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

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

(VOLUME I 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 crash data analysis are documented in this report. Two other reports document the conflict and operational analyses.

Two sets of sites, each corresponding to the left-turn median treatments, were selected from seven counties distributed throughout Florida. Sample sizes for direct left turn and right turn followed by U-turn sites were 133 and 125, respectively. All sites were located on major urban or suburban arterial roadways with raised medians and high through traffic volumes, sufficient driveway egress volumes, sufficient median widths, posted speed limits greater than 40 mph, no parking along the main road, moderate arterial segment lengths, and U-turns at directional or full median openings. Crash data corresponding to these sites were extracted from the Florida Traffic Crash Database and combined with the site characteristics. Cross section comparison of the crash history of sites with direct left turns and right turns followed by U-turns was carried out by considering both number of crashes and crash rates. Average number of crashes for sites with direct left turns and right turns followed by U-turns were 16.35 and 13.90, respectively. When crashes per million vehicle miles were considered the respective numbers were 3.2 and 2.63. Models were also developed to represent the distributions of number of crashes and crash rates, which were then compared between the two left-turn treatments. Model estimated 85th percentile crash rates for direct left turns and right turns followed by U-turns were 4.5 and 3.9 respectively.

The results indicated that safety was greater for right turns followed by U-turns than for direct left turns.

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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 continuous 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 for evaluate the traffic operational and safety impacts of these techniques.

1.2 Outline of the Report

This report on the crash data analysis of direct left turns versus U-turns consists of five chapters. Chapter 1 provides an overview of the research project, including a brief description of past research in this subject area. Chapter 2 summarizes the procedures used in this project, including a detailed description of the proposed methodology and the basic concepts such as safety rates, safety severity, and roadway classification. Chapter 3 presents the field data collection process, which involved seven counties (Hillsborough County, Pinellas County, Pasco County, Hernando County, Dade County, Palm Beach County, and Broward County) within three FDOT Districts (District 4, District 6, and

District 7). It also addresses the investigation of selected sites, traffic crash databases, and other data sources. Chapter 4 presents the results of the analysis and the impacts of these results on roadway safety. It consists of three sub-topics: data analysis, statistical analysis, and conclusions. The final chapter, Chapter 5, provides the summary and conclusions of this study.

1.3 Selection of the Study Technique

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, technique selected for analysis was the "right turn followed by U-turn as an alternative to direct left turn from a driveway or side street". The main reasons for selecting this technique were:

1) Little documentation of quantified results and conclusions regarding this technique is available although it has been identified as one of the important issues in access management.
2) It is feasible to quantify the safety and operational impacts of this technique. Both crash data and potential sites for case studies are available.
3) The results of the traffic operational and safety impacts of this technique can be applied to assist agencies like FDOT with decisions relative to closing a median opening.

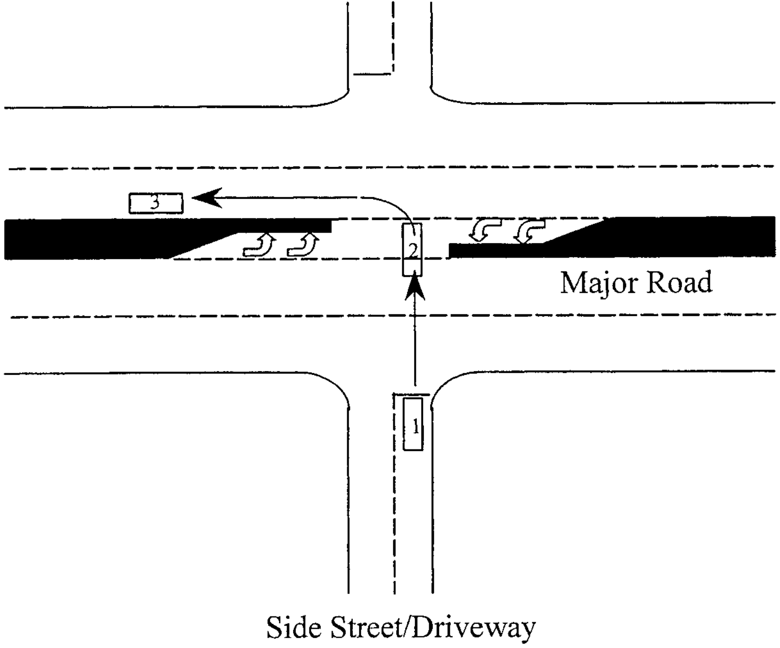
1.4 The Selected Research Subject

A number of studies about raised medians on urban or suburban arterials have been performed during the past two decades. Parker determined that the number of traffic signals per mile had a significant impact on crashes for raised median sections *(7)*. Squires and Parsonson determined that the average daily traffic and number of traffic signals per mile were related to crash frequency *(8)*. It has also been found that in high volume and heavy roadside development conditions, left turn maneuvers contribute to a disproportionately high percentage of crashes *(9)*.

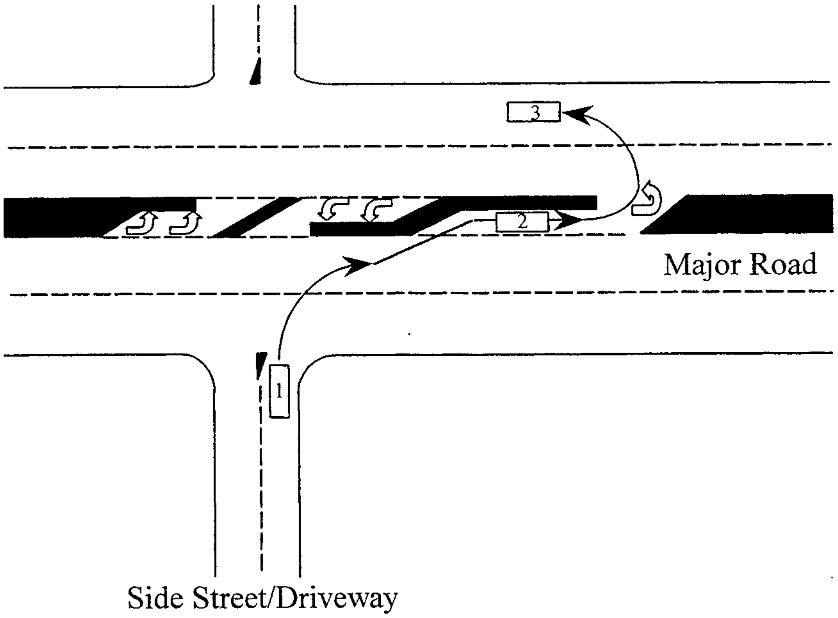
Directional median openings can restrict the left-turn egress movements from side streets or driveways onto major arterials and provide an auxiliary lane to separate left turning vehicles on major arterials from the traffic stream. Directional median openings for left turns/U-turns provide an effective way of eliminating direct left turns from driveways thereby protecting vehicles waiting to enter a driveway. Thus, directional median opening installation has been perceived by traffic engineers as an effective method of increasing vehicular safety and capacity on urban and suburban arterials. In addition, mid-block directional median openings are provided in advance of downstream-signalized intersections to accommodate U-turns. However, some individuals have expressed concerns that U-turns are generally unsafe. This research is an important step toward evaluating the safety of U-turns to address public concerns.

Figure 1.1 illustrates the movement patterns of the two alternatives analyzed in this study: (a) direct left turn, and (b) right turn followed by U-turn. In the first alternative, drivers can make direct left turns from side streets or driveways onto divided arterials through full median openings. In the second alternative, left-turn egress movements are prohibited by replacing a full median opening either with a directional median opening, which only allows left-turn ingress from arterial roads or by blocking the left-turn with a nontraversable median. Drivers would have to make right turns onto the arterial roads first and then make U-turns at downstream-unsignalized U-turn bays, or signalized intersections, if they intend to make a left turn to the arterial. The locations where the U-turn has been facilitated at signalized intersections were not considered in this study since their characteristics are expected to be different due to the signal timing involvement.

The basic concept behind forcing the U-turn is that the number of conflict points is significantly reduced, from 16 major conflicts at full median opening locations to four major conflicts at directional median openings (see Figure 1.2). This reduction in the number of major conflict points indicates a potential to improve safety. It is important to determine whether this theoretical reduction in the conflict points has actually resulted in a reduced number of crashes.

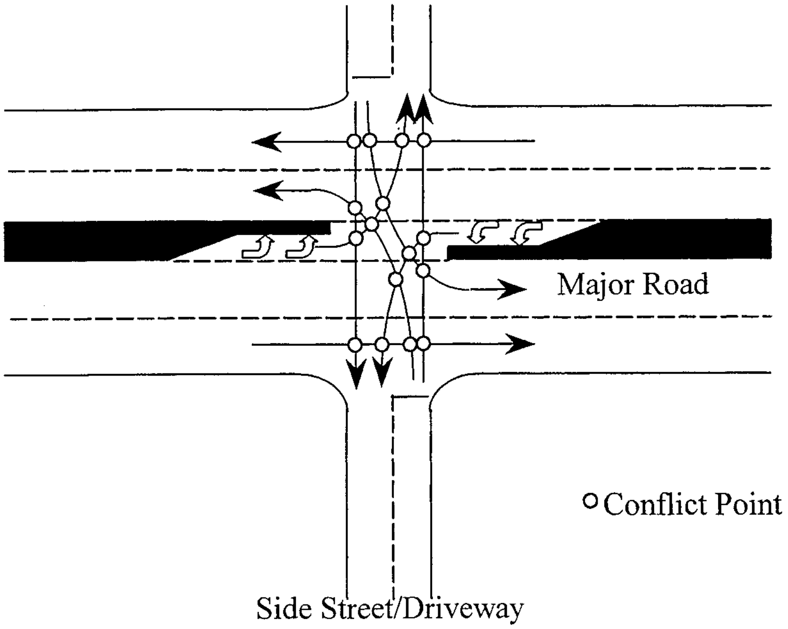


(a) Direct Left Turn Egress Movements

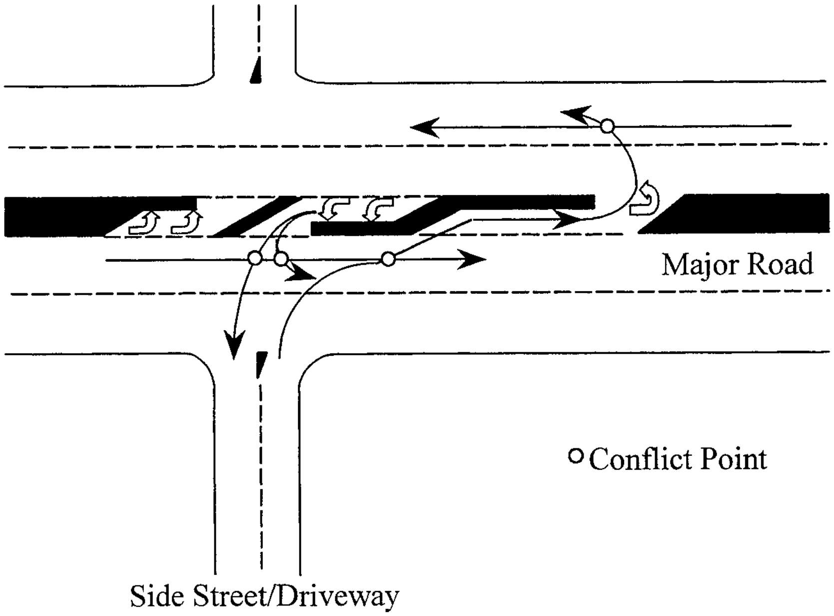


(b) Right Turn Followed by U-turn Movements

Figure 1.1 Right Turns Followed by U-turns as an Alternative to Direct Left Turns



(a) Direct Left Turns Movements (16 Conflicts)



(b) Right Turn Followed by U-turn Movements (4 Conflicts)

Figure 1.2 Crossing and Turning Conflict Points of Direct Left Turns and Right Turns Followed by U-turns

As an example, the directional right-turn followed by U-turn median design was the focus of a task force report on U.S. 19. This major thoroughfare is considered to be one of the most dangerous roadways in Florida *(10)*. Pinellas County requested $5 million for additional directional median opening projects, and substantial citizen and official testimony documented approval for this new technique and "strongly suggested increased mid-block U-turns." At the U.S. 19 task force meeting on June 5, 2000, FDOT indicated that it was still awaiting the final results on the impacts to intersections that would have to handle the U-turns. Pending this analysis, FDOT plans to make the decisions regarding the implementation of the suggested measure.

1.5 Research Objectives

This project was aimed at developing a quantitative and qualitative evaluation of the operational and safety impacts of two different egress options from driveways or side streets, a direct left turn (DLT), and a right turn followed by U-turn (RTUT). Safety situations at the locations with two alternative left turn treatments are quantified and evaluated through the crash experiences at relevant locations. The results provide a basis to judge the safety implications of U-turns, as compared to direct left turns. Results of the safety impact evaluation (crash data analysis and conflict analysis,) would be an important component of the decision making process that should be taken into consideration together with the operational implications.

1.6 Research Approach

This research included a two-stage approach to achieve the objectives and to provide practical results for the selected access management technique. The first stage was to summarize possible safety evaluation methods, to identify the feasibility of the potential applications, and to develop performance plans. The second stage of this research involved selecting sample sites, developing the inventory of traffic and geometric information, collecting field data to calibrate the evaluation methodology, analyzing crash database, and applying statistical theories.

The work program of this two-stage approach is described below.

1) Stage One:

Task 1: The study team reviewed existing studies and current efforts nationwide and locally relevant to the selected access management technique, and evaluated potential research methodologies.

Task 2: The most appropriate research methodology was determined for the selected technique by evaluating current state and local rules, regulations, and practices for access management. A quantitative and comprehensive procedure was developed for the safety analysis using traffic crash data.

2) Stage Two:

Task 3: This task involved preparing the data collection plan, field surveying for site selection, evaluating and studying related traffic and geometric variables, investigation of the data sources to gather necessary data, gathering and extracting data from both primary and secondary resources identified as most appropriate, and reviewing and verifying the crash data records.

Task 4: This task involved conducting statistical analysis, developing the models to represent the crash experiences at the selected sites, discussion of the research findings, recommendations, conclusions, and areas for future study.

1.7 Past Studies

The National Cooperative Highway Research Program (NCHRP) - Report 420 clarified the basic concept of the U-turn alternative, summarized the safety and operational experiences in current practice, and presented application guidelines *(11)*. The report indicated that directional median openings experienced 50% and 40% reductions in major and minor conflicts respectively compared with full median openings.

NCHRP Report 420 presented several guidelines and considerations in the design of medians and mentioned the advantages of the application of indirect left turns as an alternative to direct left turns. These considerations included the following *(11)*:

1) A median of at least 25 feet wide is necessary to help ensure that a crossing or left-turning vehicle, stopped in the median perpendicular to the through traffic lane, will not extend beyond the median.
2) A narrow full median opening allows only one left-turning vehicle at a time to advance into the median opening.
3) A wide median opening allows multiple vehicles to stop in the opening. However, this may create a confusing and conflicting pattern of movements, angle stopping in the median opening, and some drivers' vision obstructed by other vehicles.
4) As the intensity of land development increases, the traffic demand to access abutting properties also increases. Thus, left-turn traffic at closely spaced full median openings can "interlock". At the same time, a U-turn median opening can serve several access drives and eliminate the need for direct left-turn exit movements from driveways. Also, when U-turns are provided as an alternative to left turns, mid-block median opening width may be made with less than 30-ft width.

