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An analysis of driver behavior in response to warning beacon installations on stop signs

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An analysis of driver behavior in response to warning beacon installations on stop signs

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DEDICATION

I would like to dedicate this research effort to my father, Wenze Liu, and my mother, Weidong Wang for encouraging me to enroll into the graduate program of Iowa State University. Also, to my husband, John Panicola for being a supporting partner and helping me getting through all the difficult times

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NOMENCLATURE

AADT	Annual Average Daily Traffic
CTRE	Center for Transportation Research and Education
DF	Degree of Freedom
DOT	Department of Transportation
LED	Light Emitting Diode
NHTSA	The National Highway Traffic Safety Administration
Std.Dev	Standard Deviation
TWSC	Two-Way Stop Control
USDOT	The United States Department of Transportation

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ABSTRACT

Driver gap selection was a principal safety concern at stop-controlled rural intersections. Previous study shows that intersection crashes account for 30 percent of severe crashes and 40 percent crashes happening in rural intersections. Stop sign mounted beacons were installed and evaluated at six selected rural intersections in Iowa. Data were collected before and after installation. The treatments were evaluated by comparing brake activation distance. A two-sample test of means was applied on brake activation distance and logistic regression models were developed to compare driver behavior between before and after installation. The analysis considered differences in driver stopping behavior, including where drivers stop and when they began decelerating in advance of the intersection. Measures of effectiveness focused on unsafe driver behaviors and evaluated how the treatments affected those behaviors. The results provide insights as to the impacts of stop sign mounted beacons on driver behavior.

CHAPTER 1: INTRODUCTION

1.1 Background

The United State Department of Transportation (USDOT) (2001) indicated that transportation crashes were ranked as the seventh highest cause of death in the United States. The National Highway Traffic Safety Administration (NHTSA) (2005) showed that 95% of transportation related deaths were motor vehicle crashes. Transportation crashes would cause trauma and financial loss to victims not only themselves but also their families and friends (Li et al., 2007). A total of $242 billion was spent on economic cost of motor vehicle crashes in the United States in 2010 (NHTSA, 2015). It is approximately similar to cost $784 from each person in the United States and about 1.6 percent of the U.S. Gross Domestic Product. Rural intersection crashes happen frequently due to vehicles passing through with high approach speeds. Intersection crashes account for 30 percent of severe crashes and 6 percent of all fatal crashes (Oneyear et al., 2016). Of the fatal crashes, 40 percent of those occur in rural areas in Iowa (Iowa Department of Transportation, 2016). Unsignalized rural intersections accounted for 80% of intersection fatalities with more than 20% of fatalities happened around the United States. Different traditional treatments have been applied by transportation agencies to improve the rural intersection safety.

1.2 Research Objective

Failure to yield and underestimation of gaps are common causes for crashes at rural intersections. Vehicle types, driver behavior, the design and the capacity or the roadway condition, the pavement type, characteristics of traffic condition such as flow and density, and weather condition are also major factors that impact on traffic safety (Li et al., 2007).

Agencies try to look for treatments that can improve the safeness and reduce crashes in rural intersections. In order to improve rural intersection safety, several treatments such as overhead beacons, advance stopline rumble strips, additional reflective material on stop sign post and use of a Light Emitting Diode (LED) in stop sign face have been utilized. Treatment results show the effectiveness of flashing beacons. It is more sufficient for agencies to know the effectiveness of every treatments before investing them because maintenance is required for all treatments. The effectiveness of the various treatments is not well known. As a result, this study evaluated one of the treatments, flashing stop sign mounted beacons.

Six rural intersections were selected to receive treatments. The impact of beacons installation on stopping behavior were evaluated. The six rural intersections were all high crash intersections and have similar roadway surface conditions. All of the locations are two-way stop controlled intersections.

1.3 Thesis Structure

This thesis is organized into 6 major chapter. The background of the research problem is studying driver behavior under stop sign mounted beacons two way stop-sign controlled rural intersections. Literature reviews will show previous studies on rural intersections and driver behavior from other researchers on Chapter 2. An overall description of data and site selections will be provided on Chapter 3. Chapter 4 and 5 will be the statistical methodology and results from those analysis. Conclusion will be discussed in the end along with study limitation and future study recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 Effectiveness of Overhead Beacons

Several intersection treatments have been used to reduce crash or frequency or severity at rural intersections. One treatment is overhead beacons which not only alert drivers there is an upcoming intersection but also emphasize who has the right of way. Overhead beacons have been applied in a lot of intersections with various results.

A study of four-way with stop control on the minor streams was done by Stackhouse and Cassidy (1996) and shows that crash rate was reduced by 39% for overhead beacons in eight four-way stop control intersections in Minnesota. They used data for three years before and after of installation to evaluate the impact. Brewer and Fitzpatrick (2004) conducted a three years before to three years after study on four intersections with overhead beacons in Texas and found out a 43% reduction in crash rate. Murphy and Hummer (2007) conducted an Empirical Bayes analysis to develop crash reduction factors using thirty four four-leg two-way stop-controlled rural intersections in North Carolina where beacons were installed. Their results are listed below:

- A 12% reduction in total crashes;
- A 9% reduction in all kinds of injury crashes;
- A 40% reduction in severe injury crashes;
- A 9% reduction in frontal impact crashes;
- A 26% reduction in “ran stop sign” crashes;

Another researcher Srinivasan et al. (2008) also use Empirical Bayes to evaluate all types of beacons in North Carolina and South Carolina. The total number of test sites for this study were 90 and there were 84 sites with standard overhead beacons. Results showed angle crashes were reduced by 11.9%. Pant et al. (1999) conducted a crash analysis in Ohio for 26 rural intersections. Beacons were installed at 13 rural intersections and the other 13 were used as control. The researchers found a reduction in vehicular speeds in major stream especially when the stopping sight distance were limited. However, the stop-sign violations or crashes were both not significantly different overall. Hammer et al. (1987) also found out overhead beacons did not have a statistically impact on fatal crashes when a flashing beacon was presented. Reductions on angle crashes at all four-leg intersections regardless of type of flasher were not statistically significant by evaluating 14 intersections with yellow-red beacons and 10 intersections with red-red beacons in California. Hall (1991) conducted another study on six intersections to compare crashes after installation of overhead beacons, and the result show that crashes is not statistically significant due to sample size for after sample size is too small.

2.2 Effectiveness of Stop Sign Beacons

Srinivasan et al (2008) have also conducted studies on both all type of the effectiveness of flashing beacons and stop sign mounted beacons in rural intersections. Empirical Bayes analysis showed that angle crashes was reduced by 13.3%, injury was reduced by 10.2% and overall crashes was reduced by 12% for all type of flashing beacons. Studies also showed 58.2% reduction in angle crashes with only five sites representing.

The understanding of flashing beacons is one of the factors that impacts the effectiveness of this treatment. Stackhouse and Cassidy (1996) found out there were confusions from drivers with intersection beacons by conducting a driver opinion survey about overhead beacons from one hundred and forty four drivers. 50% of older drivers whose ages were 65 or above and 42% of younger driver whose ages were 18 to 35 claimed that they were confused when approaching intersection with beacons. As a result, many agencies have stopped using overhead beacons and are moving towards use of stop sign beacons.

2.3 The Impact on Driver Behaviors

A study conducted by Shan Bao et al. (2007) also showed that drivers' characteristics such as age can affect drivers' behaviors at high speed expressway intersections. For example, age had a significant effect on the brake pedal differential time. Both older and middle-aged drivers had the highest time to go from initial to maximum brake pedal depression in comparison to young drivers. The initial brake point for middle-aged drivers was significantly earlier than younger and older drivers. It indicated that this group responded much earlier when approaching a Two-Way Stop Control (TWSC) intersection. Based on this study, both age and drive maneuver had a significant impact on the type of stop prior to entering the intersections. Younger drivers had a higher chance of not coming to a complete stop in comparison to middle-aged drivers. All drivers were less likely to come to a complete stop prior to performing a right turn in comparison to the other two intersection maneuvers.

CHAPTER 3: DATA SELECTION

3.1 Site Selection

This study focused on two-way stop-controlled intersections at the intersection of two-lane roadways and four-lane divided highways with two-lane stop-controlled at the intersection. A database of intersection locations was created by the Iowa Department of Transportation (DOT) and Center for Transportation Research and Education (CTRE) and includes roadway characteristics for intersections and interchanges in Iowa. Rural stop control intersections were identified from the database and the following information extracted:

- Number of approaches;
- Signing by approach;
- Presence and type of medians;
- Presence and type of lighting;
- Roadway surface type;
- Channelization;

The intersection database was overlain with a crash database which was also available from the Iowa DOT. Intersections with nine or more crashes from 2010 to 2014 (5 years) were flagged and further reviewed using aerial imagery in Google. Sixty potential locations were selected based on roadway characteristic and number of crashes. Roadway characteristics not already available were extracted using aerial imagery, Google Street view, or site visits. They included:

- Advance stopline rumble strips;

- Overhead beacons;
- Stop sign beacons;
- Advance signing;
- Type of pavement markings;
- Roadway surface type;
- Presence of lighting

Selected locations were ranked based on:

- Number of crashes or crash rate;
- Intersection configuration;
- Presence of other countermeasures
- Similar characteristic on location
- Traffic Volumes

Intersections with countermeasures such as overhead beacons and other stop sign treatments, intersections that have been installed new traffic signals and intersections were located in an urban area were eliminated from the selection. Locations with rail road crossing or difficult geometry such as significant skew were also taken out from the selections.

Crashes, crash rate, and intersection configuration were three major factors for selecting final intersections. Resources were available to treat multiple approaches so the goal was to identify sufficient intersections for treatment.

Twenty three intersections were selected after the screening process described above. Next the team met with project's Technical Advisory Committee and other stakeholders and potential locations were presented. Additionally, the corresponding agency was contacted and locations where countermeasures had recently been installed or locations where agencies declined to participate were removed.

A total of 20 sites were selected. Later on, six counties were selected to be the targets of this study and intersections in those six counties were as homogenous as possible. The selected sites located in:

- The south and north approaches of intersection 21st Avenue and Lincoln Hwy in Benton County. This is an intersection of two-lane roadway. AADT of the major stream was around 6,800. The installation date is on October 21st, 2017.

