Development of Crash Modification Factor for Low-cost Median Opening Treatments at Unsignalized Intersections of Rural Divided Highways

by

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ABSTRACT

An effective access management technique is such that it has the lowest level of access control to balance traffic operation and safety. Increasing the level of control can increase the overall delay. On the other hand, no access control can be hazardous to some vehicle movements. Research shows that minor street crossing movements and left turns on the major street are the most hazardous movements. The drivers making these movements need to select a gap from two directions of oncoming traffic. Understanding driver behavior during these movements can provide better insights which will help to decide on the implementation of roadway treatments.

Alabama Department of Transportation implemented low-cost median opening treatments (i.e., stop bars/yield lines, stop/yield signs, and double yellow lines on median opening) to improve the safety of unsignalized intersections on rural divided highways. But the safety benefits of these treatments are unknown.

At first, the study aims to analyze their impact on driver behaviors using Naturalistic Driving Study (NDS) and field video data. A traffic conflict analysis is also conducted to evaluate the safety effectiveness as an indirect or surrogate method for a safety study.

Finally, crash data analysis is conducted as the direct method of the safety study. Crash modification factor (CMF) is one of the tools to quantify the effectiveness of treatment. There is no CMF for these median opening treatments in the CMF clearing house. Therefore, the study aims to develop crash modification factors (CMFs) for these median treatments and compare the results of the conflict study with the developed CMF.

The study collected NDS data, which includes video data of a total of 428 trips taken by 65 study participants. The NDS data analysis showed that major road AADT and speed play an important role in drivers' behavior at unsignalized intersections. The study also collected traffic conflict data (48 hours of video data for each location) and five years of crash data (2016 to 2020) at six groups of unsignalized intersections (treated vs. non-treated) in Alabama. The conflict analysis found that the treated intersections have 8% to 40% fewer conflict rates than the non-treated intersections.

The cross-sectional Empirical Bayes (EB) method was conducted to develop the CMF. The predicted crash frequency was estimated using the Safety Performance Functions (SPF) in the Highway Safety Manual (HSM) and a local calibration factor developed by ALDOT. The EB method was applied to calculate the expected average crash frequency for each group of intersections (treated vs. non-treated) using the predicted and observed crash frequency and the CMFs for each group of intersections.

The combined CMF for these treatments is 0.70, with a standard deviation of 0.22. The result suggests that these treatments reduce the expected crash frequency by 30%. This CMF and the traffic conflict study results can be applied to project-level decision-making.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AADT	Annual Average Daily Traffic
ALDOT	Alabama Department of Transportation
CMF	Crash Modification Factor
CRF	Crash Reduction Factor
EB	Empirical Bayes
FHWA	Federal Highway Administration
HSM	Highway Safety Manual
LCF	Local Calibration Factor
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NDS	Naturalistic Driving Study
NHTSA	National Highway Traffic Safety Administration
PET	Post Encroachment Time
SHRP	Strategic Highway Research Program
TEV	Total Entering Vehicle
TWLTL	Two-Way-Left-Turn-Lane
VMT	Vehicle Miles Travel

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Intersections are one of the most critical subject matters in transportation safety studies. Around 30% of overall crashes in the US are related to intersections (1, 2). Every year the US experiences over two million intersection crashes, resulting in 6,700 fatalities, constituting 26% of all collisions (3). Intersection crashes are likely to be the most severe because of the diverse nature of traffic management (4). Among police-reported motor vehicle crashes, around 700,000 occur at stop-controlled intersections per year, 30% resulting in injury crashes (5). Therefore, it is imperative to focus on the safety of stop-controlled intersections.

Drivers' safety at stop-controlled intersections depends, in part, on the proper understanding of the traffic control measures (i.e., stop signs/yield signs). Two stages are observed in a stop-controlled intersection with a wide median while taking a left turn from a minor road. First, the vehicle stops at the first directional roadway, goes straight after passing the stop line, stops at the median, and then takes a left turn, yielding to major road traffic. Figure 1 shows the graphical representation of the two-stage left-turn movement.

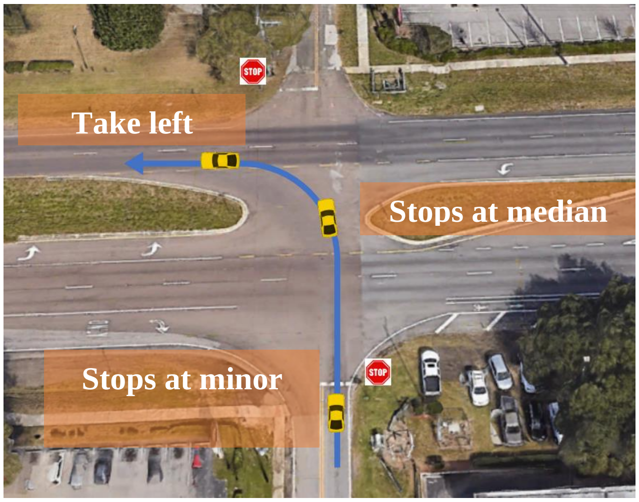


Figure 1 Two-stage left turn movement

During these two-stage left-turn movements, the driver has to face traffic from both approaches of the major road. They need to yield or stop to the major road traffic to find the suitable gap on both stages while entering the intersection and at the median opening. Therefore, it is crucial to understand the driver behavior at both stages for the safety study of the intersections. The Naturalistic Driving Study (NDS) of the second Strategic Highway Research Program (SHRP 2) provides information to understand driver behavior. This study helps understand how the driver interacts with the vehicle and the surroundings. The surrounding includes traffic control devices, roadway characteristics, and other environmental features (6).

Many access management techniques are implemented at the median to reduce the safety risk factors of these intersections. ALDOT implemented two types of low-cost median opening treatments to reduce the number of conflicts at various unsignalized intersections in Alabama. The treatments are as follows:

1. stop line, stop sign, and double yellow line

2. yield lines and yield signs and double yellow line

Figure 2 shows the two types of treatments that are implemented by ALDOT:

(a)

(b)

Figure 2 Types of median treatments implemented by ALDOT

(a) yield sign, yield line, and double yellow line; (b) stop line, stop sign, and double yellow line

Effective access control management can improve both traffic safety and operations. Therefore, it is essential to understand or evaluate the effectiveness of these treatments and compare it to high-cost access control techniques so that policymakers can make decisions on the future implementation of these treatments.

The Highway Safety Manual (HSM) provides information and tools that help practitioners make roadway design and operational decisions. One of these tools is crash modification factors, which can be used as input to the safety prediction methods. Crash modification factors (CMFs) help transportation professionals to make decisions on the investments of limited safety funds.

American Association of State Highway and Transportation Officials (AASHTO) *Highway Safety Manual* (HSM) and the Federal Highway Administration (FHWA) CMF Clearinghouse are rich sources of CMFs. There are no crash modification factors (CMFs) for the ALDOT-implemented treatments in the CMF clearinghouse. The CMF will help the practitioners predict crashes of the intersections with median treatments and make proper decisions on future implementations of the treatments.

A traffic conflict study is one of the indirect methods of evaluating the effectiveness of a treatment by observing near-crash events. The traffic control technique is an important surrogate measure where the effect of a treatment on driver behavior can also be analyzed. Therefore, this study aims to understand the impact of ALDOT-implemented treatments on driver behavior. The study adopts direct (developing CMF using predictive crash data analysis) and indirect methods of analysis (traffic conflict rates and near-crash rate analysis).

This study uses the data from two projects funded by the Alabama Department of Transportation (ALDOT). The projects are *Development of Guidance for Unsignalized Type Intersection Configuration on Rural Divided Highways (930-964)* and *Application of the Naturalistic Driving Study Dataset to Improve Design Guides & Associated Practices (930-923).*

1.2 RESEARCH OBJECTIVE

The study's objective is to review driver behaviors at unsignalized intersections during a two-stage left turn. The study aims to apply the traffic conflict technique to find the effect of the ALDOT-implemented median treatments on driver behavior and, finally, to quantify the safety effectiveness of those treatments. A crash modifications factor was developed using the cross-sectional Empirical Bayes (EB) method.

To achieve the objective of the study, the following tasks are conducted:

1. Study driver behavior during two stage-left turns, whether the driver stops at minor road stop stage and median openings using SHRP2 NDS data using field video data

2. Evaluate the effects of the ALDOT-implemented median opening access control treatments on driver behavior through comparative conflict and near-crash rate analysis (treated vs. non-treated intersections). This was done by observing traffic conflict videos at the selected study locations.

3. Develop a crash modification factor for the median opening treatments. The cross-sectional Empirical Bayes (EB) method was conducted to predict crash frequency in the study locations. Also, the available recent crash data (from 2016 to 2020) from ALDOT was collected for this method.

1.3 THESIS STRUCTURE

The structure of this report is divided into six chapters. Chapter one outlines the background, research objective, and thesis structure. Chapter two describes the literature review on driver behavior, traffic conflict study, and developing crash modification factors. Chapter three includes a detailed driver behavior study using NDS data and field video data, and chapter four consists of the traffic conflict rate analysis between the treated vs. non-treated intersections. Chapter five states the steps of developing the CMF for the median treatments. Chapter six presents the comparison of the conflict analysis results and calculated CMF. Finally, chapter seven summarizes the study's objective and results and proposes recommendations for future studies.

CHAPTER 2

LITERATURE REVIEW

This chapter outlines the current and past research on driver behavior at unsignalized intersections. Then the chapter describes previous research on traffic conflict techniques and gives an overview of crash modification factors of different median treatments. Finally, the chapter summarizes the literature and states the research gap.

2.1 DRIVER BEHAVIOR STUDY DURING TWO-STAGE LEFT TURN

One of the main factors in evaluating the roadway's safety is understanding the driver's behavior. Understanding drivers' interaction with the roadway is important so the roadways can be designed and constructed so that human errors can be minimized and the associated crashes can be reduced (7).

Human error is a significant contributing factor in most crashes (8). Figure 3 shows the relative percentages of contributing factors of crashes according to the Highway Safety Manual published by the American Association of State Highway and Transportation Officials (AASHTO) (2010) (7).

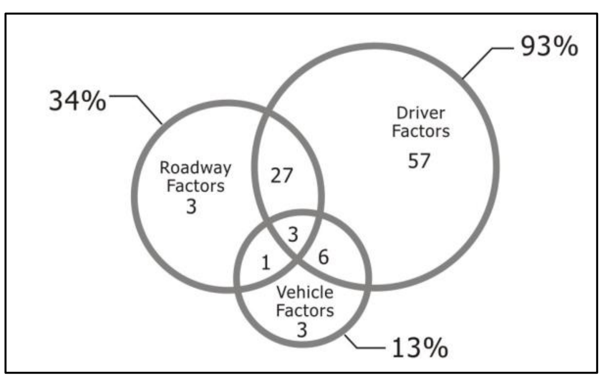


Figure 3 Crash contributing factors

The crash contributing factors are interrelated and complex. Hence direct control and prediction of human factors are difficult. These human factors can indirectly be controlled and predicted by investigating the geometric roadway design (9).

According to the HSM, drivers can be overloaded by the information they need to process while driving, which may lead to errors. Sometimes drivers rely on prior knowledge to reduce their information load and make mistakes when their expectations are unmet. Also, drivers sometimes deliberately violate traffic control devices and laws (7).