The main advantages of direct left turns when compared with right turns/U-turns include:

1) Under low major street traffic volumes, direct left turns could result in less delay and travel time.
2) Vehicles would travel comparatively shorter distances and therefore may consume less gas.

The disadvantages associated with direct left turns are:

1) Under high major street traffic volume conditions, traffic delay and travel time may greatly increase.
2) Direct left turns involve obtaining gaps in two directions at a time when the median is too narrow to safely store a vehicle. This might result in more conflicts due to the fact that vehicles making direct left turns have to yield to all other movements at a full median opening.
3) Capacity of the direct left-turn movements is seriously limited by the median storage and geometry.

4) Large trucks may block the through traffic lane when they are making direct left turns.

The main advantages of right turns followed by U-turns as compared with direct left turns include:

1) Under moderate to high traffic volumes, travel and delay could be less.
2) The capacity of a U-turn movement at the median opening is much higher than the capacity of a direct left turn movement.
3) Right turns followed by U-turns have fewer conflicts than direct left turns.
4) A left turn lane at a median opening for facilitating directional left-turn and U-turn movements can be designed to store several vehicles because storage is parallel to the through traffic lanes.
5) A single directional median opening can be used to accommodate traffic from several upstream driveways, especially when the driveway spacing is very close. Thus, when volumes are from moderate to heavy, the right turns followed by U-turns may demonstrate more advantages than direct left turns.

Several studies have addressed the safety of different median treatments. Bonneson and McCoy discussed the operational and safety effects of three alternative median treatments; raised-curb medians, continuous two-way left-turn lanes (TWLTL), and undivided cross sections; where 189 street segments, which experienced 6,391 mid-signal crashes during a 3-year period, were used to develop a regression equation that predicted the expected annual crash frequency for a street segment based on its length, average daily travel demand, median treatment, adjacent land use, and total access point density *(12)*. Benekohal utilized two methods, a crash prediction model and a before-and-after study, to assess the estimated reduction in the number of crashes on two-lane rural highways *(13)*. The two approaches were evaluated using crash data for two years before and two years after the improvements for 51 sites with a total length of 349 miles. The reduction in the total number of crashes was computed using a before-and-after study with control sites and a separate linear model.

A case study regarding right turns followed by U-turns as an alternative to direct left turns in South Florida on Oakland Park Boulevard, Ft. Lauderdale, and U.S. 1, Stuart, was performed by Vargas and Gautam *(14)*. Numerous closely spaced median openings were closed and directional median openings were installed in advance of signals. Vargas and Gautam believed that this design was more practical on six-lane roadways with a median width of 15.5 foot or less, as narrow medians are unable to shield a passenger vehicle making a left turn movement from a side street or driveway. A before-&-after study with a control section was conducted to compare the crash frequency, crash rates, and to identify crash trends or patterns. Two sites, SR 816 (Oakland Park Blvd) & SR 5 (U.S.1- Federal Highway), were selected for implementation of the median changes and one site, SR 838 (Sunrise Blvd) was selected for the control section because of the availability of the data. All of these sites were included in the FDOT high crash section list.

A Poisson distribution was assumed for the crash frequency distribution in the statistical analysis of the Vargas and Gautam study at a 95% confidence level. It was found that the overall number of crashes experienced a statistically significant reduction of 22%; angle and rear-end crashes experienced a statistically significant reductions of 35.7% and 21.7% respectively. All other types of crashes were also reduced, but these findings were not statistically significant. It was also found that the total crashes experienced a statistically significant reduction of 22% on Oakland Park Boulevard; the property-damage-only crash rate and the injury crash rate were reduced by 25% and 28%, respectively. Vargas and Gautam concluded that the median concept could reduce turning volume, increase operating speeds, and improve safety.

In addition, the FDOT had conducted a public awareness survey among the business community, residents, and customers affected by the project. Forty-eight percent of the adjacent residents favored the changes yet 63% reported being inconvenienced; 58% of truckers favored access control and only 25% felt they were inconvenienced. The business community was not severely impacted and the majority expressed their support for the implementation of this kind of access control projects. In response to the question, "Do you feel you are unduly inconvenienced in making your deliveries as a result of the current median design?" one half of the truck drivers' answered 'no'. For a similar question, 62.5% businessmen indicated that the median changes did not impinge on their business profits. Not only was the methodology of the study reasonable, but also the public awareness survey was useful in addressing public concerns. However, the study involved only two arterials located in South Florida. Additional research with more sample sites and documentation on methodology and data analysis was needed.

2. METHODOLOGY

This chapter presents a detailed description of the methodology used in this study, namely, the cross-sectional comparison method, statistical methods, and how they were applied under the given situation.

2.1 General

The flow chart shown in Figure 2.1 presents the basic steps of the methodology used in this study.

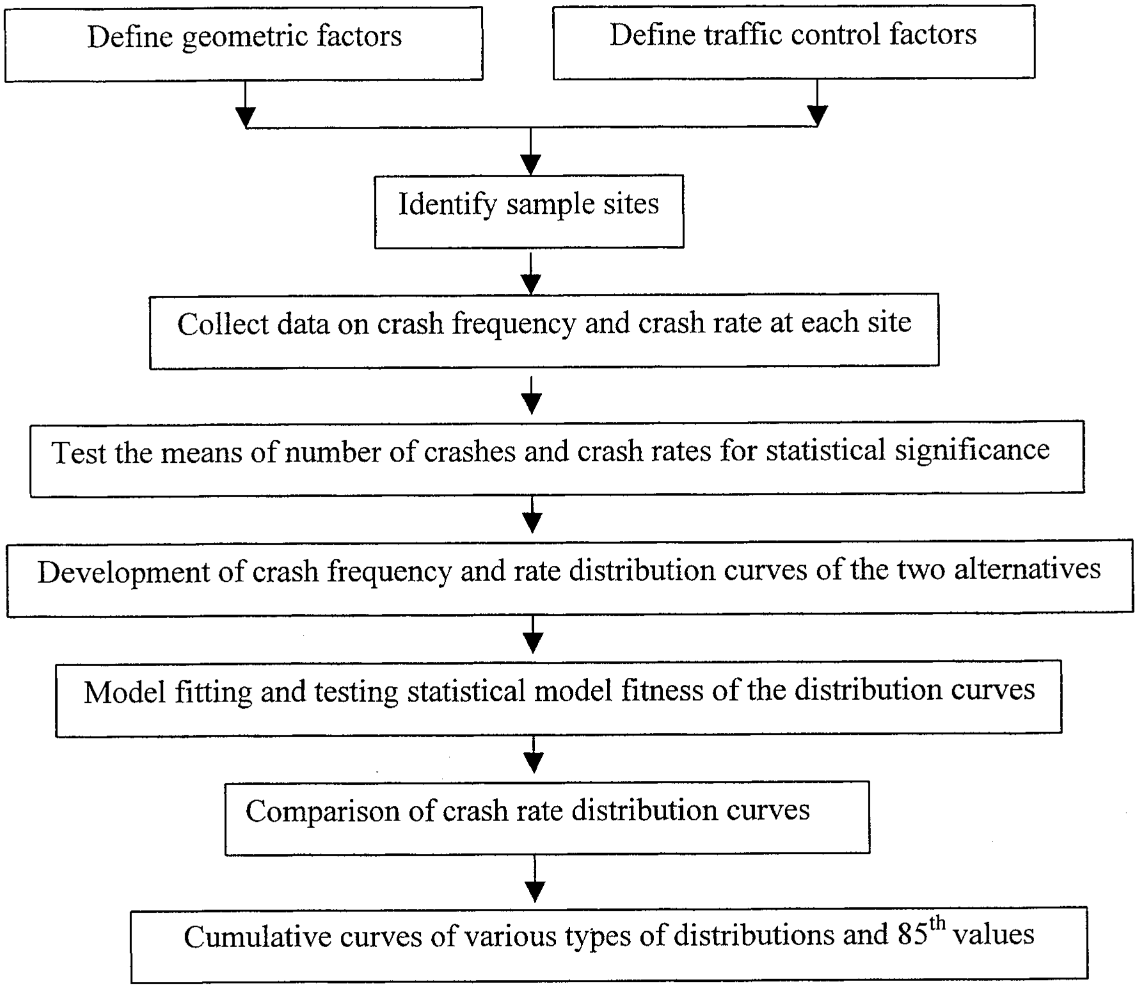


Figure 2.1 Basic Steps of the Crash Data Analysis Procedure

2.2 Cross-sectional Comparison

One of the reasonable and practically applicable methods of judging the safety effects of highway improvements is the cross-sectional comparison. This approach involves comparing the crash frequencies or crash rates of a group of sites with an access management treatment, with that of a group of untreated sites. In other words, this method compares the safety of two different groups of sites with and without the treatment under investigation. However, since the differences in other characteristics at the two sets of sites might influence the outcome, it is necessary to select the sample sites carefully so that all sites have similar traffic, geometric, driver population, and land use characteristics. If these other conditions are reasonably similar, then crash histories of a set of sites with a given alternative could be compared and statistically tested with the crash histories of another set of sites with different alternatives.

In this study, cross-sectional comparison was employed for the purpose of comparing crash frequencies and crash rates of the direct left turn versus right turn U-turn alternatives. As shown in Figure 1.1, direct left turns could be made at the full median openings opposite the driveways or side streets. In the second category, directional median openings require drivers to make right turns followed by U-turns instead of direct left turns from driveways and side streets. A study of 258 sample sites, over 100 for each type of treatment, was conducted to compare the crash frequencies and crash rates for each alternative.

The average crash rate of direct left turns was compared with that of right turns followed by U-turns. The major assumption behind this comparison was that all other traffic and geometric characteristics remained the same during the study period. The significant geometric and access control factors considered in this study included segment length, average daily traffic, posted speed limit, and number of lanes. By comparing the crash frequencies and crash rates through statistical testing, conclusions could be reached regarding the relative safety of right-turn U-turn and direct left turn movements.

The cross-sectional method has been performed on a number of previous studies involving median alternatives or access designs *(15, 16, 17)*. It is believed by traffic engineers that as long as the most influential factors such as segment length, average daily traffic (ADT), speed, and driveway/side street density are well controlled, cross-sectional analysis would provide reliable results. Some of the previous studies that successfully used the cross-sectional method are as follows. Bonneson and McCoy used cross-sectional analysis to evaluate the median treatment selections for existing arterial streets *(6)*. Gattis used cross sectional analysis to compare delay and crashes on three roadway access designs in a small city *(15)*. Council and Stewart used cross-sectional analysis to quantify the safety effects of the conversion of rural two-lane roadways to four-lane roadway *(16)*. In all of these studies cross section analysis has provided satisfactory results.

2.3 Other Methods in Transportation Safety Analysis

2.3.1 Before-and-after Approach

Before-and-after comparison is another method used in transportation engineering studies for evaluating different alternatives. In such a study, the effect of a treatment is assessed by comparing crash frequencies and/or crash rates before and after the installation of the treatment. This approach assumes that there is no other change in the geometry or traffic characteristics of the roadway except the treatment under evaluation. Sometimes, a comparison group is involved in the before-and-after approach, which makes the changes in these other characteristics to be assumed equal across two sets of sites. The role of the comparison group is to account for the effects of factors other than the treatment.

Before-and-after experiments are attractive for statistical and practical reasons. However, a before-and-after study also has obvious drawbacks. Six drawbacks are listed and discussed in the "Manual of Transportation Engineering Studies" *(18)*. First, a before-and-after experiment may require a longer time between the decision to conduct an experiment and the achievement of a conclusion than other types of experiments. Second, before-and-after experiments are very difficult to design while treatments are being implemented or after treatments have been implemented. It is difficult to obtain data for the before period from routine sources at later stages. Third, units may not react instantaneously to a treatment. Drivers encountering a traffic control device soon after its placement, for example, may not know how to react and may exhibit unusual behaviors that bias any experiment data being collected. Fourth, units may react to the treatment in an unstable or random fashion. The fifth drawback refers to changes in measures of effectiveness (MOE) through the before and after periods caused by factors other than the treatment. The sixth drawback, maturation, refers to trends in MOE values over time.

Even though overcoming measures were presented, some of the drawbacks, especially the first and the second one, are not easy to overcome. Thus, an economically and practically applicable valid method, cross-sectional analysis, was utilized in this study due mainly to the limited project duration and unavailability of accurate data for the before period. Unlike a before-and-after study where an actual change has occurred, the cross-sectional analysis bases its results on differences between two sets of data within the same time period.

2.3.2 Crash Prediction Models

Crash prediction models are also used to estimate reduction in crashes resulting from highway improvements. This approach relates safety to site characteristics. The models use crash rate or crash frequency as the dependent variable together with various site characteristics for a large number of sites over an extended period of time. The modeling approach finds a relationship between crash frequency (or crash rate), traffic characteristics (such as volume and speed), and road geometry (such as segment length and lane width). The main advantage of the prediction method is that the models can be used for the evaluation of alternative highway improvement policies. One disadvantage of this approach, however, is that it does not take into account the effects of parameters that are not included in the model. Another disadvantage is that a regression model requires a large amount of sample sites and it is time consuming to collect information involved in the model. In addition, the factor evaluated in the study, that is the left turn median treatment, may not be significant in the final model when considered together with all the other parameters. Thus, in this research, cross-sectional analysis was applied to evaluate the safety situation of right turns followed by U-turns compared to direct left-turns from driveways and side streets.

2.4 Crash Types and Crash Severity

Usually, crash severity level is recorded for each and every police reported crash. Three major levels of crash severity were considered in this study: (1) property-damage-only (PDO), (2) injury, and (3) fatality. In a property-damage-only crash, only the vehicles or other properties are damaged but no one is hurt; in an injury crash, at least one person is lightly or heavily hurt because of the crash; in a fatality crash, at least one person is dead within 30 days after the crash.

A total of 13 crash types are grouped in the FDOT's traffic crash database. One of the most common types is the rear-end crash. This type of crash usually occurs when one vehicle is stopped or slowed down and another vehicle collides with the first vehicle in the 'rear end' of the vehicle. The severity of these crashes can range from minor to severe depending on the speed of the vehicle that hits the first vehicle. Rarely do these crashes end in a fatality.

Angle crashes are also common where one vehicle tries to cross the path perpendicular to another vehicle. Again, depending on the individual speeds of the vehicles involved, the severity of these crashes can range from minor to severe. This type of crash tends to be more severe than the rear end type of crash. Usually an angle collision results in at least one injury and it is more common for this type of crash to have fatalities.

Left-turn and right-turn crashes are similar to angle crashes except it is known that one vehicle is making a turn of some sort when they cross the path of the other vehicle. The severity levels of these crashes are very similar to that of angle crashes. Another type of crash is the sideswipe crash, where a vehicle collides with the side of another vehicle when it attempts to change lanes. Compared with the other types, this type of crash has a broader range of severity. However, unless a sideswipe crash happens at an extremely high speed, these crashes do not usually end in fatalities or severe injuries. In a head on collision, two vehicles running in opposite directions collide in front of each other. This type of crash usually happens on undivided roadways with narrow lane widths and has the highest potential to result in a fatality. There are many other types of crashes that can occur but those minor crash types are not listed in detail.

2.5 Crash Frequency and Crash Rate

Both crash frequencies and crash rates are calculated in this study. The definitions of these two items are based upon the "Manual of Transportation Engineering Studies"*(18)*.

2.5.1 Crash Frequency

Crash frequency is the actual number of police reported crashes that has occurred at a certain location, which could either be a roadway section or an intersection. By ranking the number of reported crashes, safety analysts can identify crash-prone locations. The primary virtues of using crash frequency are that it is simple and it makes intuitive sense. The number of crashes at each of the sites considered in the study was obtained by using the Florida Traffic Crash Database. The distribution curve of crash frequency could provide a direct comparison of the two alternatives and the results are easily understood by the general public.