Figure 1: Intersection Location in Benton County

- The east and west approaches of 590th Street and 130th Avenue in Buena Vista County. This is an intersection of two-lane roadway. AADT of the major stream was around 3,300. The installation date is on September 24th, 2017.

Figure 2: Intersection Location in Buena Vista County

- The north and south approaches of 240th Avenue and 360th Street in Clay County. This is an intersection of two-lane roadway. AADT of the major stream was around 4,900. The installation date is on October 6th, 2017.

Figure 3: Intersection Location in Clay County

- The north and south approaches of W Avenue and 240th Street in Dallas County. This is an intersection of two-lane roadway. AADT of the major stream was around 5,600. The installation date is on October 6th, 2017.

Figure 4: Intersection Location in Dallas County

- The east and west approaches of 140th Street and Hwy 1 in Johnson County. This is an intersection of two-lane roadway. AADT of the major stream was around 5,600. The installation date is on October 21st, 2017.

Figure 5: Intersection Location in Johnson County

- The east and west approaches of 8th Street south west and U.S. Route 75 in Sioux County. This is an intersection of two-lane roadway. AADT of the major stream was around 6,800. The installation date is on September 24th, 2017.

Figure 6: Intersection Location in Sioux County

3.2 Description of Treatment and Installation

Stop sign beacons were purchased from TAPCO since their system had the option of being set to only activate at a pre-determined speed. Formal authorization was obtained from the Iowa DOT state traffic engineer to install the flashing beacon.

The beacons were installed by the team with assistance from the corresponding agency who assisted with installation and traffic control. Figure 7 shows an example of a typical beacon installation.

Figure 7: Flashing Beacon Installation

The beacon was programmed so that it only activated when the speed of an oncoming vehicle was greater than 40 miles per hour at a distance of around 700 feet before the intersection stop bar. Once the beacon activated, it flashes for 9 seconds so that driver would have enough time to notice the beacons and made adjustment if needed.

3.3 Data Collection and Reduction

The six treatment intersections were located in Benton County, Clay County, Dallas County, Johnson County, Buena Vista and Sioux County as mentioned in chapter 3.1. Video trailers (shown in Figure 8) were placed at each site before and after installation. The overall camera locations were shown in Figure 9. A two camera array were used so that a view of both the upstream and intersection area was captured. Video data could be obtained online so that the data could be stored on devices in case data missing happened on site. Figure 10 to 15 shows examples of what camera captured. The markings were placed so that the brake activation distance could be estimated.

Figure 8: Video Data Collection Array

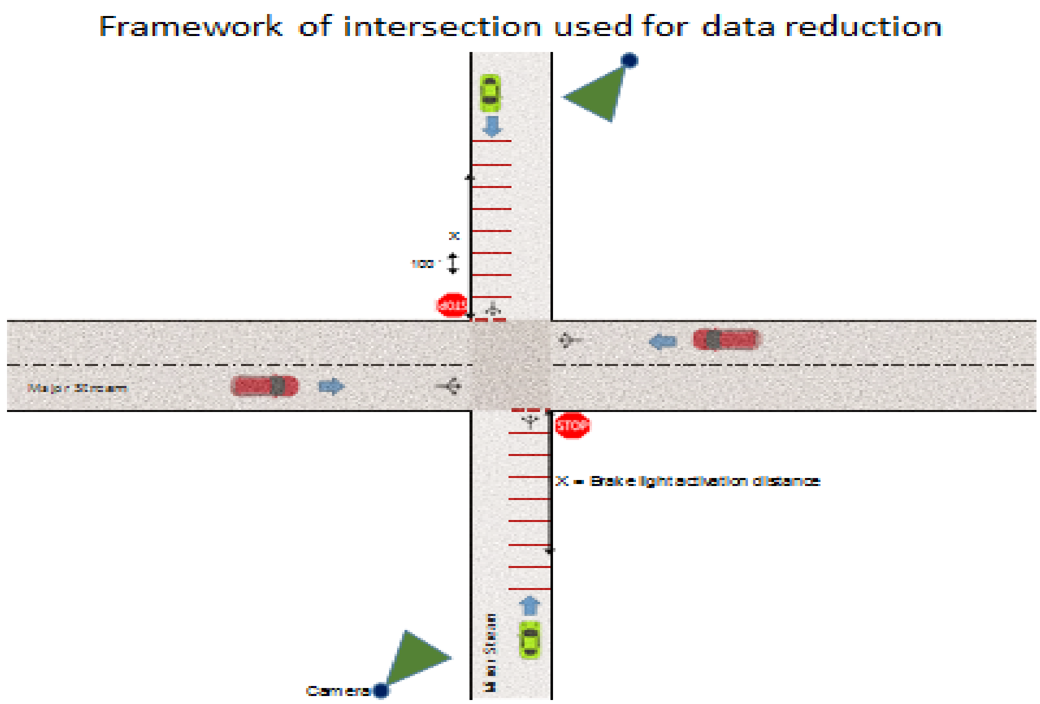

Figure 9: Video Data Collection Setup

Figure 10: The North Approach of 21st Avenue and Lincoln Hwy

Figure 11: The North Approach of 240th Avenue and 360th street

Figure 12: The South Approach of 240th Avenue and 360th street

Figure 13: The North Approach of W Avenue and 240th Street

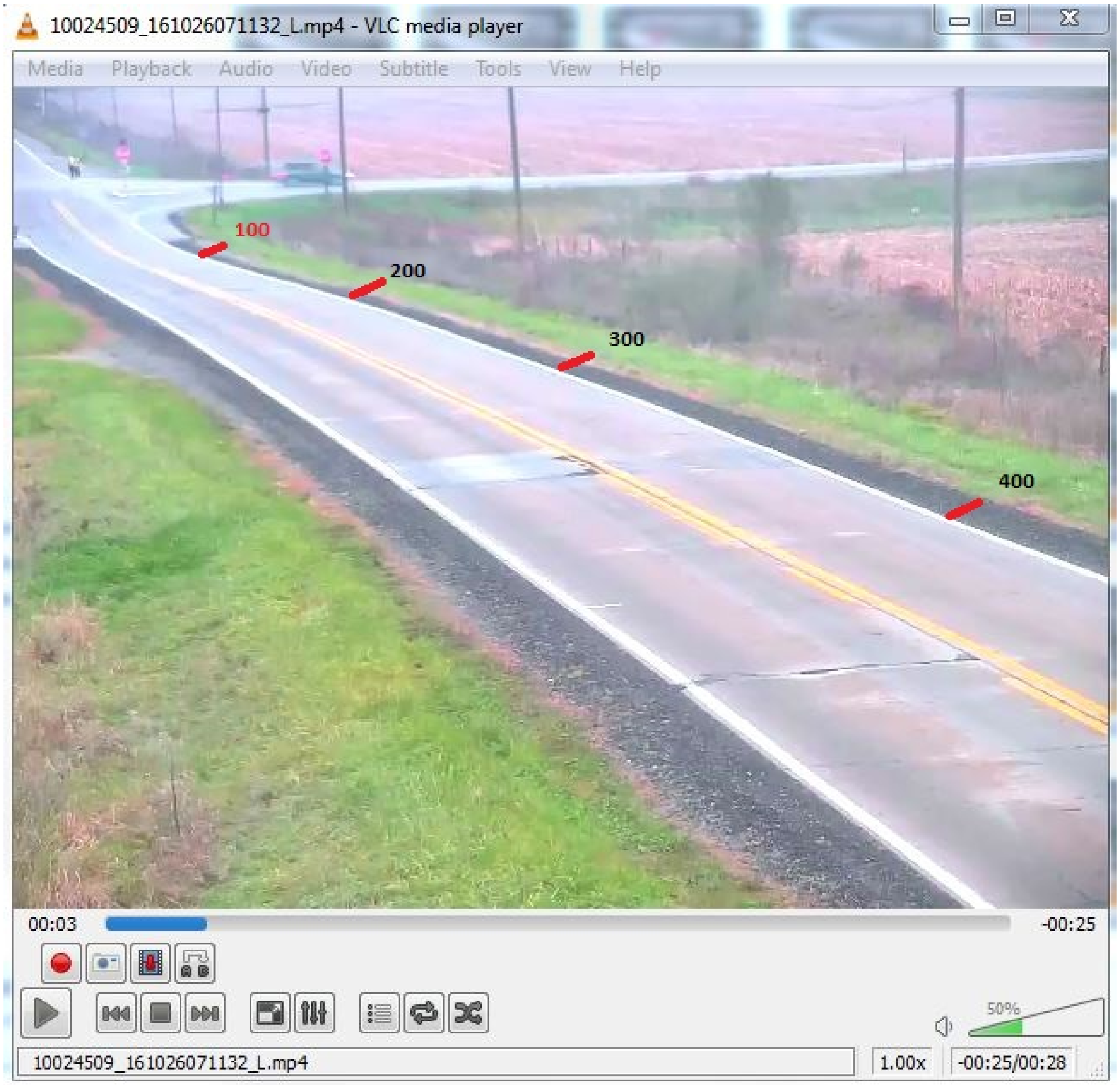

Figure 14: The South Approach of W Avenue and 240th Street

Figure 15: The West Approach of 140th Street and Hwy 1

An oncoming vehicle was reduced based on the following factors in Table 1 for each intersection. Data were manually reduced by researchers. After all events were coded from the north approach of 21st Avenue and Lincoln Hwy and 240th Avenue and 360th street, the team realized it was time consuming so they decided to sample rather code all vehicles. Since it was not feasible to reduce data for all vehicles, data was reduced for every fourth vehicle. Data were collected for before installation of the beacons and 1-month after installation. Data were only reduced from 6am to 5pm, since it was difficult to reduce data during nighttime. Data were also not reduced if severe weather was present so that conditions were similar in different time periods.

