometimes be clear whether swerving was because of a conflict or not. Using perception of deceleration of a vehicle is useful for detecting conflicts when there are no brake light indications because of a mechanical failure. However, by using this indication, conflicts may become too subjective. Even though these problems are found, brake applications, swerving, and noticeable deceleration could be used as indicators of the occurrence of traffic conflicts.

Several researchers have noted that observers are the most important element when conducting a traffic conflict study because their reliability has a serious impact on the validity of the data *(14, 29)*. Therefore, training and educating observers was one of the most important factors considered in the initial stages of the project. In order to train the observers, the *Traffic Conflict Techniques For Safety and Operations: Observers Guide* and the Center for Urban Transportation Research's *"Training Tool Kit"* were used *(14)*. With the intensive training provided and the experience gained through the research, the judgements of the observers were very reliable.

Having trained the observers, the next step was preparing the data collection forms necessary to extract the conflict data from the videotapes recorded at the selected sites. After reviewing several traffic conflict studies, it was decided that the standard forms used in general cases did not meet the needs of this research. Therefore, a special form was designed as shown in Figure 2.10. Column 1 was used for recording the time at which the conflict occurred, columns 2 to 10 were used for recording primary and secondary conflict types, column 11 was used for recording the distance between the offending and conflicting vehicle once the conflicted vehicle applied the brakes, column 12 was used to record the risk of collision score given by the observer, and the last column was used for indicating the existence of a special event.

The flow chart shown in Figure 2.11 describes the process followed by observers to record the conflicts. When a vehicle departed from the driveway the time was recorded and the observer tracked the vehicle in order to see if the movement was a DLT, RTUT, or neither of them. If the maneuver was either a RTUT or DLT, it was observed for conflicts. If a conflict occurred, the time of occurrence, conflict type, risk of collision perceived during the evasive action, and distance were recorded. The Risk Of Collision (ROC) was evaluated by assigning a score according to the level of severity of the evasive action perceived. The score values ranged from 1 to 3, with 1 being a low-risk conflict and 3 a high-risk conflict.

Site: ______________________

Data Collection Date: ______________________

Date of Data Analysis: ______________________

Observer: ______________________

Direction	
EB	
WB	
NB	
SB	

	Time Lecture			Conflict Type																		Distance	ROC Score
				C1		C2		C3		C4		C5		C6		C7		C8		C2UT			
	Hour	Minute	Second	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC				
1																							
2																							
3																							
4																							
5																							
6																							
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20																							

C = Conflict
SC = Secondary Conflict

Figure 2.10 The Form Used for Recording Traffic Conflicts.

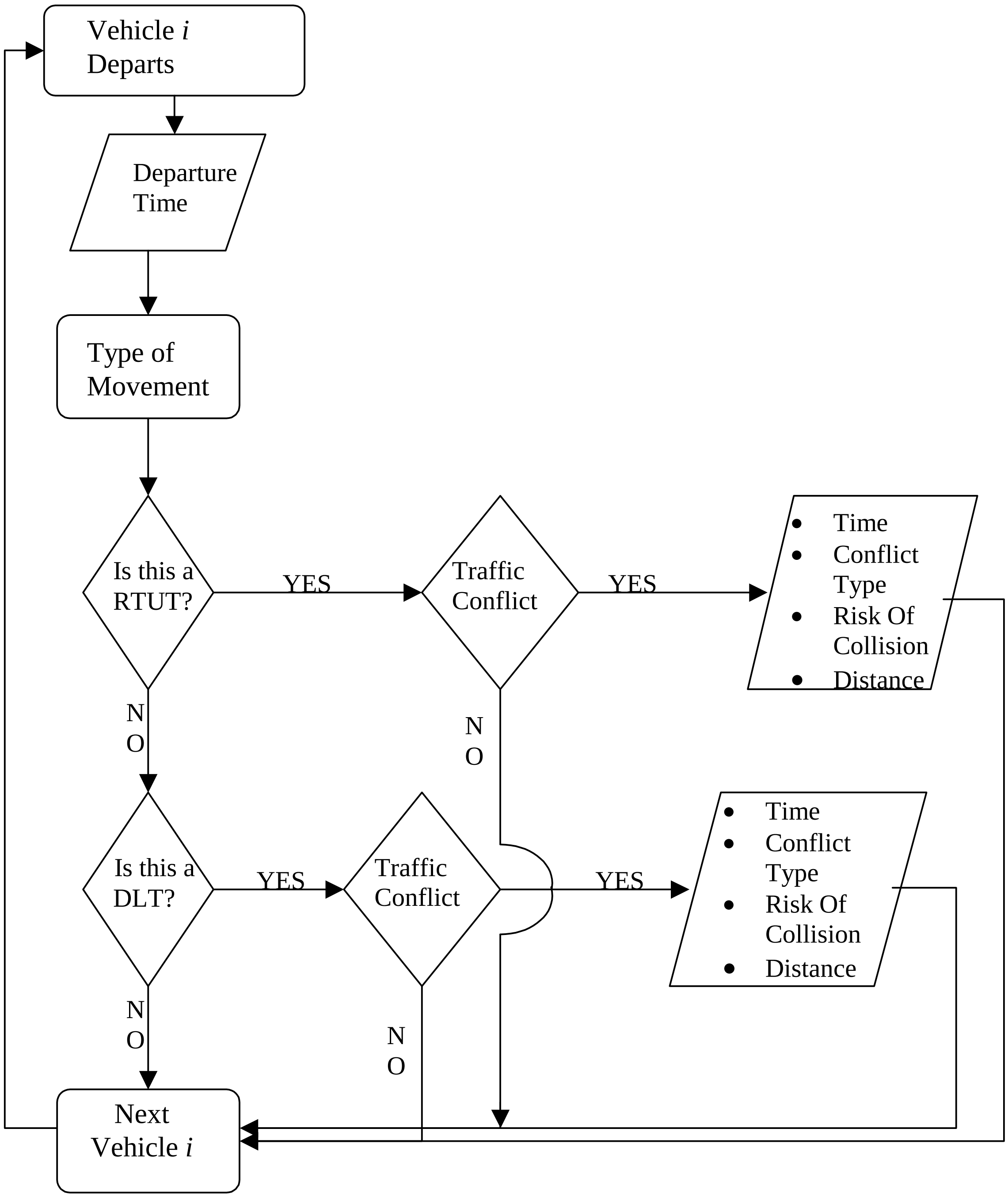

Figure 2.11 Flow Chart Describing Conflict Identification and Data Required by Observers.

2.5 Data Reduction Procedure

Once traffic conflicts were recorded and counted, steps were taken to verify the accuracy of the data before performing analyses. First, data must be reviewed so that any noticeable error or missing record could be corrected promptly. For example, a record may indicate two different types of conflicts, therefore, information on conflicts must be reviewed and only one type of conflict must be selected. It was also important to verify that data was collected at the same time in all the approaches, and to disregard those periods of time in which there were missing values. Determining daily conflict counts required that the number of conflicts collected in a site was adjusted to one day. Traditionally, conflict studies have considered eleven hours as one day, starting at 7:00 AM and ending at 6:00 PM *(13, 17, 18, 23, 25, 27).* Parker and Zegeer recommend adjusting data for those periods in which data were not collected *(13, 14).* The method calculates the number of conflicts based on the observed conflicts before and after the period in which data was not collected. The adjusted number of conflicts for non-observed periods was calculated by using the following equation:

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

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 the adjusted non-observed period conflicts were estimated, the daily numbers of conflicts were obtained by adding all the conflicts irrespective of whether they came from observations or from adjusted values for non-observed periods. When the daily numbers of conflicts were obtained, several types of conflict rates could be calculated. Table 2.1 presents the two types of rates used in this study. The first one is the ratio between the number of conflicts and the number of hours of observation. Conflicts per hour could be used to show the conflicts that might be found during different time periods such as peak and non-peak periods or the total average. The second conflict rate is the ratio between the number of conflicts and traffic volume. This rate is defined as the number of conflicts per thousand involved vehicles by maneuver type.

Table 2.1 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.

2.6 The Student's *t* Test

The Student's t test could be used to compare mean values of two samples that do not follow normal distribution. This test was used in this study to determine if the differences between conflict rates of RTUT movements were significantly different from that of DLT movements. In this test the null hypothesis (*Ho*) is that the difference between the means of the samples is equal to zero. The *t* statistic calculates the probability of the difference of the two means; say x_1 and x_2, having a value greater than or equal to the observed value. However, the *t* test assumes that the two samples belong to the same population and therefore, the variances must not be significantly different. This condition has to be verified by using the *F* test before the *t* test is performed *(36).*

The variance ratio test, known as the *F* test, compares the difference between the variances of two samples. The *F* test adopts the null hypothesis (*Ho*) that the two samples belong to the same population. The *F* statistic is calculated as:

$$F = \frac{S_1^{\,2}}{S_2^{\,2}}$$

where, S_1^2 and S_2^2 are the variances of the samples, and $S_1^2 > S_2^2$.

If the calculated *F* value exceeds the critical *F* value, the null hypothesis is rejected and the variances are considered to be significantly different. Once the difference between variances is verified to be not significant, the *t* value can be calculated as:

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\dfrac{\sum\left(x_1 - \overline{x_1}\right)^2 + \sum\left(x_2 - \overline{x_2}\right)^2}{\left(n_1 - 1\right) + \left(n_2 - 1\right)} \times \left(\dfrac{n_1 + n_2}{n_1 n_2}\right)}}$$

where, x_1 and x_2 = observations from the two samples,
n_1 and n_2 = number of observations in the two samples,
$\overline{x_1}$ and $\overline{x_2}$ = mean values of the observations from two samples.

If the calculated *t* value is greater than the critical *t* value at a given level of significance, the null hypothesis is rejected and it could be concluded that the difference between the two conflict rates is significant.

2.7 One-way Analysis of Variance (ANOVA) Test

The Analysis of Variance is a method used for determining whether two sets of data are significantly different from each other. The analysis of variance splits the variance of all the elements into variance between samples and variance within samples. These are calculated as the sum of the squares of deviations divided by the corresponding degrees of freedom, and compared by the *F* test, *(36).* The ANOVA test was used for determining if the severity of both RTUT and DLT movements was significantly different from each other. The null hypothesis (*Ho*) assumed that the severity of conflicts generated by RTUT movements was not different from that of conflicts generated by DLT movements. If the calculated F value was greater than the critical F value, then the null hypothesis was rejected and the difference would be significant.

3. DATA COLLECTION

This chapter describes the procedure followed during data collection and reduction and also includes the details of the selected sites, equipment used, procedure followed in the field, and data reduction process.

3.1 Description of Study Locations

Ten sites around the Tampa Bay area were selected for data collection based on the criteria described previously. Figure 3.1 shows the location of these sites. Table 3.1 presents a description of the geometric characteristics of the selected sites. Figure 3.2 illustrates the general layout and location of cameras for Sites 1, 3-After improvement, and 4. Figure 3.2 illustrates the general layout of Sites 2, 3-Before improvement, 4, 5, 6, and 7.

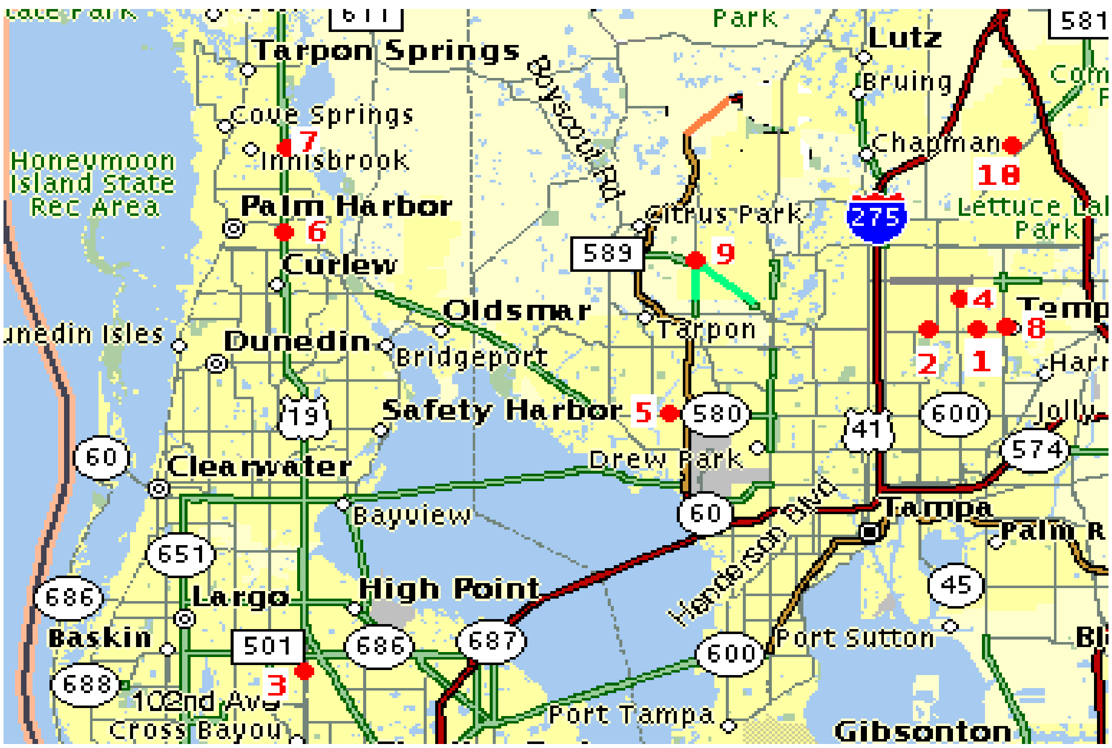

Figure 3.1 Location of Selected Sites.