According to the California Driver Handbook, a driver has to come to a complete stop before entering intersections, whether there is a conflict or not (10). The violation of the stop sign trend started a long time ago. According to two studies from 1976 and 1981, violation of stopping behavior is more than 50% (11,12). The driver shows two types of violations from the actual conduct. One group decelerates the vehicle before the stop line but does not come to a complete stop. Another group entirely ignores the stopping behavior and keeps moving toward intersections (13). A recent study aligns with these past findings, where nearly half of the drivers do not stop at stop-controlled intersections (14). The prime reason behind this violation is poor stop sign compliance. According to some studies, at stop-controlled intersections, stop sign violation accounts for 60% to 70% of all crashes (5,15).

2.1.1 Driver-Stopping Behavior in Median Openings

Past research had focused mainly on stopping behavior before vehicles entered the intersection. In the case of median opening, studies have mainly focused on the capacity analysis of the median (16,17). There is a shortage of research on driver-stopping behavior on the median.

This study aims to fill this gap by analyzing two-stage left-turn behavior in terms of stop conditions at both stages.

One of the significant reasons past studies focused less on stopping behavior at the median opening is the difficulty in data collection. In many cases, studies on driving behavior analysis at a stop-controlled intersection have been conducted through manual observation and taking survey opinions (13,18,19,20,21). Manual observation is hectic and sometimes might be problematic because of one-time observation of an event by a single/limited person. Wen (2021) did one study using video-based trajectory data to ensure high-resolution vehicle data to classify different types of driving behavior at a stop-controlled intersection (22). However, video data collection requires data collected from significant upstream distances. Also, multiple video data collection arrays are needed. Most importantly, this video data system cannot collect driver characteristics.

The Second Strategic Highway Research Program (SHRP 2) Naturalistic Driving Study (NDS) database provides detailed information for two-stage left turn driving behaviors on stopped, controlled intersections. The trip information includes vehicle speed, acceleration/deceleration rate, pedal brake information, and driver-related data (23). NDS data can successfully capture stopping behavior at the median opening. Thus, NDS data can overcome the drawbacks stated above (23). So, this study uses NDS data to evaluate the stopping behavior.

2.2 TRAFFIC CONFLICT ANALYSIS

Traffic safety analysis may be conducted using direct and indirect methods while evaluating the safety risk factor of a particular site. Crash data is a direct measure of highway safety, considering a high number of crashes in a specific location indicates that the roadway or traffic operation safety in that location is being compromised. But the problem with crash data analysis is that we need to wait for the crash to occur.

On the other hand, indirect safety measurement, also known as surrogate safety measures, provides a surrogate methodology when crash frequencies are unavailable or when crash frequencies are low or have not been collected. Conflict studies are one of the indirect measurements of safety. Direct observation of a site is conducted to examine "near-crash" events as an indirect measure of potential crash problems at a location (7).

According to HSM, drivers' error is mostly related to human physical, perceptual, and cognitive limitations, but these errors may not result in crashes. It may be because drivers can compensate for other drivers' errors or because the circumstances are sometimes forgiving. For example, there may be enough space to maneuver and avoid a crash (7). That is why the near crash or conflicts are more frequent than actual crash occurrences. The study found a conflict-to-crash ratio of about 2,000 to 1 at urban intersections (24). The traffic Conflict Technique is one of the most important methods to measure highway intersections' crash potential without waiting for crashes to happen (25).

Williams (1981) and Grayson and Hakkert (1987) gave detailed information regarding the traffic conflict technique (26,27). The first explicit research was done by Perkins and Harris (1968) (28). This study defined a traffic conflict simply as any evasive action taken by a driver to avoid a collision. Hayward (1972) conceptualized conflict severity as the time distance between the point of evasive action and the hypothetical collision point (if no evasive action had taken place) (29).

Allen (1977) recognized that a collision could occur without evasive action. This study introduced the concept of "post-encroachment time" (PET) (30). PET is defined as the time between the moment the first vehicle crosses a path and the moment the second reach that path of the first (Figure 4) (31). The PET value indicates the extent to which they missed each other. Lower values of PET are shown as possibly critical.

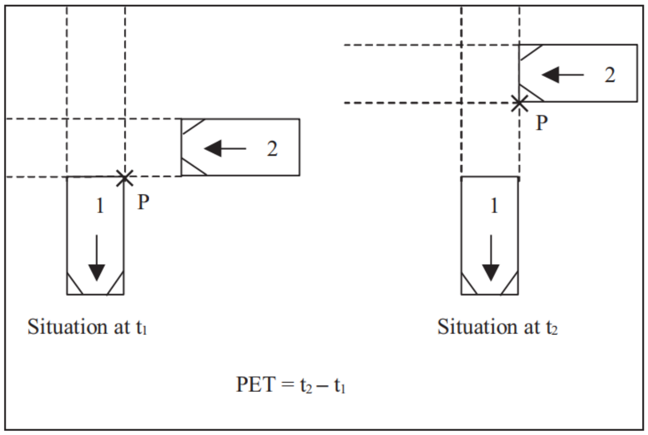


Figure 4 Definition of Post-encroachment Time (PET)

Traffic conflict studies have been used to evaluate the safety effectiveness of various countermeasures at unsignalized intersections. (32,33,34).

2.3 CRASH MODIFICATION FACTORS FOR MEDIAN TREATMENTS

A crash modification factor (CMF) is defined as the ratio of the expected crash frequency with improvement over that without improvement. It is used to predict the expected number of crashes after implementing a countermeasure at a specific site. It quantifies the effect of a countermeasure or a treatment

The CMF Clearinghouse stores all the CMFs listed in the HSM. Users can search for a CMF listed in HSM using filters on the Search Results page.

From the CMF clearing house, we can find many CMFs for a countermeasure that are used as access control management techniques on medians. But all these median treatments require high costs or greater time to implement. For example, many CMFs were found for widening the median width, installing raised median, or adding a Two-Way-Left-Turn-Lane (TWLTL) to the major approach of an unsignalized 3-leg intersection, etc. (35).

ALDOT implemented two types of low-cost median opening treatments instead of expensive treatments as an access control technique. They are (1) stop line, stop sign, and double yellow lines; (2) yield lines and yield signs and double yellow line. But there is no known CMF for the ALDOT implemented stop signs or yield signs on median treatments in the CMF clearing house. There are studies on stop signs and stop lines in minor roads or other locations. But there are no separate studies for these treatments on a median.

2.4 SUMMARY

There are few previous studies on the two-stage left turn driver behaviors at unsignalized intersections with wide medians. Especially study on driver behavior in median openings is very rare due to the difficulty in data collection. NDS study can help in this regard. Understanding driver-stopping behavior in the median opening can help decide whether there is any need for any access control management technique to reduce the crash risk. The literature also shows that the conflict study using PET can be a good indirect measure to evaluate the safety and effectiveness of the treatments. Again, the CMF clearing house does not have any CMF for the two types of median opening access control treatments (stop sign/ line and yield sign/ line) in Alabama.

Therefore, the study first analyses the driver behavior at stopped-controlled intersections without any median treatment using the NDS data. Then this study aims to analyze the stopping behavior at 12 different intersections in Alabama categorized into treated and non-treated intersections. The traffic conflict analysis is also conducted on these treated and non-treated intersections. Furthermore, the study aims to collect the crash data of these 12 study intersections and develop crash modification factors to understand the effect of these treatments on actual crashes.

CHAPTER 3

STUDY OF DRIVER BEHAVIOR DURING TWO-STAGE LEFT TURN IN UNSIGNALIZED INTERSECTIONS USING NDS DATA AND FIELD VIDEO DATA

The chapter includes the driver behavior analysis using NDS data and field video data. The study locations, data collection, and methodology are described for both data. The stopping behavior is analyzed using both the data. The results of the driver behavior study are presented, and finally, a comparison between the results of the analysis of NDS data and field data are presented.

3.1 DRIVER BEHAVIOR ANALYSIS USING NDS DATA

3.1.1 Study Location

Six locations from Florida that were available from the NDS database were used for the driver behavior analysis. The aerial view of the selected intersections for the analysis is presented in Figure 5. The arrow on the images indicates the driver's direction from the minor road to the major road. None of these intersections have any traffic control measures at the medians.

(a) FL1.0: US Hwy 41 and Flamingo Dr. (b) FL2.0: US Hwy 41 and Miller Mac Rd

(c) FL3.0 US Hwy 41/Leisey Rd (d) FL5.0 N 56th St/Gibson Ave

(e) FL6.1 N 56th St and E 27th Ave (f) FL7.0 E Fowler Ave and Williams Rd

Figure 5 Selected locations for two-stage left turn analysis using NDS data

Table 1 lists the information on geometric designs and traffic characteristics at selected study locations. The study goal is to find the impact of geometric design and traffic characteristics on driving behavior. Therefore, the six locations are categorized into four types based on their road geometry and major and minor road speed limits. Site FL1.0, FL2.0, and FL3.0 are termed as Type 1: 3-leg with high major road speed. All three locations are 3-leg intersections with the same major road AADT and speed limit. Despite being a 3-leg intersection, FL5.0 is separated from type 1 because of low major road speed limits and AADT. This location is Type 2: 3-leg with low major road speed. Similarly, FL6.1 and FL7.0 are Type 3: 4-leg with low major road speed and Type 4: 4-leg with high major road speed. None of these types of intersections had any kind of signage or pavement marking at the median opening.

Table 1 Details of study locations

Site ID	Intersection Name	Type of location	Major Rd Speed limit (mph)	Minor Rd Speed Limit (mph)	Major Rd AADT	Median width (ft)	Intersection Type
FL1.0	US Hwy 41/Flamingo	Type 1: 3-leg with high major road speed	55	25	33,000	40	3-Leg
FL2.0	US Hwy 41/Miller Mac Rd		55	35	33,000	40	3-Leg
FL3.0	US Hwy 41/Leisey Rd		55	25	33,000	40	3-Leg
FL5.0	N 56th St/Gibson Ave	Type 2: 3-leg with low major road speed	40	20	27,000	40	3-Leg
FL6.1	N 56th St/E 27th Ave	Type 3: 4-leg with low major road speed	40	20	27,000	40	4-Leg
FL7.0	E Fowler Ave/Williams Rd	Type 4: 4-leg with high major road speed	55	40	26,000	44	4-Leg

3.1.2 Methodology

The NDS database contains individual videos of taking a left turn from minor to major roads. The video frames move along with the vehicle since the camera is set at the front of the vehicle taking the trip. One of the major tasks of two-stage stopping behavior analysis is to count the number of vehicles exactly stopped at the minor road and the median. Defining the exact stop condition has been found challenging in the past also. The subjective definition of stop condition has confused law enforcement and drivers while making violation charges (18,36). NDS database has the advantage of finding exact stop conditions.

NDS database has a speed value associated with every time frame of a video. Figure 6 shows the chronological time frames while the vehicle took a left turn. The bottom left corner of a particular frame shows the time series value. Frames 2 and 3 show the same position of the vehicle, but the time series values are different, indicating the stopped position of the vehicle at a minor road stop sign. Similarly, frames 5 to 6 show the stopped position of the vehicle at the median. If the speed value is zero at the selected time frame, vehicles are considered in stop condition. For this study, trip videos with time-series data were observed manually, and information regarding the stopping behavior of each trip was recorded for each trip. (For example, the value for a stopped condition at a minor road/median was taken as 1 and 0 for not stopping).