Table 1: Definition of Coding Factors

Term	Definitions
Vehicle Type	1 - Motorcycle; 2 - Passenger Car; 3 - Minivan/SUV; 4 - Pickup; 5 - Buses; 6 - single unit; 7 - multi-unit; 8 - Farm vehicle
First Time Vehicle Appears in the Video	Time that vehicle start to enter the video
Brake Activation Time	Time that the driver applies the brake
Brake Activation Time	Distance between target vehicle and the intersection when the driver applied the brake
Number in Queue (Thru/Left)	Number of vehicles that are in queue for going through and turning left
Number in Queue (Right)	Number of vehicles that are in queue for turning right
Following	If target vehicle is following another vehicle
Beacon Status	1 - Activated; 2 - Not activated
System Activation Time	Time that beacons start to be activated
Number of Times Braking	Number of time that's vehicles hit the brake
Vehicle Stopped at Opposing Minor Road	0 - No; 1 - Yes
Number of Vehicles Visible	Perpendicular, measured as they cross center of intersection
Turning Movement	1 - Left; 2 - Through; 3 - Right
Type of Stop	1 - Complete Stop; 2 - Slow Rolling (Clear Braking); 3 - Fast Rolling (Cruise Pass); 4 - No Slow
Stop Location	1 - Before stop bar; 2 - At stop bar; 3 - After stop bar; 4 - Non-stop
Conflict Type	Write down the type of conflict
Time of Conflict	Time that the conflict happens
Weather	1 - Clear; 2 - Rain
Lighting Condition	1 - Daytime; 2 - Dawn/dusk
Pavement Surface	1 - Dry; 2 - Wet

CHAPTER 4: STATISTICAL METHODOLOGY

4.1 Descriptive Statistics

Data were separated into “Before”, “1-month After”, and “12-months After”. Study areas included north and south approaches of intersection 21st Avenue and Lincoln Hwy, east and west approaches of 590th Street and 130th Avenue, north and south approaches of 240th Avenue and 360th Street, north and south approaches of W Avenue and 240th Street, and the west approach of 140th Street and Hwy 1. The total number of vehicles that were coded in before and after one month are listed in Table 2. Only the south approach of 240th Avenue and 360th Street and the north approach of W Avenue and 240th Street have after 12-months treatments data. As a result, this study only focused on comparing “Before” and “1-month After” data based on different approaches.

Table 2: Data Summary

Location	Before	1-month After
The North Approach of 21st Avenue and Lincoln Hwy	881	1056
The South Approach of 21st Avenue and Lincoln Hwy	548	1517
The East Approach of 590th Street and 130th Avenue	200	201
The West Approach of 590th Street and 130th Avenue	200	202
The North Approach of 240th Avenue and 360th Street	2076	1215
The South Approach of 240th Avenue and 360th Street	200	200
The North Approach of W Avenue and 240th Street	200	201
The South Approach of W Avenue and 240th Street	302	200
The West Approach of 140th Street and Hwy 1	200	201

All datasets included most of the variables from Table 3. Brake activation distances were coded in 50 feet intervals and the maximum was 500 feet and the minimum was 0 foot. The coder estimated vehicle’s position between the approximate two 100-foot marks and then distance was estimated in 50-foot interval. The coding format for brake activation distances is listed below:

Table 3: Brake Activation Distances Codding Definition

Distance (ft)	Definition
500	500 ≥ Distance > 450
450	450 ≥ Distance > 400
400	400 ≥ Distance > 350
350	350 ≥ Distance > 300
300	300 ≥ Distance > 250
250	250 ≥ Distance > 200
200	200 ≥ Distance > 150
150	150 ≥ Distance > 100
100	100 ≥ Distance > 50
50	50 ≥ Distance > 0
0	Distance = 0

Number of vehicles in queue for two different conditions (turning right or turning left/going through) were listed into separated categories. The percentage of if oncoming vehicle was following another vehicle; the percentage of beacons activated; the percentage of if the oncoming vehicle brake more than once; the percentage of there was another vehicle stopped at the opposing minor road; number of vehicles passing through major stream; the percentage of different turning movements, types of stop, and stop locations were all taken into accounted from Table 4 to Table 12.

Table 4: Descriptive Statistics for Driver Behavior in the North Approach of 21st Avenue and Lincoln Hwy

	Before Treatments		**1-month After**	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std.Dev**
Distance (ft)	450	71.70	460	77.28
Number in Queue (Right)	0	0.15	0	0.71
Number in Queue (Thru/Left)	0	0.63	1	1.20
Percentage of Following Another Vehicle	21%	0.41	50%	0.50
Percentage of Beacons Activated	N/A	N/A	79%	0.41
Percentage of Braking More Than Once	8%	0.28	33%	0.47
Percentage of Vehicle Stopped at Opposing Minor Road	39%	0.61	25%	0.43
Number of Vehicles Visible	4	4.55	3	3.45
Percentage of Turning Left	49%	0.50	38%	0.49
Percentage of Going Through	42%	0.49	46%	0.50
Percentage of Turning Right	9%	0.28	61%	0.53
Percentage of Completed Stop	89%	0.32	96%	0.19
Percentage of Slow Rolling	10%	0.30	4%	0.19
Percentage of Fast Rolling	1%	0.10	0%	0.05
Percentage of No Slow	0%	0.06	0%	0.00
Percentage of Stop Before Bar	16%	0.36	53%	0.50
Percentage of Stop at Stop Bar	73%	0.45	38%	0.49
Percentage of Stop After Stop Bar	3%	0.16	5%	0.21
Percentage of Non-Stop	9%	0.29	4%	0.19

Table 5: Descriptive Statistics for Driver Behavior in the South Approach of 21st Avenue and Lincoln Hwy

	Before Treatments		1-month After	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std.Dev**
Distance (ft)	245	143.95	430	97.34
Number in Queue (Right)	0	0.00	0	0.08
Number in Queue (Thru/Left)	0	0.00	0	0.23
Percentage of Following Another Vehicle	12%	0.33	4%	0.20
Percentage of Beacons Activated	N/A	N/A	67%	0.47
Percentage of Braking More Than Once	7%	0.26	2%	0.13
Percentage of Vehicle Stopped at Opposing Minor Road	23%	0.51	33%	0.47
Number of Vehicles Visible	4	3.13	3	3.44
Percentage of Turning Left	13%	0.34	12%	0.32
Percentage of Going Through	32%	0.47	32%	0.47
Percentage of Turning Right	55%	0.50	56%	0.50
Percentage of Completed Stop	59%	0.49	99%	0.10
Percentage of Slow Rolling	36%	0.48	1%	0.09
Percentage of Fast Rolling	5%	0.22	0%	0.00
Percentage of No Slow	0%	0.04	0%	0.00
Percentage of Stop Before Bar	0%	0.00	0%	0.06
Percentage of Stop at Stop Bar	45%	0.50	99%	0.11
Percentage of Stop After Stop Bar	14%	0.35	0%	0.00
Percentage of Non-Stop	41%	0.49	1%	0.08

Table 6: Descriptive Statistics for Driver Behavior in the East Approach of 590th Street and 130th Avenue

	Before Treatments		1-month After	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std.Dev**
Distance (ft)	400	118.91	440	81.99
Number in Queue (Right)	0	0.15	0	0.41
Number in Queue (Thru/Left)	1	0.98	3	1.47
Percentage of Following Another Vehicle	8%	0.27	8%	0.27
Percentage of Beacons Activated	N/A	N/A	35%	0.48
Percentage of Braking More Than Once	22%	0.41	33%	0.47
Percentage of Vehicle Stopped at Opposing Minor Road	41%	0.49	48%	0.50
Number of Vehicles Visible	2	1.68	3	2.27
Percentage of Turning Left	18%	0.38	10%	0.31
Percentage of Going Through	72%	0.45	86%	0.35
Percentage of Turning Right	11%	0.31	4%	0.20
Percentage of Completed Stop	78%	0.42	79%	0.41
Percentage of Slow Rolling	21%	0.41	20%	0.40
Percentage of Fast Rolling	2%	0.12	1%	0.10
Percentage of No Slow	1%	0.07	0%	0.00
Percentage of Stop Before Bar	35%	0.48	6%	0.23
Percentage of Stop at Stop Bar	55%	0.50	93%	0.26
Percentage of Stop After Stop Bar	3%	0.16	2%	0.12
Percentage of Non-Stop	9%	0.28	0%	0.00

Table 7: Descriptive Statistics for Driver Behavior in the West Approach of 590th Street and 130th Avenue

	Before Treatments		1-month After	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std.Dev**
Distance (ft)	450	88.16	480	46.72
Number in Queue (Right)	0	0.41	0	0.63
Number in Queue (Thru/Left)	0	0.79	2	1.22
Percentage of Following Another Vehicle	39%	0.49	7%	0.26
Percentage of Beacons Activated	N/A	N/A	25%	0.43
Percentage of Braking More Than Once	36%	0.48	29%	0.46
Percentage of Vehicle Stopped at Opposing Minor Road	32%	0.47	22%	0.42
Number of Vehicles Visible	2	1.86	3	2.26
Percentage of Turning Left	21%	0.41	36%	0.48
Percentage of Going Through	58%	0.50	51%	0.50
Percentage of Turning Right	22%	0.41	14%	0.35
Percentage of Completed Stop	46%	0.50	80%	0.40
Percentage of Slow Rolling	34%	0.48	20%	0.40
Percentage of Fast Rolling	19%	0.39	0%	0.00
Percentage of No Slow	1%	0.10	0%	0.00
Percentage of Stop Before Bar	48%	0.50	10%	0.30
Percentage of Stop at Stop Bar	35%	0.48	87%	0.34
Percentage of Stop After Stop Bar	9%	0.28	4%	0.18
Percentage of Non-Stop	9%	0.29	0%	0.00

Table 8: Descriptive Statistics for Driver Behavior in the North Approach of 240th Avenue and 360th Street