Table 3.1 Descriptions of the Selected Sites.

Intersection	Site ID	Number of Lanes		Maneuver allowed by Median		Posted Speed	Distances (ft)		
		Arterial	Driveway	DLT	RTUT	(mph)	A	B	C
Fowler Ave. & 46th St.	1	3	1	No	Yes	50	950	800	700
Fowler Ave. & 19th St.	2	4	2	Yes	Yes	45	700	570	1350
US 19 & 116th Ave.	3	3 & 4	1	Yes	Yes	55	600	420	1620
Bruce B. Downs & Medical Center	4	3	1	Yes	Yes	45	870	970	1160
Hillsborough Ave. & Golden St.	5	3	2	Yes	Yes	45	850	300	750
US 19 & Enterprise Center	6	3	1	Yes	Yes	55	1700	550	4750
US 19 & Innisbrook	7	3	2	Yes	Yes	55	5280	600	5808
Fowler Ave. & 52nd St.	8	3	1	No	Yes	50	1200	580	530
Gunn Highway & Hangert	9	2	2	Yes	Yes	45	2120	590	2238
Bruce B Downs & Pebble Creek	10	2	1	No	Yes	45	1000	850	850

NOTE: Distance A: Distance from driveway to upstream signal.

Distance B: Distance from driveway to U-turn bay.

Distance C: Distance from U-turn bay to downstream signal

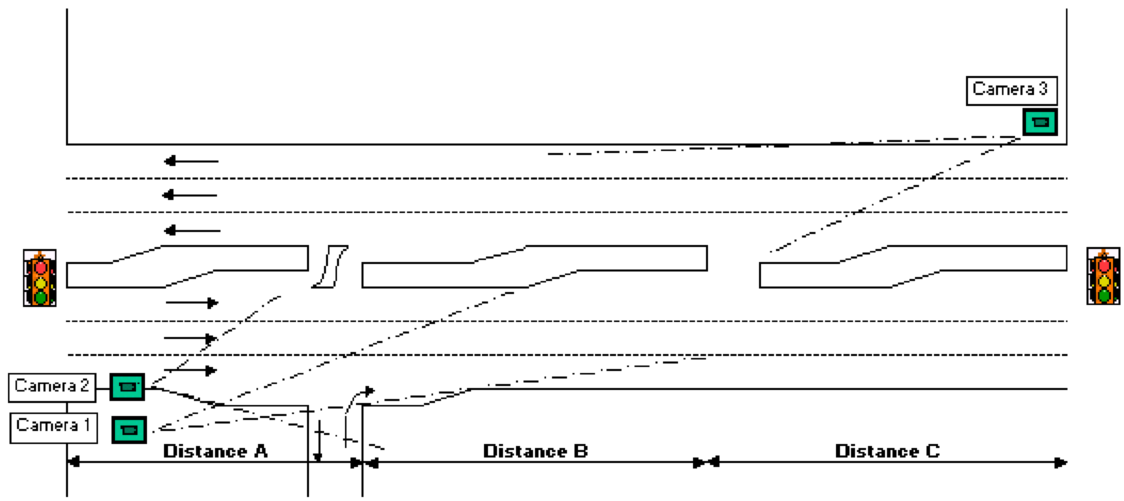

Figure 3.2 General Layout of Sites 1, 3-After Improvement, and 8.

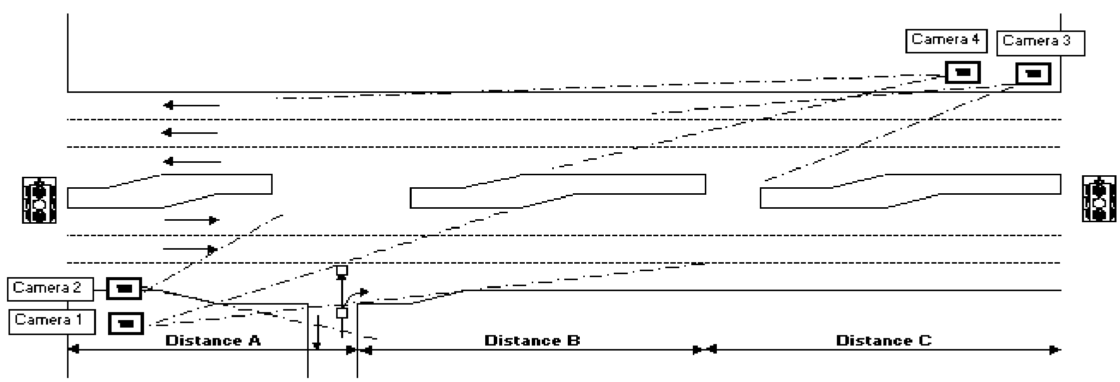

Figure 3.3 General Layout of Sites 2, 3-Before Improvement, 4, 5, 6 and 7.

Site 1 is located in Tampa, on Fowler Avenue and 46th Street. Fowler Avenue is a major divided arterial oriented in the east-west direction with three lanes in each direction. 46th Street is a local street with one lane in each direction. The median on Fowler Ave. is raised and at 46th Street it becomes a directional median opening. Because of this, drivers that come from 46th St. who want to take Fowler Avenue to the west have to make RTUT. The posted speed limit is 50 mph.

Site 2 is located on Fowler Avenue and 17th Street, beside the University Square Mall. At this point, Fowler Avenue still is a six-lane road divided with a raised median. However, there is a full median opening located across the driveway. The driveway has two lanes for egress of vehicles, which provides the options of DLT and RTUT movements to drivers. The posted speed limit is 45 mph.

Site 3 is located on US 19 and 116th Avenue, in Pinellas County. US 19 is a major arterial oriented in the north-south direction, with three and four lanes on the southbound and northbound, respectively. The northbound and southbound lanes are separated by a raised median. The posted speed limit in this segment is 55 mph. This site is of special interest because the median was improved within the data collection time period. Initially, a full median opening allowed vehicles to make DLT maneuvers, whereas after the improvement only right turns were permitted. Therefore, a before and after study of this site could be conducted to provide insightful information about DLT and RTUT maneuvers, without the concern of having different site characteristics.

Site 4 is located on Bruce B. Downs Blvd. and 131st Avenue. This site is located at the entrance to the parking lot of the Veteran's Hospital. Bruce B. Downs is an arterial with three lanes in each direction at the selected location. It is oriented in the north-south direction and has a posted speed limit of 45 mph. The driveway has one lane for egress.

Site 5 is located on Hillsborough Avenue at the driveway for Verizon, a major telecommunications employer. The driveway permits ingress to and egress from Verizon's offices. Hillsborough Avenue is an arterial oriented in the east-west direction with three lanes in each direction. Eastbound and westbound lanes are divided by a raised median. This site presents a full median opening located across the driveway. The driveway has two lanes for egress, where one lane is used for left turns and the other lane is for right turns. The posted speed limit in this segment is 45 mph.

Site 6 is located on US 19 and Enterprise Center in the Palm Harbor area of Pinellas County. The driveway is adjacent to an office building. US 19 is a major arterial with three lanes in each direction, separated by a raised median. The driveway has only one lane for egress. On this site drivers have the option to make either DLT or RTUT maneuvers. The posted speed limit is 55 mph.

Site 7 is located on US 19 and Innisbrook in the Tarpon Springs area of Pinellas County. In this case, the driveway provides access and egress for residents living in nearby complexes. In this segment, US 19 still has three lanes in each direction and is divided with a raised median.

Site 8 is located on Fowler Avenue and 52nd Street in the Temple Terrace area. Fowler Avenue is a major divided arterial oriented in the east-west direction, with three lanes in each direction. 52nd Street is a local street with one lane in each direction serving residents and customers of surrounding residential areas and stores, including a supermarket. The median is raised and restricts DLT maneuvers with a directional median opening. The posted speed limit is 50 mph.

Site 9 is located on Gunn Highway and Hangert Street. Gunn Highway is a divided arterial oriented in the northwest direction, with two lanes in each direction. Hangert St. provides access and egress to residents living in nearby complexes. In this segment the posted speed limit is 45 mph.

Site 10 is located on Bruce B. Downs Blvd. and Pebble Creek in the New Tampa area. Bruce B. Downs Blvd. is a divided arterial oriented in the northwest direction, with two lanes in each direction. The driveway has one lane for the egress of vehicles and the median restricts DLT movements. The posted speed limit is 45 mph.

3.2 Data Collection Equipment

At the beginning of the study, manual traffic conflict observers were considered as the data collection methodology, as several past conflict studies had utilized that method. However, two reasons supported the idea of using video cameras, instead. First, it would be extremely difficult to record traffic conflicts and traffic volumes at the same time because the observer had to track and identify the maneuver that each vehicle made when it departed from the driveway. Second, onsite observations cannot easily be verified, which is of special concern when the observer has to register several types of conflicts *(21).* In contrast, using video cameras would allow the observer to review all the conflicts that might have occurred at the site, and if a doubt persists, the videotape can be replayed until the matter is clarified and a more informative decision can be made. Also, technological advances on video cameras allow a precise registration of the time the conflict occurred *(21).* Nevertheless, using video cameras for gathering conflict data requires several hours reducing data from videos.

Three cameras were used for recording conflicts. Two of the cameras, Sony DCRTRV320 Digital 8™ and Sony DCR-VX700, were digital cameras so that movements on the arterial would be captured with a very high quality. The other video camera, a Sony CCDTRV68, was used to record movements on the U-turn bay when an extra camera was needed.

Although the cameras had high resolution, an important factor had to be resolved before beginning data collection. If the cameras were set up close to the ground level, it would have been impossible to collect all the traffic conflicts since the vehicles traveling in the inner lane would be covered by other vehicles traveling on the middle or outer lanes. A solution for this problem was to install the camera at an adequate height that is at least 15 ft above the ground, by using scaffolding. The advantages of using scaffolding were that it provided a stable and safe means of providing enough height to install cameras, and it was not as expensive as the other equipment, such as bucket and scissors lifters. The scaffolding and cameras were positioned and installed according to the needs of each site, as previously shown in Figures 3.1 and 3.2.

Traffic volumes were also recorded while collecting data. An automatic data recorder ADR-1000 from Peek Traffic™ was used to obtain the traffic volume on the arterial. Right-turn, direct left-turn, left-turn in, and right turn plus U -Turn maneuver volumes were obtained from videos.

3.3. Field Procedure

Data were collected during weekdays under normal traffic conditions, good weather, and dry pavement conditions. Weekdays in this study were considered as from Monday through Thursday, where normal conditions are expected to prevail. Also, data were collected during peak and non-peak periods. The morning peak period between 7:00 AM and 9:00 AM, and afternoon peak period between 4:00 PM and 6:00 PM were considered in this study. However, not all the data were collected during the same time period for all sites because every site has different land uses, which changes the driveway volume pattern. For example, Site 2 was located near a mall, which means that there were few vehicles between 7:00 AM and 12:00 PM. Therefore, data was collected between 2:00 PM and 6:00 PM.

Two other important factors were considered in the data collection and reduction process. First, all cameras and counters were synchronized before the start of the data collection. The purpose of this was to eliminate tedious data matching such as vehicle's color and model, especially when 3 or 4 cameras were involved simultaneously. Second, when installing the cameras on the scaffolding, it was very important to set them at a good angle and zoom in order to accurately detect brake lights or any other evasive maneuvers.

3.4. Data Reduction

Data was reduced from videotapes by following the procedure explained in the flow chart described in the methodology section. Each vehicle from the driveway under investigation was tracked down and departure time from the driveway, arrival time either at the left-turn storage area or at the U-turn bay, and departure time from the U-turn bay or median opening were recorded. Then, the videos from the cameras located on the opposite bound side were reviewed at that specific time, which accelerated the reduction process without affecting the quality. Another advantage of doing this was that this information could later be used to determine each maneuver volume. It is important to highlight that the data reduction process was very time consuming and the approximately three to four hours of time was required to reduce one hour of video recorded in the field.

Based on the information recorded on the form designed for that purpose, a database was created in order to analyze the data collected from videos in a fast and efficient way. The software used was Microsoft Access because of its user-friendly characteristics and its capability to export information to spreadsheets, such as Excel. The database consisted of three tables that contained the information recorded in the form used for reducing data from videos, departure time of vehicles leaving the driveway, and information of the traffic volume on the arterial. Several queries were designed in such a way that conflicts, arterial volume, and maneuver volume would be assigned to the respective 15 minute-interval of the day. For example, interval 1 corresponds to the time period between 7:00 AM and 7:15 AM, and so on. After the queries were run, their results were exported to an Excel spreadsheet so that further data analysis could be performed.

4. DATA ANALYSIS

This chapter describes the number of conflicts and conflict rates for both DLT and RTUT movements and a safety comparison between the two alternatives. Conflict severity related to these two maneuvers are also presented and compared.

4.1. Descriptive Analysis

It was first necessary to verify if the sample size of the data collected was satisfactory, and therefore minimum sample size was estimated using the equation described previously with a confidence level of 95 percent. Moreover, the percentage of vehicles associated with each movement and conflict type was calculated in order to evaluate the proportion of vehicles involved in a conflict, as presented in Tables 4.1 and 4.2. The sample size requirement was not met for the last two sites, which were four-lane roads. Therefore, the conflict data analyses presented in this chapter were based on the data collected at the sites with six or more lanes only.