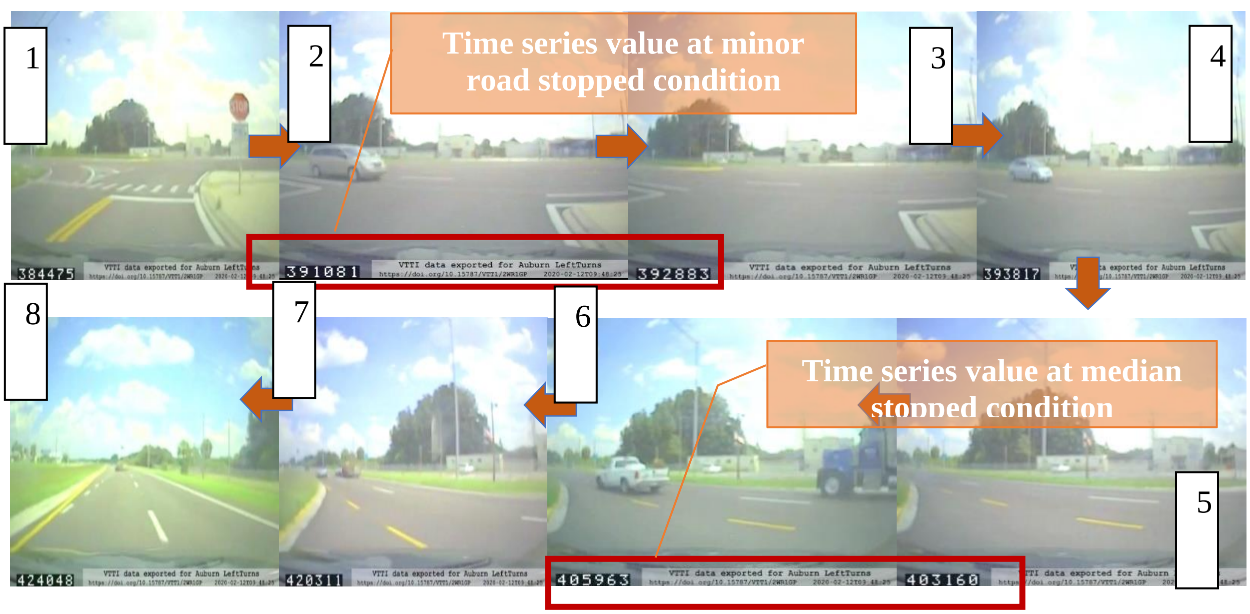


Figure 6 Video frames with the timestamp of a complete left turn movement (used to identify actual stop condition)

3.1.2.1 Correction for True Stop Condition

One of the significant advantages of using NDS data is that it can identify true stop conditions at the minor road utilizing the time frame associated with the data extraction method. Figure 7 illustrates the influence of the preceding car of a queue on the stopping behavior. While recording the stopping behavior, it was observed that some vehicles stopped in a queue at the minor road and then started to move, following the preceding vehicle without stopping at the stop sign. This is not a true stop condition if the driving behavior is influenced by the preceding vehicle. So, vehicles reaching the stop sign without any queue or not influenced by the preceding vehicle in a queue were counted as the stopped vehicle.

Figure 7: Time frames of a trip video showing the effect of the preceding vehicle (Frame 1: The driver sees the stopped vehicle; Frame 2: stops behind the vehicle; Frame 3 to 6: The driver starts to move following the preceding vehicle without stopping at the stop sign)

3.1.2.2 Driver and trip allocation

Table 2 describes the number of trips and study participants for all six locations. A total of 428 trips were recorded, and it was then matched with the participant data available in the NDS database. During the study, it was found that 53 unique participants took these 428 trips. Some participants took only one trip, and some participants took several trips. If a participant has taken trips for more than one location, it was considered a different study participant considering different behavior for a different location. Thus, a total of 65 study participants were evaluated for six intersections.

Table 2 Description of trips and participants for each location

Location	Total number of study participants	Total no. of trips	Percentage of trips by location
FL1.0	17	94	22%
FL2.0	6	161	38%
FL3.0	8	29	7%
FL5.0	8	40	9%
FL6.1	5	40	9%
FL7.0	21	64	15%
Total	65	428	100%

For the analysis purpose, recorded stopping behavior was divided into four different categories for a single two-stage left-turn maneuver. The categories are drivers stopped at the minor road stop sign, drivers stopped at the median opening, drivers stopped at both minor roads and the median, and drivers who did not stop at any stage. The categories are mutually exclusive, which means the percentages of the four categories will not add up to 100%. However, the driver stopping or not stopping at one category will add up to 100%. For example, if at location Fl 1.0, 51% of drivers stooped at minor road stop signs, it means 49% of them did not stop at the minor road stop sign.

3.1.3 Results and Discussion

Two-stage left turn behavior analysis was conducted on the individual intersection and also overall. Table 3 shows the analysis of stopping behavior for six locations. Finally, the analysis was conducted based on the type of location to understand the effect of geometric and traffic conditions of the intersections on driver-stopping behavior. The results are further discussed in the next section.

Table 3 Two-stage left turn-stopping behavior for each location

Location	No. of study participants	Stopped at minor road stop sign	Stopped at median	Stopped at both minor road and median	Did not stop at any stage
FL1.0	17	51%	19%	5%	35%
FL2.0	6	65%	10%	1%	26%
FL3.0	8	70%	14%	12%	28%
FL5.0	8	57%	9%	5%	39%
FL6.1	5	80%	28%	27%	19%
FL7.0	21	38%	6%	5%	61%
Total	65	53%	13%	7%	41%

The results are shown graphically in figure 8 and figure 9 for better understanding. Figure 8 shows the result of the analysis of stopping behavior for all locations. Overall, the percentage of drivers stopping at minor roads is around 53% which means a substantial percentage (47%) of drivers did not stop at minor road stop-controlled intersections. The result aligns with past studies where 50% of the drivers are found not to stop at minor road speed stop-controlled intersections (12,14,15). This minor road stop control intersection needs more attention from both the design and maintenance points of view.

Minimal percentages of drivers stop at the median (13%). A huge percentage of drivers (87%) did not stop at the median opening. In these intersections, there was no pavement marking or signage on the median opening. Therefore, more focus should be given to median opening treatments to control the driver behavior at the median opening.

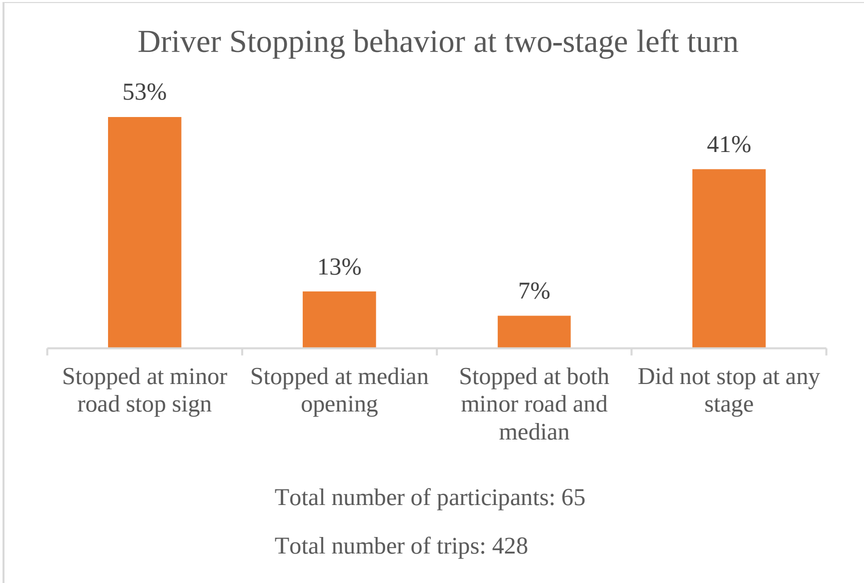


Figure 8 Driver behavior for all locations

Figure 9 shows the result of the analysis of driver behavior by type of location. A higher percentage of drivers did not stop at a 4-leg intersection (type 4), having a major road speed limit of 55 mph. The scenario is not the same for a 3-leg intersection (type 1) with the same major road speed limit. So, the major road speed limit alone is not playing a role in driving behavior. However, it can be explained with the combination of AADT and a minor road speed limit. AADT of type 4 (26,000) is less than type 1 (33,000). The same major road speed limit with less traffic at the type 4 intersection (compared to type 1) leaves more gaps for minor road drivers, leading to more violations. Moreover, a higher minor road speed limit at the type 4 intersection increases the violation of stopping the behavior.

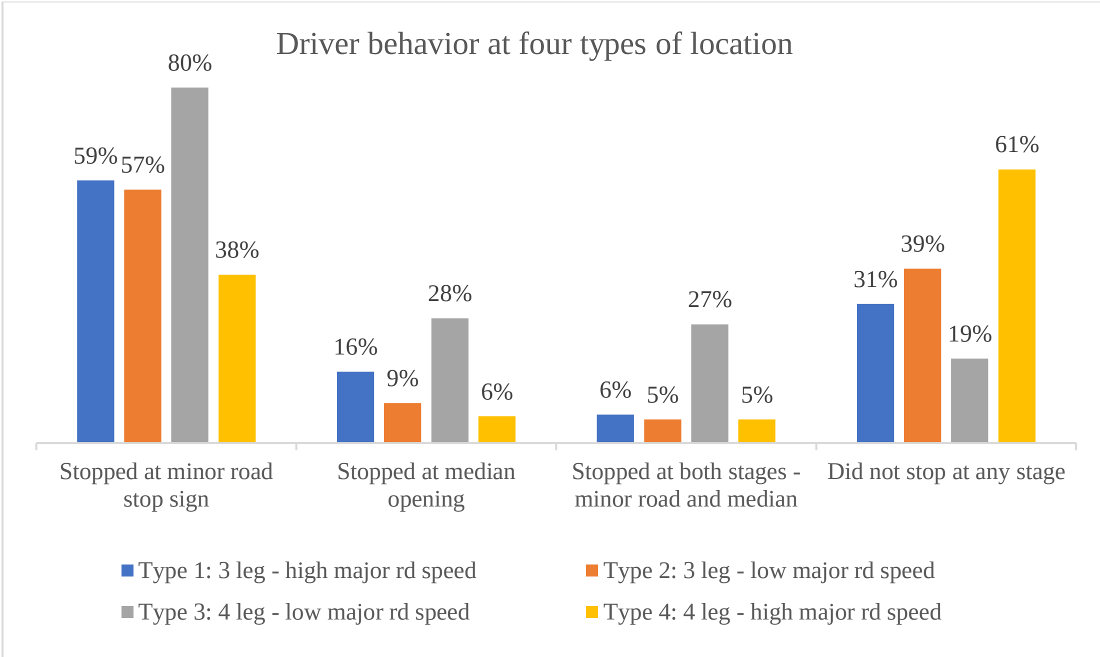


Figure 9 Driver stopping behavior by type of locations

Both type 3 and type 4 are 4-leg intersections. Despite this, type 3 has the highest vehicle percentage stopped on a minor road. In this case, major road AADT is the same for both types; however, the speed limit is much lower for type 3. Due to the same traffic but high speed on the major road, minor road drivers will get fewer gaps, encouraging them to abide by the stopping rules. Furthermore, a lower minor road speed limit of type 3 location (compared to type 4) also might encourage a driver to become less aggressive and maintain the rules.