	Before Treatments		1-month After	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std.Dev**
Distance (ft)	470	82.92	495	30.41
Number in Queue (Right)	0	0.31	1	0.83
Number in Queue (Thru/Left)	1	1.29	1	1.22
Percentage of Following Another Vehicle	25%	0.43	77%	0.42
Percentage of Beacons Activated	N/A	N/A	90%	0.31
Percentage of Braking More Than Once	26%	0.44	15%	0.36
Percentage of Vehicle Stopped at Opposing Minor Road	18%	0.38	30%	0.46
Number of Vehicles Visible	4	3.62	2	1.67
Percentage of Turning Left	49%	0.50	35%	0.48
Percentage of Going Through	33%	0.47	44%	0.50
Percentage of Turning Right	18%	0.38	21%	0.41
Percentage of Completed Stop	80%	0.40	99%	0.10
Percentage of Slow Rolling	18%	0.38	1%	0.10
Percentage of Fast Rolling	2%	0.14	0%	0.00
Percentage of No Slow	0%	0.02	0%	0.00
Percentage of Stop Before Bar	10%	0.30	79%	0.41
Percentage of Stop at Stop Bar	79%	0.41	21%	0.41
Percentage of Stop After Stop Bar	8%	0.27	0%	0.00
Percentage of Non-Stop	3%	0.17	0%	0.00

Table 9: Descriptive Statistics for Driver Behavior in the South Approach of 240th Avenue and 360th Street

	Before Treatments		1-month After	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std.Dev**
Distance (ft)	480	58.22	370	118.50
Number in Queue (Right)	0	0.59	0	0.35
Number in Queue (Thru/Left)	1	1.85	1	0.99
Percentage of Following Another Vehicle	17%	0.38	30%	0.46
Percentage of Beacons Activated	N/A	N/A	56%	0.50
Percentage of Braking More Than Once	55%	0.50	43%	0.50
Percentage of Vehicle Stopped at Opposing Minor Road	27%	0.45	22%	0.42
Number of Vehicles Visible	5	5.77	3	2.81
Percentage of Turning Left	42%	0.50	57%	0.50
Percentage of Going Through	49%	0.50	19%	0.39
Percentage of Turning Right	9%	0.29	24%	0.43
Percentage of Completed Stop	73%	0.45	41%	0.49
Percentage of Slow Rolling	26%	0.44	57%	0.50
Percentage of Fast Rolling	1%	0.10	2%	0.12
Percentage of No Slow	0%	0.00	1%	0.07
Percentage of Stop Before Bar	14%	0.34	9%	0.28
Percentage of Stop at Stop Bar	74%	0.44	57%	0.50
Percentage of Stop After Stop Bar	8%	0.26	32%	0.50
Percentage of Non-Stop	5%	0.22	3%	0.16

Table 10: Descriptive Statistics for Driver Behavior in the North Approach of W Avenue and 240th Street

	Before Treatments		1-month After	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std.Dev**
Distance (ft)	470	231.31	415	114.82
Number in Queue (Right)	0	0.76	0	0.26
Number in Queue (Thru/Left)	1	0.83	0	0.71
Percentage of Following Another Vehicle	13%	0.34	7%	0.26
Percentage of Beacons Activated	N/A	N/A	56%	0.50
Percentage of Braking More Than Once	46%	0.50	19%	0.40
Percentage of Vehicle Stopped at Opposing Minor Road	21%	0.41	23%	0.42
Number of Vehicles Visible	3	2.22	2	1.98
Percentage of Turning Left	28%	0.45	23%	0.42
Percentage of Going Through	57%	0.50	62%	0.49
Percentage of Turning Right	16%	0.37	14%	0.35
Percentage of Completed Stop	76%	0.43	76%	0.43
Percentage of Slow Rolling	22%	0.42	22%	0.42
Percentage of Fast Rolling	3%	0.16	2%	0.12
Percentage of No Slow	0%	0.00	0%	0.00
Percentage of Stop Before Bar	42%	0.49	49%	0.50
Percentage of Stop at Stop Bar	52%	0.50	45%	0.50
Percentage of Stop After Stop Bar	7%	0.26	4%	0.18
Percentage of Non-Stop	0%	0.00	2%	0.14

Table 11: Descriptive Statistics for Driver Behavior in the South Approach of W Avenue and 240th Street

	Before Treatments		1-month After	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std.Dev**
Distance (ft)	470	63.12	475	81.55
Number in Queue (Right)	0	0.00	0	0.71
Number in Queue (Thru/Left)	0	0.66	1	1.27
Percentage of Following Another Vehicle	18%	0.38	14%	0.34
Percentage of Beacons Activated	N/A	N/A	57%	0.50
Percentage of Braking More Than Once	30%	0.46	54%	0.50
Percentage of Vehicle Stopped at Opposing Minor Road	18%	0.38	5%	0.22
Number of Vehicles Visible	2	1.70	3	3.21
Percentage of Turning Left	39%	0.49	20%	0.40
Percentage of Going Through	46%	0.50	41%	0.49
Percentage of Turning Right	15%	0.36	40%	0.49
Percentage of Completed Stop	91%	0.29	57%	0.50
Percentage of Slow Rolling	6%	0.24	38%	0.49
Percentage of Fast Rolling	3%	0.17	6%	0.24
Percentage of No Slow	0%	0.00	0%	0.00
Percentage of Stop Before Bar	16%	0.37	19%	0.39
Percentage of Stop at Stop Bar	66%	0.47	73%	0.45
Percentage of Stop After Stop Bar	15%	0.36	9%	0.28
Percentage of Non-Stop	3%	0.16	0%	0.07

Table 12: Descriptive Statistics for Driver Behavior in the West Approach of 140th Street and Hwy 1

	Before Treatments		1-month After	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std.Dev**
Distance (ft)	460	74.26	420	120.53
Number in Queue (Right)	0	0.56	0	0.44
Number in Queue (Thru/Left)	0	0.68	0	0.39
Percentage of Following Another Vehicle	33%	0.47	8%	0.26
Percentage of Beacons Activated	N/A	N/A	14%	0.35
Percentage of Braking More Than Once	30%	0.46	8%	0.26
Percentage of Vehicle Stopped at Opposing Minor Road	25%	0.43	8%	0.26
Number of Vehicles Visible	2	1.30	3	2.79
Percentage of Turning Left	34%	0.48	16%	0.37
Percentage of Going Through	39%	0.49	20%	0.40
Percentage of Turning Right	28%	0.45	64%	0.48
Percentage of Completed Stop	80%	0.40	93%	0.26
Percentage of Slow Rolling	19%	0.39	7%	0.26
Percentage of Fast Rolling	2%	0.12	1%	0.07
Percentage of No Slow	0%	0.00	0%	0.00
Percentage of Stop Before Bar	84%	0.37	81%	0.39
Percentage of Stop at Stop Bar	11%	0.31	14%	0.35
Percentage of Stop After Stop Bar	5%	0.22	5%	0.22
Percentage of Non-Stop	0%	0.00	0%	0.00

The brake activation distance was in a range of plus or minus 50 feet because due to the codding process discussed previously. Brake activation distances increased by 185 (±50) feet in the south approach of 21st Avenue and Lincoln Hwy, and around 50 (±50) feet in the rest of the approaches except the south approach of 240th Avenue and 360th Street, the north approach of W Avenue and 240th Street, and the west approach of 140th Street and Hwy 1 while comparing Before and 1-month After data. The south approach of 240th Avenue and 360th Street decreased 110 (±50) feet and the north approach of W Avenue and 240th Street and the west approach of 140th Street and Hwy 1 decreased around 50 (±50) feet.

The post mounted flashing beacons were activated at the highest rate for the north approach of 240th Avenue and 360th Street. Vehicles in the north approach of 21st Avenue and Lincoln Hwy were the second county that has the highest beacons activation rate. It indicated vehicles approaching those intersections were mostly with a speed that was higher than 40 miles per hour while other vehicles driving on major streams. Beacons activated less than 50% in east and west approaches of 590th Street and 130th Avenue and west approach of 140th Street and Hwy 1. It might indicate that vehicles normally approached to those intersections with lower speeds. It could also indicate there were normally no vehicle driving on the major streams when target vehicle approached. The type of stop and stop location will be compared in the next subchapter.

4.2 Type of Stop and Stop Location Frequency Comparison

Type of stop and stop locations frequency for before and after treatments are shown below for different county approaches.

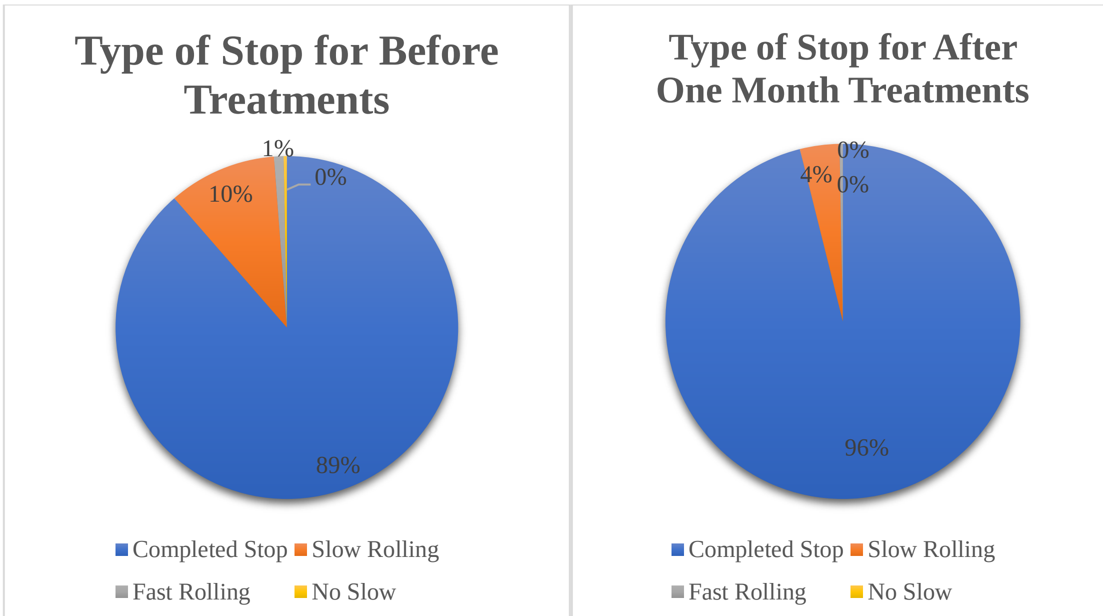

Figure 16: Type of Stop Comparison for the North Approach of 21st Avenue and Lincoln Hwy