The average number of crashes, which is the arithmetic mean of number of crashes, was calculated for each treatment based on the selected sets of sites. In statistical inference, the mean is generally the most efficient estimator of the central tendency of the population characteristics being studied. The average number of crashes for treatment j is defined as:

$$\overline{N}_j = \frac{\sum_{i=1}^{Y} N_i}{Y}$$

where,

$\overline{N}_j$ = average number of crashes for sites with treatment j,

N_i = number of crashes at site i,

Y = total number of sites with treatment j.

The reduction in the average number of crashes from one left turn treatment to another (i.e. from direct left turns to right-turns followed by U-turns) was computed by comparing the results.

$$R = \frac{N_{DLT} - N_{RTUT}}{N_{DLT}} \text{x} 100$$

where,

R = percent reduction in the average number of crashes,

N_{DLT} = average number of crashes for direct left turns,

N_{RTUT} = average number of crashes for right turns followed by U-turns.

The median represents the middle value in a series of measurements that have been ranked in order of magnitude and divides the measurements into two equal parts. In this study, the measurement is either one of the two types of movements. When the number of observations is odd, the median is the middle value in the list of ranked measurements. For an even number of ranked measurements, the median is the arithmetic mean of the two middle values. The median is also used as a useful average measure because it is less affected by extreme values than is the arithmetic mean.

2.5.2 Crash Rate

Crash-prone locations are also identified by crash rates, which are defined as crashes per million vehicle miles traveled for segments or crashes per million entering vehicles for spots. Crash rates are used as a criterion for identifying high crash locations and statistical tests could be applied to determine whether the crash rate "is significantly different" compared with a predetermined crash rate for segments or locations with similar characteristics. This study used crash rates for a segment and the formula is:

$$\text{Crash Rate for the Segment} = \frac{1{,}000{,}000 \times A}{365 \times T \times V \times L}$$

where,

A = number of police reported crashes,

T = time frame of the analysis (years),
V = average daily traffic,
L = length of the segment (miles).

The main concern over the use of crash rates is trying to reduce the influence of traffic volume on the result and thus to improve the accuracy of the safety analysis. Traffic volume, or the average daily traffic volume (ADT), is a variable that has previously been suggested as possibly being able to affect crash rates, although its exact effect on crash rate is not yet well understood *(19)*. It is believed that the crash frequency tends to increase as the through way traffic volume (or ADT) goes up even though there are many others factors affecting the situation. In this study, the corresponding ADT for each site was obtained according to the date of the crash. In other words, the time period for the volume data matches the time period of the crash data being analyzed. The average of crash rates, which is the arithmetic mean of crash rates, was calculated for each left turn treatment. The average crash rate for treatment j is defined as:

$$\overline{C}_j = \frac{\sum_{i=1}^{Y} C_i}{Y}$$

where,

$\overline{C}_j$ = average crash rate for sites with treatment j,
C_i = crash rate for site i,
X = total number of sites with treatment j.

The reduction in average crash rate from one treatment to another, for example, from direct left turns to right-turns followed by U-turns, R, was computed by comparing the results:

$$R = \frac{C_{DLT} - C_{RTUT}}{C_{DLT}} \text{x} 100$$

where,

R = percent reduction in the average crash rate,
C_{DLT} = average crash rate for direct left turns,
C_{RTUT} = average crash rate for right turns followed by U-turns.

In traffic safety studies, safety ratio is another parameter to indicate whether a segment of highway contains an abnormal amount of crashes. An unusually (high) crash segment or spot is determined by using the following formula:

$$SafetyRatio = \frac{Actual\ Crash\ Rate}{Critical\ Crash\ Rate} \geq 1$$

The critical crash rate is a function of the segment length, traffic volume, and the average crash rate for the category of highway being tested. Only these segments or spots, which had a safety ratio greater than or equal to 1.0, are considered as high crash locations. Although the safety ratio is a useful index to compare safety effects, the value is not always available. In this research, segments selected had comparable characteristics, which means that their safety ratios could be expected or assumed to be similar. Thus, it was unnecessary to utilize crash ratio in this study.

2.6 The Test of Hypotheses on the Equality of Two Means

The test of "hypothesis on the equality of two means" was used to test whether the reductions in crash rates (or number of crashes) from one movement to another movement was significantly different, for example from direct left turns to right turns followed by U-turns *(20)*. It is assumed that there are two populations of interest, say X_1 and X_2, where X_1 has an unknown mean μ_1 and known variance σ_1^2, and that X_2 has an unknown mean μ_2 and known variance σ_2^2. The process is to test whether the two populations have the same mean μ_1 and μ_2. The statement H_0: $\mu_1 = \mu_2$ is called the null hypothesis and the statement H_1: $\mu_1 \neq \mu_2$ is called the alternative hypothesis or:

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

The test procedure is based on the fact that the difference in sample means of the two populations of interest, $\overline{X}_1 - \overline{X}_2$, will fit the normal distribution of:

$$\overline{X}_1 - \overline{X}_2 \sim N\left(\mu_1 - \mu_2, \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2} \right)$$

If the null hypothesis H$_0$: $\mu_1 = \mu_2$ is true, the test statistic Z_0 will follow the N (0,1) distribution:

$$Z_0 = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

Therefore, the procedure for testing H$_0$ is to calculate the test statistic Z_0 in the equation above and reject the null hypothesis if:

$$Z_0 > Z_{a/2} \text{ or } Z_0 < -Z_{a/2}$$

where α is the level of significance for the test.

If the sample sizes are sufficiently large enough (n_1 and n_2 >=30), these procedures are approximately valid regardless of whether or not the underlying population fits the Normal Distribution. If the variance, σ^2, is unknown, it can be replaced by the square of the standard deviation, which is:

$$S^2 \cong \frac{1}{n} \sum_1^n \left(X_i - \overline{X}\right)^2$$

where,

n = sample size,

$\overline{X}$ = mean of the sample,

X_i = value of the ith observation.

2.7 Statistical Model Fitness of Crash Number (or Crash Rate) Distribution

In this study, the crash-rate distribution and distribution of number of crashes were plotted for each type of treatment. The Chi-square goodness-of-fit test was used to test the hypothesis whether the crash rates follow a particular standard probability distribution *(20)*. The test procedure requires a set of randomly chosen samples of size n from the population X, whose probability density function is unknown. These n observations are then plotted into a frequency histogram of *k* class intervals. The Chi-square test is briefly described below.

Let O_i represent the observed frequency in the i^{th} class interval. The expected frequency in the i^{th} class interval, denoted E_i, can be calculated from the assumed probability distribution. The test statistic, χ_0^2, is:

$$\chi_0^2 = \sum_{i=1}^{k} \frac{O_i - E_i}{E_i}$$

It can be shown that χ_0^2 approximately follows the Chi-square distribution with *k-p-1* degrees of freedom, where p represents the number of parameters of the hypothesized distribution estimated by sample statistics. This approximation improves as *n* increases. The null hypothesis H_0, which X conforms to the hypothesized distribution, would be rejected if $\chi_0^2 > \chi_{\alpha,k-p-1}^2$; otherwise, the null hypothesis should be accepted.

2.8 Statistical Distribution Models

Several statistical distribution models were tested to determine which one the crash rate distribution (or distribution of number of crashes) had the best fit. The Poisson distribution and Log-normal distribution, which best fit distributions for the number of crashes and crash rate respectively, are discussed in this section.

2.8.1 Poisson Distribution

One of the most useful discrete distributions is the Poisson distribution. The Poisson distribution may be developed in two ways, and both are instructive as they indicate the circumstances where this distribution may be expected to apply in practice. In defining the Poisson process, we initially consider a collection of arbitrary, time-oriented occurrences, often called "arrivals" or "births". The random variable of interest, say X_t, is the number of arrivals that occur on the interval [0, t]. The range space is $R_{X_t} = \{0,1,2,...\}$. In developing the distribution of X_t, it is necessary to make some assumptions, the plausibility of which is supported by considerable empirical evidence. The first assumption is that the number of arrivals during non-overlapping time intervals are independent random variables. Second, we make the assumption that there exists a positive quantity λ such that for any small time interval, Δt, the relative postulates are satisfied. The parameter λ is sometimes called the mean arrival rate or mean occurrence rate. For fixed t where c = λt, the Poisson distribution is

$$P(x) = \frac{n!}{x!(n-x)!} p^x (1-p)^{n-x} \quad : \quad x = 0, 1, 2, \ldots$$

$$= 0 \quad : \quad \text{Otherwise}$$

The mean of the Poisson distribution is c and the variance is also c, which is c = λt.

2.8.2 Log-normal Distribution

The definition of the Log-normal distribution is described here as it is closely related to the crash data analysis conducted in this study. The Log-normal distribution is the continuous probability distribution of a random variable whose logarithm follows the normal distribution. The random variable x has the range space of $R_x = \{x : 0 < x < \infty\}$ and $y = \ln x$, is normally distributed with two parameters, mean μ_γ and variance σ_y^2. The density function of x, say $f(x)$, is defined as:

$$f(x) = \frac{1}{x\sigma_y\sqrt{2\pi}} e^{-\frac{1}{2}\left[\frac{\ln x - \mu_y}{\sigma_y}\right]^2}$$

The mean $E(x)$ and the variance $V(x)$ of the log-normal distribution are:

$$E(x) = e^{\mu_y + \frac{1}{2}\sigma_y^2}$$

and

$$V(x) = e^{2\mu_y + \sigma_y^2}\left(e^{\sigma_y^2} - 1\right)$$

3. DATA COLLECTION

The purpose of this chapter is to describe the process of site selection and data collection performed in this research. This chapter addresses criteria to define an arterial segment or a segment length, the FDOT coding system for identifying roadways, and the procedures for gathering relevant crash data and creating a specific crash database for the research.

3.1 Criteria for Arterial Segment Definition

This research study was intended to concentrate on urban or suburban major arterials with large through traffic volumes. The following criteria were used to define an arterial segment, as related to the study objectives:

1) Major urban or suburban arterial roadways with 4 lanes, 6 lanes, or more and with raised medians,
2) Large through traffic volume with key commercial or residential developments,
3) Active driveways or side streets with sufficiently high driveway egress volumes,
4) Sufficient median widths approximately ranging from 25 to 40 feet,
5) Posted speed limit between 40 and 55 mph on the major roadway,
6) Direct access from abutting properties,
7) No angle curb or parallel parking along the main road,
8) Moderate arterial segment lengths ranging from 0.07 to 0.25 miles, and
9) U-turn provided at directional or full median openings, and not at signalized intersections.

Following these criteria ensured that the candidate list of field study sites did not involve low-volume roadways, two-lane roadways, rural highways, expressways, roads through small towns, and low-speed collector streets. Rural highways were initially considered to be included in this study. However, during the field site selection process it was difficult to find active access points with sufficient driveway volumes; so rural roadway situations were not included.

3.2 Segment Length

Crash rates (crashes per million vehicle miles traveled) were computed by dividing the number of crashes that have occurred on a section per year by the segment length and the average daily traffic volume. The segment length affects the magnitude of the crash rate and different segment lengths may lead to different conclusions in crash rate comparison of the two alternative left-turn treatments.

Resende and Benekohal analyzed the influence of segment lengths on crash rates and showed that it influenced the geometric variables used in crash predictions for rural interstate highways and rural two-lane highways *(21)*. To get reliable crash models, they presented that the rates should be computed based on segment lengths of 0.5 miles or longer. However, Resende and Benekohal's study involved rural highways, where the geometric, land use, and traffic conditions were considerably different from the study sites of this project, which were located on arterials in highly populated urban or suburban areas. Thus, the suggested value, 0.5 mile or longer was not considered as appropriate for used as the criteria for obtaining the section length in this study. Resende and Benekohal did agree that their study didn't imply that short sections should be deleted from the data sets. It showed that crash rates computed from too short and too long sections could lead to misrepresentation of real conditions. Attention must be paid in collecting and investigating the most standardized number of sections as possible, so groups of similar section lengths could be created.

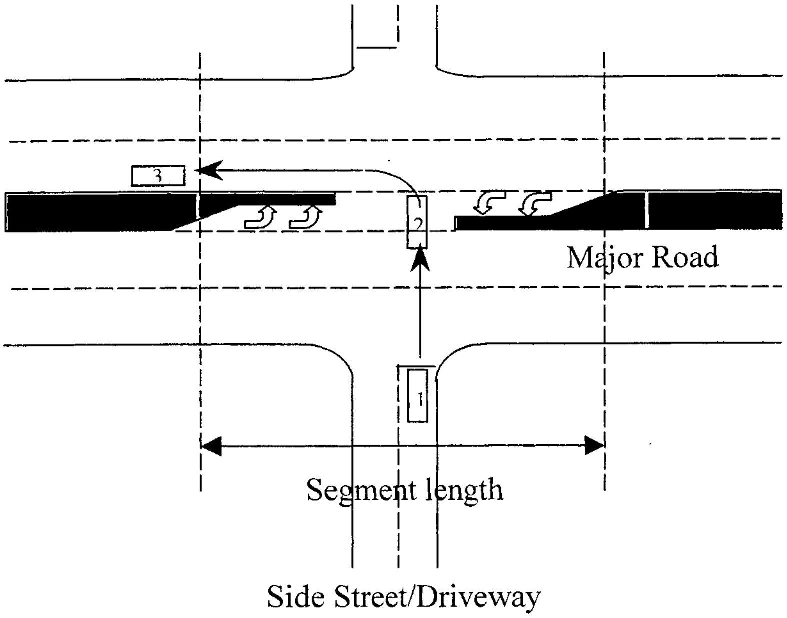
Criteria for establishing segment length were found in several other papers studying median treatments for urban arterial streets, although none of them provided a detailed discussion on how the criteria were identified *(6, 12)*. Council and Stewart chose a section length of 0.07 miles as the minimum length for which reported crash locations could be considered reliable for merging with the roadway inventory database *(16)*. In highway safety improvement programs, it was presented that all highway segments used to calculate the safety ratio were 0.101 miles to 3 miles *(22)*. Bonneson and McCoy constructed a safety model to predict the expected annual frequency for a quarter-mile segment of arterial streets, that is, the signal spacing is 1,000 feet or more *(17)*. Bonneson and McCoy presented the concept that the evaluation of the operational and safety effects of the three alternative median treatments was limited to their "mid-signal" performance. Their field observation of 71 arterials with a raised-curb median indicated that 93 percent had at least one median opening and that U-turn activity at these openings was negligible. In this context, the primary effects of a median treatment were assumed to occur outside of the functional boundary of any signalized intersection located on the arterial.

This project defined a segment as an urban or suburban arterial street section bounded by signalized intersections, but having only unsignalized access points (driveways or side streets) along its length. The multi-lane roadway segments for analysis were selected to represent a wide array of geographical locations. The segments considered in this study had one type of mid-block median treatment. Segment lengths ranging from 0.05 miles to 0.25 miles were selected to consider similar section lengths for the sample sites and to avoid the influence of adjoining active access points. Also, the downstream distance to the access point was long enough so that drivers favor the movements at median openings rather than at the downstream-signalized intersections. In other words, U-turns at the study sites were facilitated at either directional or full median openings and not at the signalized intersections. This was to avoid the effects of signal timings on U-turns. In addition, sites selected were those active access points with frequent driveway volume. At each site, an observer spent at least an hour during peak hours by the driveway or the side street checking whether the throughway volume and driveway left-turn egress and/or right turn followed by U-turn volume were sufficiently large enough to be used in this study.