In general, a 3-leg intersection is finer than a 4-leg intersection with respect to stopping behavior at the median opening. Of 3-leg intersections, type 1 has the highest percentage. A combination of high speed and AADT might provide less gap for vehicles at the median opening that might encourage them to stop before completing the second stage of the left-turn movement.

3.1.4 Summary

The stopping behavior study shows that a huge percentage (87%) of drivers do not stop at the median while taking a left turn from the minor road approaches as these medians do not have any traffic control measures. Also, the stopping behavior is influenced by the traffic characteristics such as the major road speed and the major road AADT. Therefore, in the next step, this study will try to find what is the effect of traffic control measures in the medians on driver behavior by comparing stopping behavior on treated and non-treated medians using the field video data.

3.2 DRIVER BEHAVIOR ANALYSIS USING FIELD VIDEO DATA

3.2.1 Study Intersections

A total of 12 intersections in Alabama were selected in this study. At first, six intersections were selected, which had the median opening treatments implemented by ALDOT. Three of the selected intersections had stop lines/signs control, and the other three had just yield lines/sign control. Then six other intersections were selected with no median opening treatments. The 12 intersections were paired into six different groups having similar road geometry and traffic characteristic, one having access control and one without any access control on the medians. Each study location meets the following criteria: unsignalized intersection on multilane divided highways, wide median (> 30 ft), and major road with high-speed limit (> 45 mph).

Table 4 shows the detailed geometric design features and median treatments at the six pairs of study locations. All the study locations are on four-lane divided highways with left-turn bays on the major roads. Geometric design features, major road traffic volumes, and speeds are very similar within each group of study locations.

Groups 1, 2, and 3 have the median treatments of yield signs and yield lines. Groups 3,4 and 6 have stop signs and stop lines as the median treatment.

Figure 10 shows the Google Map Street View of the six groups of the study locations. The pictures are paired into six groups, treated intersections are on the left, and non-treated intersections are presented on the right side.

Table 4 Study Intersection details

Intersection Group	Type	Route	Median Width (ft)	Median Opening Width (ft)	Major Rd Speed Limit (mph)	Median Treatments
Group 1	Treated	U.S. 80 & AL 25	42	72	65	Yield lines and yield signs; line; painted triangle islands. double yellow
	Non-treated	U.S. 80 & AL 97	43	62	65	-
Group 2	Treated	U.S. 431 & AL 169	60	90	65	Yield lines and yield signs; double yellow line (faded)
	Non-treated	U.S.431 & Cutchin Dr	55	90	65	-
Group 3	Treated	US 280 & Cty Rd 21	45	85	65	Yield lines and yield signs; double yellow line
	Non-treated	U.S.280 & Cty Rd 87	55	90	65	-
Group 4	Treated	U.S.280 & Cty Rd 40	70	50	65	Stop lines and stop signs; double yellow line
	Non-treated	U.S.280 & Cty Rd 87	55	70	65	-
Group 5	Treated	U.S. 84 & AL 51	70	40	65	Stop lines and stop signs; tapered on median opening two sides; double yellow line.
	Non-treated	U.S. 84 & AL 533	50	80	65	-
Group 6	Treated	Atlanta Hwy & Somerset Dr	70	40	55	Stop lines and stop signs; double yellow line
	Non-treated	Atlanta Hwy & New Haven Blvd	40	60	55	

Intersection group 1

Treated

Non-treated

Intersection group 2

Treated

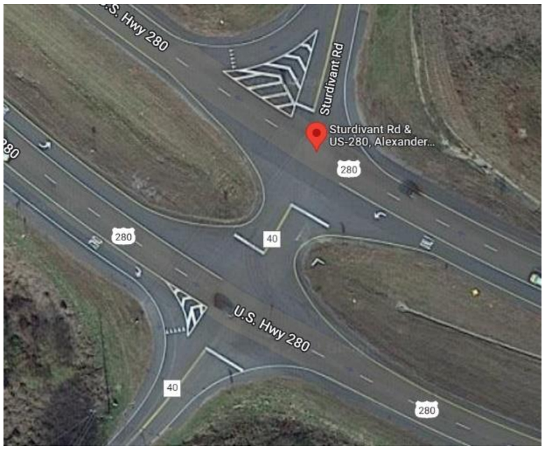
Non-treated

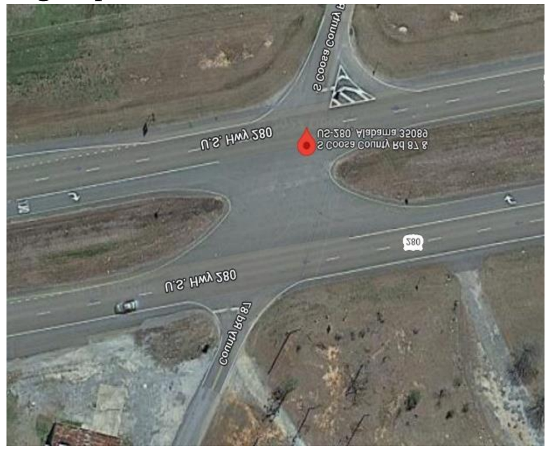
Intersection group 3

Treated

Non-treated

Intersection group 4





Treated Non-treated

Intersection group 5

Treated Non-treated

Intersection group 6

Treated Non-treated

Figure 10 Selected Intersections for field video data collections

3.2.2 Data Collection and Methodology

A total of 48 hours of videos were recorded for each location. Finally, 16 hours of video were observed manually. Sixteen hours of the video consists of 8 hours of video of a day, including 3 hours of morning period (6 am to 9 am), 2 hours of midday (11 am to 1 pm), and 3 hours of evening period (6 pm to 9 pm).

Figure 11 shows the screenshot of the video data. The study recorded whether the vehicle stopped or not at the median opening.

Figure 11 Screenshot of recorded video

3.2.3 Results and Discussion

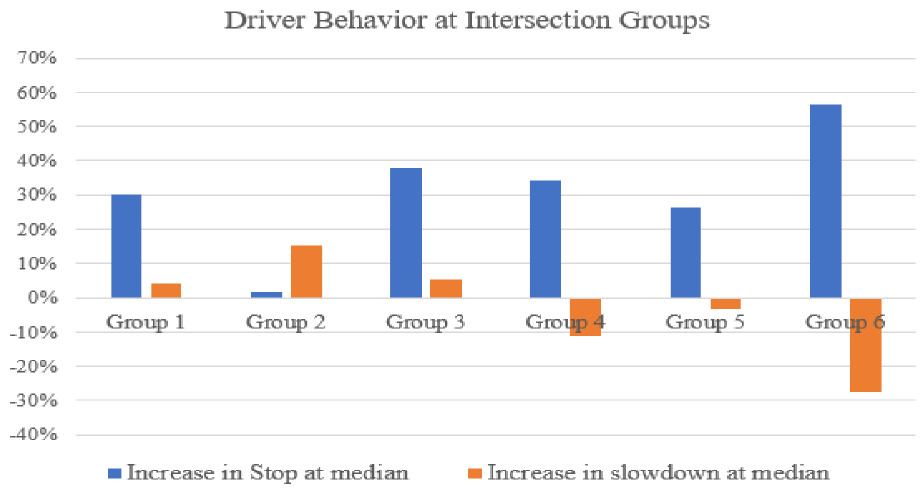
Table 5 summarizes the stopping behavior at median openings in treated and non-treated. The percentages of stop condition on the median are higher in treated intersections for all the groups of intersections, which indicate that the treatment has some effect on driver behavior. The percentage of a slowdown is higher for the first three groups and lower in the last three groups of intersections.

Table 5 Summary of conflict study results

Intersection Group	Type	Stop at median	Slowdown at median	Did not stop at median
Group 1	Treated	35.14%	9%	56%
	Non-treated	5.02%	5%	90%
Group 2	Treated	6.10%	27%	67%
	Non-treated	4.34%	11%	84%
Group 3	Treated	51.71%	22%	26%
	Non-treated	13.64%	17%	69%
Group 4	Treated	47.98%	6%	46%
	Non-treated	13.64%	17%	69%
Group 5	Treated	52.05%	37%	11%
	Non-treated	25.51%	40%	34%
Group 6	Treated	98.95%	0%	1%
	Non-treated	42.44%	28%	30%

The result can be better understood with the graphical representation. Figure 12 shows the difference in percentages of stopping behavior in the treated intersection from non-treated intersections. The percentage of stopping in the median increases in all the intersections because of the presence of treatments. However, the percentage in the latter three groups is high than the first three groups of intersections since the last three groups have the stop sign treatment.

For the same reason, the percentage of slowdown decreased in the last three groups as the drivers tended to stop more than slow down. But the intersections with yield sign treatments have increased in slowdown conditions at medians. This result indicates that the treatments are well followed by most of the drivers.



Intersection Group	Median Treatments
Group 1	Yield lines and yield signs; painted triangle islands.
Group 2	Yield lines and yield signs; double yellow line (faded)
Group 3	Yield lines and yield signs; double yellow line
Group 4	Stop lines and stop signs; double yellow line
Group 5	Stop lines and stop signs; tapered on median opening two sides; double yellow line.
Group 6	Stop lines and stop signs; double yellow line

Figure 12 Results of effectiveness of median treatments on driver behavior

3.3 STATISTICAL SIGNIFICANCE OF STOPPING BEHAVIOR

Unrelated proportion tests were conducted to determine the effect of treatment on the stopping behavior at the median opening.

The null hypothesis is that there is no difference between the means of the number of vehicles stopped at the median opening for the treated and non-treated intersection.

$$H_0 = p_N - p_T$$

Therefore, $H_1 = p_N \neq p_T$

The test results are shown in Table 6. The results indicate that there is a significant difference between the number of vehicles stopped at the median opening of non-treated intersections and treated intersections for all the groups except group 2. The p-value is less than 0.05 for groups 1,3,4,5 and 6. We, therefore, reject the null hypothesis, and there is evidence that the proportion of conflicts in treated intersections is different from the proportion of conflicts in non-treated intersections. This is true for groups 1,3,4,5, and 6.

Group 2 has a p-value that is greater than 0.05. We, therefore, cannot reject the null hypothesis for this group. Though this group has a better percentage of stopping at the median opening in the treated intersections than the non-treated intersections, the result is not significant. The group two treatment is faded. This could be one reason behind the stopping percentages being relatively low for group 2.

Table 6 Statistical test results for stopping behavior

Intersection Group	**Test name**	**Sample**	**Standard Error**	**p-value**	**Accept/Reject null hypothesis (95% CI)**
Group 1	Unrelated proportion test	N_T = 296 N_N = 916	0.022017	<0.00001	Reject
Group 2		N_T = 328 N_N = 692	0.014479	0.224175	Accept
Group 3		N_T = 938 N_N = 198	0.038914	<0.00001	Reject
Group 4		N_T = 446 N_N = 196	0.041488	<0.00001	Reject
Group 5		N_T = 684 N_N = 588	0.027525	<0.00001	Reject
Group 6		N_T = 856 N_N = 714	0.022435	<0.00001	Reject

3.4 COMPARISON OF STOPPING BEHAVIOR ANALYSIS USING NDS AND FIELD VIDEO DATA

The stopping behavior using NDS data and field video data was compared. In both studies, the average percentage of drivers stopping at the median opening is taken. For NDS data, the non-treated intersections were evaluated. For field data, treated and non-treated intersections were evaluated.