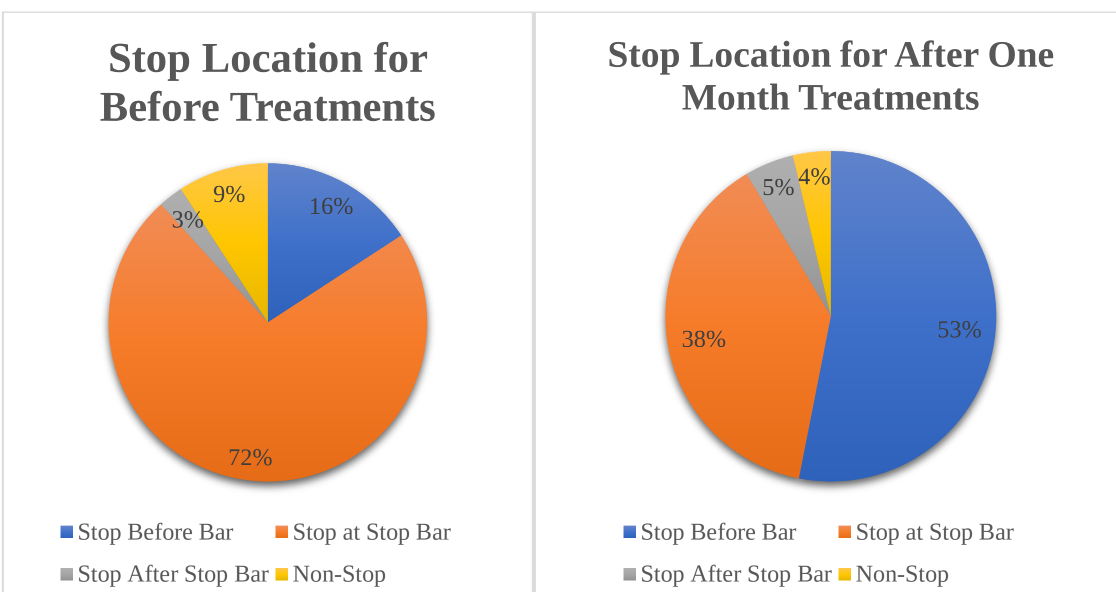

Figure 17: Stop Location Comparison for the North Approach of 21st Avenue and Lincoln Hwy

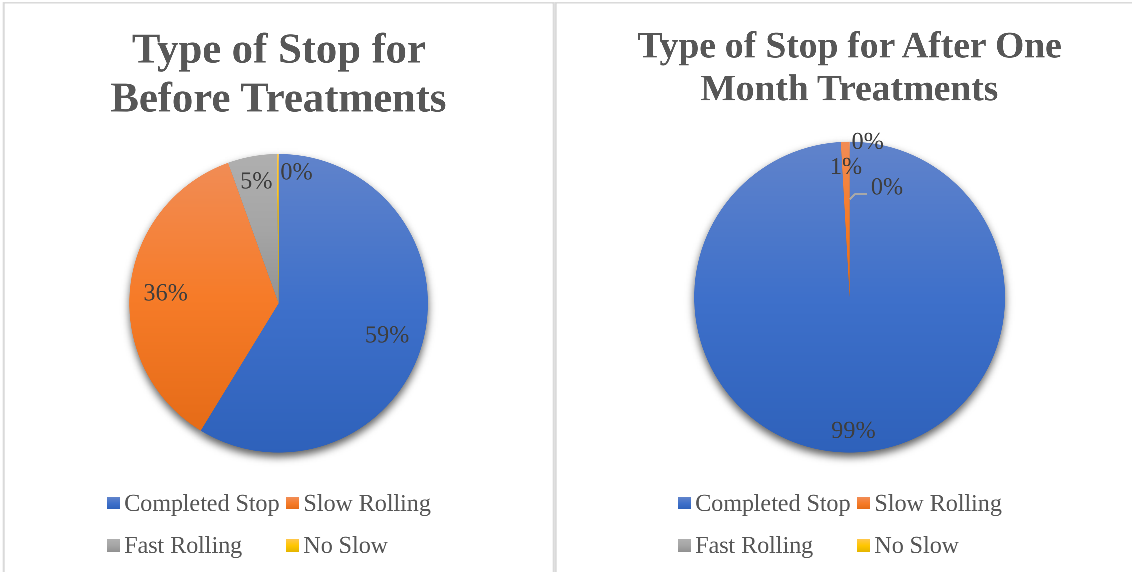

Figure 18: Type of Stop for the South Approach of 21st Avenue and Lincoln Hwy

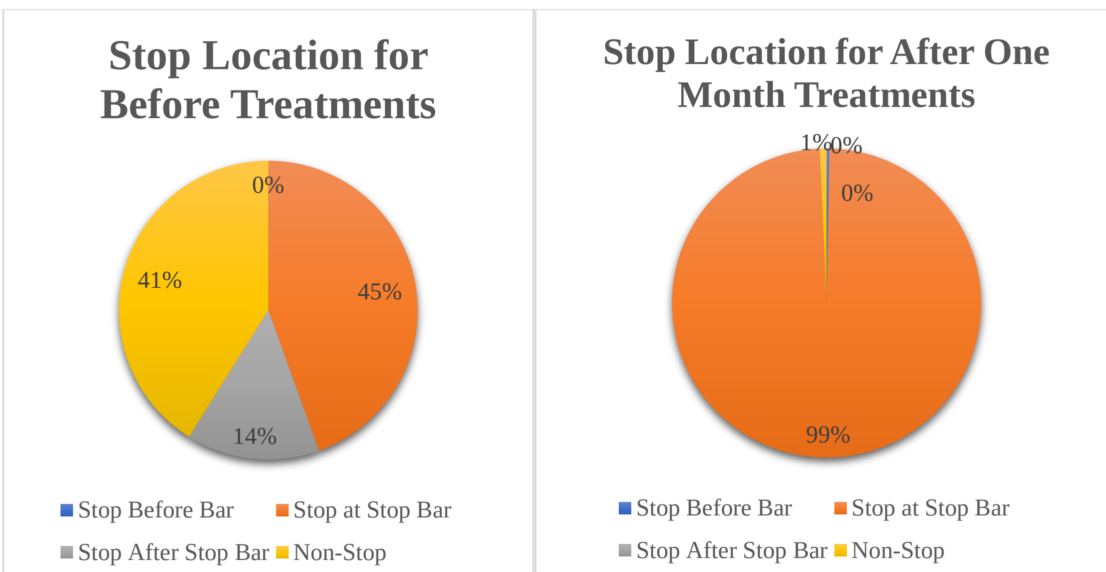

Figure 19: Type of Stop for the South Approach of 21st Avenue and Lincoln Hwy

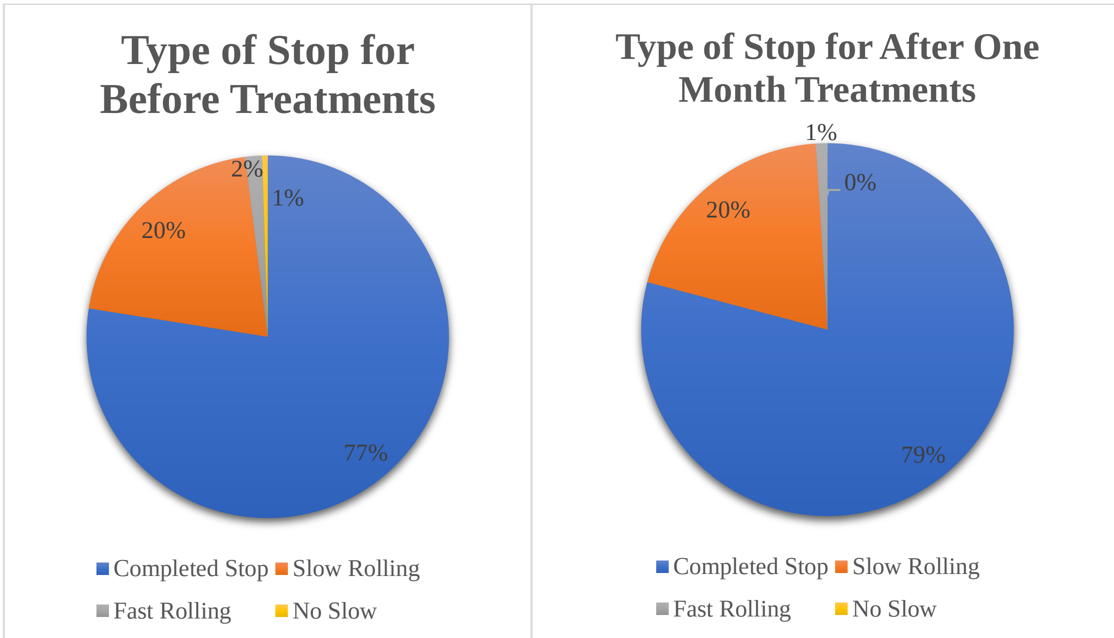

Figure 20: Type of Stop for the East Approach of 590th Street and 130th Avenue

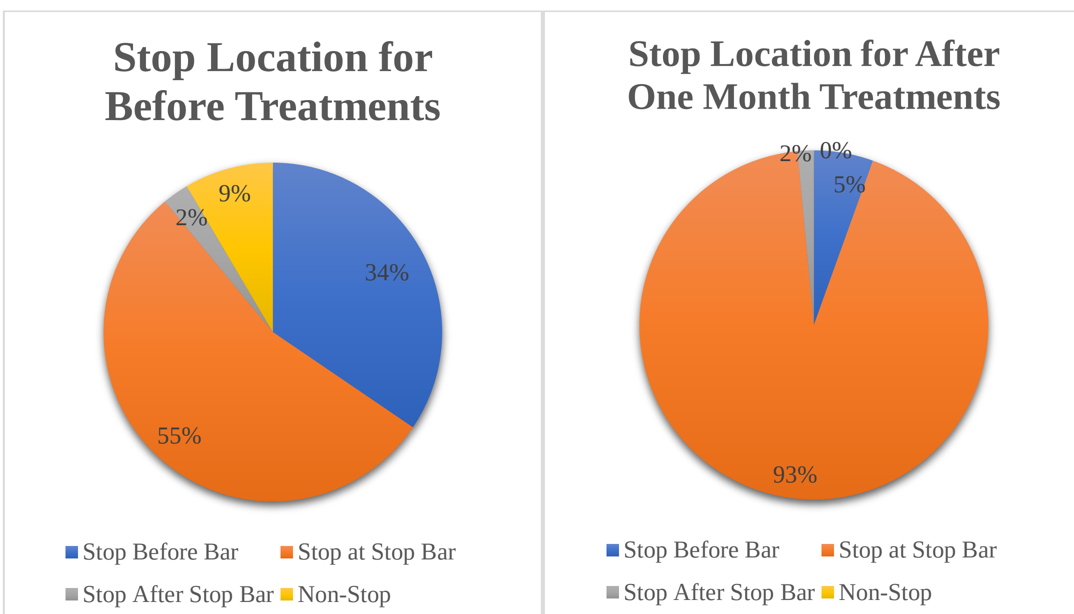

Figure 21: Stop Location Comparison for the East Approach of 590th Street and 130th Avenue