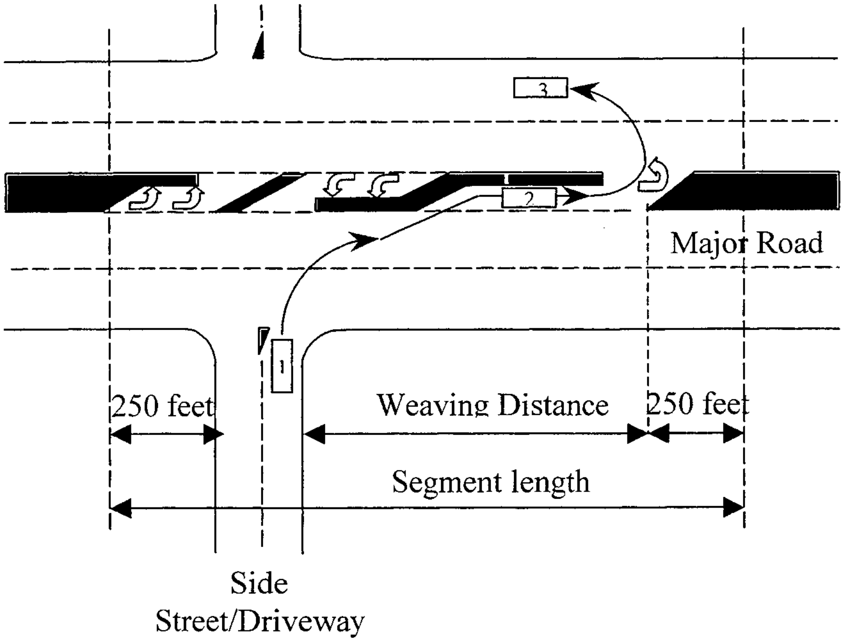
Figure 3.1 illustrates the sketches of how the segment lengths were defined in this study. The figure shows that in right turn followed by U-turn movement, a segment length consisted of four parts, i.e. the driveway width, weaving distance, and extended 250 feet from both the left and right side of the segment. Because the crash information in FDOT's crash database was originally recorded by the policemen who filed the crash reports and the recoded distances were all estimated values, it was possible that there were some inaccurate distances in the crash database. Additionally, some crashes related to the turning movement may not exactly happen at the spot. Therefore, the extension of 250 feet on both sides of the segment was expected to increase the accuracy of the analysis in this study. In direct left turn movements, the segment lengths were much shorter because they didn't have weaving distances. This might artificially change the results as the crash rates of two different site geometries are compared to each other. Thus, the segment length for the sites with direct left turns was defined as the average segment length of sample sites with right turns followed by U-turns. This was aimed at creating two groups of similar segment lengths between the two alternative left turn treatments and to increase the accuracy of the analysis accordingly.

3.3 Location of the Study Sites

Florida consists of seven FDOT districts and they are numbered as District One through District Seven. Figure 3.2 shows the locations of these districts in Florida. Another district, District Eight or the Turnpike District, is responsible for the operations, maintenance, and construction of the toll roads in Florida. The sample sites for this study were first collected within two districts, District One and District Seven. However, after noticing that not enough sample sites in District One and Seven were available, the other districts were contacted to expand the sample. District Four and Six were found as having a large number of candidate sites available. Finally, sample sites were selected from seven counties (Hillsborough, Pinellas, Pasco, Dade, Hernando, Palm Beach, and Broward) within three FDOT districts, District Four, Six, and Seven. The sites available from District One were located on county roads making it difficult to get compatible crash histories. Therefore those sites were not considered in the analysis.



(a) Direct Left Turn Egress Movements



(b) Right Turn Followed by U-turn Movements

Figure 3.1 Determination of Segment Lengths

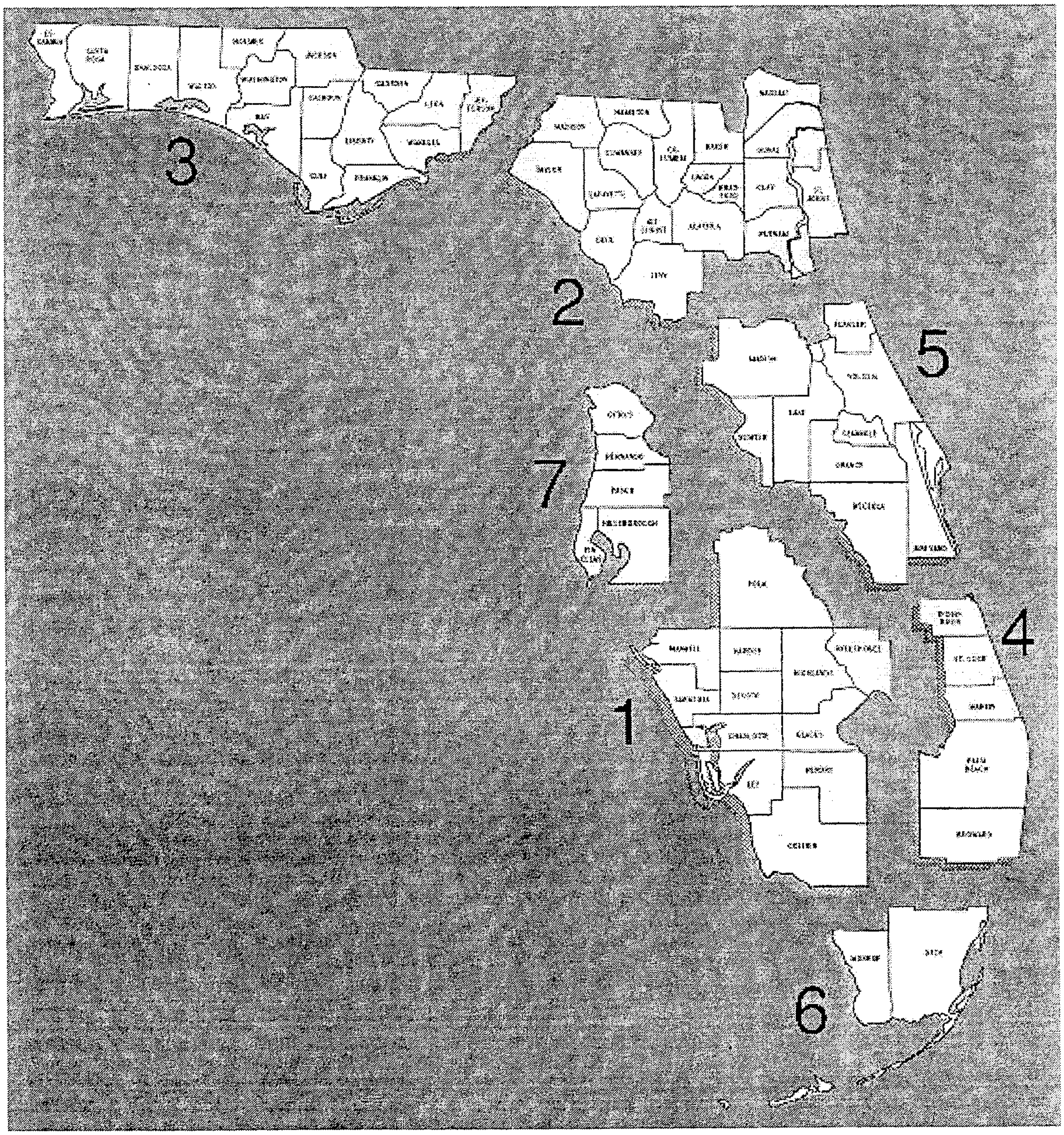


Figure 3.2 FDOT Florida Districts Map*

*Source: Adopted from the website of Florida Department of Transportation

3.4 Section Number and Milepost

The state roads and the crash locations in FDOT's crash database are recorded by using a code that utilizes FDOT section number and milepost. The main purpose of this system is to make the crash information consistent with the Street Line Diagram, which is a technical resource normally used by state road planners and traffic engineers. To perform the crash data analysis using the FDOT crash database, the definitions of section number and milepost must be clearly defined. Every roadway section on the state highway system in Florida has been identified with an eight-digit code by FDOT. This code is called "section" number, which uniquely defines that roadway. As described in Figure 3.3, the section number consists of a county number, a section number, and a subsection number. The first two digits correspond to the county number, the next three numbers are the actual section numbers for the roadway, and the last three numbers are known as the subsection number. Usually, a subsection is "000". If a roadway is reconfigured, the subsection number may be recorded as "001".

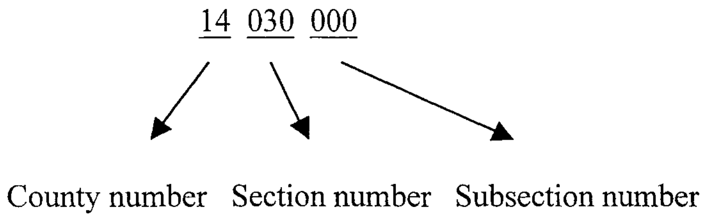


Figure 3.3 Roadway Section Numbering System

Milepost is used to describe those interacting points on the roadway, such as intersections, crossing interstates, driveways, and key commercial developments. Most roadways are labeled either from south to north or from west to east by FDOT. Thus, milepost zero is normally labeled at the southernmost or westernmost terminus of the road within that county. For example, US 19 in Pasco County (Section 14030) begins at the Pasco/Pinellas county line as milepost 0.000. An intersecting street 1.018 miles away to the south, which is State Road 595, will have a milepost of 1.018. Mileposts are rounded to the third digit after the decimal points because 0.001 miles equals 5.28 feet.

3.5 Site Selection

Site selection was one of the most difficult and time-consuming parts in this research. More than one hundred roadways in five FDOT districts were investigated. For each potential site, a simple sketch was drawn to record geometric information and all the relevant distances (such as weaving distance, driveway width, median width, etc.) were measured using an engineering measuring wheel. A total of 258 sites were identified as suitable sites for this study, based on the similarity of characteristics and availability one or both turning options: (1) right turns followed by U-turns, and (2) direct left turns. Considerable effort was made during the field surveys to obtain the traffic and geometric information, and supplementary information was obtained by reviewing video logs, street line diagrams, and aerial photographs.

A summary of the sample sizes is shown in Table 3.2. The total sample consisted of 133 sites with direct left turns from driveways and side streets. The number of study locations at which left turn was facilitated by right turns followed by U-turns was 125. Initially a large number of sites with both alternatives, where the drivers were capable of either making a direct left turn or right turn followed by U-turn was also considered. However, crash data analysis of these sites were later discarded, as these sites were unable to provide any useful information on the safety evaluation of the two alternatives.

Table 3.1 Summary of the Sample Sizes

County	Direct Left Turns			Right Turns/U-turns		
	4 lanes	6 lanes	8 lanes	4 lanes	6 lanes	8 lanes
Hernando	0	1	0	0	3	0
Hillsborough	13	24	2	3	20	2
Pasco	2	2	0	0	12	0
Pinellas	9	29	2	2	20	0
Broward	0	31	0	2	42	0
Dade	2	0	0	0	2	0
Palm Beach	4	9	0	10	15	3
Total	133			125		

The process of site selection can be explained in three steps.

Step 1: Field Study

First, the FDOT State Highway System and roadway inventory report of each county was studied as they provided the preliminary information needed to identify potential sites, such as the number of roadway lanes, posted speed, and the median opening types. Potential candidate sites were chosen from the reports using the criteria listed above. Then, field surveys were conducted to check whether the real traffic and geometric conditions of those sites match the requirements of this study. For each site, the surveyor spent a certain time period to check whether the throughway volume, driveway left turn out and/or right turn/U-turn volume was sufficiently large. Simple sketches with geometric information were drawn and details of traffic characteristics were recorded. The information gathered and recorded is as follows: major roadway name, driveway name, upstream signalized intersection name and distance to the driveway, downstream signalized intersection name and distance to the driveway, segment length, number of through traffic lanes, number of driveway lanes, posted speed, through-way volume category (high, medium, or low), land use (commercial/residential), and rural/urban nature. The traffic and geometric information, such as posted speed, signal installation, and weaving distances, were based primarily on the field data collections. Other important resources were obtained from documents provided by FDOT and/or county governments.

Step 2: Extracting Additional Information

The arterial photograph maps and the Straight-Line Diagrams were obtained from the corresponding FDOT district office. Using these two resources, geometric requirements were checked again for each site and required information was obtained. The specific information obtained for each site is listed as follows:

1) Section and subsection number of the major road,

2) Milepost of the driveway, upstream signal, and downstream signal,

3) The section distance between the two signals within which the driveway is located, and

4) Important variables to certain treatments such as weaving distances, land use type, lane width, and median width.

Step 3: Checking Site History

The MPO Transportation Improvement Program of each county was reviewed to confirm that no significant construction had taken place at the selected study sites during those years that crashes were counted and analyzed in this project. The road histories of selected sites were also discussed with the traffic engineers and other experts working on project management in FDOT. If there was an uncertainty on a selected individual site, the FDOT project investment was checked for further verification.

3.6 Setting-up of the Crash Database

This section provides the general information about the creation of the crash database solely for the purpose of this project. The crash data used in this study was extracted from the crash and roadway files of the FDOT's traffic crash database. The FDOT file contained 13 record types. Each record type contains approximately 20 variables. In this study, crash data of three consecutive years, from 1996 through 1998, were used for the analysis process. It is commonly believed that three years will usually provide a sufficient number of crashes for analysis while reducing the possibility of extraneous factors influencing the crash data. Changes that have occurred at the site during the analysis period can result in changes to the crash characteristics *(23)*. These include changes in the surrounding land use in addition to changes at the site itself. These changes have a higher probability of occurring, as the analysis period becomes longer. A time frame of three years is the most common choice as it is a good trade-off (represents a compromise) between the desire for larger samples and the desire that conditions have not changed much within the time frame.

To reduce the calculation time and allow time for further analysis, this project created its own crash data set based upon the FDOT crash data described above. A total of 106 variables were chosen, which were believed to be useful in further analyses. A computer program was written for extracting FDOT crash data and a large project crash database was developed. This database mainly included the time log record, crash characteristics record, vehicle record, and property damage record, covering seven counties from Year 1996 to 1998. The database was used in the statistical analysis discussed in the next section of this report. The size of the database and the extraction process were crosschecked to ensure the accuracy of the analyses. When summarizing crash data for a merge, additional data were kept intentionally in case of the need for further study. It is considered as more economical to have extra information in a computer file than to discover later that needed information has been lost during the merge and must be rebuilt from the original recording system.

3.7 Combining Crash Data with Site Information

Once the sample sites had been collected, corresponding spreadsheet was developed using Microsoft Excel. This spreadsheet consisted of geometric and traffic information such as: roadway name, land use type (commercial or residential), the number of throughway lanes, posted speed, the estimated weaving distances for U-turns, the distances between the access points and the upstream or downstream signalized intersections, county name, and segment origin and destination. All the information about distances between access points (driveways or side streets) and bounded signals were expressed uniformly using mileage and milepost codes. The spreadsheet was then converted into Statistical Analysis System (SAS) format *(24)*. After this, the crash counts and the average daily traffic for selected sites were extracted from the project database by using a computer program written in SAS language.