Figure 13 shows the comparative stopping behavior analysis using NDS and field video data. From the figure, it can be seen that in non-treated intersections, for both NDS and field data, the percentage of stopping at the median opening is very low (13% and 17%, respectively). Both the percentages are very close also. On the other hand, the average percentages are very high (49%) in treated intersections compared to non-treated intersections.

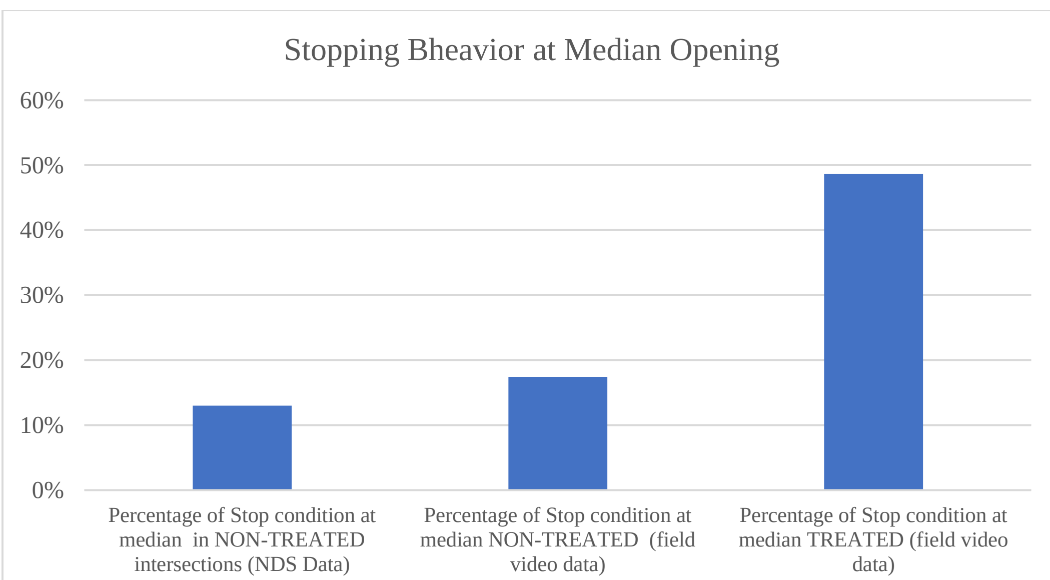


Figure 13 Comparison of stopping behavior at the median opening in treated and non-treated intersections using NDS and field video data

CHAPTER 4

TRAFFIC CONFLICT ANALYSIS OF TREATED AND NON-TREATED INTERSECTIONS

This chapter outlines the methodology of traffic conflict analysis. The comparative analysis between treated and non-treated intersections are presented in this chapter. The results are then summarized with statistical significance test.

4.1 DATA COLLECTION

The study focuses on finding if the median treatment is effective in having a difference in traffic conflict rates between the treated and non-treated intersections described in the previous chapter (chapter 3, part 3.2.1). For the conflict rate analysis, the study observed the videos manually, and the traffic conflicts were recorded with Post Encroachment Time (PET). The traffic counts from the minor road approaches were recorded. The methodology of the traffic conflict rates is described in the next section.

4.2 METHODOLOGY

The study used the traffic conflict study as an indirect method of safety performance evaluation technique to evaluate the safety effectiveness at the median opening; a traffic conflict is an observable event that would cause a crash unless one of the involved parties slows down, changes lanes, or accelerates to avoid collision (37). In this study, the following performance measures are used:

- **Traffic Conflicts Rate**: The following equation states the definition of conflict rate used in this study:

Conflict Rate (per left-turn volume) = $\frac{Number\ of\ total\ conflicts}{Number\ of\ Total\ left\ turning\ vehicle}$ x 100

- **PET:** PET is defined as the time between the moment the first vehicle crosses a path and the moment that the second reach that path of the first (31). Lower values of PET are indicated as possibly critical. In this study, PET smaller than 3s is considered a potential conflict, and PET equal to or less than 1s is considered a critical conflict (near crash).
- **Near Crash** Rate: The following equation states the definition of conflict rate used in this study:

  Near crash rate (per left-turn volume) = $\frac{Number\ of\ total\ conflicts\ with\ PET\ value\ 1s\ or\ lower}{Number\ of\ Total\ left\ turning\ vehicle}$ x 100

4.3 RESULTS OF THE COMPARATIVE CONFLICT RATE ANALYSIS

The above-mentioned performance measures were used to analyze the safety effect of treatments, including the yield sign and yield line at the median and the stop sign and lines at the median. The first three groups of the study locations are used to evaluate the safety effectiveness of yield signs and yield lines, and the last three groups are for the stop sign and stop line.

Table 7 presents the conflict rate analysis results. The traffic volume, conflicts, and near-crash events were observed from the video data. Then the conflict rate and near-crash rate are calculated using the equations described in the methodology. In all the groups, the treated intersections have fewer conflict rates and near-crash rates than the non-treated intersections. For example, group 6 has the highest percentage of conflict rate (88.8%) in the non-treated intersection. In other words, this non-treated intersection had around 89 conflict events per 100 left-turning traffic volumes. The treated intersection, on the other hand, had around 49 conflicts per 100 left-turning traffic volumes. Therefore, the treated intersection has 40 fewer conflicts per 100 left-turning volumes than the non-treated intersection.

Figures 14 and 15 are the graphical representations of the conflict rate ad near crash rate study. The result shows that the treated intersections have 8% to 40% fewer conflict rates than the non-treated intersections.

Table 7 Summary of conflict rate and near-crash rate study

Intersection Group	Type	No. of traffic volume (left turn)	No. of observed Conflicts	Conflict Rate	No. of Observed Near-Crash events	Near crash Rate
Group 1	Treated	296	96	32.43%	6	2.03%
	Non-treated	916	410	44.76%	20	2.18%
Group 2	Treated	328	30	9.15%	2	0.61%
	Non-treated	692	174	25.14%	49	7.08%
Group 3	Treated	938	88	9.38%	25	2.67%
	Non-treated	198	73	36.87%	29	14.65%
Group 4	Treated	446	130	29.15%	6	1.35%
	Non-treated	198	73	36.87%	29	14.65%
Group 5	Treated	684	210	30.70%	12	1.75%
	Non-treated	588	380	64.63%	18	3.06%
Group 6	Treated	856	418	48.83%	10	1.17%
	Non-treated	714	634	88.80%	44	6.16%

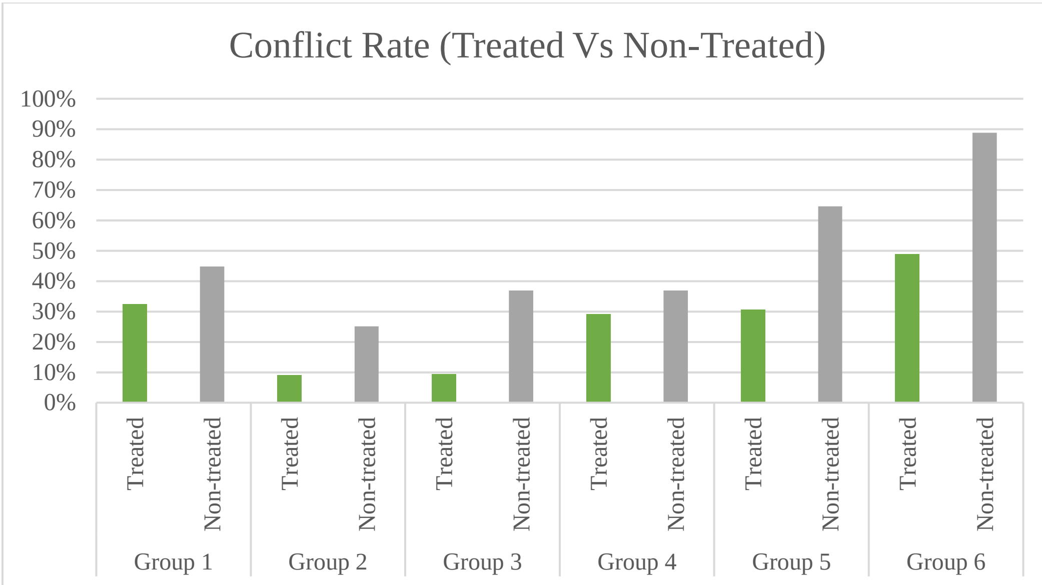


Figure 14 Results of the conflict rate analysis

The differences in near-crash rates are very different for each group. The differences in near-crash rates range from 0.16% to 13.3% from non-treated to treated intersections. But overall, all the treated intersections had fewer near-crash rates than the non-treated ones.

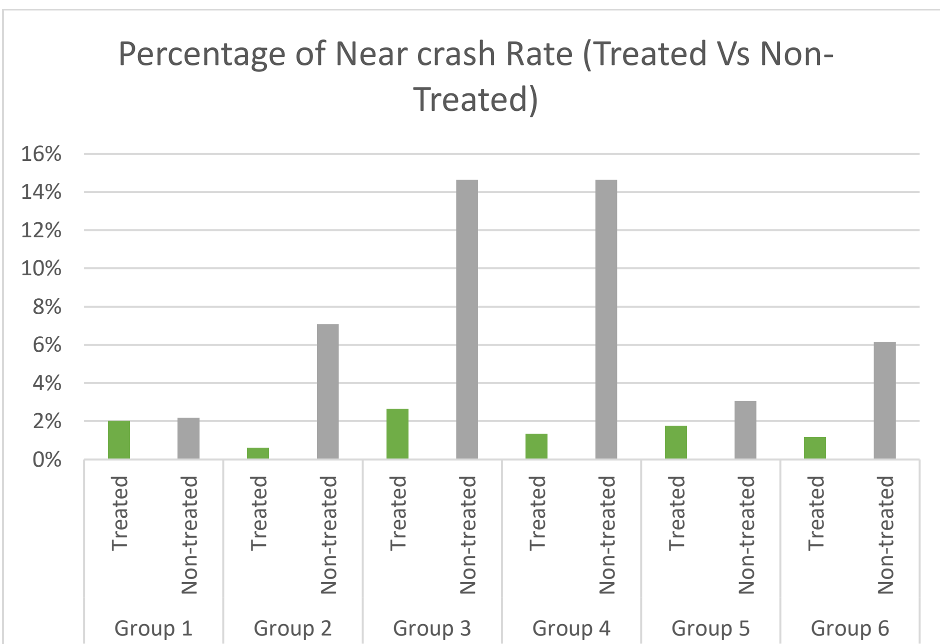


Figure 15 Results of near crash rate analysis

4.4 STATISTICAL SIGNIFICANCE OF THE RESULT

Unrelated proportion tests were conducted to determine the effect of treatment on no. of observed conflicts for each group

The null hypothesis is that there is no difference between the means of no. of observed conflicts for the treated and non-treated intersection.

$$H_0 = p_N - p_T$$

Therefore, $H_1 = p_N \neq p_T$

The test results are shown in Table 8. The results indicate there is a significant difference between the number of observed conflicts of non-treated intersections and treated intersections. The p-value for all the groups is less than .05. We, therefore, reject the null hypothesis, and there is evidence that the proportion of conflicts in treated intersections is different from the proportion of conflicts in non-treated intersections. This is true for all six groups.