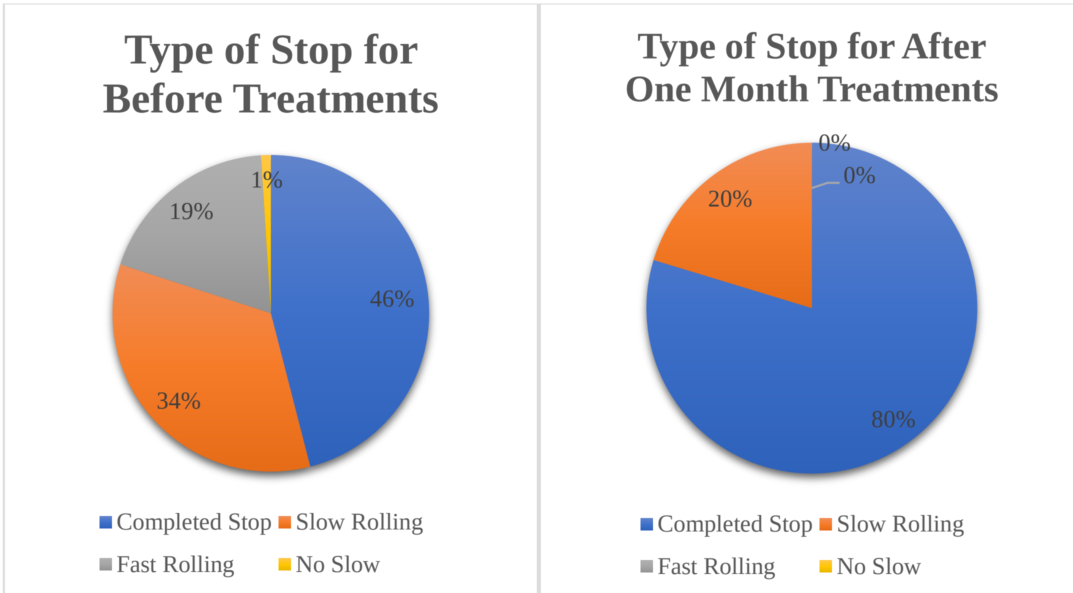

Figure 22: Type of Stop Comparison for the West Approach of 590th Street and 130th Avenue