One problem encountered during the data manipulation was that the codes of roadway inventory and crash data were not compatible with each other in some instances. The inventory was coded by mileage, roadway names, and cross road names while the FDOT crash data was categorized by a specific code, crash number, and milepost. In the next step, CountyID, SectionID, and milepost were used as the common elements to summarize the crashes that occurred in each particular segment. Finally, the crash data file was arranged in the format of one record (crash number) per crash. Relevant information such as crash severity and type of the crash were also included in the final short listed crash dataset prepared specifically for the purpose of this project. Preliminary results were then transferred to Microsoft Access to sort data and to plot the diagrams for illustrative purposes.

3.8 County Crash Database

With the intention of expanding the number of sites, computerized crash data files were obtained from several Florida counties as well. Initial efforts were to combine the county crash databases with the state database because of the following advantages of county database:

1) More recent crash data – 1999 crashes – were available in several counties.

2) The county databases cover not only long-form crash reports, but also short-form reports meaning that it provides not only the more serious crashes, but also almost all the police reported crash information within the individual county.

3) Crash information on county roads is available making it possible to increase the sample size.

However, after several attempts, it was realized that the disadvantages of the county database were hard to overcome, irrespective of the advantages. The problems included the following:

1) Resources from some of the local agencies were unavailable.

2) The format of the county database is totally different from the state's database. It sorts the crash observations by the nature of the roadway and the distances from the crossed intersection. As the county roads were not included in the Street Line Diagram, it was impossible to merge the state data and county data based on milepost index.

3) The use of two databases at the same time may incur confusion and inaccuracy of the results due to non-uniformity.

Due to these considerations that could have resulted in less reliability of the findings, sample sites selected on county roads were not considered in the data analysis and it was decided to not to use the county crash databases in the analysis.

4. DATA ANALYSIS AND RESEARCH FINDINGS

4.1 Outline of Data Analysis

As mentioned previously, the cross-sectional comparison was conducted to compare the safety effects of the two left-turn alternatives; direct left turns, and right-turns followed by U-turns. The sample sites were divided into two categories according to the type of left-turn movement from the driveway that they facilitated. In the first category, drivers can make direct left turns from side streets or driveways onto divided arterials through full median openings. In category two, full median openings had been replaced either by directional median openings or median closures, so that the drivers can only make right turns followed by U-turns instead of direct left turns.

First, each category had their sample sites grouped by (1) crash severity, such as property-damage-only (PDO) and injury/fatality, and by (2) typical crash types, such as rear end, sideswipe, and angle. After this, the average number of crashes and crash rates were calculated for the two categories using the data from 1996 to 1998 for total crashes, by crash severity and by typical crash type. The results in one category were compared with the other counterpart category by considering the corresponding average number of crashes or crash rate. The comparisons were followed by statistical significance tests at 95% confidence levels.

Second, the crash frequency or crash rate distribution curves of the two groups were plotted and were compared with their counterparts in the other category. The Chi-square tests at a 95% confidence level were then performed to determine which statistical model best fit the number of crashes or crash rate distributions. It was found that the crash number distributions of all movements followed the Poisson model and the crash rate distributions of all movements followed the Log-normal model.

Third, the corresponding cumulative crash curves were plotted by applying the calculated Poisson parameters back into the original Poisson model:

$$Y = \frac{\lambda^x \exp(-\lambda)}{x!}$$

Also, the corresponding crash rate cumulative curves were plotted by applying the calculated Log-normal parameters back into the original Log-normal model, Y = ln X. Finally, the 85th and the 50th percentile values on the cumulative curves of the two movements were compared.

4.2 Comparison of Number of Crashes

Tables 4.1 through 4.3 summarize the average number of crashes for all types of crash groups mentioned above: (1) total crashes, (2) property-damage-only and injury/fatality crashes, and (3) three typical crash types. In the direct left turn category, a total of 2175 crashes were found (see Table 4.1); 1386 (or 63.7%) of the total were property-damage-only crashes; and the others, 789 (or 36.3%) were injury/fatality crashes (see Table 4.2). There were total of 1738 crashes for the right-turn/U-turn movement; the property-damage-only crashes were 1231 (or 70.8%) and the injury/fatality crashes were 507 (or 29.2%). Table 4.3 shows that for each category, rear-end type of crashes consisted of the largest percentage of total crashes, 37.52% in direct left turns, and 39.58% in right turns/U-turns. Angle crashes were the second largest type of crashes.

Table 4.1 Summary of the Total Number of Crashes

Statistics	Direct Left Turns	Right Turns/U-turns
No. of Sites	133	125
Total No. of Crashes	2175	1738
Average No. of Crashes	16.35	13.90
Standard Deviation	12.58	10.38
Median	14	12

Table 4.2 Summary of the Number of Crashes by Severity

Crash Severity	Statistics	Direct Left Turns	Right Turns/U-turns
Property-Damage-Only Crashes	No. of Crashes (% of Total)	1386 (63.7%)	1231 (70.8%)
	Average	11.08	10.52
	Std. Deviation	8.77	7.86
	Median	9	9
Injury/ Fatality Crashes	No. of Crashes (% of Total)	789 (36.3%)	507 (29.2%)
	Average	6.31	4.92
	Std. Deviation	4.72	3.07
	Median	5	4.5

Table 4.3 Summary of the Number of Crashes by Crash Type

Crash Type	Statistics	Direct Left Turns	Right Turns/U-turns
Rear-end Crashes	No. of Crashes (% of Total)	816 (37.52%)	688 (39.58%)
	Average	6.80	6.49
	Standard Deviation	6.31	4.90
	Median	5	6
Sideswipe Crashes	No. of Crashes (% of Total)	117 (5.38%)	141 (8.11%)
	Average	1.75	2.31
	Standard Deviation	1.05	1.30
	Median	1	1.5
Angle Crashes	No. of Crashes (% of Total)	583 (26.80%)	373 (21.46%)
	Average	5.35	4.20
	Standard Deviation	4.48	3.55
	Median	4	3

Figure 4.1 shows the comparison of the average number of crashes for the two categories. The differences in the average number of crashes between direct left turns (category one) and right turns followed by U-turns (category two) were computed by type of crashes and by crash severity. The figure shows that when comparing the sites with right turns followed by U-turns with the direct left-turns, there was a reduction in the average number of crashes for all levels of crash severity for the U-turn option. For rear-end and angle crashes the average number of crashes was lower for the right turn followed by U-turns as compared to the direct left turn. However, the number of sideswipe crashes of right turns followed by U-turns was larger than that of the direct left-turn movements. This could be a result of the additional weaving required by the right turn U-turn alternative.

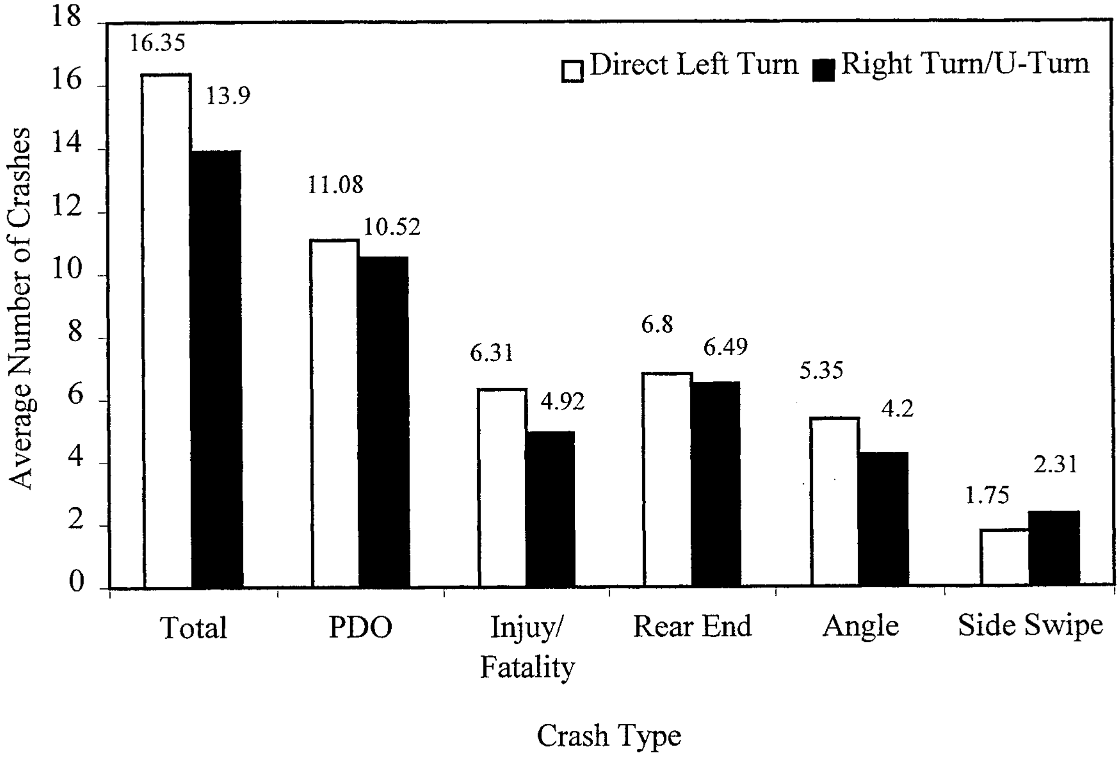


Figure 4.1 Comparisons of Average Number of Crashes between Direct Left Turns and Right Turns Followed by U-turns

Tables 4.4 provides more detailed information about the comparison of the number of crashes for the two alternatives. The average numbers of crashes are listed and the statistical significance of the average number of crashes for each crash group was tested at a 95% confidence level. The statistical test explained in the methodology section was used for this purpose. A more detailed explanation is provided below.

Table 4.4 Comparisons of Average Number of Crashes for Direct Left Turns and Right Turns followed by U-turns

Crash Statistics		Average Number of Crashes			
		Direct Left Turns (1)	Right Turns /U-turns (2)	Difference* (%)	Statistical Significance $\alpha = 0.05$
Total		16.35	13.90	14.98	No
Crash Severity	PDO**	11.08	10.52	5.05	No
	Injury/ Fatality	6.31	4.92	22.02	Yes
Typical Crash Types	Rear End	6.80	6.49	4.56	No
	Sideswipe	1.75	2.31	-32.0	Yes
	Angle	5.35	4.20	21.50	Yes

* Difference in Average Number of Crashes = 100% * [(1) - (2)] / (1)

** Property Damage Only

As an example, the statistical significance test of total crashes between right turns followed by U-turns and direct left turns is discussed here. It was assumed that there were two populations of interest, number of crashes at sites with direct left turns, X_1, and number of crashes at sites with right turns followed by U-turns, X_2. The population of direct left turns has mean μ_1. Its sample mean, $\overline{X}_1$, equaled 16.35 and its standard deviation, s_1, was 12.58. The population of right turns followed by U-turns has mean μ_2. Its sample mean, $\overline{X}_2$ =13.90 and its standard deviation, s_2, was 10.38. The process was to test whether the average number of crashes for right turns followed by U-turns and direct left turns were significantly different. The null hypothesis was H_0: $\mu_1 = \mu_2$ and the alternative hypothesis was H_1: $\mu_1 \neq \mu_2$. The test procedure was based on the fact that the difference in sample means of the two populations of interest, $\overline{X}_1 - \overline{X}_2$, will fit the normal distribution of:

$$\overline{X}_1 - \overline{X}_2 \sim N\left(\mu_1 - \mu_2, \frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right) = N\left(16.35 - 13.90, \frac{(12.58)^2}{133} + \frac{(10.38)^2}{125}\right)$$

If the null hypothesis H_0: $\mu_1 = \mu_2$ is true, the test statistic Z_0 will follow the N (0,1) distribution.

$$Z_0 = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} = \frac{16.35 - 13.90}{\sqrt{\frac{(12.58)^2}{133} + \frac{(10.38)^2}{125}}} = 1.71$$

Because Z_0, which equals 1.71, is smaller than $Z_{a/2}$, which equals 1.96, the null hypothesis that crash number distributions of right turns followed by U-turns and direct left turns are not significantly different cannot be rejected. Therefore, the average number of total crashes was 16.35 for direct left turns as compared with 13.90 for right turns followed by U-turns, which experienced a difference of 14.98% which was not statistically significant at the selected level of confidence.

Statistical significance for the other crash types was determined in the same way. The injury/fatality number of crashes decreased by 22.02%, from 6.31 for direct left turns to 4.92 for right-turns followed by U-turns. This difference was statistically significant at 95% level. Among different crash types, angle and sideswipe crashes indicated statistically significant differences between the two left turn treatments. In the case of sideswipe crashes, right turn indicated a higher average number of crashes than the direct left turn movements (2.31 and 1.75 respectively) even though the magnitudes of such crashes were lower. As for angle crashes the average direct left turn number of crashes (5.35) was much larger than that of the right turn U-turn movements (4.2).

The influence of traffic volume on the number of crashes has also been studied in this project by using the two selected sets of sites. It has long been believed that as the average daily traffic volume (ADT) increases, the number of crashes might also increase.

Figure 4.2 and Figure 4.3 show the relationship between ADT and number of crashes for direct left turn and right turn U-turn movements respectively. It indicates that number of crashes increases with the increase of ADT. Thus, the detailed analysis was conducted based on crash rate, in which the influence of traffic volume was taken into consideration.

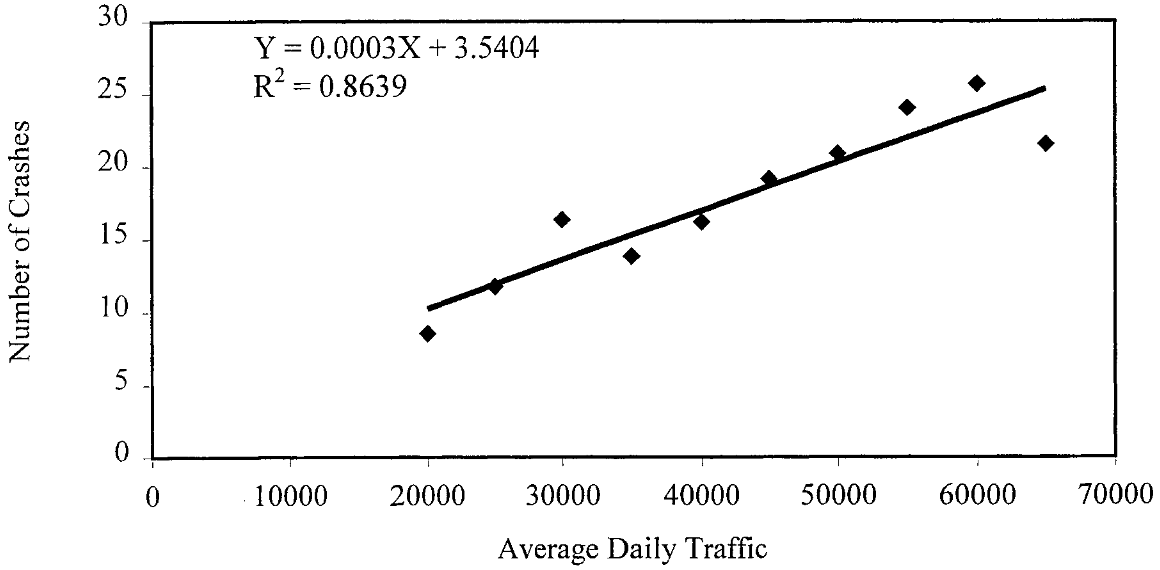


Figure 4.2 Number of Crashes vs. Average Daily Traffic for Direct Left Turns

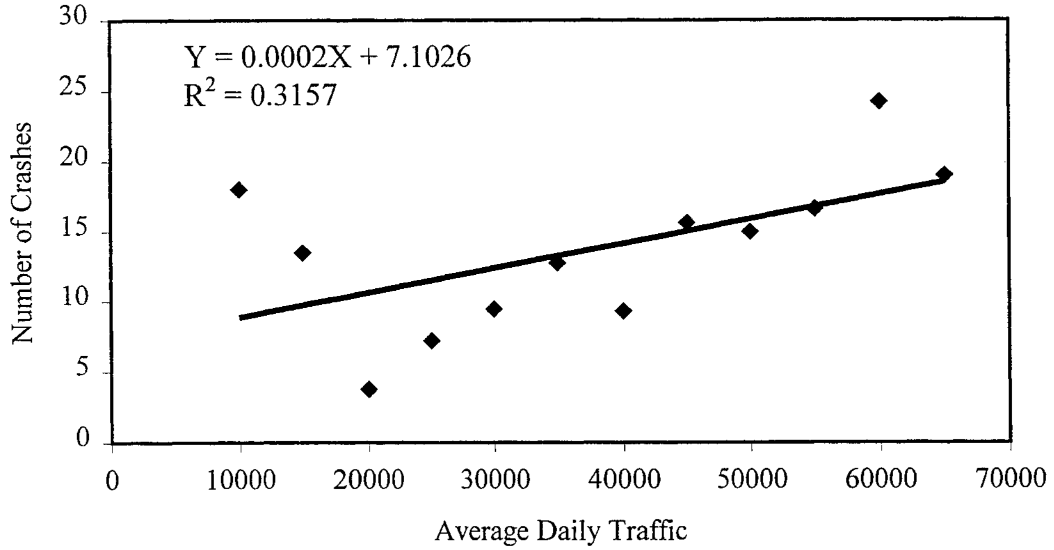


Figure 4.3 Number of Crashes vs. Average Daily Traffic for Right Turns Followed by U-turns