Table 8 Statistical test results for traffic conflict

Intersection Group	Test name	Sample	Standard Error	p-value	Accept/Reject null hypothesis (95% CI)
Group 1	Unrelated proportion test	$N_T = 296$ $N_N = 916$	0.03297	0.000191	Reject
Group 2		$N_T = 328$ $N_N = 692$	0.026	<0.00001	Reject
Group 3		$N_T = 938$ $N_N = 198$	0.02728	<0.00001	Reject
Group 4		$N_T = 446$ $N_N = 196$	0.0398	0.041911	Reject
Group 5		$N_T = 684$ $N_N = 588$	0.02805	<0.00001	Reject
Group 6		$N_T = 856$ $N_N = 714$	0.0238	<0.00001	Reject

CHAPTER 5

DEVELOPMENT OF CRASH MODIFICATION FACTOR OF MEDIAN OPENING TREATMENTS USING CROSS-SECTIONAL EB METHOD

The chapter describes the steps in developing CMF for treatments. This chapter also describes the crash data extraction process, describes the cross-sectional and EB method in developing CMF. All the equations, models, and procedures are described in detail in this chapter. Finally, the CMF value with standard deviation is presented in this chapter.

5.1 DATA COLLECTION FOR DEVELOPING CMF

The HSM describes that there are three types of data required to develop CMF:

- **Crash Data:** The data elements in a crash report describe the overall characteristics of the crash. While the specifics and level of detail of this data vary from state to state, in general, the most basic crash data consist of the crash location, date and time, crash severity and collision type, and basic information about the roadway, vehicles, and people involved. For this study, the most recent crash data (2016-2020) were collected from ALDOT for the six groups of study intersections. The intersections were located by filtering the following criteria:
    - Latitude/longitude
    - County/City Name
    - Route Name
    - Intersecting Street

Then the left turn-related crashes were extracted for the study intersections. The Crash Extraction Criteria are described below:

- Intersection Related/At intersection Crash
- CU Vehicle Maneuvers: Turning left
- Crash Severity: All

In this study, all types of crash severity were selected because of the low number of crashes in each intersection.

- **Facility Data:** The roadway or intersection inventory data provide information about the physical characteristics of the accident site. The most basic roadway inventory data typically include roadway classification, number of lanes, length, presence of medians, and shoulder width. The study intersections detail was already collected in the traffic conflict study, and it was described in chapter five.
- **Traffic Volume Data:** In most cases, the traffic volume data required for the methods in the HSM are annual average daily traffic (AADT). Other data that may be used for crash analysis include intersection total entering vehicles (TEV) and vehicle miles traveled (VMT) on a roadway segment, which is a measure of segment length and traffic volume. In this study, the major and minor road AADT data was collected from the Alabama Traffic Data website (38). The traffic volume data was collected for five study years (2016 to 2020). The study year and the county of the study intersection were input in the search filter. The AADT value was recorded for both major and minor approaches of each intersection. The screenshot of the website is presented in Figure 16.

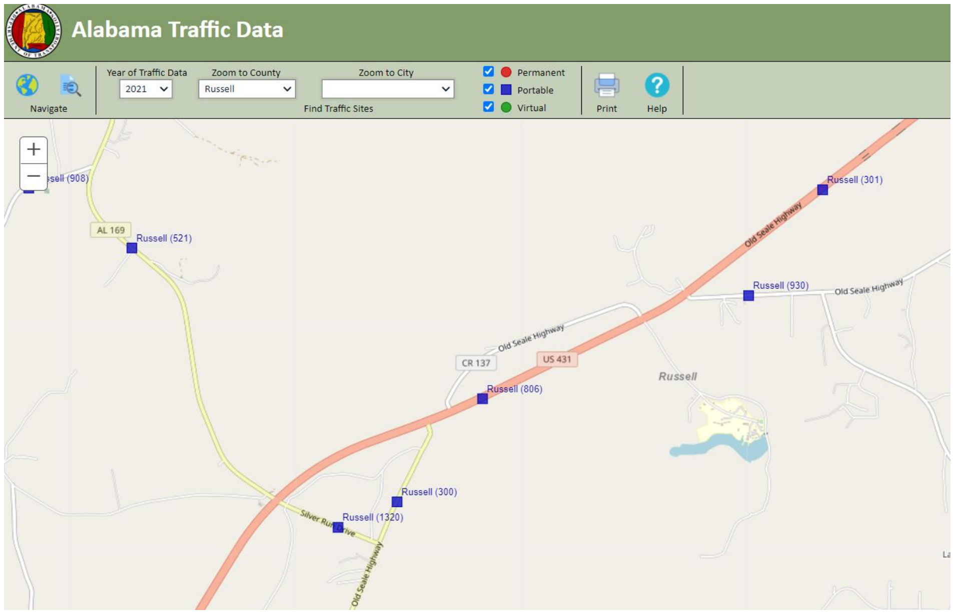


Figure 16 Collection of AADT from Alabama traffic data website

5.2 OVERVIEW OF DEVELOPING CRASH MODIFICATION FACTOR

The crash modification factor (CMF) is the ratio of the crash frequency with improvement over that without improvement. The average crash frequency is the number of crashes in a year. It is identified as the total number of crashes divided by the total number of observed years. The following equation shows the relationship between the crash modification factor and average crash frequency.

$$\text{Crash Modification Factor} = \frac{\textbf{\textit{Average Crash Frequency in Treated Intersections}}}{\textbf{\textit{Average Crash Frequency in Non-treated Intersections}}}$$

In this study cross-sectional study has been conducted to calculate the ratio. The average crash frequency for treated and non-treated intersections is calculated following the predictive method in HSM.

5.2.1 Observational Cross-Sectional Study

According to HSM, the scope of an observational cross-sectional study is the evaluation of a treatment where there are few roadways or facilities where treatment was implemented, and there are many roadways or facilities that are similar, except they do not have the treatment of interest. Data are collected for a specific time period for both groups. The crash estimation based on the crash frequencies for one group is compared with the crash estimation of the other group. In this study, the cross-sectional method was selected because the before and after the crash was not available. Since the correct implementation period of the treatments was not known. The crash data was collected for the same time period for two groups of intersections (treated vs. non-treated).

5.2.2 Predictive Method

The predictive method presented in HSM Part C provides the methodology to estimate the expected average crash frequency of a site, facility, or roadway network for a given time period, geometric design and traffic control features, and traffic volumes (AADT) (7). The expected average crash frequency, $N_{expected,}$ is estimated using a predictive model estimate of crash frequency, $N_{predicted}$ (referred to as the predicted average crash frequency), and, where available, observed crash frequency, $N_{observed}$.

The basic elements of the predictive method are:

- **Safety Performance Functions (SPFs):** The statistical" base" models are used to estimate the average crash frequency for a facility type with specified base conditions. In this study, The SPF presented in the HSM for intersection segments on divided multilane highways is used.

- **Crash Modification Factors (CMFs):** CMFs are multiplied with the crash frequency predicted by the SPF to account for the difference between site conditions and specified base conditions.
- **Calibration factor (CR):** multiplied with the crash frequency predicted by the SPF to account for differences between the jurisdictions. The recently developed CR for Alabama is used in the study.

5.2.3 Empirical Bayes (EB) method

The EB Method is used to combine the estimation from the statistical model with the observed crash frequency at the specific site. A weighting factor is applied to the two estimates to reflect the model's statistical reliability. The EB Method is a key tool to compensate for the potential bias due to regression-to-the-mean. The EB Method is used in the HSM because it is best suited to the context of the HSM. When observed crash data is not available or applicable, the EB Method does not apply. If the EB Method is applicable only when the predicted and observed crashes are both available for the study sites. According to HSM, at least two years of observed crash frequency data are desirable to apply the EB Method. According to HSM, the historical crash data on any facility (i.e., the number of recorded crashes in a given period) is referred to as the "observed crash frequency." In this study, observed crash frequency data of five years period were available for study intersection.

5.3 STEPS IN DEVELOPING CRASH MODIFICATION FACTOR

The detailed step-by-step procedure for calculating the desired CMF is described in the following sections. The steps are conducted for all the study locations. Step 1 to 4 is calculated for all the study years.

5.3.1 Step 1: Determine and Apply the Appropriate Safety Performance Function (SPF) For Each Site's Facility Type and Traffic Control Features.

The following equation (HSM equation 11-4) is the equation to calculate the predicted number of crashes for all intersection types.

$$N_{predicted\ int} = N_{spf\ int} \times CR \times (CMF_{1i} \times CMF_{1i} \times \ldots \times CMF_{4i})$$

Where,

$N_{predicted\ int}$ = predicted average crash frequency for an individual intersection for the selected year;

$N_{spf\ int}$ = predicted average crash frequency for an intersection with base conditions;

$CMF_{1i} \ldots CMF_{4i}$ = Crash Modification Factors for intersections

CR = calibration factor for intersections of a specific type

The SPF presented in the HSM for intersection segments on divided multilane highways is used to calculate $N_{spf\ int.}$ The SPF for crash frequency stated in HSM Equations 11-11

$$N_{spf\ int.} = \exp[a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})]$$

Where,

$N_{spf\ int}$ = SPF estimate of intersection-related expected average crash frequency for base conditions;

$AADT_{maj}$ = AADT (vehicles per day) for major road approaches;

$AADT_{min}$ = AADT (vehicles per day) for minor road approaches;

a, b, c, d = regression coefficients.

The intersection SPFs for rural multilane highways are applicable to the following AADT ranges:

- 3ST: *AADTmaj* 0 to 78,300 vehicles per day and
  AADTmin 0 to 23,000 vehicles per day

- 4ST: *AADTmaj* 0 to 78,300 vehicles per day and

  AADTmin 0 to 7,400 vehicles per day

The collected AADT of major and minor is within the applicable range.

The regression coefficient is taken from the HSM Exhibit 11-11, which is represented in Table 9:

Table 9 SPF Coefficients for Three- and Four-leg Intersections with minor road Stop Control

Intersection type/severity level	a	b	c	Overdispersion parameter (fixed k)[a]
4ST Total	-10.008	0.848	0.448	0.494
4ST Fatal and injury	-11.554	0.888	0.525	0.742
4ST Fatal and injury[b]	-10.734	0.828	0.412	0.655
3ST Total	-12.526	1.204	0.236	0.460
3ST Fatal and injury	-12.664	1.107	0.272	0.569
3ST Fatal and injury[b]	-11.989	1.013	0.228	0.566

NOTE: [a] This value should be used directly as the overdispersion parameter; no further computation is required.
[b] Using the KABCO scale, these include only KAB accidents. Crashes with severity level C (possible injury) are not included.

5.3.2 Step 2. Calculate Combined Crash Modification Factors (CMFs) to Adjust Base Conditions to Site-Specific Condition

The SPF used in step 1 includes the effect of traffic volume (AADT). The base condition incorporates the following conditions of geometric design and traffic control features:

- Intersection skew angle: 0°
- Intersection left-turn lanes: 0, except on stop-controlled approaches
- Intersection right-turn lanes: 0, except on stop-controlled approaches
- Lighting: None

The SPF used for based conditions need to be adjusted to site-specific geometric design and traffic control features by applying the appropriate CMFs. The equations and exhibits relating to CMFs for stop-controlled intersections are summarized in Table 10:

Table 10 CMFs required to adjust from base condition

CMFs to adjust the base condition	Equation/Exhibit in HSM
Intersection Angle	Equation 11-18/11-20
Left-Turn Lane on Major Road	Exhibit 11-32
Right-Turn Lane on Major Road	Exhibit 11-33
Lighting	Equation 11-22

Finally, a combined CMF is calculated by multiplying all the CMFs

5.3.3 Step 3. Calculate Number of Predicted Crashes $N_{predicted}$ using SPF, Combined CMF, and Local Calibration Factor (LCF)

The number of predicted crashes $N_{predicted}$ crash is calculated by multiplying Nspf, combined CMF (calculated in the previous steps) with the Local Calibration factor (LCF) of Alabama to calibrate the function to the location of the study intersections. LCFs for Alabama were taken from the ALDOT report.