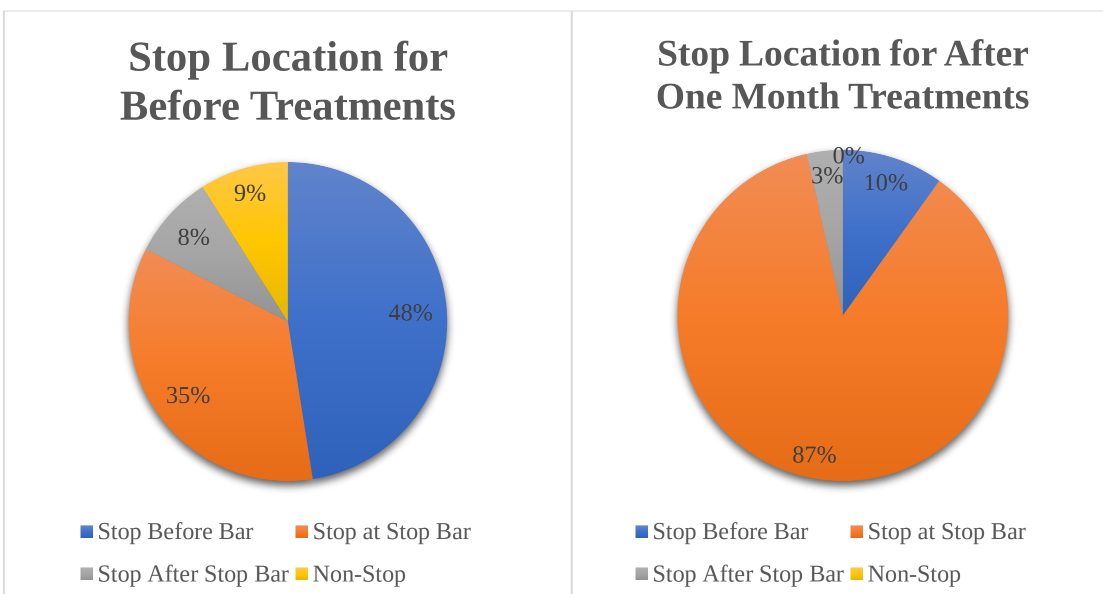

Figure 23: Stop Location for the West Approach of 590th Street and 130th Avenue

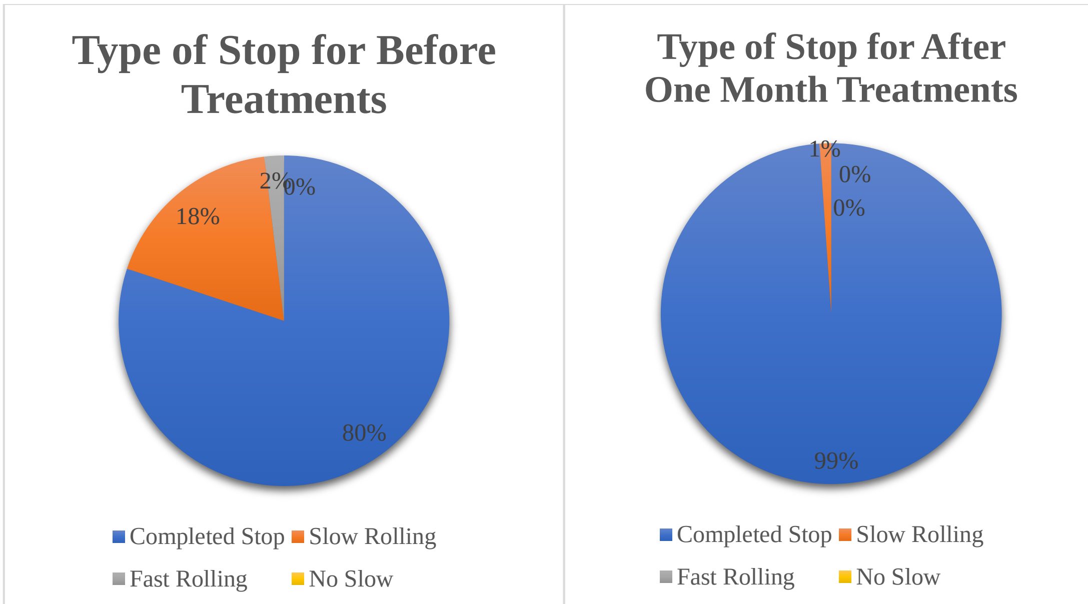

Figure 24: Type of Stop for the North Approach of 240th Avenue and 360th Street

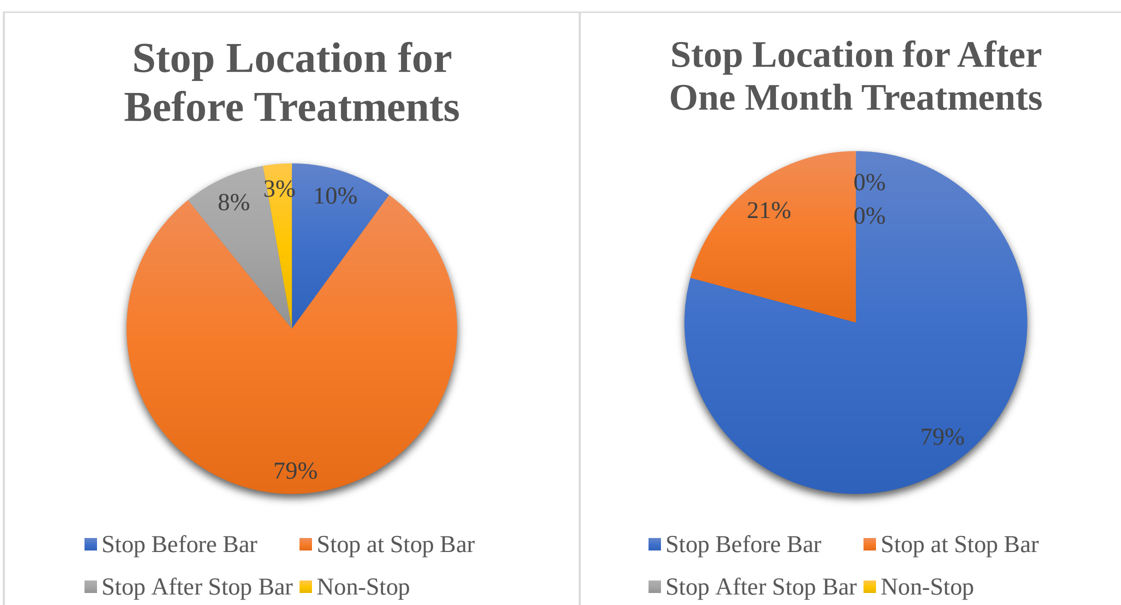

Figure 25: Stop Location for the North Approach of 240th Avenue and 360th Street

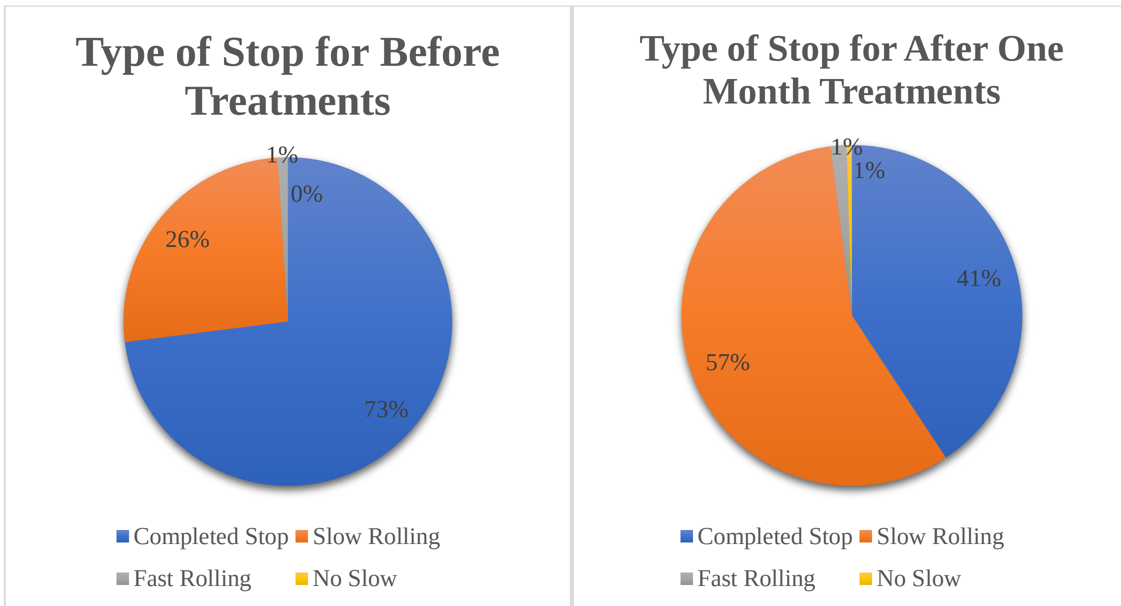

Figure 26: Type of Stop for the South Approach of 240th Avenue and 360th Street

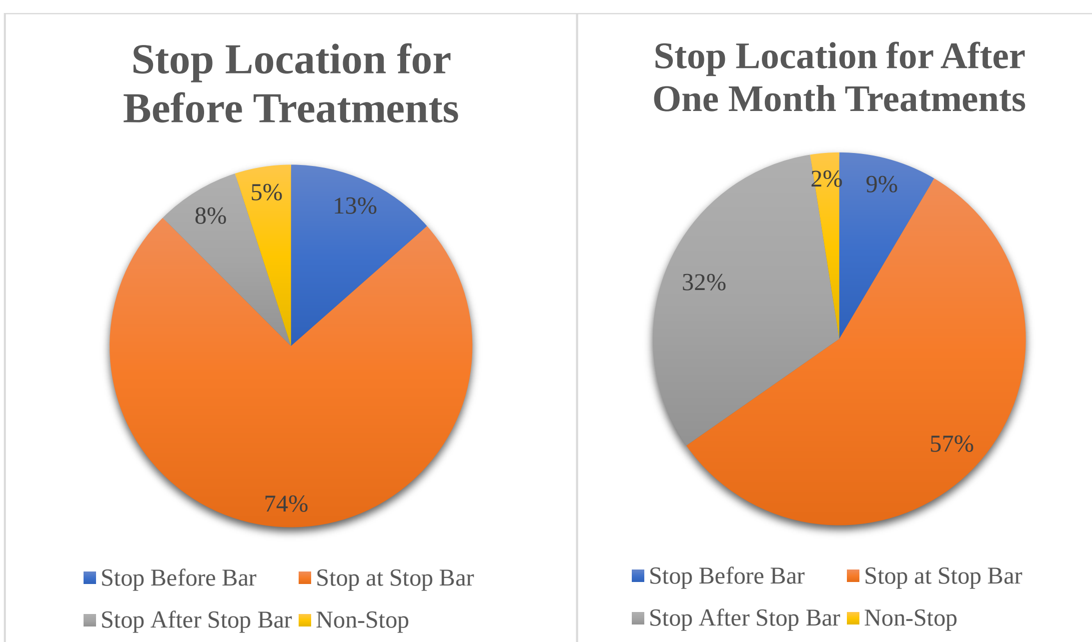

Figure 27: Stop Location for the South Approach of 240th Avenue and 360th Street

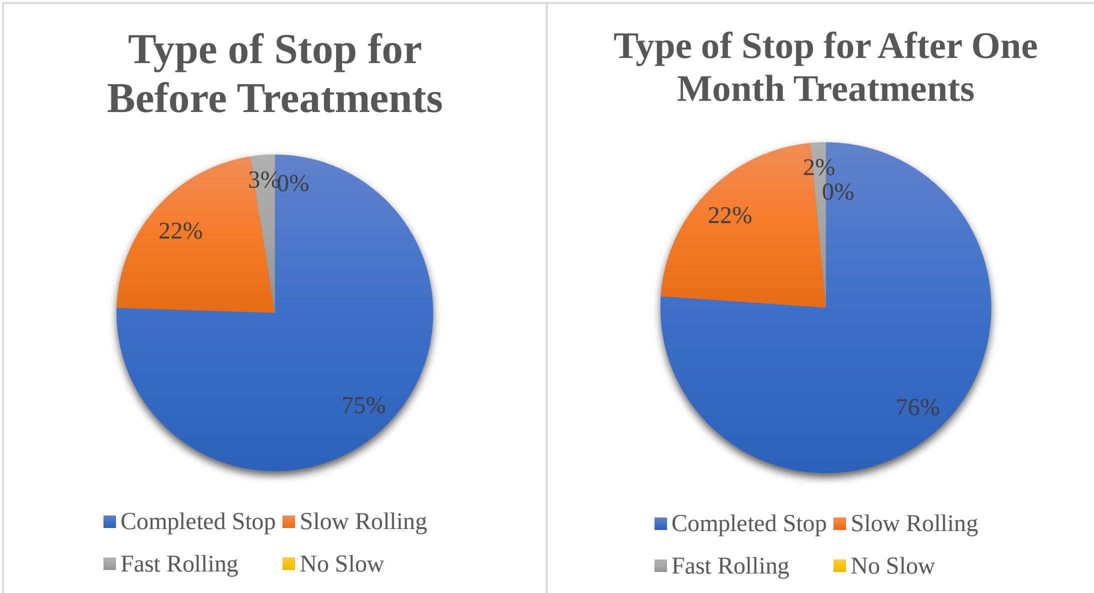

Figure 28: Type of Stop for the North Approach of W Avenue and 240th Street

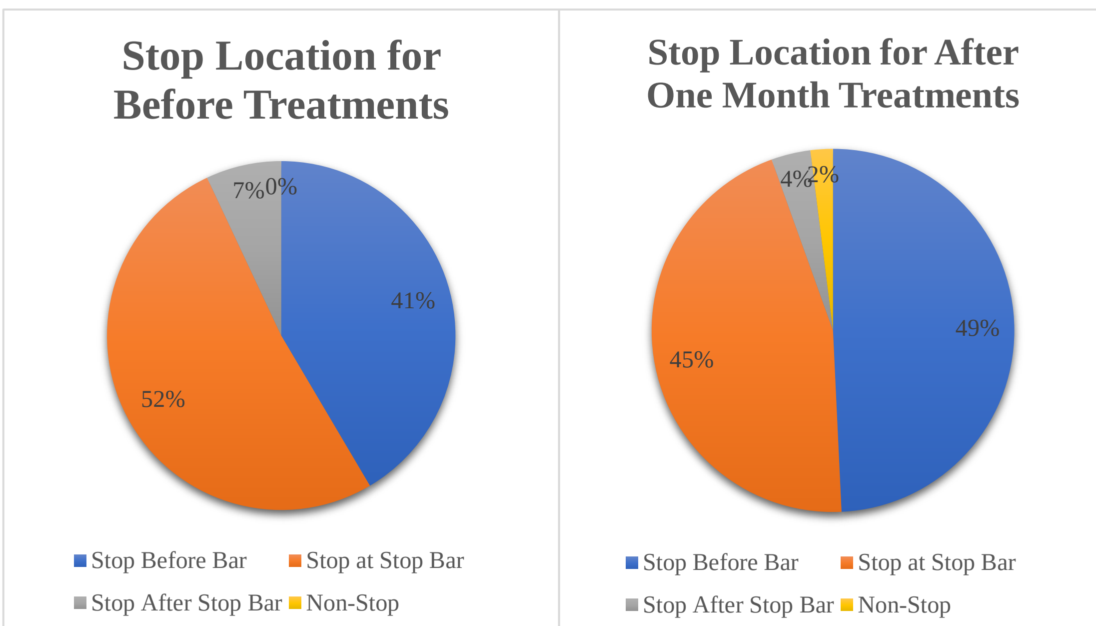

Figure 29: Stop Location for the North Approach of W Avenue and 240th Street

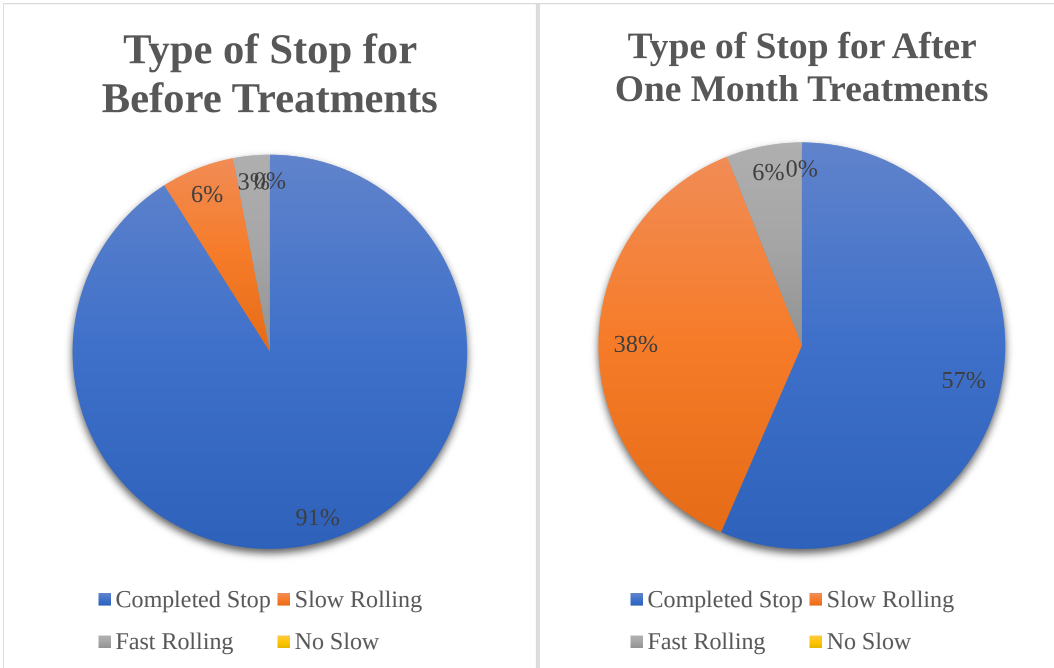

Figure 30: Type of Stop for the South Approach of W Avenue and 240th Street

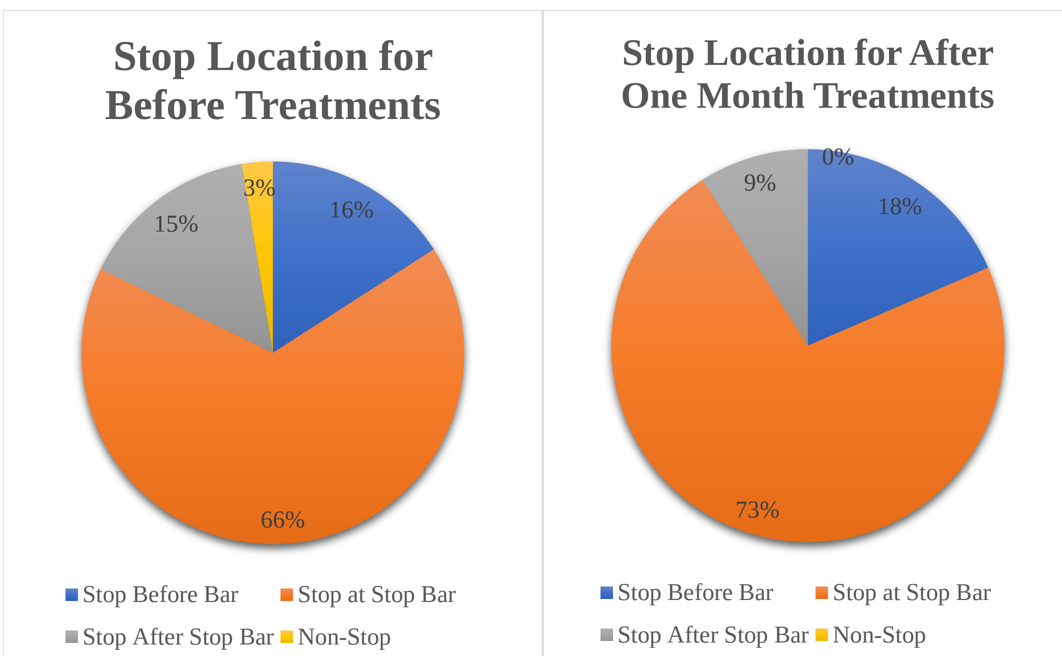

Figure 31: Stop Location for the South Approach of W Avenue and 240th Street

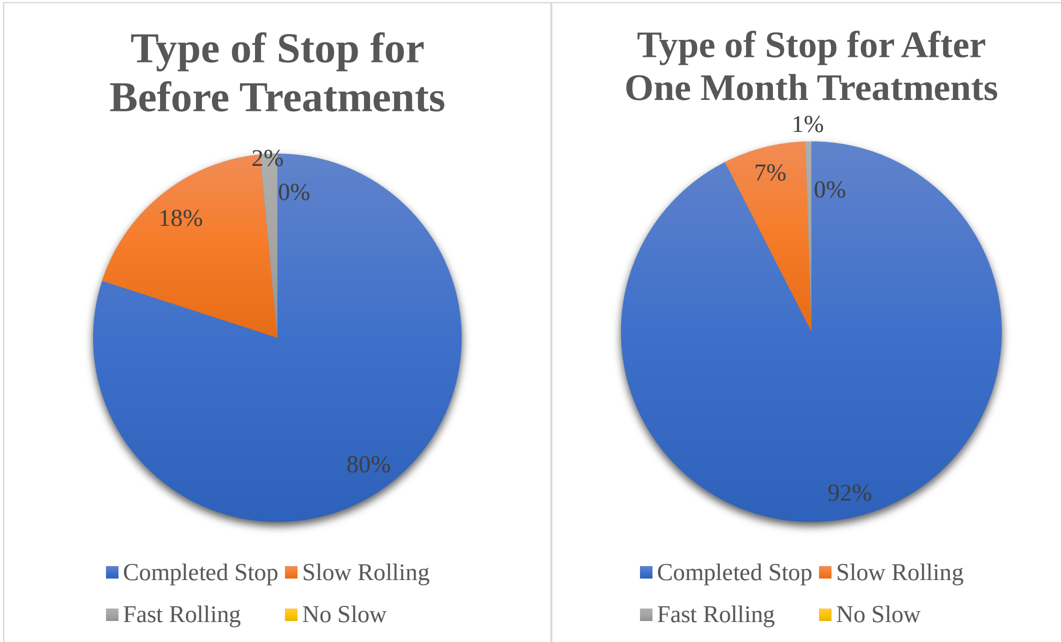

Figure 32: Type of Stop for the West Approach of 140th Street and Hwy 1

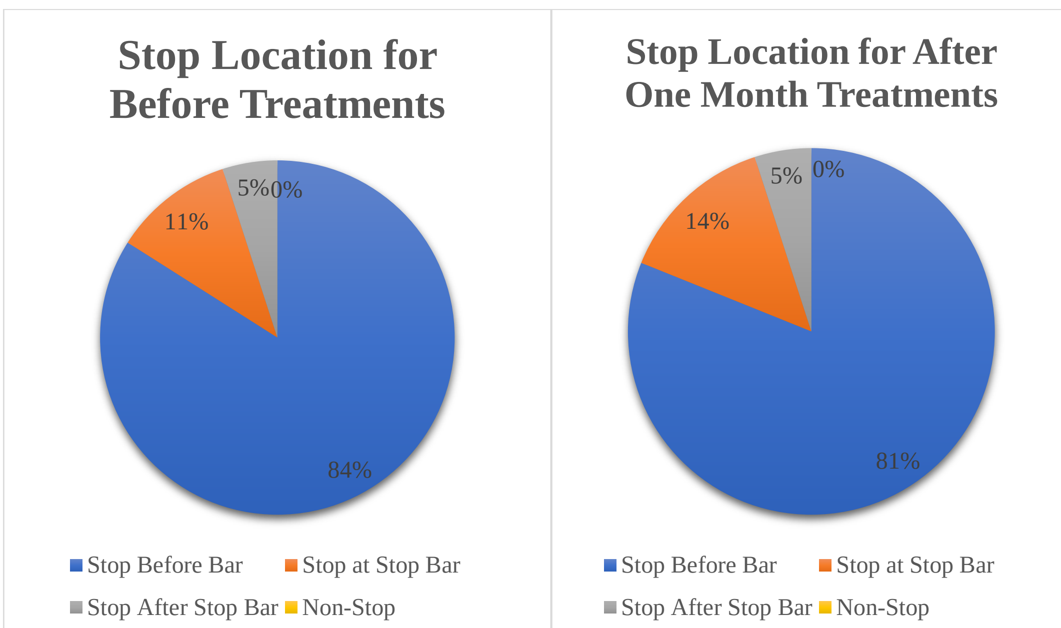

Figure 33: Stop Location for the West Approach of 140th Street and Hwy 1

Drivers stopped completely more often in after than before treatments for all county approaches except the south approaches of 240th Avenue and 360th Street and W Avenue and 240th Street while comparing Before and 1-month After data. There were 7% increase in the north approach of 21st Avenue and Lincoln Hwy; 40% increase in the south approach of 21st Avenue and Lincoln Hwy; 2% increase in the east approach of Buena Vista County; 32% increase in the west approach of 590th Street and 130th Avenue; 19% increase in the north approach of 240th Avenue and 360th Street; 32% decrease in the south approach of 240th Avenue and 360th Street; 1% increase in the north approach of W Avenue and 240th Street; 34% decrease in the south approach of W Avenue and 240th Street; and 12% increase in the west approach of 140th Street and Hwy 1.