Table 4.1 Verification of Sample Size for RTUT Movement

Conflict Type (1)	Average Number of Conflicts (2)	RTUT Vehicles (3)	P_{RTUT} (4)=(2)/(3	n (5)	Sample Size Satisfied (Yes/No)
C1	57.4	1372	0.04	62	Yes
C2	64.9	1372	0.05	69	Yes
C3	68.3	1372	0.05	73	Yes
C4	73.4	1372	0.05	78	Yes
C2UT	35.8	1372	0.03	39	Yes

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

Table 4.2 Verification of Sample Size for DLT Movement.

Conflict Type (1)	Average Number of Conflicts (2)	DLT maneuver Vehicles (3)	P_{DLT} (4)=(2)/(3	n (5)	Sample Size Satisfied
C5	180.8	1430	0.13	170	Yes
C6	106.6	1430	0.07	106	Yes
C7	13.9	1430	0.01	15	Yes
C8	78.6	1430	0.05	80	Yes

P_{DLT} = Percentage of DLT vehicles involved in a conflict.

n = Number of vehicles estimated for sample size.

A descriptive analysis was performed to evaluate the information gathered in the field. Table 4.3 presents a summary of the total of 1654 conflicts collected in the field at eight sites and used in the analyses. If data from both directions at a given time period was not available, such data were disregarded in the analysis.

Table 4.4 presents a summary of the average number of conflicts by conflict type for each of the sites with three or more lanes in each direction.

Also, 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 4.5, and Figures 4.1 to 4.7 graphically illustrate the individual data at each site except for site 3, for all conflict types. Since site 3 experienced a median closure making it an ideal site for conducting a before and after type of evaluation, analysis results related to that site are documented separately in Chapter 5.

Table 4.3 Summary of the Total Number of Observations.

Site	Conflicts	Conflict Type									Total
		C1	C2	C3	C4	C5	C6	C7	C8	C2UT	
1	No.	64	22	23	15	N/A	N/A	N/A	N/A	28	152
	(%)	42.1	14.5	15.1	9.9	-	-	-	-	18.4	100
2	No.	4	9	3	3	75	221	5	36	-	356
	(%)	1.1	2.5	0.8	0.8	21.1	62.1	1.4	10.1	-	100
3	No.	15	17	15	6	150	71	18	74	5	371
Before	(%)	4	4.6	4	1.6	40.4	19.1	4.9	19.9	1.3	100
3	No.	40	36	89	118	N/A	N/A	N/A	N/A	44	327
After	(%)	12.2	11	27.2	36.1	-	-	-	-	13.5	100
4	No.	1	9	2	2	37	18	-	12	-	81
	(%)	1.2	11.1	2.5	2.5	45.7	22.2		14.8	-	100
5	No.	2	11	2	1	39	22	3	17	-	97
	(%)	2.1	11.3	2.1	1	40.2	22.7	3.1	17.5	-	100
6	No.	1	12	3	9	24	1	2	11	2	65
	(%)	1.5	18.5	4.6	13.8	36.9	1.5	3.1	16.9	3.1	100
7	No.	2	15	5	-	41	14	1	21	-	99
	(%)	2	15.2	5.1	-	41.4	14.1	1	21.2	-	100
8	No.	26	22	22	18	N/A	N/A	N/A	N/A	18	106
	(%)	24.5	20.8	20.8	17	-	-	-	-	17	100
TOTAL		155	153	164	172	366	347	29	171	97	1654

Table 4.4 Average Number of Conflicts Used for Analysis.

Site	Description	Conflict Type									Total
		C1	C2	C3	C4	C5	C6	C7	C8	C2UT	
1	No.	21.2	7.6	7.1	4.5	N/A	N/A	N/A	N/A	8.3	48.7
	(%)	43.5	15.6	14.6	9.2	-	-	-	-	17	100
2	No.	0.6	1.3	0.5	0.4	10.3	32.3	0.7	5.3	-	51.4
	(%)	1.2	2.5	1	0.8	20	62.8	1.4	10.3		100
3	No.	8.5	9.3	8.7	4	93.5	44.5	10.8	41.9	2.5	223.7
Before	(%)	3.8	4.2	3.9	1.8	41.8	19.9	4.8	18.7	1.1	100
3	No.	16.6	15.5	37.4	53.4	N/A	N/A	N/A	N/A	17.4	140.3
After	(%)	11.8	11	26.7	38.1	-	-	-	-	12.4	100
4	No.	0.5	6.5	1.5	1.5	26	14	-	9	-	59
	(%)	0.8	11	2.5	2.5	44.1	23.7	-	15.3	-	100
5	No.	0.5	3.7	0.5	0.25	15	7.3	0.9	5.4	-	33.6
	(%)	1.5	11	1.5	0.7	44.7	21.8	2.7	16.1	-	100
6	No.	0.5	6	2	4.5	13	0.5	1	5.5	1	34
	(%)	1.5	17.6	5.9	13.2	38.2	1.5	2.9	16.2	2.9	100
7	No.	1	7.5	2.5	-	23	8	0.5	11.5	-	54
	(%)	1.9	13.9	4.6	-	42.6	14.8	0.9	21.3	-	100
8	No.	8	7.6	8.2	4.8	N/A	N/A	N/A	N/A	6.6	35.2
	(%)	22.7	21.6	23.3	13.6	-	-	-	-	18.8	100
TOTAL		57.4	65	68.4	73.3	180.8	106.6	13.9	78.6	35.8	679.9

Table 4.5 Average Daily Number of Conflicts.

Site	Conflict Type									Total
	C1	C2	C3	C4	C5	C6	C7	C8	C2UT	
1	27.2	10.6	7.8	9.8	N/A	N/A	N/A	N/A	13.5	68.9
2	0.7	1.4	0.6	0.4	11.3	67.5	0.8	16.5	-	99.2
3	8.5	13.3	10.7	4.0	117.	44.5	14.8	43.8	2.5	259.6
3	16.6	15.5	37.4	53.3	N/A	N/A	N/A	N/A	17.4	140.3
4	0.5	7.5	2.5	3.0	34.0	17.5	-	10.0	-	75
5	0.5	3.7	0.5	0.3	45.0	7.3	0.9	5.4	-	63.6
6	0.5	6.0	2.0	4.5	22.0	0.5	1.0	5.5	1.0	43
7	1.0	8.0	3.5	-	29.5	12.0	0.5	15.5	-	70
8	26.1	9.6	19.2	4.8	N/A	N/A	N/A	N/A	15.6	75.3

At Site 1, approximately 34 percent of all the conflicts were related to U-turn maneuvers (i.e. Conflict types C2U-T and C4). Of these, 42 percent corresponded to the U-turn maneuver itself, and 58 percent to conflict type C2UT. Conflict types C1, C2, and C3 accounted for 39, 15, and 12 percent of the total conflicts, respectively, as shown in Figure 4.1.

At Site 2, the average number of daily conflicts was considerably higher for DLT movements (97%) than that of RTUT movements (3%), as shown in Figure 4.2. It is interesting to note that 70 percent of the conflicts associated with DLT movements were of type C6, which is explained by a high volume of left-turning vehicles into the driveway. The high left-turn in volume is caused by the location of the driveway, which was located nearby a mall. Also, it is interesting that the daily average number of conflict type C8 was 46 percent higher than that of conflict type C5. This may be the result of the lack of sight suffered by drivers waiting in the median storage area. The lack of sight was due to high left turning vehicles into the mall and the involvement of different vehicles on the median.

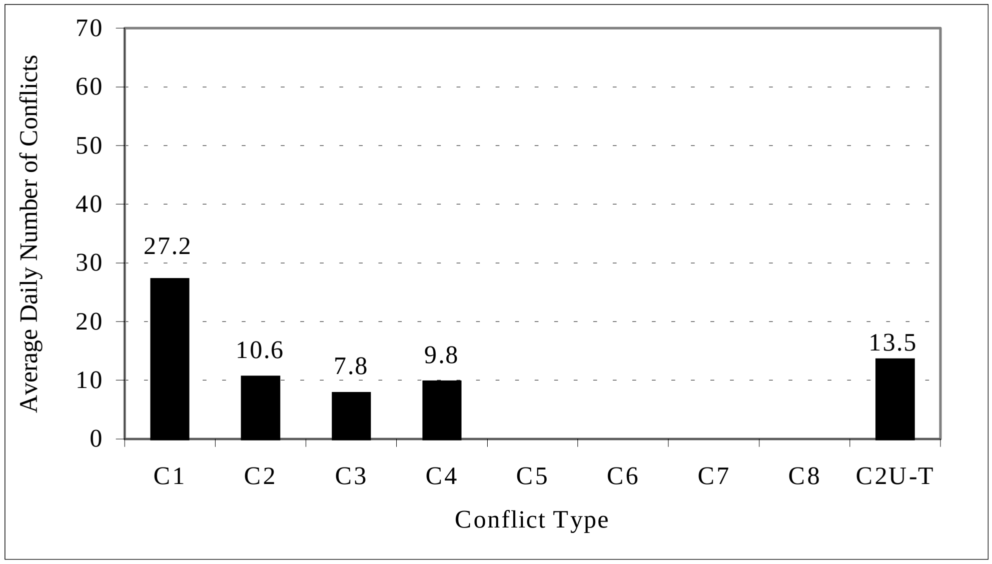

Figure 4.1 Number of Daily Conflicts by Type, Site 1.

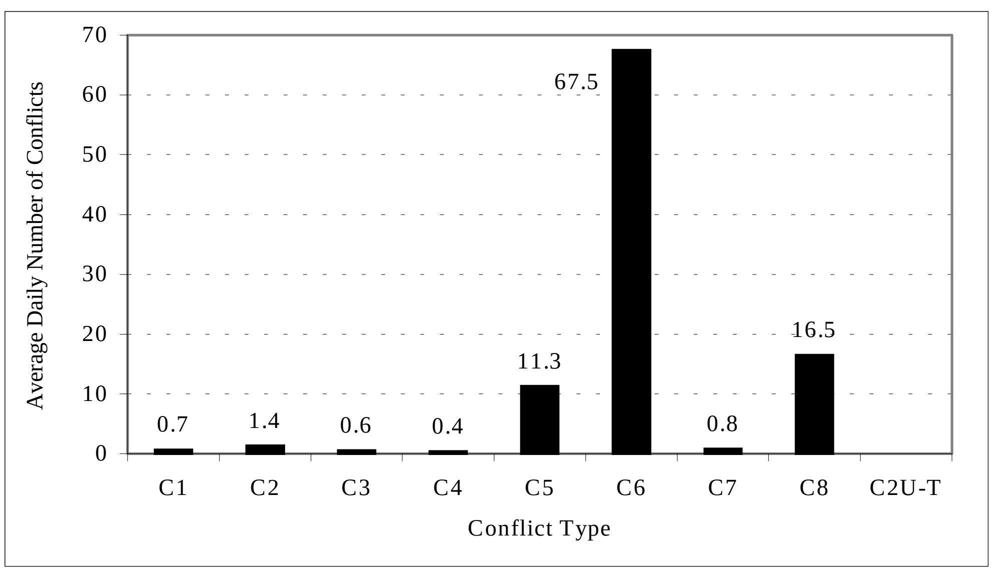

Figure 4.2 Number of Daily Conflicts by Type, Site 2.

Conflict types observed at Site 3 are explained in more detail in Chapter 5. Site 4 had a higher percentage of DLT movements rather than RTUT movements. This explains why DLT accounted for 82 percent of all the conflicts, as shown in Figure 4.3. Approximately 55, 29, and 16 percent of the conflicts corresponded to DLT conflict types C5, C6, and C8, respectively. The high percentage of conflict type C5 may be due to the narrow width and length of the median storage area. It was frequently observed that left turning vehicles encroached on through-traffic lanes.

Figure 4.4 shows the number of daily conflicts at Site 5. Conflicts related to DLT movements were 92 percent of the total conflicts counted. Conflict types C5, C6, C7, and C8 accounted for 77, 12, 2 and 9 percent of all the conflicts, respectively. Data further shows that the number of conflicts of type C6 was 36 percent higher than that of conflict type C8.

At Site 6, 67 percent of the total conflicts corresponded to DLT movements whereas 33 percent corresponded to RTUT movements, as shown in Figure 4.5. Among the conflicts related to DLT movements, conflict types C5, C6, C7, and C8 accounted for 76, 2, 3 and 19 percent respectively. With regard to conflicts associated with RTUT maneuvers, 43, 14, 32, 7, and 4 percent corresponded to conflict types C2, C3, C4, C2U-T, and C1; respectively. A possible reason for the high number of conflict type C2 can be attributed to vehicles traveling at high speeds on the through-traffic lanes. These values also show that 39 percent of the conflicts were associated with U-turn maneuvers.

At Site 7, DLT conflicts accounted for 82 percent of the total while RTUT conflicts only accounted for 18 percent. The most common type of conflict among those related to DLT maneuvers is C5, with 52 percent, followed by conflict type C8, with 27 percent, and conflict types C6 and C7. As for conflicts related to RTUT conflicts, the most common conflict type was C2, which consisted of 68 percent of all the conflicts, followed by conflict types C3 and C1. The high percentage of conflict types C2 and C3 may be explained by the high speed of through traffic vehicles. See Figure 4.6.