The relationship between the average number of crashes and average daily traffic volume (ADT) in each movement was studied by grouping the segments according to their ADT value and plotting the average number of crashes for each ADT range. Regression analysis was then carried out to find a linear trend line that best "fits" the observed data. Both the equation for this linear trend line and the coefficient of determination (R^2) were given in each figure. The coefficient of determination is the percent of the variance in the number of crashes explained by the variance in the independent variable, ADT. Thus, a R^2 of 0.87 percent indicates that 87 percent of the variance in the number of crashes is accounted for by the variance in the independent variable. Therefore, the closer the R^2 value is to 1.0, the stronger the relationship between the number of crashes and ADT. Figure 4.4 is the comparison of these two regression models. It shows that when traffic volume is considerably lager than 36,000 vehicles per day, right turns followed by U-turn locations have experienced fewer crashes than direct left turn locations.

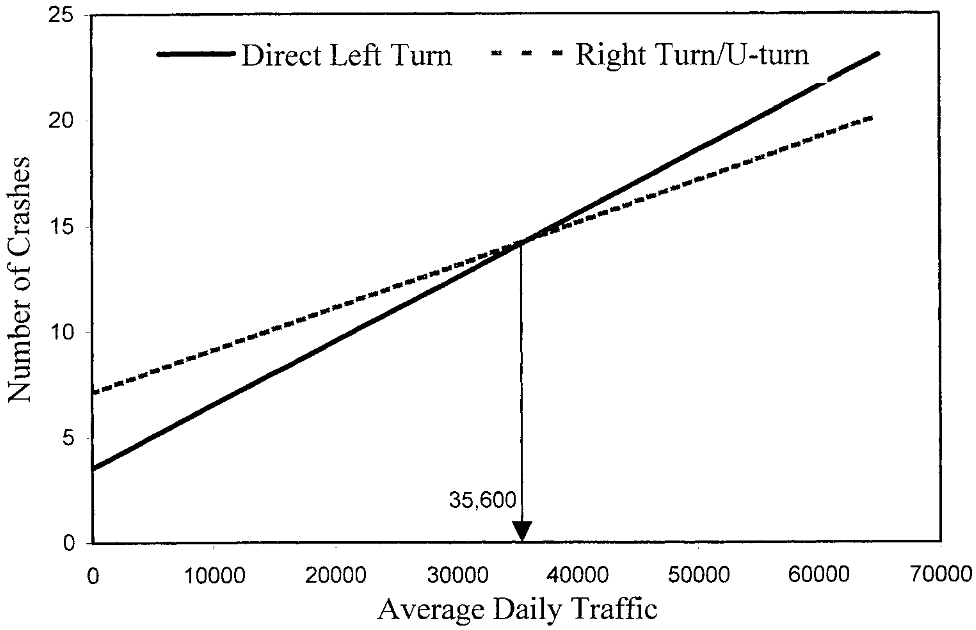


Figure 4.4 Comparison of Linear Regression Results for Two Movements

4.3 Comparison of Average Crash Rates

Traffic volume or ADT, is a variable that has previously been suggested as possibly being able to affect number of crashes. Findings in the previous section have also indicated that there has been a relationship at the selected set of sites as well. Therefore, in this section, crash rates were used instead of the number of crashes to reduce the influence of traffic volume on the final outcome and thus to improve the accuracy of the analysis. In this study, the ADT for each site was obtained corresponding to the date of the crash. For each segment, the crash rate is defined as crashes per million vehicle miles (MVM) traveled. For example, if site A had 12 crashes from year 1996 to year 1998, the average daily traffic (ADT) is 43,500, and the segment length for this site is 0.114 miles, then the crash rate for this site A would be,

$$\text{Crash Rate for the Segment} = \frac{1{,}000{,}000 \times 12}{365 \mathit{days} \times 43{,}500 \mathit{vpd} \times 3 \mathit{years} \times 0.144 \mathit{mile}}$$

$$= 1.75 \ \mathit{crashes\ per\ MVM}$$

The average crash rate is the arithmetic mean of crash rates of all the sample sites for a certain type of crash category. Tables 4.5 through 4.7 provide the details about the crash rates as well as the standard deviation and median for different types of crash groups. The median represents the middle value in a series of values of that category.

Table 4.5 Summary of the Total Crash Rates

Parameter	Direct Left Turns (Crashes per MVM)	Right Turns/U-turns (Crashes per MVM)
Average	3.20	2.63
Standard Deviation	2.41	1.95
Median	2.59	2.29

Table 4.6 Summary of Crash Rates for Property-Damage-Only Crashes and Injury/Fatality Crashes

Crash Severity	Statistics	Direct Left Turns	Right Turns/ U-turns
Property-Damage-Only	Average Crash Rate	2.18	2.04
	Standard Deviation	1.74	1.58
	Median	1.69	1.65
Injury/ Fatality	Average Crash Rate	1.21	0.88
	Standard Deviation	0.86	0.59
	Median	1.04	0.72

Table 4.7 Summary of Crash Rates for Typical Crash Types

Crash Type	Statistics	Direct Left Turns	Right Turns/ U-turns
Rear-end	Average	1.28	1.12
	Standard Deviation	1.07	0.76
	Median	0.91	0.97
Sideswipe	Average	0.36	0.44
	Standard Deviation	0.35	0.31
	Median	0.26	0.35
Angle	Average	1.06	0.81
	Standard Deviation	0.96	0.82
	Median	0.90	0.55

Figure 4.5 shows the average crash rate comparison of the two movements. The differences in crash rates between full median openings (category one) and directional median openings (category two) were computed for each of the crash group. Figure 5.5 shows that there is a consistent crash rate reduction from direct left turns to right turns followed by U-turns for all types of crash groups except for the sideswipe crash type.

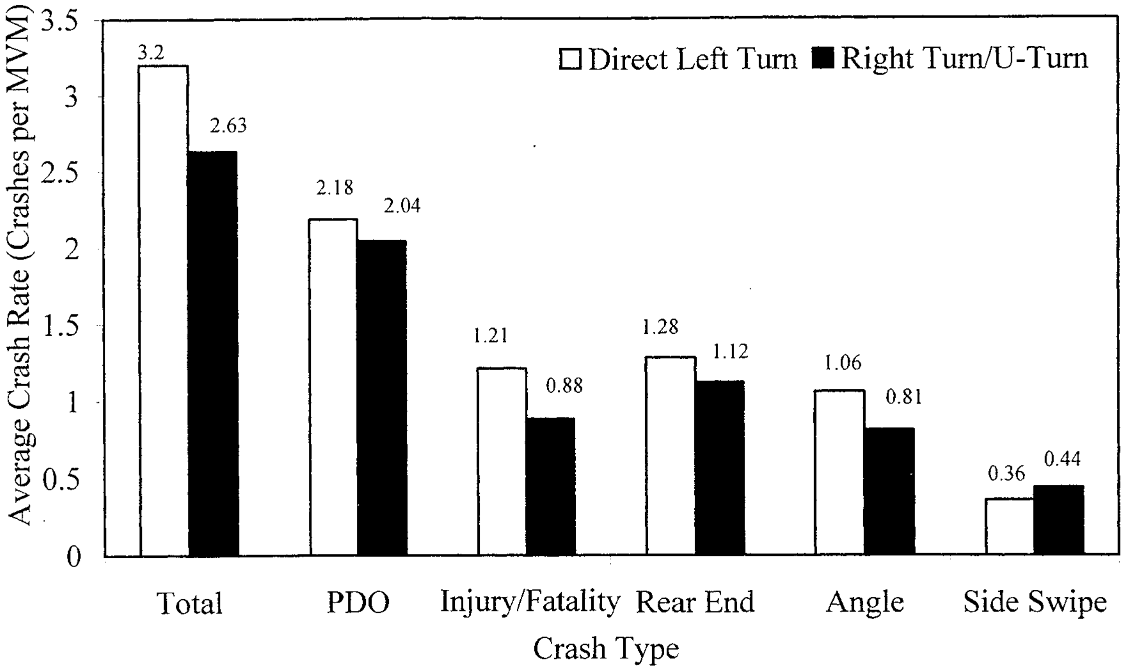


Figure 4.5 Average Crash Rate Comparisons between Direct Left Turns and Right Turns Followed by U-turns

The crash rates were listed and the statistical significance of the difference in the crash rates between the two groups was tested at 95% confidence level. As an example, the application of the statistical significance test of total crash rates between right turns followed by U-turns and direct left turns is discussed in this paragraph. It was assumed that there were two populations of interest, direct left turns (X_1) and right turns/U-turns (X_2). The total crash rate of direct left turns has mean μ_1. Its sample mean, $\overline{X}_1$, equals 3.20, and its standard deviation, s_1, is 2.41. The total crash rate of right turns/U-turns has mean μ_2. Its sample mean, $\overline{X}_2$ equals 2.63 and its standard deviation, s_2, is 1.95. The process is to test whether the average crash number of right turns/U-turns and direct left turns are significantly different. The null hypothesis is H_0: $\mu_1 = \mu_2$ and the alternative hypothesis is H_1: $\mu_1 \neq \mu_2$. The test procedure is based on the fact that the difference in sample means of the two populations of interest, $\overline{X}_1 - \overline{X}_2$, will fit the normal distribution of:

$$\overline{X}_1 - \overline{X}_2 \sim N\left(\mu_1 - \mu_2, \frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right) = N\left(3.20 - 2.63, \frac{(2.41)^2}{133} + \frac{(1.95)^2}{125}\right)$$

If the null hypothesis H$_0$: $\mu_1 = \mu_2$ is true, the test statistic Z_0 will follow the N (0,1) distribution.

$$Z_0 = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} = \frac{3.20 - 2.63}{\sqrt{\frac{(2.41)^2}{133} + \frac{(1.95)^2}{125}}} = 2.09$$

Because Z_0, which equals to 2.09, is larger than $Z_{\alpha/2}$, which equals to 1.96, the null hypothesis that crash rates corresponding to right turns/U-turns and direct left turns are not significantly different could be rejected. Statistical difference between crash rates for the other categories are evaluated in the same way detailed information is given in Table 4.8.

Table 4.8 Average Crash Rate Comparison of Direct Left Turns and Right Turns followed by U-turns for Total Crashes, Crash Severity, and Typical Crash Types, 1996-1998

Crash Statistics		Crash Rate (Crashes per MVM)			
		Direct Left Turns (1)	Right Turns / U-turns (2)	Difference * (%)	Statistical Significance $\alpha = 0.05$
Total		3.20	2.63	17.8	Yes
Crash Severity	PDO**	2.18	2.04	6.4	No
	Injury/ Fatality	1.21	0.88	27.3	Yes
Typical Crash Types	Rear End	1.28	1.12	13.3	No
	Sideswipe	0.36	0.44	-19.5	No
	Angle	1.06	0.81	24.5	Yes

* Difference in Average Crash Rates = 100% * [(1) - (2)] / (1)

** Property Damage Only

4.4 Chi-square Tests

The distribution curves of the number of crashes for each movement were then plotted. For each movement, the number of those segments that has a crash number located in a certain range were plotted as data points on the frequency distribution curve. When all the points (number of segments) on one distribution curve were summed, the number would always equal the total sites studied for that specific type of treatment. For example, the sum of the points on the curve for right turns followed by U-turns equals 125, which is the total number of sample sites studied for that movement. Then, the actual crash rate distribution curves of all the sites for each category were plotted. For each movement, the number of segments that has a crash rate located in a certain range is plotted as data points on the distribution curve. Similar to the frequency distributions of the number of crashes, when all the points (number of segments) on one distribution curve are summed, the number will always equal the total sites studied for that specific type of treatment. One of the differences between distributions of number of crashes and crash rates is that number of crashes is of discrete nature while crash rates are continuous.

Several discrete statistical models were reviewed and tested to determine which one best fit the crash number distributions. The Chi-square tests proved that number of crashes of all movements followed Poisson models at a 95% confidence level. Table 4.9 is the summary of the test results based on the null hypothesis that the data is in accordance with the Poisson distribution. As an example, the calculation procedure of the crash number distribution of direct left turns is discussed in this paragraph. The mean of the assumed Poisson distribution in this example is unknown and must be estimated from the sample data. The estimate of the mean of number of crashes is the sample average. From the cumulative Poisson distribution equation, the expected frequencies as $E_i = np_i$ can be computed, where p_i is the theoretical and hypothesized probability associated with the i^{th} class interval, and n is the total number of observations. The expected frequencies are obtained by multiplying the sample size with the respective probabilities. Accordingly, the test statistic is:

$$\chi_0^2 = SUM\,[(O_i - E_i)^2 / (E_i)]$$

where, O_i = observed frequency, and
E_i = expected frequency.

Table 4.9 Chi-square Tests of Poisson Model Fitness for Distributions of Number of Crashes

Movement Type	Sample Size	Estimated Chi-square Value χ_0^2	Critical Value $\chi^2_{\alpha,k-p-1}$	H$_0$ Rejected*?
Direct Left Turns	133	4.75	12.59	No
Right Turns/ U-turns	125	8.99	12.59	No

* H$_0$: Distribution of the number of crashes follows Poisson distribution.