LCF for three-leg intersection (3ST) for Alabama = 0.571

LCF for three-leg intersection (4ST) for Alabama = 0.531

5.3.4 Step 4. Calculate the Number of Left turn Crashes

The number of predicted crashes $N_{predicted}$ crash calculated in the previous step represents all types of crashes in the intersections. But our objective is to find the effects of the treatment only on the left turn-related crashes. The observed crashes collected for each calculate the left turn crashes. Therefore, it is required to find the number of predicted left-turn crashes. First, the study finds the total number of crashes on stopped-controlled intersections in Alabama between the years 2016 to 2020. Then the total number of crashes that occurred while taking a left turn was also recorded for the same period. Finally, it was observed that 23.4% of all intersection-related crashes on stopped-controlled intersections were left-turn-related crashes in Alabama. Therefore, the left-turn crash factor =0.234 is considered to find the predicted number of crashes which is used in the following equation. This value is used for all the study intersections.

$N_{predicted}$ (left turn crashes) = $N_{predicted}$ (all intersection-related crashes) × Left turn crash factor

5.3.5 Step 5. Calculate Number of Predicted Crashes for all Study Years

Steps 1 to 4 are repeated for each study year.

5.3.6. Step 6. Calculate Average Expected Crash Frequency for Each Site

As discussed in the previous section describing the EB method, the number of expected crashes is calculated using the following equation:

$$Nexpected = w \times Npredicted + (1\text{-}w) \times Nobserved$$

Where,

Weighting adjustment factors, $w = \frac{1}{1 + k \times \Sigma(Npredicted\ for\ all\ study\ year)}$

K = overdispersion factor

The overdispersion factor K is taken from HSM Exhibit 11-11.

Steps 1 to 6 are conducted for all the groups of intersections (treated vs. non-treated)

5.3.7 Step 7. Calculate CMF for each group of intersections from $N_{expected}$ of Treated and Non-treated Intersections

Finally, the CMF is calculated using the following equation:

$$\text{CMF} = \frac{Nexpected\ for\ treated\ Intersection}{Nexpected\ for\ non\ treated\ Intersection}$$

The following tables (table 11 and 12) summarizes the procedures conducted in the above steps. Table 11 shows the calculation of the treated intersection in group 1. Table 12 shows the calculation worksheet for developing the CMF for intersection group 1. All other calculation worksheets are presented in the appendix at the end of the report.

Table 11 Sample calculation of combined CMF for adjustment from the base condition to the site-specific condition

CMFs	Equation/Exhibit in HSM	CMF for the specific site
Intersection Angle	Equation 11-20: $CMF_1 = \frac{0.053xSKEW}{1.43 + 0.53xSKEW} + 1$ Skew angle = 53^0	1.079
Left-Turn Lane on Major Road	CMF_2 from Exhibit 11-32	0.72
Right-Turn Lane on Major Road	CMF_3 from Exhibit 11-33	0.86
Lighting	Equation 11-22 $CMF_4 = 1.0 - 0.38xP$ P= proportion of total accidents for unlighted intersections that occur at night = 0.273 (Exhibit 11-34)	0.89626
Combined CMF =	CMF_1 x CMF_2 x CMF_3 x CMF_4	0.372

Table 12 Calculation worksheet for Crash Modification Factors of intersection group 1

				Treated Intersection					
(1)	(2)	(2)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4) *(5) *(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7) *(8)	No. of observed crashes $N_{observed}$
2020	5145	1596	1.72	0.372	0.531	0.34	0.234	0.08	1
2019	5369	1758	1.86			0.37		0.09	0
2018	4206	1664	1.48			0.29		0.07	0
2017	4740	1800	1.69			0.33		0.08	0
2016	3580	2050	1.42			0.28		0.07	1
Overdispersion Parameter, k (Exhibit 11-11) = 0.494						Calculated Weighting adjustment factors, w = 0.843			
$N_{expected}$						**0.127**			
				Non-treated Intersection					
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4) *(5) *(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7) *(8)	No. of observed crashes $N_{observed}$
2020	8674	1486	2.59	0.345	0.531	0.47	0.234	0.11	1
2019	9391	1500	2.79			0.51		0.12	1
2018	8388	1367	2.43			0.44		0.10	1
2017	8920	1370	2.56			0.46		0.11	1
2016	9200	1480	2.724			0.49		0.12	0
Overdispersion Parameter, k Exhibit 11-11 = 0.494						Calculated Weighting adjustment factors, w = 0.783 (Equation 2)			
$N_{expected}$						**0.262**			

5.4 CRASH MODIFICATION FACTOR RESULTS

Table 13 shows the result of the crash modifications. This procedure is done only in the available study locations. All the CMFs are found to be less than one except for group 2. This means the treatment can reduce the number of expected crashes for most of the study intersections. The average CMF is 0.70, representing the reduction in expected crashes after the implementation of the study treatment.

Table 13 Results of CMF calculations in six groups of intersections

Intersection Group	**$N_{expected}$ Treated Site**	**$N_{expected}$ Non-Treated Site**	**CMF**	**Mean CMF**	**SD**
Group 1	0.127	0.262	0.48	0.70	0.22
Group 2	0.287	0.287	1.00		
Group 3	0.136	0.186	0.73		
Group 4	0.144	0.186	0.77		
Group 5	0.096	0.121	0.79		
Group 6	0.259	0.655	0.40		

5.5 STATISTICAL SIGNIFICANCE OF CMF

The average CMF is 0.70, with a standard deviation of 0.22.

The lower and upper limits of the 95% confidence interval are the following:

Lower limit: 0.70 – 1.96*0.22 = 0.70 – 0.4312 = **0.27**

Upper limit: 0.70 + 1.96*0.22 = 0.70 + 0.4312 = **1.13**

Since the 95% confidence interval (0.27, 1.13) includes 1.0, this CMF is not statistically different from 1.0.

The reason for the high Standard Deviation:

- Small Sample Size

- Crash frequency is less than 1 for each site.

Cross-sectional studies are usually suitable for areas where there is more than one similar site for one group of intersections. This procedure is done on a very limited number of sites. Also, due to the unavailability of enough study sites, the one average CMF is calculated for two types of median opening treatments.

CHAPTER 6

COMPARISON OF CONFLICT STUDY RESULTS AND CALCULATED CMFS

This chapter summarizes the results from the conflict study and CMF calculations and presents a comparison of the results between these two methods.

6.1 COMPARING THE CRASH FREQUENCY AND CONFLICT RATE

The traffic conflict analysis showed that the treated intersections had 8% to 40% fewer conflict rates than the non-treated intersections. These differences in conflict rate or near-crash rate for each group are calculated by the following equation:

The difference in conflict rate/near-crash rate = Conflict/near-crash rate of the non-treated intersection of a group – conflict/near-crash rate of a treated intersection of the same group.

The crash reduction factor is calculated from the calculated CMFs using the following equation:

Crash Reduction Factor (CRF) = 1 – CMF

In this study, the crash reduction factor represented the difference in expected crash frequency and was presented as percentages to compare the results.

The difference in estimated crash frequency = CRF x 100

Table 14 summarizes the results.

- All the groups of intersections show positive results in reducing expected crash frequency except intersection group 2. The reason behind this could be that the yield lines in this intersection are faded.
- The average estimated crash difference percentage for stop sign treatment is higher than that of a yield sign. This result aligns with the conflict rate analysis.
- However, the highest difference in the estimated crash frequency among the first three groups of intersections is in group 1. The treated intersection of this group has an extra pavement marking called painted triangle islands. Future studies can be conducted with more study sites to find the effect of this pavement marking.
- The highest difference in conflict rate and also in expected crash frequency is intersection group 6.
- When taking the average for the two types of treatments, the average value for a conflict rate difference is 22.9%, and the average value for an estimated crash frequency difference is 30%.

Table 14 Comparison of conflict rate, near-crash rate, and expected crash frequency

Intersection Group	Difference in conflict rate	Difference in near-crash rate	Difference in estimated crash frequency	Median Treatment Type
Group 1	12.33%	0.16%	52%	Yield lines and yield signs; line; painted triangle islands. double yellow
Group 2	16%	6.47%	0%	Yield lines and yield signs; double yellow line (faded)
Group 3	27.49%	11.98%	27%	Yield lines and yield signs; double yellow line
Avg for Yield Sign Treatment	**18.6%**	**6.2%**	**26%**	**-**
Group 4	7.72%	13.30%	23%	Stop lines and stop signs; double yellow line

Group 5	33.92%	1.31%	21%	Stop lines and stop signs; tapered on median opening two sides; double yellow line.
Group 6	39.96%	4.99%	60%	Stop lines and stop signs; double yellow line
Avg for Stop Sign Treatment	**27.2%**	**6.53%**	**35%**	**-**
Avg for total	**22.9%**	**6.9%**	**30%**	**-**

The graphical representation of the comparative results is illustrated in Figures 17 and 18. All the treatment except group 2 has some difference in conflict rate and expected crash frequency. Group 2 treatment has no impact (0%) on the estimated crash frequency. The difference in the near-crash rate is less than the conflict rate and expected crash frequency in all the groups.

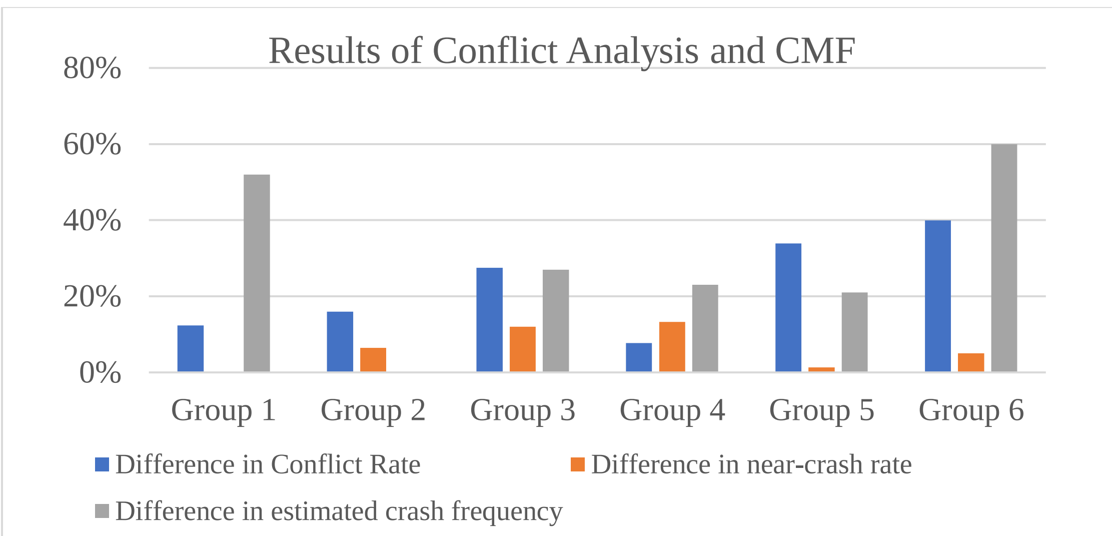


Figure 17 Comparative Results of Conflict Study and CMF Study

The conflict rate and the expected average crash frequency show similar results. Overall, the stop sign treatment is found to be more effective in having fewer conflict rates, near-crash rates, and the expected average crash frequency.