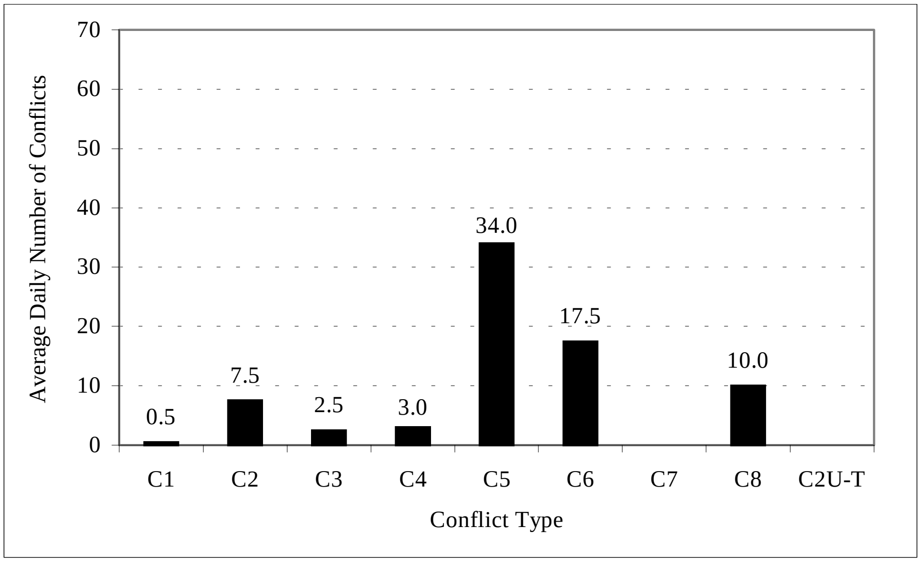

Figure 4.3 Number of Daily Conflicts by Type, Site 4.

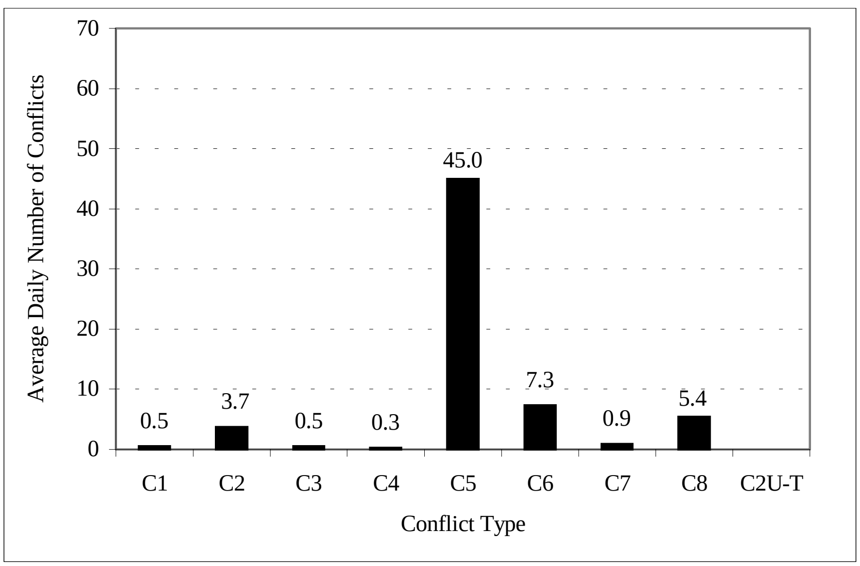

Figure 4.4 Number of Daily Conflicts by Type, Site 5.

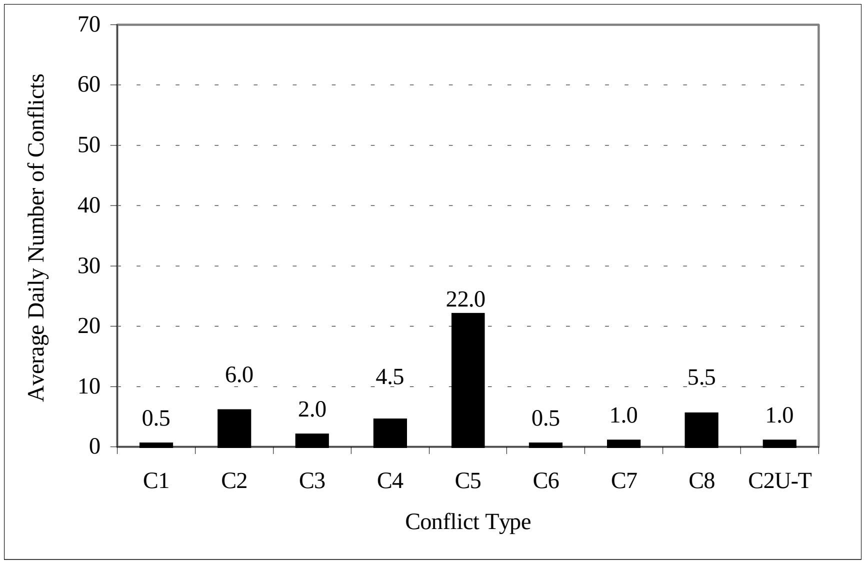

Figure 4.5 Number of Daily Conflicts by Type, Site 6.

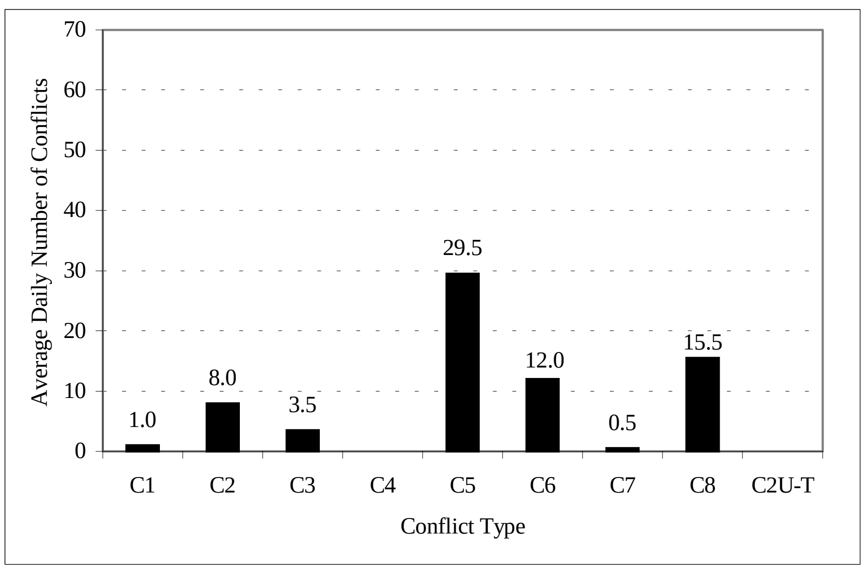

Figure 4.6 Number of Daily Conflicts by Type, Site 7.

At Site 8, it was found that 27 percent of the conflicts were related to the U-turn maneuver (i.e. conflict types C4 and C2U-T) while the others accounted for 73, as shown in Figure 32. When comparing conflict types C4 and C2U-T, it was found that the number of conflict type C4 was 69 percent lower than that of conflict type C2U-T. Figure 4.7 also shows that the most frequent conflict types on this site were conflict type C1 and C3, with 35 and 25 percent, respectively. This may be caused by a limited weaving distance.

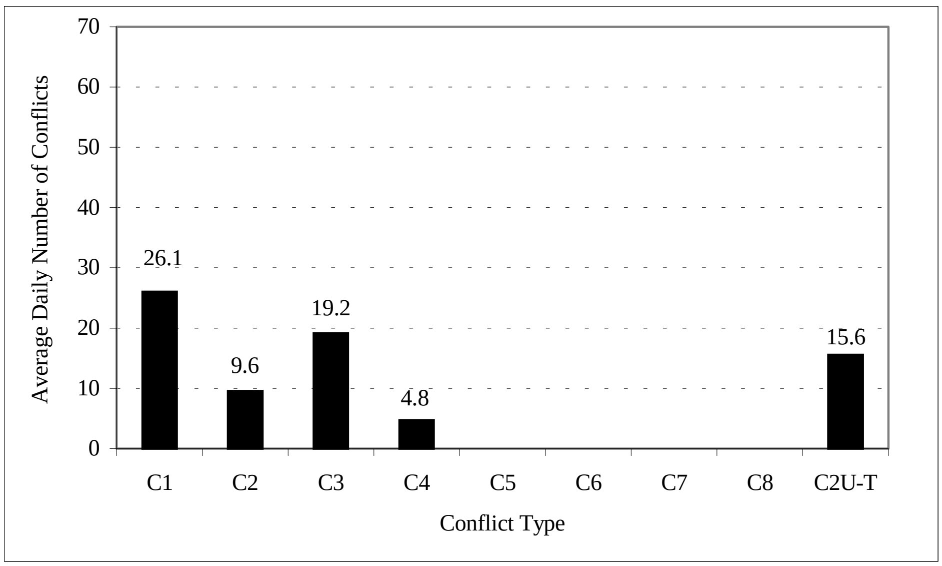

Figure 4.7 Number of Daily Conflicts by Type, Site 8.

When data was pooled by maneuver type, results previously presented vary. Figure 4.8 shows the average number of daily conflicts for RTUT movements. An average of 94.8 daily conflicts can be observed in one day, with 24 percent corresponding to conflict types C1 and C4, followed closely by conflict type C3 with 23 percent, then by conflict type C2U-T with 16 percent and finally conflict type C2 with 13 percent. This data indicates that on average 40 percent of the conflicts correspond to the U-turn maneuver, 24 percent to conflict type C1, 23 percent to conflict type C3, and finally conflict type C2 with 13 percent. It is important to note that conflict type C1 occurred most of the time either on the middle or inner lane, contrary to what was expected at the beginning of the study.

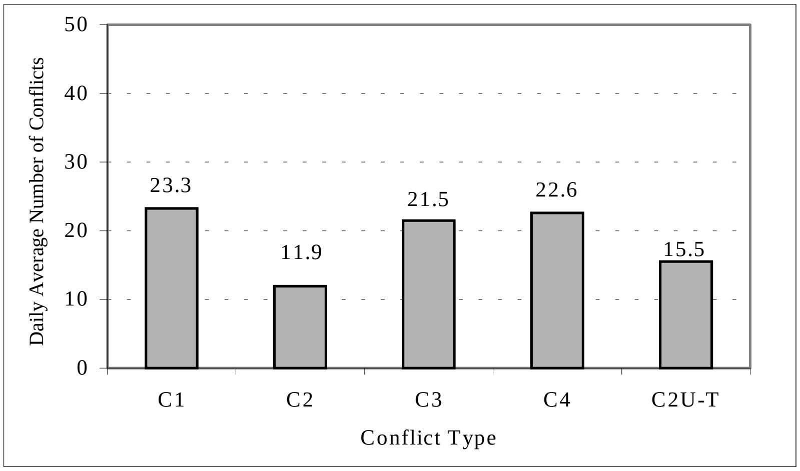

Figure 4.8 Average Number of Daily Conflicts by Type, RTUT Movement.

Figure 4.9 shows the average number of daily conflicts created by DLT movements. An average of 87.2 daily conflicts can be counted in one day; from which 50 percent correspond to conflict type C5, 29 percent to conflict type C6, 18 percent to conflicts type C8, and 3 percent to conflict type C7. These results suggest that left turn in volume has an important impact on DLT movements from a driveway. Also, as it was expected from the beginning most of the conflicts are due to the left turn itself.

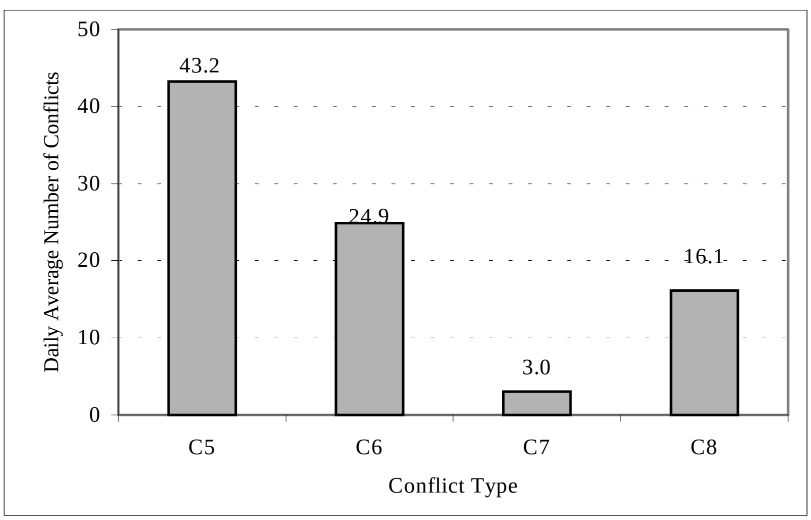

Figure 4.9 Average Number of Daily Conflicts by Type, DLT Movement.

A comparison of the average number of conflicts shown in Figures 4.8 and 4.9 suggests that the total number of conflicts due to DLT movements are 8 percent lower than that of RTUT movements. This result may be misleading because different factors could affect the occurrence of traffic conflicts. For example, the volume of RTUT movements is different from that of DLT movements. Hence, the use of conflict rates seems to be a more appropriate means to compare the effect of the maneuvers compared in this study. The values presented in Figures 4.8 and 4.9 only depict what type of conflicts and how many of them would be found by maneuver type.

4.2. Conflict Rates

Two types of rates were calculated for the purpose of safety analysis. First, the number of conflicts per hour of observation was used at each site and then the average value is presented. Second, the number of conflicts per thousand involved vehicles was calculated and values are presented.

4.2.1. Conflicts per hour

Figure 4.10 presents the average hourly rate of RTUT conflicts by time period. Interestingly, the number of conflicts per hour of observation during non-peak hour periods was 10 percent higher than that of peak periods. In addition, by analyzing the differences among conflict types, different trends could be observed. For example, conflicts due to U-turns were reduced by 65 percent during peak hours, which might be explained by drivers being more careful when selecting an adequate gap for making the maneuver. As of the other types of conflicts, C3 decreased by 19 percent, and C2 was reduced by 76 percent whereas conflict type C1 increased by 76 percent.