For direct left turns the value of the test statistics was 4.75. Because the critical value, 12.59, is larger than the calculated value, χ_0^2 = 4.75, there is no statistical evidence that the crash number distribution does not follow a Poisson distribution. As discussed in the methodology section of this report, the equation for Poisson model is:

$$Y = \frac{4.0^x \exp(-4.0)}{x!}.$$

The optimal parameter for Poisson distribution was calculated using least square fitting method. Firstly, all the crash numbers were divided into several uniform intervals, e.g., number of crashes from zero to three belongs to interval one, number of crashes from four to six belongs to interval two, and so on. The interval number is taken as x. Then, the frequency for each interval, or the number of segments that have crashes located within that interval, was calculated. This number was divided by the total number of segments and taken as equal to parameter Y. Since Poisson distribution is a function of variable x, the ideal Y for each variable x can be calculated as follows:

$$Y = \frac{\lambda^x \exp(-\lambda)}{x!}$$

These ideal Y's are dependent of the function parameter, λ. The value of λ could be calculated from the mean of *x*, *E(x)*, i.e., $\lambda = E(x)$. The sum of the square of the difference between ideal Y and real Y for all variable *x* is used as a criterion to find the Poisson distribution curve, which fits the real distribution best. By varying the beginning of the first interval and the width of the interval, a minimum of square sum will be found and the corresponding parameter, λ, would be the optimal parameter. By following the same methodology, the crash number distribution of right turns followed by U-turns and both choices were also calculated. The crash number distribution of right turns/U-turns is:

$$Y = \frac{3.86^{x} \exp(-3.86)}{x!}$$

After the parameters were placed back into the original Poisson equation, the corresponding calculated Poisson distribution curve was plotted in the same figure with the real data distribution curve to visually compare the fitness of the model. The corresponding "ideal" Poisson distribution cumulative curve for each movement was plotted. In the case of the data used in this study, the cumulative curve means each value of y (the number of segments with crash rate located in a certain range) was added to the prior value until the total sample segments for that type of treatment was reached.

The Chi-square tests proved that crash rates of all the movements followed Log-normal models at a 95% confidence level. Table 4.10 provides the summary of the results that test the null hypothesis that the crash rate distribution follows Log-normal distribution.

Table 4.10 Chi-square Tests of Log-normal Model Fitness for Crash Rate Distributions

Movement Type	Sample Size	Estimated Chi-square Value χ_0^2	Critical Value $\chi^2_{\alpha,k-p-1}$	H_0 Rejected?
Direct Left Turns	133	4.15	12.59	No
Right Turns/ U-turns	125	3.59	14.07	No

4.5 Comparison of Distributions of Number of Crashes

The actual distribution curve of the number of crashes along with the ideal Poisson distribution curve for each category was drawn in Figures 4.6 and 4.7. The ideal Poisson distribution curve was drawn by applying the calculated Poisson parameters back into the original Poisson model. From the figures, it shows that the actual crash distribution and the ideal one match with each other, indicating the accuracy of the Chi-square tests mentioned in the previous section. The "ideal" distribution curves of the two categories were then plotted and compared in Figure 4.8. From Figure 4.8, it can be clearly seen that the maximum value of right turn U-turn distribution is smaller than that for direct left turns. As shown in Figure 4.8, although they have similar patterns, the right-turn U-turn distribution is shifted to the left side of the direct left turn distribution, representing a decreasing crash trend of right turns/U-turns against direct left turns.

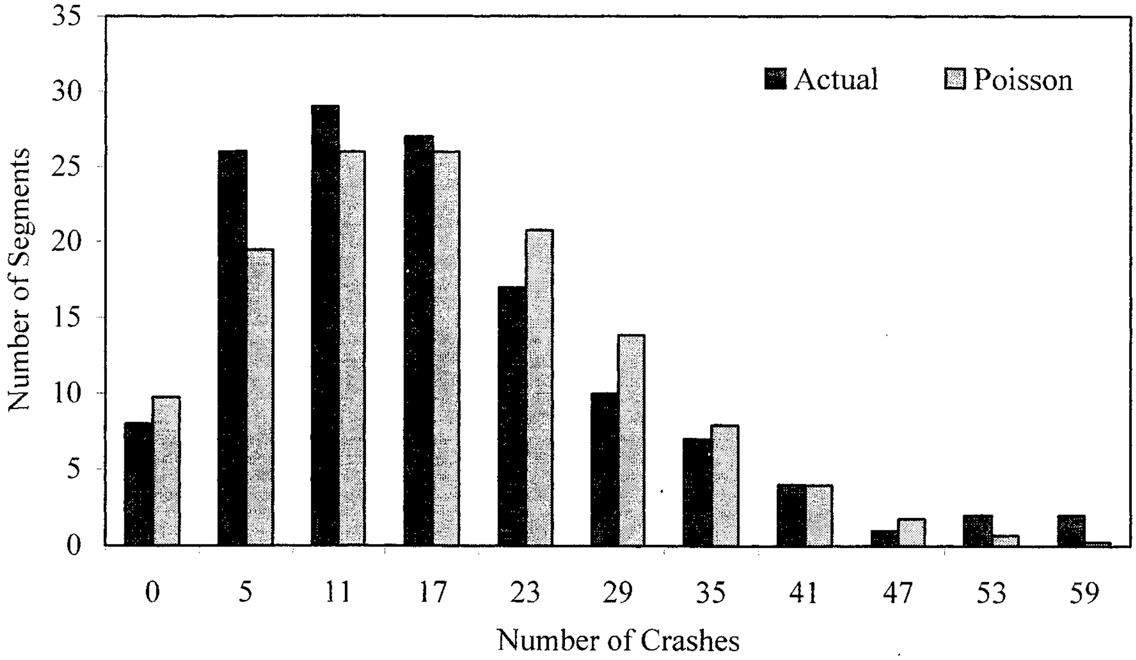


Figure 4.6 Distributions of Number of Crashes for Direct Left Turns

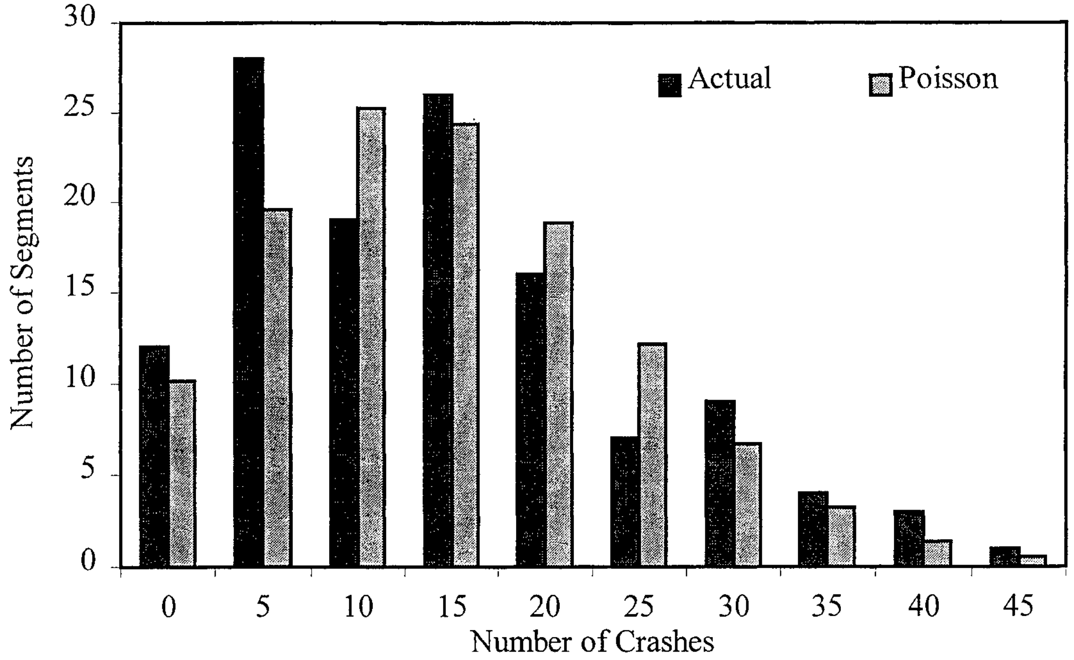


Figure 4.7 Distributions of Number of Crashes for Right Turns followed by U-turns

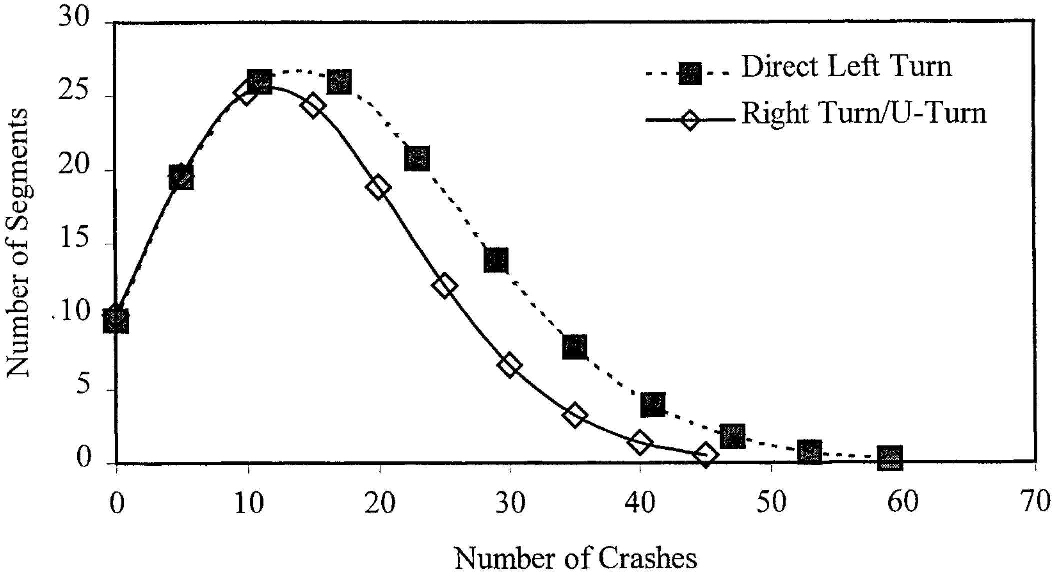


Figure 4.8 Distribution Curves of Number of Crashes for Direct Left Turns and Right Turns Followed by U-turns

4.6 Comparison of Crash Rate Distributions

Similar to the crash number distribution curves, the actual crash rate distribution curves along with the ideal Log-normal distribution curves for direct left turns and right turns followed by U-turns were plotted (see Figure 4.9, and 4.10). From the figures, it could be seen that the actual distributions and the theoretical distributions matched each other to a satisfactory level. As shown in Figure 4.11, although they have approximately the same patterns, the right-turns/U-turns distribution shifted to the left side of the direct left turn distribution and both choices, representing a decreasing trend of crash rates for right turns followed by U-turns compared to direct left turns. Therefore, it indicates that right-turns followed by U-turns are generally safer than direct left turns.

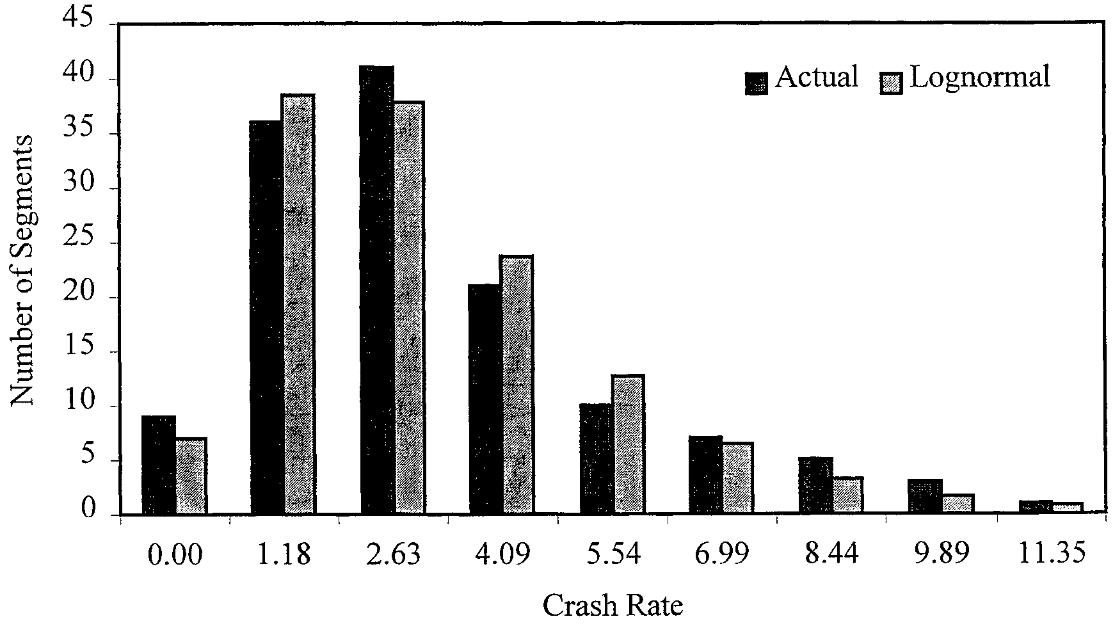


Figure 4.9 Crash Rate Distributions for Direct Left Turns

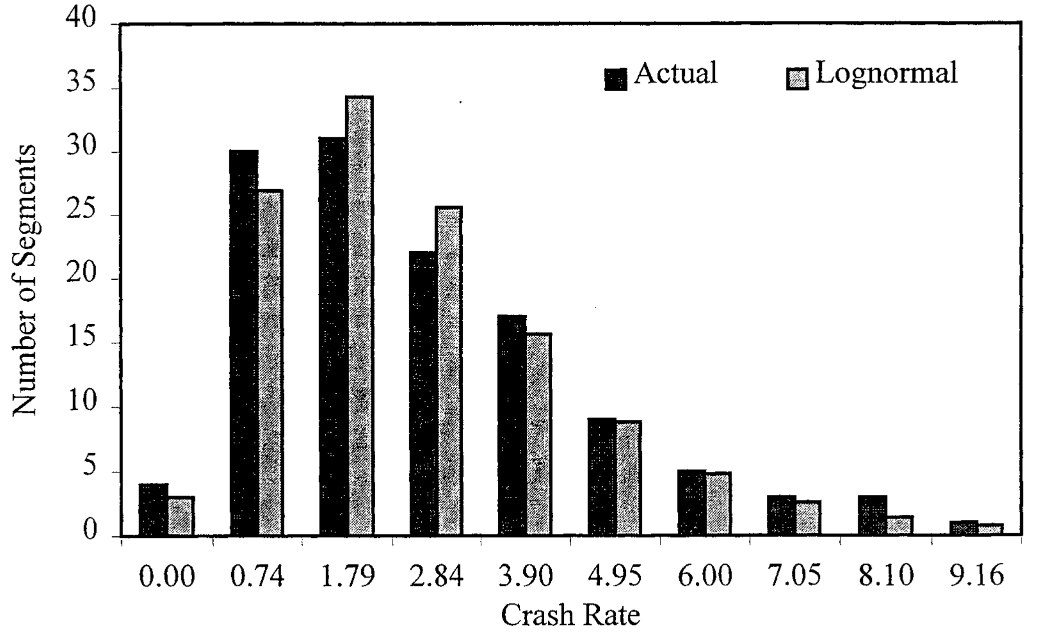


Figure 4.10 Crash Rate Distributions for Right Turns Followed by U-turns

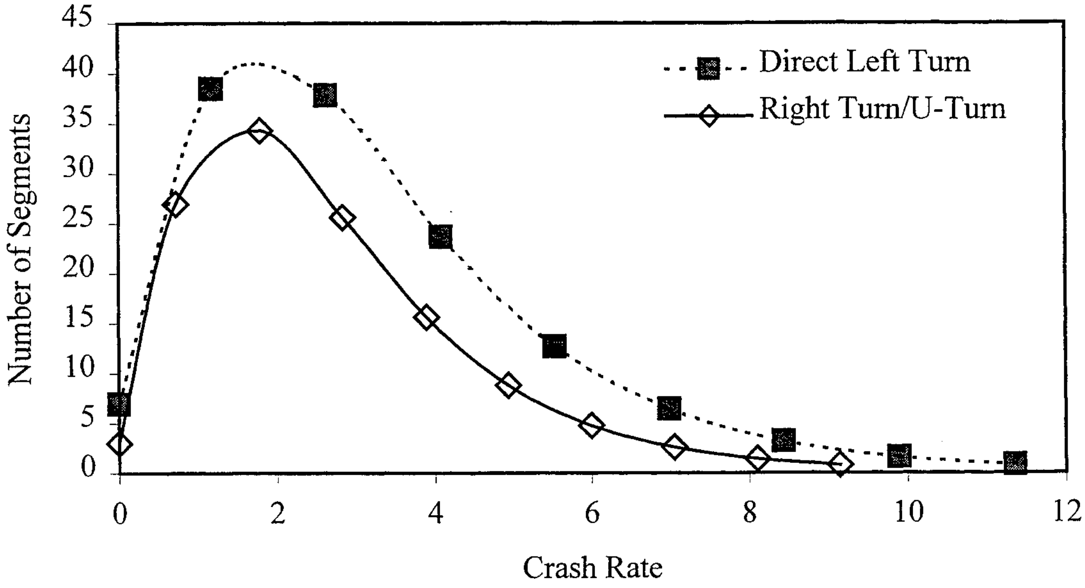


Figure 4.11 Crash Rate Distribution Curves for Direct Left Turns and Right Turns Followed by U-turns

4.7 The 50th and 85th Percentile Values

The 50th and 85th percentile values were marked on each movement's cumulative curves. The 50th percentile value is the calculated average crash rate (or average crash number) and the 85th percentile value represents the point where 85 percent of all the sites have crash rates (or number of crashes) no larger than the corresponding value. The reason for using the 85th percentile is that statistically most of the data points should have values smaller than the 85th percentile. The data in the top 15 percent could be regarded as abnormal. These two percentiles are commonly used in engineering analysis. In the analysis of number of crashes, the 50th percentile value for direct left turns, and right-turns followed by U-turns were 13.2, and 11.2, respectively (see Figure 4.12). The 85th percentile value of right-turns followed by U-turns, 22.1, is less than that of direct left turns, 26.8. Of these two alternative left-turn movements, the analysis of the number of crashes indicated that the right turn followed by U-turn is safer.