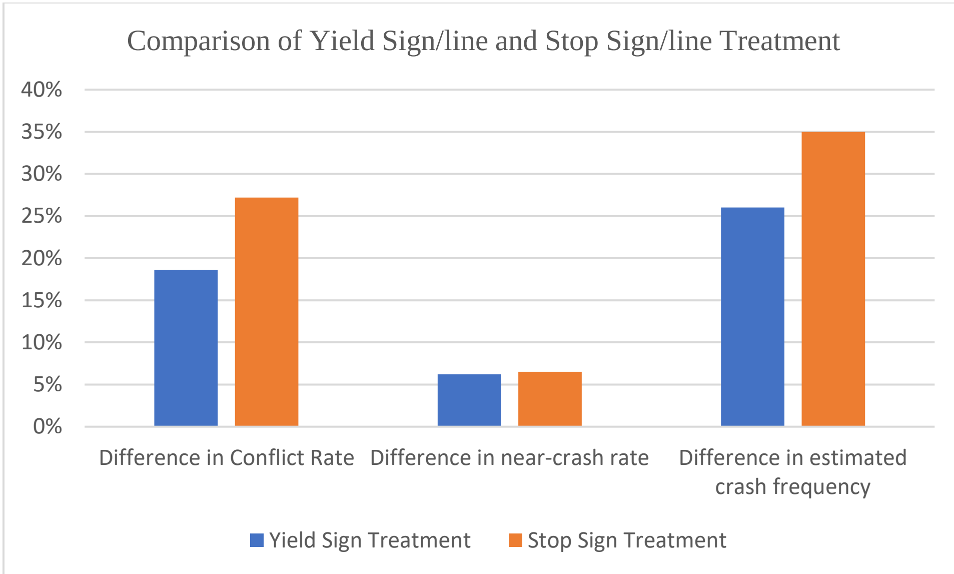


Figure 18 Effectiveness comparison of Yield Sign/line and Stop Sign/line Treatment

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This chapter outlines conclusions and recommendations for future studies. The overview of the whole report is summarized, and concluding remarks are presented in this chapter. Finally, some recommendations for future study are proposed in this section.

7.1 CONCLUSIONS

The objective of this study was to evaluate the effectiveness of the two types of median treatment that are implemented by ALDOT. Firstly, A driver behavior analysis was conducted using NDS data and field video data. The study shows that only 13% (using NDS data) and 17% (from field data) of drivers stopped at the non-treated median openings. On the other hand, in the case of treated intersections, 49% (from field video data) of drivers stopped at the median opening. The statistical test also shows that for most of the groups, there is a significant difference in the drivers stopping behavior between the treated and non-treated intersections. This result indicates that the treatment has an effect on driver-stopping behavior on median opening.

Therefore, this study indicates that there is a need for median treatments to ensure the safety of the overall intersection. Also, the study shows that major road AADT and high major road speed influence the driver's behavior while taking a left turn on a major road. The conflict rate analysis was conducted on intersections with a high major road speed limit.

The conflict rate analysis shows that there is a significant difference in the number of observed conflicts between the treated and non-treated intersections. The treated intersections have 8% to 40% fewer conflict rates than the non-treated intersections. Stop signs are more effective than yield signs.

The calculated mean CMF is 0.70. This type of median treatment can reduce expected crash frequency by 30%. The CMF, along with the conflict study result, shows that these treatments have an overall positive impact on traffic safety.

7.2 RECOMMENDATIONS

The recommendations for future study based on this report are outlined below:

- Future studies can be conducted on a large number of sites using the cross-sectional EB method to get a CMF value with low standard error.
- CMF for different severity levels can be calculated with a large number of sites. Thus, benefit-cost analysis is also possible for these treatments.
- In the future, separate studies can be conducted on yield sign and stop sign treatment with a large number of study sites.
- The study focuses on left-turn-related crashes; in the future, this study can be conducted on crashes for all movements.

Although the standard deviation for the calculated CMF is very high, this CMF, along with the result of the conflict rate analysis, indicates that there is a positive effect of these median treatments on the overall safety and operation of the intersections.

The study focuses on the left turn-related crash; therefore, these treatments can be implemented at unsignalized intersections with high left turn-related crashes.

One of the main important facts is these treatments are very low in cost. Installing signalized intersections requires a lot of study and design decisions, which are costly and time-dependent. Instead of implementing expensive access management techniques, these treatments can be a good solution to reduce risk factors of the intersection. This study will help the policymakers understand the effect of access control treatments on driver behavior and help them in making a decision on the future implementations of these types of treatments.

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APPENDIX

A.1 Calculation Worksheet for Crash Modification Factor: Intersection group 2

Treated Intersection									
(1)	(2)	(2)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4)*(5)*(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7)*(8)	No. of observed crashes $N_{observed}$
2020	10362	938	2.46	0.372	0.531	0.49	0.234	0.11	1
2019	11227	1085	2.81			0.56		0.13	1
2018	11114	1085	2.78			0.55		0.13	0
2017	11000	1110	2.79			0.55		0.13	1
2016	11000	1110	2.79			0.55		0.13	1
Overdispersion Parameter, k (Exhibit 11-11) = 0.494						Calculated Weighting adjustment factors, w = 0.762			
$N_{expected}$						0.287			

Non-treated Intersection									
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4)*(5)*(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7)*(8)	No. of observed crashes $N_{observed}$
2020	10362	1770	3.26	0.372	0.531	0.65	0.234	0.15	0
2019	11227	1852	3.57			0.71		0.17	0
2018	11114	1847	3.53			0.70		0.16	0
2017	11000	1950	3.59			0.71		0.17	2
2016	11000	1860	3.51			0.70		0.16	1
Overdispersion Parameter, k Exhibit 11-11 = 0.494						Calculated Weighting adjustment factors, w = 0.714			
$N_{expected}$						0.287			

A.2 Calculation Worksheet for Crash Modification Factor: Intersection group 3

Treated Intersection									
(1)	(2)	(2)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4)*(5)*(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7)*(8)	No. of observed crashes $N_{observed}$
2020	16138	1534	4.46	0.374	0.531	0.88	0.234	0.207	0
2019	16327	1534	4.50			0.89		0.209	0
2018	15754	1534	4.37			0.87		0.203	0
2017	15210	1550	4.26			0.85		0.198	0
2016	15470	1680	4.48			0.89		0.208	0
Overdispersion Parameter, k (Exhibit 11-11) = 0.494						Calculated Weighting adjustment factors, w = 0.664			
$N_{expected}$						0.136			

Non-treated Intersection									
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4)*(5)*(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7)*(8)	No. of observed crashes $N_{observed}$
2020	14809	1016	3.45	0.376	0.531	0.69	0.234	0.161	0
2019	16102	1148	3.91			0.78		0.182	0
2018	15795	1285	4.04			0.81		0.189	0
2017	15600	1285	4.00			0.80		0.187	1
2016	14760	1280	3.81			0.76		0.178	0
Overdispersion Parameter, k Exhibit 11-11 = 0.494						Calculated Weighting adjustment factors, w = 0.693			
$N_{expected}$						0.186			

A.3 Calculation Worksheet for Crash Modification Factor: Intersection group 4

Treated Intersection									
(1)	(2)	(2)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4)*(5)*(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7)*(8)	No. of observed crashes $N_{observed}$
2020	17309	1667	4.91	0.365	0.531	0.95	0.234	0.222	0
2019	17494	1667	4.95			0.96		0.224	0
2018	17351	1667	4.92			0.95		0.223	0
2017	16890	1690	4.84			0.94		0.219	0
2016	17190	1690	4.91			0.95		0.222	0
Overdispersion Parameter, k (Exhibit 11-11) = 0.494						Calculated Weighting adjustment factors, w = 0.645			
		$N_{expected}$				0.144			

Non-treated Intersection									
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4)*(5)*(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7)*(8)	No. of observed crashes $N_{observed}$
2020	14809	1016	3.45	0.376	0.531	0.69	0.234	0.161	0
2019	16102	1148	3.91			0.78		0.182	0
2018	15795	1285	4.04			0.81		0.189	0
2017	15600	1285	4.00			0.80		0.187	1
2016	14760	1280	3.81			0.76		0.178	0
Overdispersion Parameter, k Exhibit 11-11 = 0.494						Calculated Weighting adjustment factors, w = 0.693			
		$N_{expected}$				0.186			

A.4 Calculation Worksheet for Crash Modification Factor: Intersection group 5

Treated Intersection									
(1)	(2)	(2)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4)*(5)*(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7)*(8)	No. of observed crashes $N_{observed}$
2020	7538	1123	0.89	0.466	0.571	0.24	0.234	0.055	0
2019	7641	1035	0.88			0.24		0.055	1
2018	7496	1022	0.86			0.23		0.054	1
2017	8010	1120	0.95			0.25		0.059	0
2016	8010	1000	0.93			0.25		0.058	0
Overdispersion Parameter, k (Exhibit 11-11) = 0.460						Calculated Weighting adjustment factors, w = 0.885			
		$N_{expected}$						**0.096**	
Non-treated Intersection									
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4)*(5)*(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7)*(8)	No. of observed crashes $N_{observed}$
2020	6456	1021	1.71	0.358	0.531	0.32	0.234	0.076	0
2019	6477	1021	1.71			0.33		0.076	0
2018	6395	1021	1.69			0.32		0.075	2
2017	5720	921	1.47			0.28		0.066	0
2016	5610	921	1.45			0.28		0.064	0
Overdispersion Parameter, k Exhibit 11-11 = 0.494						Calculated Weighting adjustment factors, w = 0.849			
		$N_{expected}$						**0.121**	

A.5 Calculation Worksheet for Crash Modification Factor: Intersection group 6

Treated Intersection									
(1)	(2)	(2)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4)*(5)*(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7)*(8)	No. of observed crashes $N_{observed}$
2020	23954	2098	7.17	0.345	0.531	1.31	0.234	0.307	0
2019	24433	2140	7.36			1.35		0.315	1
2018	23954	2098	7.17			1.31		0.307	0
2017	23484	2057	6.99			1.28		0.299	0
2016	23023	2017	6.81			1.25		0.292	0
Overdispersion Parameter, k (Exhibit 11-11) = 0.460						Calculated Weighting adjustment factors, w = 0.570			
		$N_{expected}$						**0.259**	

Non-treated Intersection									
Year	$AADT_{maj}$	$AADT_{min}$	N_{spf} (HSM Eqn 11-1)	Combined CMF	Local Calibration Factor, LCF	Predicted Crashes (all intersection related crash) = (4)*(5)*(6)	Factor for left-turn crash	No. of Predicted crash (left turn crash) $N_{predicted}$ = (7)*(8)	No. of observed crashes $N_{observed}$
2020	19619	1750	7.17	0.345	0.531	1.02	0.234	0.239	0
2019	24433	1785	7.36			1.24		0.291	6
2018	25433	1750	7.17			1.27		0.298	0
2017	24410	1716	6.99			1.22		0.285	0
2016	24460	1683	6.81			1.21		0.283	0
Overdispersion Parameter, k Exhibit 11-11 = 0.494						Calculated Weighting adjustment factors, w = 0.591			
		$N_{expected}$						**0.659**	