On the other hand, DLT movements created more conflicts during peak hours, as shown in Figure 4.11. The hourly conflict rate of DLT movements was 23 percent higher than that of RTUT conflicts. Conflict type C5 increased by 10 percent, C6 by 2 percent, C7 by 62 percent, and C8 by 105 percent. It is interesting that conflict type C6 slightly increased during peak hours, which may indicate that the effect of left-turn in movements is contingent on vehicles making DLT movements.

Figure 4.12 shows the comparison of the total average number of conflicts per hour of the two maneuvers. In general, the DLT conflict rate was 51 percent higher than the conflict rate of RTUT maneuvers. By desegregating data into peak and non peak periods, the conflict rates of DLT conflicts were 29 and 75 percent higher than those of RTUT maneuvers during non-peak and peak hours, respectively.

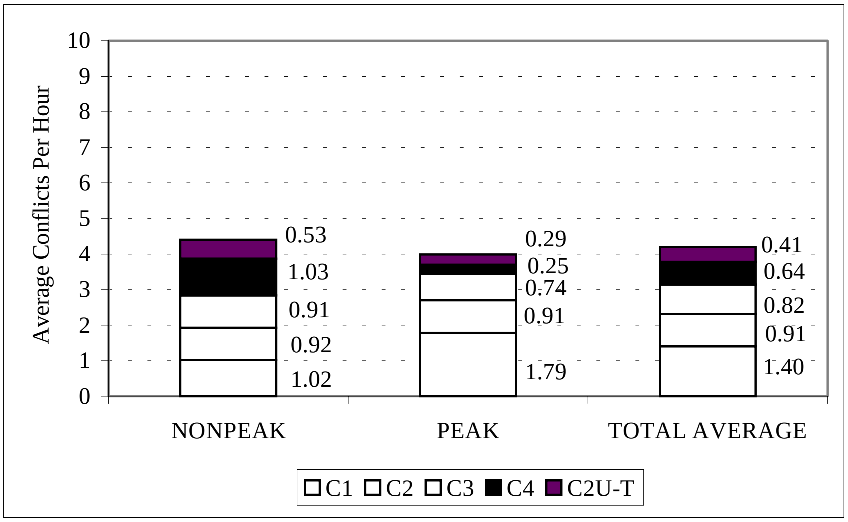

Figure 4.10 Conflicts by Time Period, RTUT Movement.

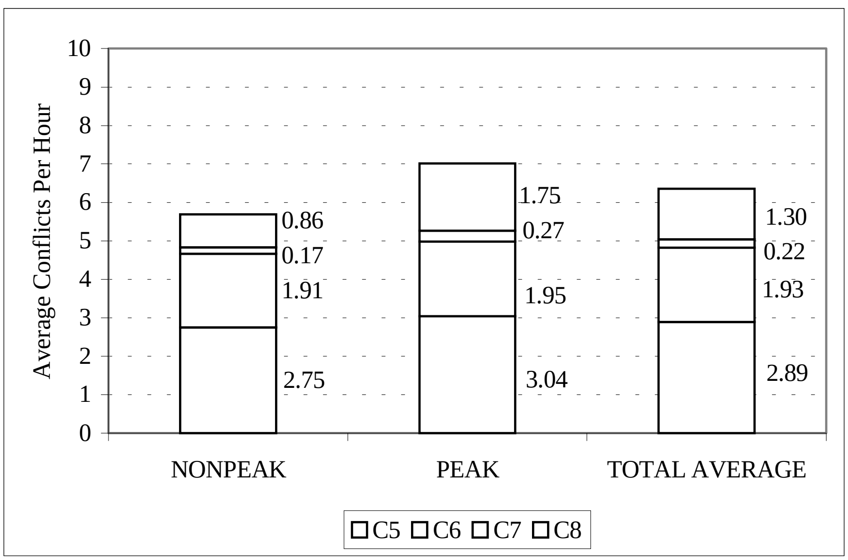

Figure 4.11 Conflicts by Time Period, DLT Movement.

4.2.2. 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 the best for calculating the conflict rate. The total number of conflicts, through traffic vehicles, maneuvering vehicles, and conflict rates were obtained for each site. Table 4.6 presents the number of conflicts per thousand involved vehicles at each site. The values given in Table 4.6 indicate that except for site 6 the other sites had lower conflict rates for RTUT movements. Moreover, Table 4.6 indicates that the average conflict rate for RTUT was 38 percent lower than that of DLT movements.

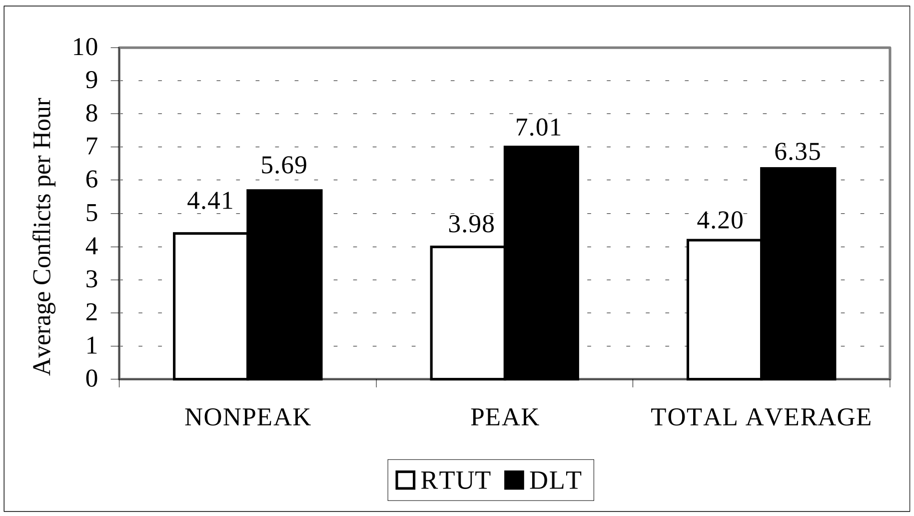

Figure 4.12 Comparison Average Hourly Conflicts Between RTUT and DLT Movements by Time Period.

4.3. Severity Analysis

The severity of conflicts was analyzed by considering two approaches. A subjective score, which was based on the Risk of Collision (ROC) of the maneuver and an objective score, which was based on the concept of Time to Collision (TTC). Each conflict received ROC and TTC scores in order to evaluate the severity of the conflicts for both RTUT and DLT maneuvers. These scores are given in Table 4.7.

Table 4.6 Number of Conflicts per Thousand Involved Vehicles.

Site	DLT	RTUT
1	N/A	19.61
2	39.36	10.12
3 Before	49.11	19.02
3 After	N/A	36.80
4	28.46	11.69
5	26.90	12.10
6	11.33	17.74
7	26.12	12.41
8	N/A	28.90
Average	30.21	18.71

Table 4.7 Time To Collision (TTC) and Risk Of Collision (ROC) Scores

TTC and ROC Scores	TTC	ROC
1	1.51 < TTC seconds	Low Risk
2	1.00 – 1.50 seconds	Medium Risk
3	0.00 – 0.99 seconds	High Risk

The severity of traffic conflicts was determined by the sum of both ROC and TTC scores. Therefore, the overall severity score ranged from 2 to 6. However, it was not possible to define a TTC value for conflict types C6 and C7 because these maneuvers do not occupy the same path and speed data was not available for calculating the TTC value. Therefore conflicts types C6 and C7 were not assigned TTC scores.

Hence, two approaches were selected for comparing the severity between movements. First, all the conflicts generated by RTUT and DLT movements were compared based on the ROC scores, and second, a comparison of those conflicts with both TTC and ROC scores was performed for the two movements. The frequency and cumulative frequency of the severity for each conflict type with ROC and TTC scores were calculated and illustrated in Figures 4.13 through 4.19.

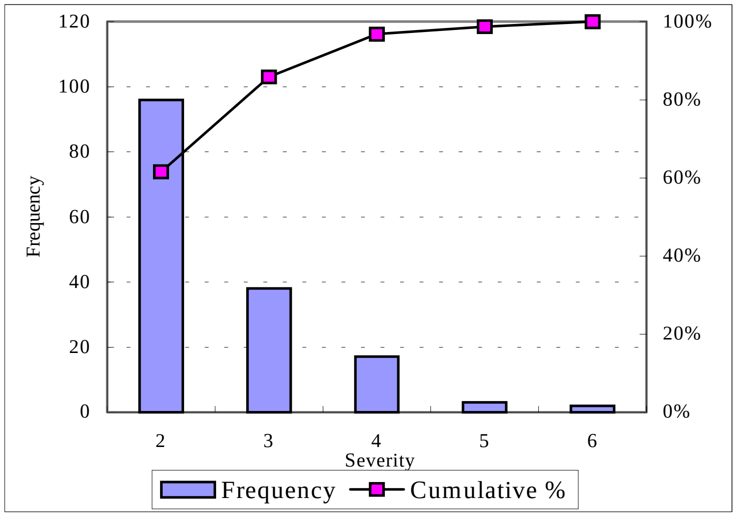

Figure 4.13 Distribution of Severity, Conflict Type C1.

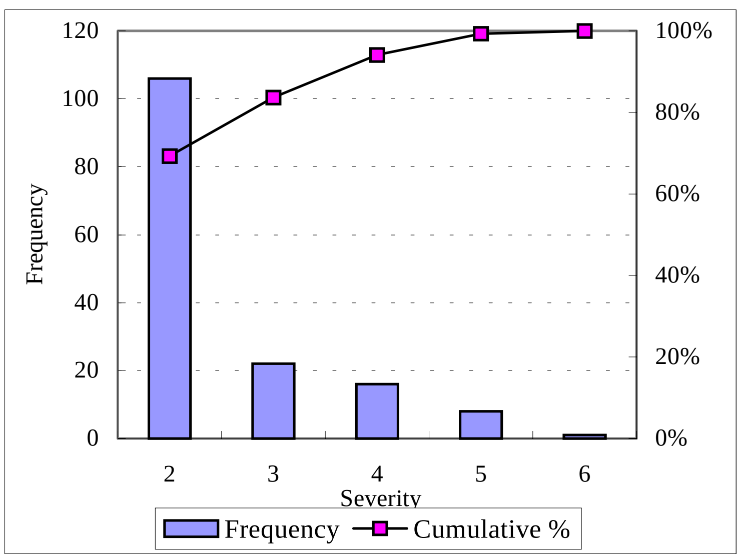

Figure 4.14 Distribution of Severity, Conflict Type C2.

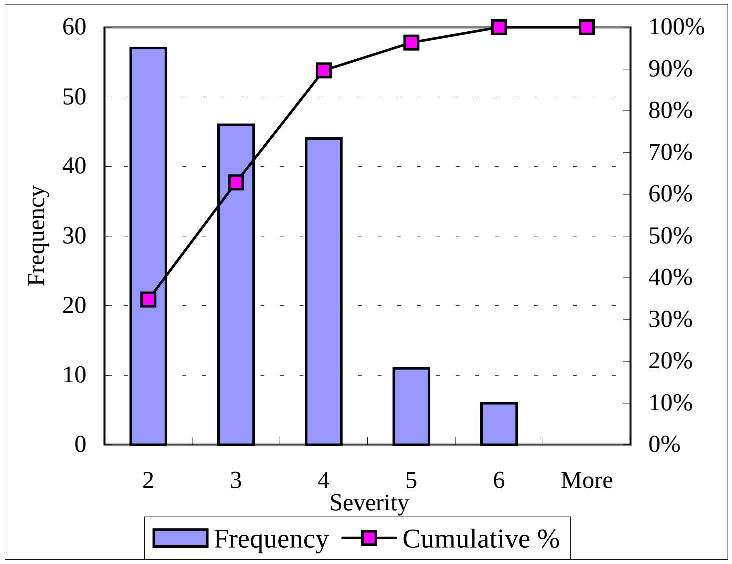

Figure 4.15 Distribution of Severity, Conflict Type C3.

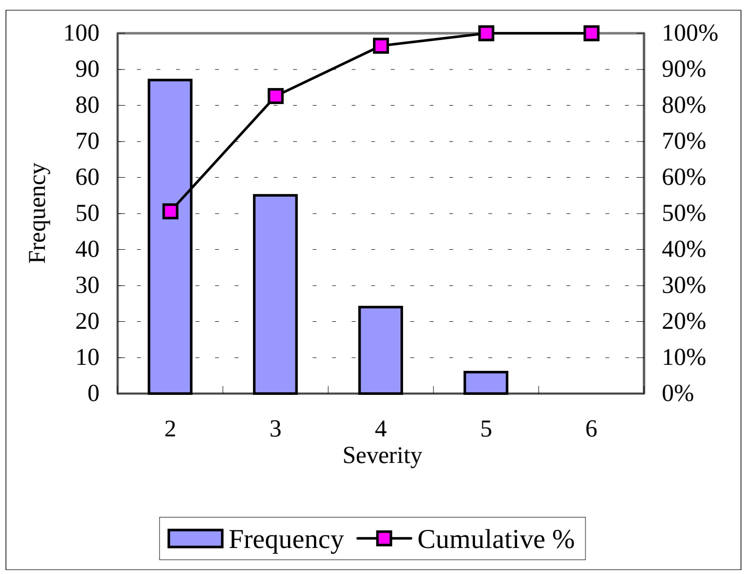

Figure 4.16 Distribution of Severity, Conflict Type C4.