In crash rate analysis, the 50th percentile of direct left turns, and right-turns followed by U-turns were 1.7, and 1.6, respectively (see Figure 4.13). The 85th percentile crash rate per MVM value of right-turns followed by U-turns, 3.9, is less than that of direct left turns, 4.5, indicating that it is safer.

4.8 Summary

The comparisons of the two movements indicated that the overall crash rate of right turns followed by U-turns were less than direct left turns at a 95% confidence level. Although there were no significant differences between right turns/U-turns and direct left turns in average property-damage-only crash rates, the average injury/fatality crash rate of right turns/U-turns was significantly smaller than that of direct left turns. Distributions of the number of crashes and crash rates of both movements followed Poisson and Log-normal models, respectively. The actual distributions of number of crashes and the crash rates for each category matched well with their corresponding calculated models. The comparisons of best fitted number of crashes (or crash rate) distributions and their corresponding cumulative curves both indicated that right turns followed by U-turns had the smallest values, suggesting that it would be the safer design as compared to direct left turns.

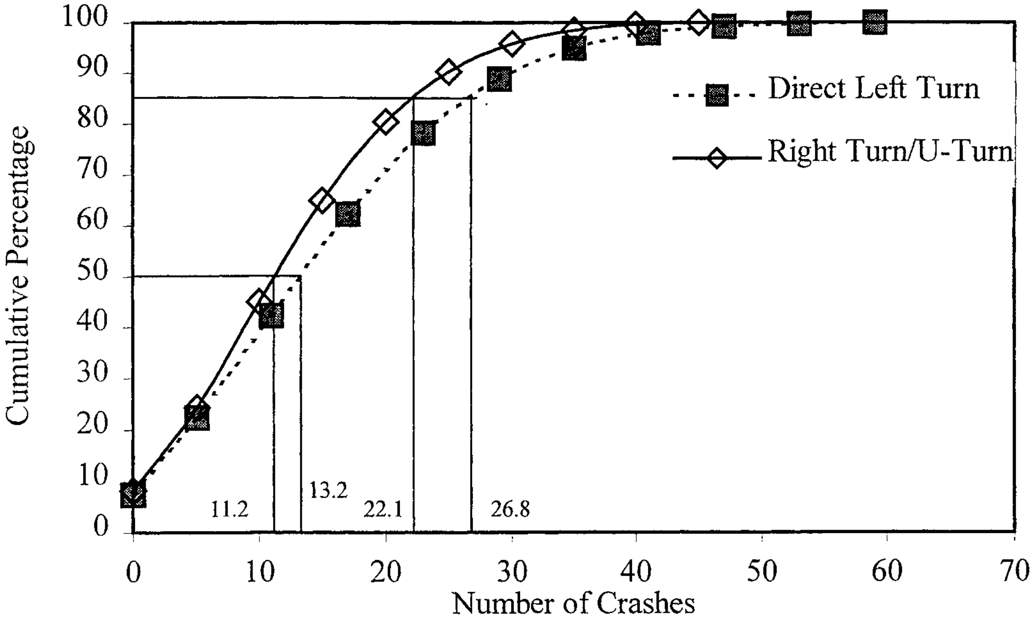


Figure 4.12 Comparisons of Cumulative Distributions of the Number of Crashes for Direct Left Turns and Right Turns Followed by U-turns

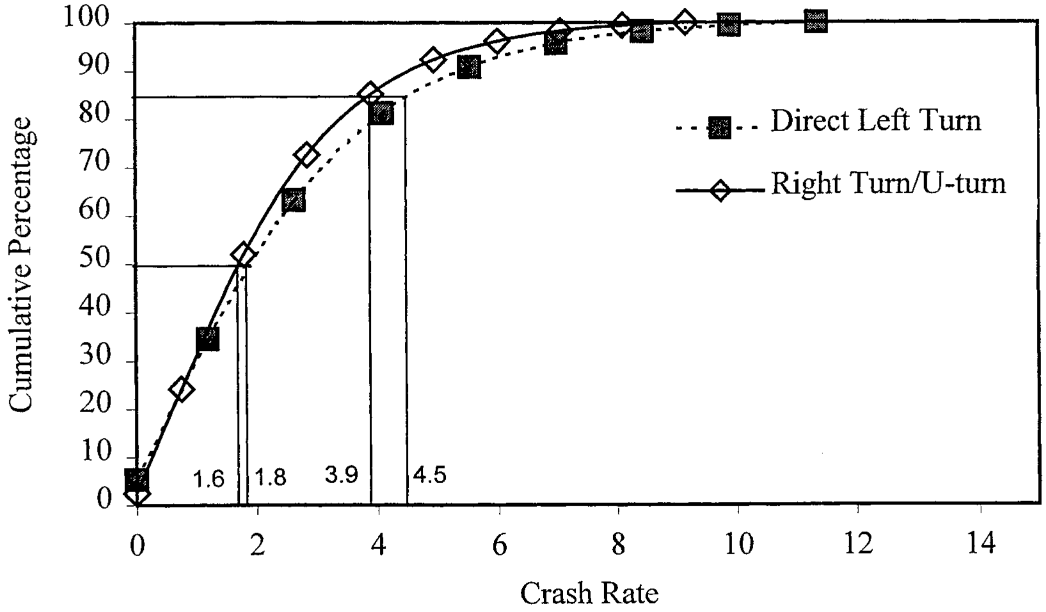


Figure 4.13 Comparisons of Cumulative Distributions of Crash Rate for Direct Left Turns and Right Turns Followed by U-turns

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary

The purpose of this study was to make a qualitative comparison of two left turn movement types (direct left turns, and right-turns followed by U-turns) to broadly evaluate the relative impacts of allowing direct left turn movements from side streets or driveways onto divided arterials through full median openings, versus right turn followed by U-turn movements, where full median openings are closed or replaced by directional median openings, so drivers can only make right turns followed by U-turns instead of direct left turns. The results provide a basis for judging the safety implications of U-turns as compared to direct left turns, and the geometric and traffic conditions under which right turns followed by U-turns are preferred over direct left turns from a safety point of view.

A total of 258 sample sites, consisting of over 100 for each type of movement, were selected and used to compare the crash frequencies and the crash rates that occurred in set of sites with one movement with those occurred in the other. Cross-sectional evaluation was utilized as the main approach to compare the safety effects. The significant factors considered in the site selection process included segment length, average daily traffic, and number of lanes. The FDOT crash database from 1996 to 1998 was used for the crash data acquisition function because of the relative ease in the gathering of crash and other related data.

In the analysis, each type of movement had its sample sites grouped by (1) crash severity, such as property-damage-only (PDO) and injury/fatality, and by (2) typical crash types, such as rear end, sideswipe and angle. After this, number of crashes and crash rates were obtained corresponding to the two movements using the data for total crashes, for each crash severity, and for each typical crash type. The values in one movement were compared with their counterparts in the other by calculating the corresponding crash rate (or crash number) differences. The comparisons were followed by statistical significance tests at 95% confidence levels. For further analysis, this study explored the crash rate distributions and crash number distributions of the two movements. Then, the crash rate (or crash number) distribution curves of all the groups in one category were plotted and were compared with their counterparts in the other categories. Chi-square tests at a 95% confidence level were then performed to determine which statistical model best fitted the crash rate (or crash number) distributions. It was found that the crash number distributions of all movements followed the Poisson model and the crash rate distributions of all movements followed the Log-normal model to a satisfactory level. Then, the corresponding crash number cumulative curves were plotted by applying the calculated Poisson parameters back into the original Poisson model. Also, the corresponding crash rate cumulative curves were plotted by applying the calculated Log-normal parameters back into the original Log-normal model. Last, the 50th and the 85th percentile values on the cumulative curves of the three movements were compared.

5.2 Conclusions

After reviewing over 258 sites in seven Florida counties, the results indicated that on major divided arterial roadways with large traffic volumes, high speed, and moderate to high driveway/side-street volumes, the implementation of the U-turn concept for roadway access control could lead to a statistically significant reduction of total crashes in both the crash frequency and the crash rate. Although the property-damage-only average crash numbers are similar among the three types of movements, the injury/fatality crash rate of right turns followed by U-turns was much less than that of the others; this shows that the U-turn concept has a beneficial impact on safety versus the typical full median opening design. According to the analysis and results of the previous chapters the following conclusions can be obtained:

1) Of the 2175 direct left-turn crashes, 63.7% of the total were property-damage-only crashes and the others, 36.3% were injury/fatality crashes. Of the 1738 total crashes for the right-turn/U-turn movement; the property-damage-only crashes were responsible for 70.8% of the total and the injury/fatality crashes make-up the other, 29.2%.

2) For each movement type, rear-end type of crashes occupy the largest percentage of total crashes, 37.52% in direct left turns, and 39.58% in right turns followed by U-turns. Angle crashes were the second largest type of crashes.

3) In the average crash rate comparison, the overall crash rate for right turns followed by U-turns was 17.8% less than that of direct left turns. The corresponding percentage reduction for property-damage-only crash rates was only 6.4%, which was not statistically significant. However, the injury/fatality crash rate for right turns followed by U-turns was 27.3% less than for direct left-turns.

4) The rear-end crash rate and angle crash rate of right turns followed by U-turns were 13.3% and 24.5%, respectively than the direct left-turns. However, the sideswipe crash rate was 19.4% higher. Of these three percentage changes above, only the difference in angle crash type was statistically significant.

5) The lower rear-end and angle crash rates may be explained by the fact that right-turns followed by U-turns have less conflict points than the direct left turns. The reason that right turns followed by U-turns have more sideswipe crashes may be explained by the fact that the driving patterns of right turns followed by U-turns require drivers to make more weaving maneuvers, which is related to the sideswipe crash type.

6) The Chi-square tests indicated that the distribution of the number of crashes of all movements followed Poisson models at a 95% confidence level. The theoretical distribution curves for the number of curves were then plotted and compared. Although the two curves follow similar patterns, the right-turns/U-turns distribution is shifted more to the left side, indicating better safety as compared to direct left turns.

7) The Chi-square tests indicated that crash rate distributions of all movements followed Log-normal models at a 95% confidence level. The theoretical crash rate distribution curves of the two categories were then plotted and compared which again indicated that right-turns followed by U-turns is safer than the direct left-turn.

8) In the analysis of number of crashes, the 50th percentile of direct left turns, and right-turns/U-turns are 13.2, and 11.2, respectively. The 85th percentile of right-turns/U-

turns, 22.1, was less than that of direct left turns, 26.8. This is consistent with the previous findings that right-turns/U-turns are less dangerous.

9) The 50th and 85th percentile values were marked on each movement's cumulative curves. In crash rate analysis, the 50th percentile of direct left turns, and right-turns/U-turns are 1.7, and 1.6, respectively. The 85th percentile of right-turns/U-turns, 3.9, is less than that of direct left turns, 4.5. Of these two movements, right turn/U-turn demonstrated the higher level of safety in terms of crashes.

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APPENDICES

Appendix A: Glossary of Terms

Various access control management terms that are related to this study are defined as follows (Source: "Access Management, Location and Design, Participant Notebook"):

Access: the ability to enter or leave a public street or highway from an abutting private property or another public street.

Access Point: the connection of a driveway at the right-of-way line to the highway

ADT: the annual average two-way daily traffic volume. It represents the total annual traffic for the year, divided by 365.

Channelizing Island: an area within the roadway not for vehicular movement; designed to control and direct specific movements of traffic to definite channels. The island may be defined by paint, raised bars, curbs, or other devices.

Conflict: a traffic event that causes evasive action by a driver to avoid collision with another vehicle, usually designated by a light application or evasive lane change.

Conflict Point: an area where intersecting traffic merges, diverges, or crosses.

Control of Access: the condition in which the right of owners or occupants of land abutting to a roadway is controlled by public authority.

Delay: the time consumed while traffic or a specified component of traffic is impeded in its movement by some element over which it has no control.

Driveway: the physical connection between a public street or highway and an abutting private tract of land.

Downstream: the direction along the roadway toward which the vehicle flow under consideration is moving.

Guideline: a recommended value, which reflects good engineering practice and which should be followed in most situations.

Highway: the entire width between the boundary lines of every publicly maintained way when any part thereof is open to public use for purposes of vehicular travel.

Egress: the exit of vehicular traffic from abutting properties to a highway.

Ingress: the entrance of vehicular traffic to abutting properties from a highway.

Lane: the portion of a roadway for the movement of a single line of vehicles and does not include the gutter or shoulder of the roadway.

Roadway Median: the physical portion of a highway separating the traveled ways for opposing traffic flows.

Roadway Median Opening: a gap in a median provided for crossing and turning traffic.

Merging: the process by which two separate traffic streams moving in the same general direction combine or unite to form a single stream.

M.U.T.C.D.: the manual on uniform traffic control devices

Roadway: that portion of a highway improved, designed or ordinarily used for vehicular travel exclusive of the shoulder. In the event a highway includes two or more separate roadways, "roadway" refers to any such roadway separately but not to all such roadways collectively.

Rural: any area not included in a business, industrial, or residential zone of moderate or high density, whether or not it is within the boundaries of a municipality.

Urban: any territory within an incorporated area or with frontage on a highway which is at least 50% built up with structures devoted to business, industry, or dwelling houses for a distance of a quarter of a mile or more.

Weaving Maneuvers: the crossing of traffic streams moving in the same general direction accomplished by merging and diverging.