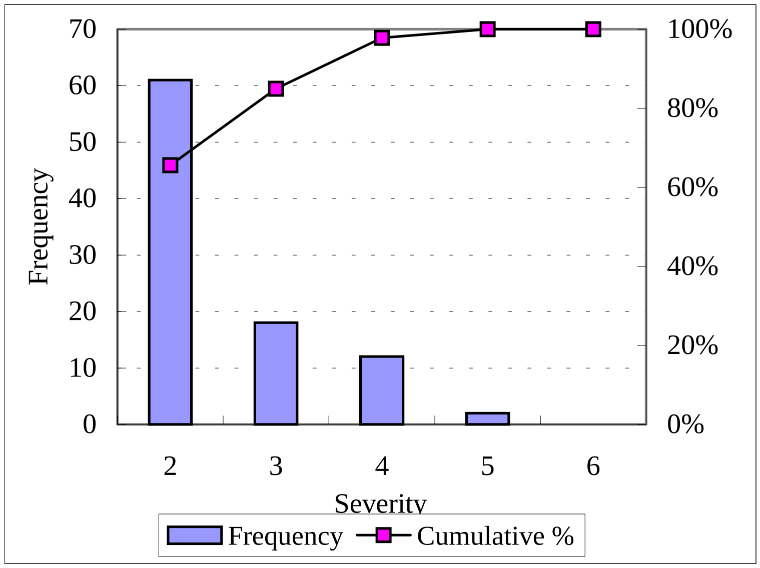

Figure 4.17 Distribution of Severity, Conflict Type C2U-T.

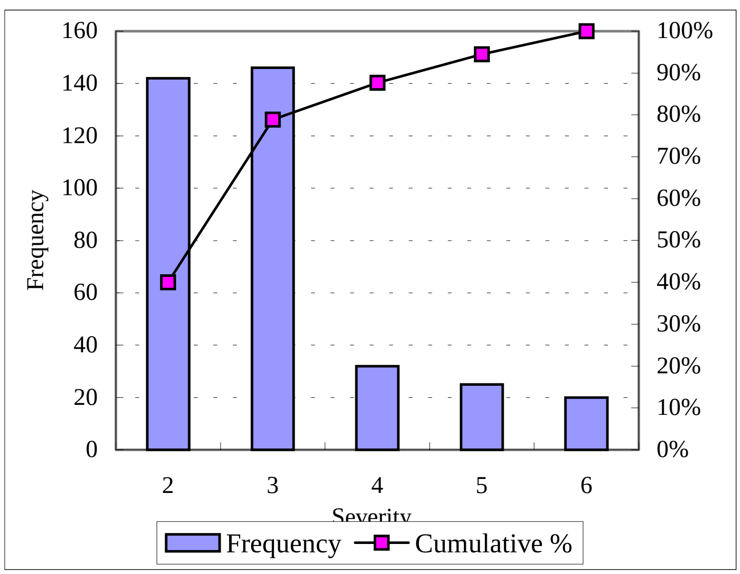

Figure 4.18 Distribution of Severity, Conflict Type C5.

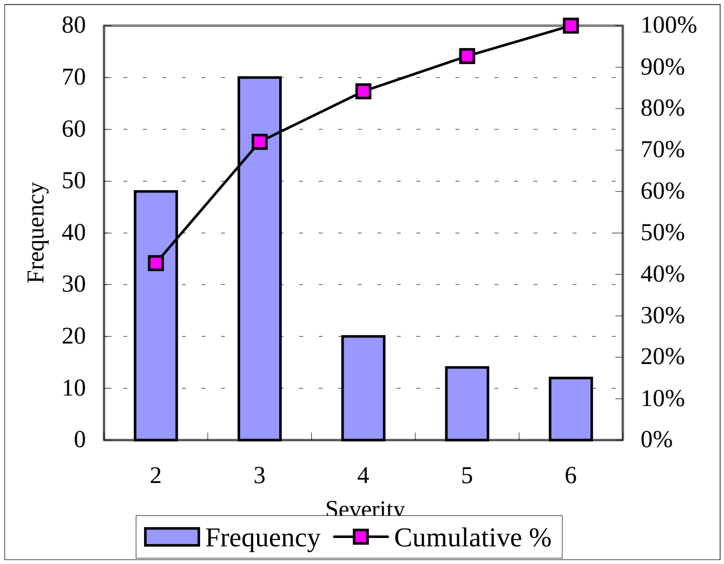

Figure 4.19 Distribution of Severity, Conflict Type C8.

Based on these figures, the 15th, 50th, 85th, and 95th percentile values were calculated for all conflicts with both ROC and TTC scores. These values are given in Table 4.8.

Table 4.8 Severity Percentiles by Movement and Conflict Type.

Movement	Conflict Type	Severity			
		15th	50th	85th	95th
RTUT	C1	2.0	2.0	3.0	4.0
	C2	2.0	2.0	4.0	5.0
	C3	2.0	3.0	4.0	5.0
	C4	2.0	2.0	4.0	4.0
	C2U-T	2.0	2.0	3.2	4.0
DLT	C5	2.0	3.0	4.0	6.0
	C8	2.0	3.0	5.0	6.0

Table 4.8 suggests that fifty percent of the time, conflict type C3 could be considered riskier than other conflicts involved in a RTUT maneuver. However, eighty five percent of the time conflict type C1 and C2U-T are considered to have a medium severity

whereas the other conflict types have a severity score of 4, which might be interpreted as medium. Regarding the severity of conflicts associated with DLT movements the results are also interesting. Fifty percent of the time the severity of conflict types C5 and C8 will be considered as low-medium severity, whereas eighty five percent of the time conflict type C8 will be riskier than conflict type C5. This may be due to the lack of visibility for drivers waiting for a gap, and that they may get onto the major road by “trial and error”. When comparing the severity scores of RTUT and DLT movements, DLT conflicts seem to have a higher severity.

Figures 4.20 and 4.21 graphically illustrate the average severity values for both DLT and RTUT movements. Figure 47 illustrates the overall severity of conflicts based on ROC scores, while Figure 48 illustrates the overall severity of conflicts when both TTC and ROC scores are analyzed. Both Figure 47 and Figure 48 indicated that conflicts generated by RTUT movements have a lower severity than conflicts generated by DLT movements.

To determine if the severity of DLT conflicts was significantly different from the severity of RTUT movements, Analysis of Variance (ANOVA) tests were conducted. ANOVA tests were calculated by using Microsoft Excel’s Analysis of Data Tool. The null and alternative hypothesis, *Ho* and *Ha*, for the ANOVA tests were stated as:

> *Ho:* Severity of RTUT movements is not different from that of DLT movements.
> *Ha:* Severity of RTUT movements is different from that of DLT movements.

A 0.05 level of significance (α) was selected for the ANOVA test, and results are presented in Tables 4.9 and 4.10. Table 14 presents the results when RTUT and DLT maneuvers are compared based on the ROC score, while Table 15 presents the results of the test when both ROC and TTC scores are considered.

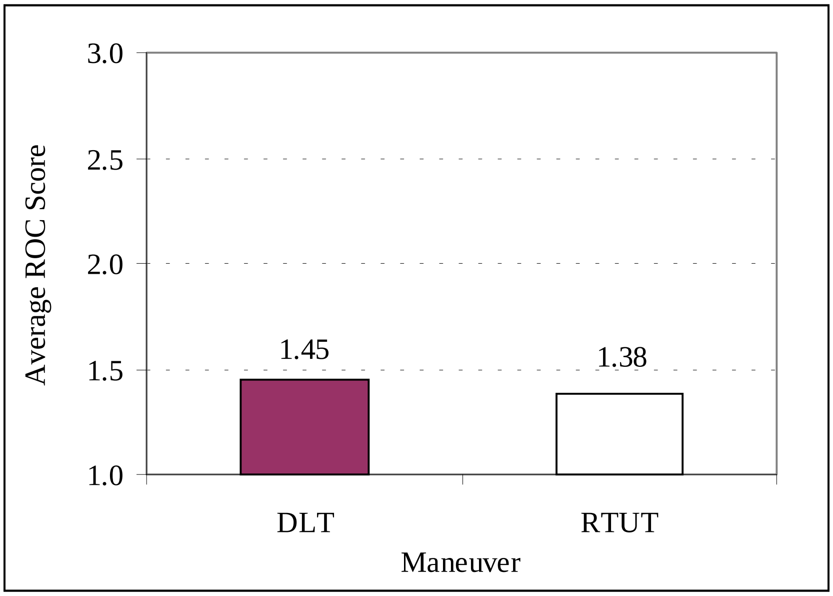

Figure 4.20 Comparison of Overall Severity of Conflicts Considering ROC Scores.

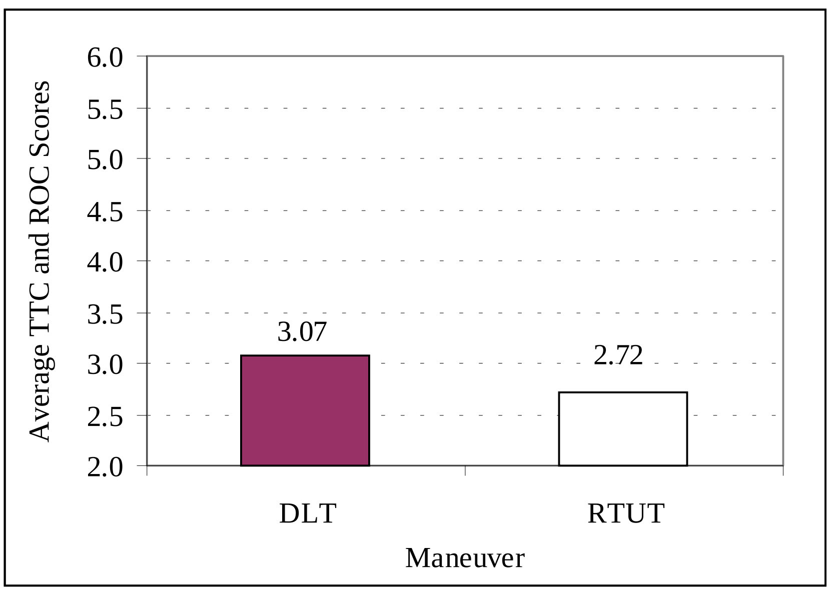

Figure 4.21 Comparison of Overall Severity of Conflicts Considering ROC and TTC Scores.

Table 4.9 ANOVA Test Results to Test Severity Differences Between RTUT and DLT Maneuvers Considering ROC Score Only.

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
RTUT Severity	738	1016	1.376694	0.286675
DLT Severity	902	1311	1.453437	0.40571

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.390546	1	2.390546	6.788409	0.009258	3.847134
Within Groups	576.8235	1638	0.352151			
Total	579.214	1639				

Table 4.10 ANOVA Test Results to Test Severity Differences Between RTUT and DLT Maneuvers Considering Both ROC and TTC Scores

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
RTUT Severity	738	2005	2.716802	0.906122
DLT Severity	529	1623	3.068053	1.294602

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	38.01631	1	38.01631	35.58679	3.1E-09	3.848811
Within Groups	1351.362	1265	1.06827			
Total	1389.378	1266				

The result of the ANOVA test on the severity of RTUT and DLT movements based on the ROC score indicated that the F value (6.79) at the 5% level of significance was larger than the critical F value (3.84). Thus, the null hypothesis of equal level of severity is rejected. The ANOVA test on the severity of those conflicts with both TTC and ROC scores indicated similar results. The F value (35.59) at the 5 percent level of significance was much larger than the critical F value (3.84), thus, the null hypothesis was rejected too. These results indicate that the level of severity of DLT conflicts compared to that of RTUT conflicts is higher and significant at a confidence level of 95 percent.

4.4. 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 the 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.

5. CASE STUDY: BEFORE AND AFTER COMPARISON

This chapter presents the results obtained by analyzing the conflict data at a site where the full median opening was converted to a directional median opening. A before and after comparison of average number of conflicts, conflict rates, and severity levels of conflicts at the site are presented.

5.1. Descriptive Analysis

The site located on U.S. 19 and 116th Avenue was the subject of a geometric improvement related to left-turn movements from the side street. Initially, the median was a full median opening that allowed vehicles from the local street (116th) to either turn left directly or to turn right and then make a U-turn at a median opening located 400 feet from the street in order to travel northbound. The median opening was approximately 120 feet in length, which allowed three or more vehicles to wait in the median storage area while impeding the movement of other vehicles. The median opening was closed and converted into a directional median opening, so that vehicles departing from the side street could only turn to the right. A detailed analysis of the conflicts observed at this site was conducted because this site allows the possibility to examine and evaluate the implications of changing a full median opening to a directional median opening in the frame of a before and after study, without the influence of the site variables.

A total of 371 conflicts were recorded during the before period and a total of 327 conflicts during the after period. After the average number of conflicts was calculated the number of daily conflicts was calculated. Figures 5.1 and 5.2 present the daily number of conflicts for before and after time periods. As it was expected the number of conflicts due to RTUT maneuvers would increase since more vehicles perform such maneuvers. However, the total average numbers of daily conflicts during before and after time periods were 238 and 140 conflicts respectively, which was a reduction of 41 percent. This suggests that even if the number of conflicts due to RTUT movements has increased the application of RTUT instead of DLT maneuver indeed reduced the total number of conflicts. Although the comparison of Figures 5.1 and 5.2 provide important information regarding the reduction in the daily number of conflicts, it is much more meaningful to use conflict rates for evaluating the changes because they can take into account the factors such as corresponding traffic volumes that generate conflicts, as well as its effect during different time periods.

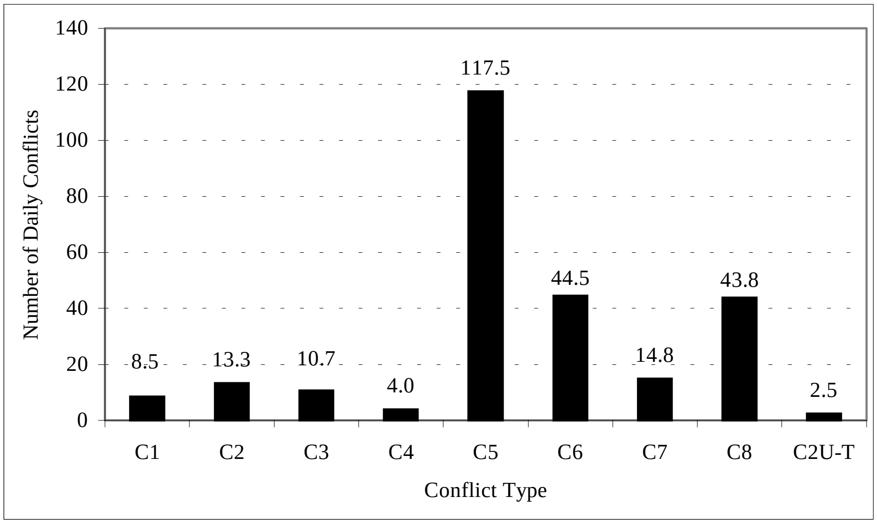

Figure 5.1 Number of Daily Conflicts by Type Before the Improvement.

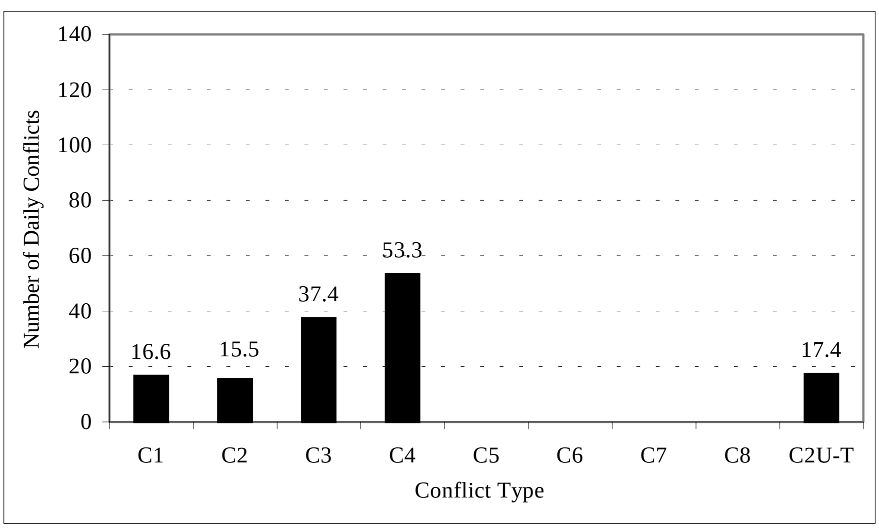

Figure 5.2 Number of Daily Conflicts by Type After the Improvement

5.2. Conflict Rates

5.2.1. Conflicts per Hour

Table 5.1 presents conflict rates corresponding to the vehicles turning to the left during the before period. As expected the largest number of conflicts was due to the left turn movement itself (conflict type C5), followed by conflicts due to the interaction between left turn in and left turn out movements (conflict type C6), conflict types C8 and C7. These findings suggested that the influence of left turn in vehicles on vehicles coming out of the driveway was important. Number of conflicts per hour during peak and non-peak periods were 23.92 and 19.00 respectively whereas the mean total conflict rate was 21.46. The data on DLT conflicts are not available for the after period as that movement was prohibited.

Table 5.1 Number of Conflicts per Hour for DLT Movements during Before Period

	Time Period	Conflict Type				Total
		C5	C6	C7	C8	(conflicts/hour)
Before	Non Peak Rate	10.60	4.60	1.00	2.80	19.00
	Peak Conflict Rate	10.13	5.38	1.46	6.96	23.92
	Total Conflict Rate	10.36	4.99	1.23	4.88	21.46

Table 5.2 and Figures 5.3 through 5.5 present conflict rates for each type of conflict by time period and the total for the before and after periods. Values given in Table 5.2 indicate that conflicts caused specifically by the U-turn maneuver drastically increased after the improvement due to the increase in the RTUT volume. Total average number of RTUT conflicts per hour during before and after time periods were 3.72 and 12.60 respectively. However, it was interesting to note that the conflict rate during peak hours was about 9 percent lower than that of non-peak hours for the after period. This may be because U-turn conflicts (C4), and merging conflicts (C1) may decrease due to drivers

being more careful in selecting gaps when the through traffic volume on the arterial is high.

Table 5.2 Number of Conflicts per Hour for RTUT Movements during Before and After Periods

	Time Period	Conflict Type					Total (conflicts/hour)
		C1	C2	C3	C4	C2U-T	
Before	Non-Peak Rate	0.80	0.80	0.80	0.40	0.40	3.20
	Peak Conflict Rate	1.13	1.34	1.17	0.50	0.13	4.25
	Total Conflict Rate	0.96	1.07	0.98	0.45	0.26	3.72
After	Non-Peak Rate	1.67	1.26	3.39	5.35	1.48	13.14
	Peak Conflict Rate	1.23	1.67	3.42	3.98	1.77	12.06
	Total Conflict Rate	1.45	1.47	3.4	4.66	1.62	12.60

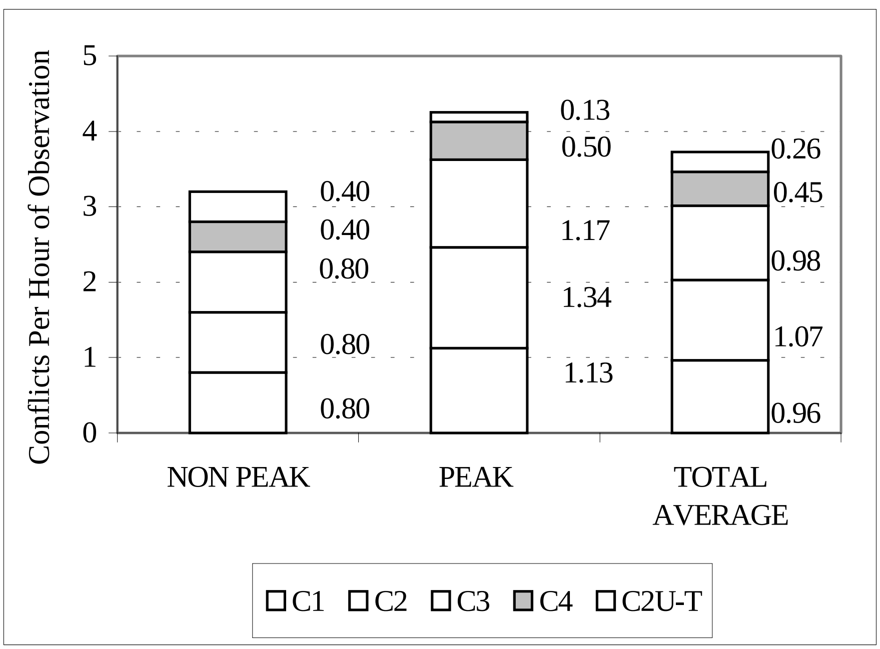

Figure 5.3 Conflicts per Hour of Observation by Time Period - RTUT Movements Before Improvements.

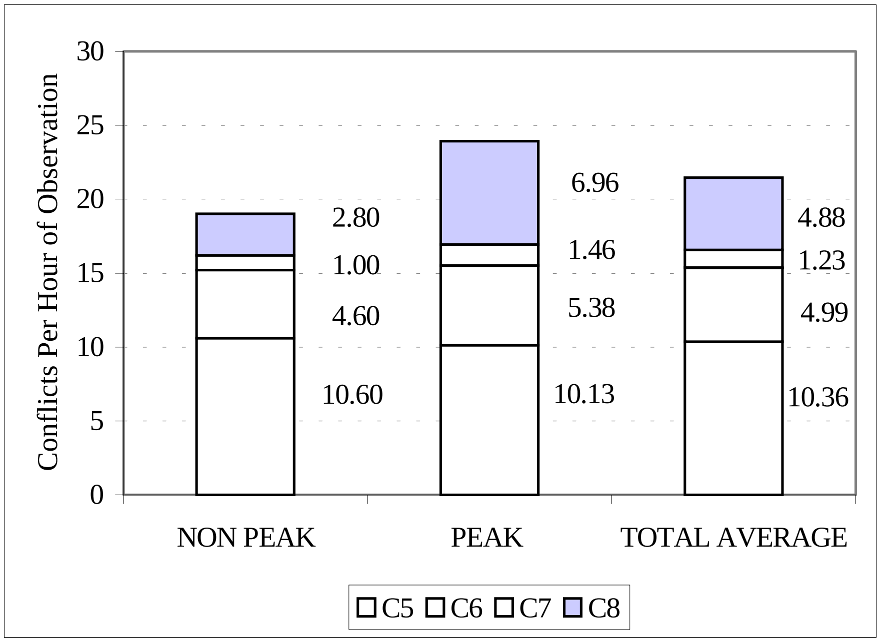

Figure 5.4 Conflicts per Hour of Observation by Time Period - DLT Movements Before Improvements.

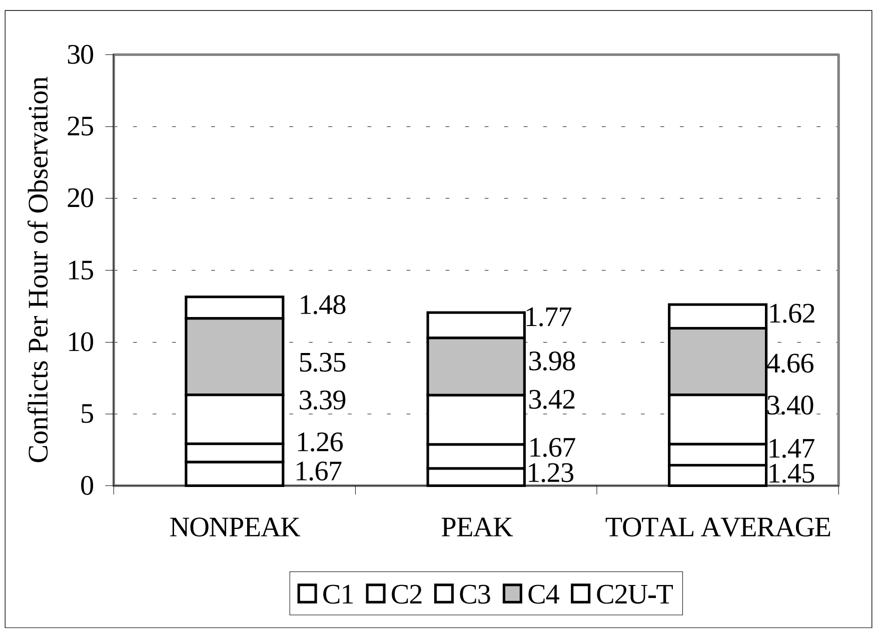

Figure 5.5 Conflicts per Hour of Observation by Time Period - RTUT Movements After Improvements.

The comparison between the total number of conflicts per hour during before and after time periods and the reduction in the number of conflicts given in Table 5.3 suggested an important fact. The number of conflicts per hour was reduced by 41.3 percent when the DLT technique was prohibited by forcing such drivers to make RTUT.

Table 5.3 Comparison of Total Number of Conflicts per Hour During Before and After Time Periods

Number of Conflicts/Hour During the Before Period			Number of Conflicts/Hour During the After Period			Reduction %
Due to DLT	Due to RTUT	Total	Due to DLT	Due to RTUT	Total	(Before-After) x 100 / Before
Peak Period						
23.92	3.20	27.12	0	13.14	13.14	51.5 %
Non Peak Period						
19.00	4.25	23.25	0	12.06	12.06	48.1 %
Total Average						
21.46	3.72	25.18	0	12.60	12.60	49.9 %

5.2.2. Conflicts per Thousand Involved Vehicles

The average number of conflicts and traffic volumes during different times of the day were calculated for both before and after periods, which were the basis for the development of conflict rates. The conflict rate was calculated by dividing the average number of conflicts by the square root of the product of the volumes involved since it had a better correlation, based on findings of several previous studies *(17, 26, 36).* Two different methods were used for calculating these values. The first method involved the calculation of the conflict rate for every conflict type for each hour of the day. Then, for each type of conflict the number of conflicts was divided by the square root of the product of the major road and the maneuver volume. After the rate was calculated for every conflict type, the rate for a determined hour was calculated as the summation of the conflict rate for the types of conflicts involved. In other words, the hourly rate for conflicts associated with DLT movements was calculated as the summation of the rates of conflicts types C5, C6, C7, and C8, whereas the rate for conflicts related to RTUT movements corresponded to the summation of conflicts types C1, C2, C3, C4, and C2U-T. Then, an average value of all the hours was calculated and taken as the final conflict rate. Table 5.4 presents the conflict rate for each and every hour and the average value for before and after time periods estimated by using this method.

The second method consisted of obtaining the total average number of conflicts that occurred during an eleven-hour day for each conflict. Then, these values were divided by the square root of the product of the total volume on the arterial and the total volume of the maneuver in the day. Table 5.5 presents the values calculated by using this method. Since values obtained by using both methods were very similar to each other, it was assumed that both methods could be applied for calculating the number of conflicts per thousand involved vehicles.

Table 5.4 Average Number of Conflicts per Thousand Involved Vehicles, Method 1

Time	Conflicts Per Thousand Involved Vehicles			
	Before			After
	DLT	RTUT	Both Types	RTUT (3)
7:00 - 8:00	103.45	15.26	118.71	26.82
8:00 - 9:00	71.73	26.21	97.94	27.85
9:00 - 10:00	40.80	13.88	54.68	37.08
10:00 - 11:00	35.11	20.20	55.31	53.63
11:00 - 12:00	32.38	18.62	51.00	61.96
12:00 - 13:00	51.70	21.94	73.64	27.48
13:00 - 14:00	57.05	5.38	62.43	32.82
14:00 - 15:00	43.90	11.72	55.62	44.86
15:00 - 16:00	37.85	34.37	72.22	34.49
16:00 - 17:00	51.35	26.19	77.54	46.28
17:00 - 18:00	51.91	13.68	65.59	28.04
AVERAGE	52.47	18.86	71.33	38.30

Table 5.5 Average Number of Conflicts per Thousand Involved Vehicles, Method 2.

Conflict Type	Conflicts Per Thousand Involved Vehicles			
	Before			After
	DLT	RTUT	Both Types	RTUT
C1	N/A	4.15	4.15	4.35
C2	N/A	6.51	6.51	4.07
C3	N/A	5.20	5.20	9.82
C4	N/A	1.95	1.95	14.00
C5	26.15	N/A	26.15	N/A
C6	9.90	N/A	9.90	N/A
C7	3.30	N/A	3.30	N/A
C8	9.76	N/A	9.76	N/A
C2U-T	N/A	1.22	1.22	4.57
TOTAL	49.11	19.02	68.13	36.80

To determine if the conflict rates of before and after periods are significantly different, a *t*-test was conducted using the values in Table 5.4. This statistical test could be performed even if the underlying distribution does not follow the Normal Distribution. Nevertheless, if a *t*-test is going to be conducted, it must first be verified whether the variances of the samples are significantly different as the type of *t*-test depends on the variances of the two populations. This was evaluated by applying the variance ratio test, known as the *F* test. The null and alternative hypotheses in this test were:

H_0: The variances of the two samples belong to the same population
$H_{a:}$ Null hypothesis is not true.

A level of significance selected for this test was 5 percent. Table 5.6 presents the results of the *F* test, based on the values given in Table 5.4 for before and after time periods. Results shown in Table 5.6 indicate that at 95 percent confidence level the F statistic for the test was 3.050 whereas the critical F statistic was 2.978. The p-value for the test was 0.046 indicating that the null hypothesis cannot be accepted at a 5 percent level of significance or the difference between variances was significant. Therefore the *t*-test was conducted to compare the two mean conflict rates considering unequal variances. If the calculated *t* value at a given level of significance is greater than the critical *t*, the null hypothesis is rejected and it could be concluded that the difference is significant, otherwise the difference is not significant. The null and alternative hypothesis for the *t*-test were as follows:

H_0: The conflict rates during before and after periods are equal.

H_a: The null hypothesis is not true.

Table 5.6 Results of the F Test to Check the Variances of Conflict Rates During Before and After Periods

F-Test Two-Sample for Variances		
Parameter	Before	After
Mean	71.33	38.30
Variance	430.38	141.09
Observations	11	11
F	3.050	
P(F<=f) one-tail	0.046	
F Critical one-tail	2.978	

Table 5.7 presents the results of the *t*-test for comparing the mean conflict rates during before and after time periods, assuming unequal variances. Since the value of the calculated *t* statistic (4.58) was much greater than the critical *t* statistic with 5 percent level of significance (1.75), the null hypothesis was rejected and the differences between the conflict rates could be considered significantly different at the 95 percent confidence level. Therefore, prohibition of DLT through the median closure where such movements were replaced by RTUT reduced the number of conflicts as well as conflict rates thereby improving safety.

Table 5.7 Results of the *t*-test Comparing Differences Between Conflict Rates During Before and After Periods

t-Test: Two-Sample Assuming Unequal Variances		
Parameter	Before	After
Mean	71.33	38.30
Variance	430.38	141.09
Observations	11	11
t Stat	4.583	
P(T<=t) one-tail	0.0001	
t Critical one-tail	1.745	

5.3. Severity Analysis

As previously mentioned, the severity of each conflict was obtained and analyzed using two approaches for before and after periods. Table 5.8 and 5.9 present the 15th, 50th, 85th, and 95th percentile severity levels calculated for all conflicts by using the index that used both ROC and TTC scores for before and after periods. They suggest that 50% of the time conflicts related to RTUT maneuvers were more severe than those related to DLT maneuvers. However, a different outcome can be expected 85% of the time because the severity of DLT conflicts seems to be higher than that of RTUT conflicts

Table 5.8 Percentiles of Severity for DLT and RTUT Maneuvers for Before Period

Movement	Conflict	Percentile			
RTUT	Type	15th	50th	85th	95th
	C1	2.0	2.0	4.0	4.0
	C2	2.0	2.0	3.0	4.2
	C3	2.0	3.0	4.0	4.0
	C4	2.8	3.5	4.3	4.8
	C2U-T	4.0	4.0	4.0	4.0
DLT	C5	2.0	3.0	4.0	5.5
	C8	2.0	3.0	5.0	6.0

Table 5.9 Percentiles of Severity for RTUT Maneuvers for After Period

Movement	Conflict	Percentile			
RTUT	Type	15th	50th	85th	95th
	C1	2.0	2.0	3.0	4.0
	C2	2.0	2.0	2.8	4.0
	C3	2.0	3.0	4.0	5.0
	C4	2.0	3.0	4.0	4.0
	C2U-T	2.0	2.0	3.0	4.0

Table 5.9 presents severity values for the conflicts that occurred after the improvement was done. In general it seems that the severity of RTUT conflicts is the same as that of the before period. Nevertheless, the severity of conflict types C3 (lane change conflict) increased to a medium-high level and the severity of U-turns decreased to a medium level.

Analysis of Variance (ANOVA) tests were conducted in order to determine if there was a significant difference in the severity of conflicts before and after the improvement. The null and alternative hypothesis, *Ho* and *Ha*, for the ANOVA tests were:

Ho: Severity levels of RTUT movements is similar to that of DLT movements
Ha: Severity levels of RTUT movements is different from that of DLT movements

A 0.05 level of significance was selected for the ANOVA test, and the results are presented in Table 5.10. The result of the ANOVA test on the severity of RTUT and DLT movements based on the ROC score indicates that the F value (25.83) was larger than the critical F value (3.85) at the 5 percent level of significance. Thus, the difference is highly significant and null hypothesis of equal level of severity is rejected. In other words the severity levels of DLT and RTUT are different when considering the ROC score and therefore by replacing DLT by RTUT the seriousness of conflicts could be reduced according to the findings at this site.

Table 5.10 ANOVA Test Results to Test Severity Differences Between RTUT and DLT Movements Considering ROC Score

SUMMARY						
Groups			*Count*	*Sum*	*Average*	*Variance*
DLT			313	497	1.58786	0.44819
RTUT			327	441	1.34862	0.26459
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9.153	1	9.153	25.8286	4.9E-07	3.85607
Within Groups	226.091	638	0.35437			
Total	235.244	639				

Table 5.11 presents results of the ANOVA test on the severity of DLT and RTUT conflicts by using both TTC and ROC scores. The F value for the test (89.09) at the 5 percent level of significance was much larger than the critical F value (3.85) and also, the p statistic was much lower than the selected 0.05 level. Thus, the null hypothesis of equal severity levels was rejected and the difference could be considered to be significant. These results indicate that the level of severity of RTUT conflicts as compared to that of DLT conflicts was lower when considering both ROC and TTC scores, which was significant at a confidence level of 95 percent.

According to these findings it could be seen that irrespective of the type of index used in evaluating the severity, whether it is ROC or ROC and TTC, severities of DLT conflicts were much higher than those of RTUT conflicts at the site where the before and after study was conducted. This is an indication that the seriousness of traffic conflicts occurring at a site could be reduced by replacing DLT with RTUT.

Table 5.11 ANOVA Test Results to Test Severity Differences Between RTUT and DLT Movements by Considering both ROC and TTC Scores, After Improvement

SUMMARY						
Groups			Count	Sum	Average	Variance
DLT			224	408	1.82143	0.43434
RTUT			327	441	1.34862	0.26459
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	29.7172	1	29.7172	89.0961	1.1E-19	3.85845
Within Groups	183.114	549	0.33354			
Total	212.831	550				

It was also interesting to test if there was a significant difference in the severity of RTUT conflicts before and after the improvement. This was because it could be expected that after the geometric change was done more vehicles would make a RTUT movement making it possible to change the severities. An ANOVA test was performed at the 5 percent level of significance to test whether there was a significant difference and results are given in Table 5.12. For this case, the F statistic for the test was 0.79 and the critical F statistic was 3.86. Also, the p-value for the test was 0.37 which is much larger than the 0.05 level selected for the test. Therefore it could be concluded that the differences in the severity levels of RTUT conflicts before and after the geometric change were not significant at the 95 percent confidence level.

5.4. Summary

A before and after comparison was performed to evaluate the safety effects of closing a full median opening, thereby forcing drivers from the side street to make right turns. Results indicated that the number of conflicts and the conflict rates were significantly reduced by implementing the RTUT technique. Moreover, the severity of the conflicts generated by RTUT movements was lower than that of conflicts generated by DLT movements.

Table 5.12 ANOVA Test Results to Test Severity Differences for RTUT Conflicts Before and After Improvement

SUMMARY						
Groups			Count	Sum	Average	Variance
RTUT Before Improvement			58	82	1.41379	0.24682
RTUT After Improvement			327	441	1.34862	0.26459
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.20922	1	0.20922	0.79871	0.37204	3.86585
Within Groups	100.326	383	0.26195			
Total	100.535	384				

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6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Transportation engineers and planners have used access management to improve operational and safety conditions of the road system. One of the objectives of access management is to reduce the number of conflict points. In particular, access management actions often seek to minimize direct left turn (DLT) movements from driveways as they generate many conflict points and increase the potential for traffic crashes. Medians are used to replace DLT movements with right turn movements followed by U-turns (RTUT).

This report is one of three reports that evaluated the safety and traffic operational effects of direct left turns versus right turns followed by U-turns from driveways or side streets. This research focused on evaluating the safety of RTUT and DLT movements using traffic conflicts. A total of ten sites were selected for conducting the investigation. However, two sites on four-lane roads were disregarded because they did not meet the sample size required for evaluating these maneuvers. The average number of daily traffic conflicts was calculated for each site and evaluated by conflict type. Nine types of conflicts were selected for this study, five of them corresponded to conflicts generated by RTUT movements while the rest corresponded to DLT movements. It was found that the most common conflict type generated by DLT movements was the left-turn maneuver itself (Conflict type C5), followed by conflicts between left-turn and left-turn in movements (Conflict type C6), then by conflicts of left turn vehicles departing from the median storage area, and finally, the conflicts between DLT and left turning vehicles into a driveway located on the opposite side of the driveway studied. These values suggested that left turn in volume had an important impact on vehicles making a DLT movement from a driveway.

The conflict distribution for RTUT movements was shared almost equally by all the conflict types. Most of the conflicts occurred because of the right turn maneuver (Conflict type C1), followed very closely by changing lanes (Conflict type C3), then by conflicts created by slow U-turn vehicles on the major road (Conflict type C2U-T) and finally a right turning vehicle slow on the same direction.

A comparison of the total average number of conflicts per hour of the two maneuvers showed that RTUT conflicts had a conflict rate 34 percent lower than that of DLT movements. When the data were analyzed by time period, that is peak and non-peak hours, the RTUT conflicts were slightly higher during non-peak hours; whereas DLT conflicts where higher during peak hours. The number of conflicts related to DLT movements was 29 percent higher than that of RTUT movements, while during non-peak hours it was 75 percent higher. In addition, a comparison of the number of conflicts per thousand involved vehicles was performed. Results indicated that RTUT movements generated 38 percent fewer conflicts per thousand vehicles than DLT movements.

The severity of conflicts was analyzed by means of subjective and objective methods. Two types of analyses showed that the severity of conflicts caused by RTUT movements was lower than that of DLT conflicts at the 95 percent confidence level.

The before and after comparison showed that there was a significant difference between the conflict rates of RTUT and DLT maneuvers. Additionally, the analysis of the severity of RTUT conflicts and DLT conflicts showed a significant difference at the 95 percent confidence level. On the other hand, a comparison of the severity of conflicts caused by RTUT maneuvers before and after the improvement showed that the difference between them was not significant.

6.2 Conclusions

The analysis of RTUT and DLT from driveways using traffic conflicts resulted in several conclusions. These are presented in the following paragraphs.

A comparison of the number of conflicts per hour of RTUT and DLT movements suggested that RTUT movements indeed generate fewer conflicts per hour. In addition, when the effect of traffic volume was accounted into the comparison by means of a conflict rate, results also showed the effectiveness of RTUT movements in reducing the number of conflicts on six-lane roads.

Not only did RTUT movements reduce the number of conflicts, but also the severity of them. Findings of this study indicated that RTUT conflicts had an overall severity significantly lower than that of DLT movements.

Finally, based on the before and after comparison, replacing the DLT with RTUT is an appropriate method for improving the safety of road users.

6.3 Recommendations

It would be useful to continue this research to evaluate the RTUT technique on four lane roads. Also, more relationships between conflicts generated by RTUT movements and other geometric characteristics should be studied such as weaving length and median width.

This study is limited to locations where the U-turn is made at median openings. It could be extended to evaluate the U-turns at signalized intersections and to address the effect of signal timing on RTUT movements. Better signal timing may allow more vehicles to turn right and make a U-turn while preserving the operational and safety characteristics of the road system.

Also it is advisable to check the crash history of the site where the case study was performed. In addition, another traffic conflict study should be performed again at that site, as this would help to evaluate if there has been a significant change in the number of traffic conflicts generated by vehicles making RTUT movements.

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