As discussed in Chapter 4.1, the results of south approach of 240th Avenue and 360th Street might show different driver behaviors for before and after treatments. There was almost 0% of drivers did fast rolling or not slow while approaching the intersection for after treatments groups. Those changes could indicate driver might pay more attention and they started to drive safer than before the post mounted beacons have been installed.

Drivers tended to do less or not do non-stop based on 1-month After data. It showed a clear decrease on the percentage for drivers who wouldn’t stop at stop bar for all county approaches. It was an improvement to notice a drop on non-stop behavior because it is one of the major reasons that angle crashes happened in rural intersections. The frequency figures of stop location showed that drivers normally stopped before or at stop bar in before treatments group. The changes of shifting from stopping before stop bar to stopping after stop bar were varied based on different county approaches.

4.3 Two-Sample Test of Means

Statistical analyses were conducted to examine if stop sign mounted beacons would have an impact on driver stopping behaviors. The means for brake activation distances that were between target vehicles and the upcoming intersections for Before and 1-month After data based on different county approaches were compared.

The two population variances were not equal and the variances were weighted by sample size. A Welch's t-test was applied for the upcoming analysis. Equations for utilizing Welch's t-Test were listed below:

$$t^* = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Where $\bar{X}_1$ and $\bar{X}_2$ were the sample means brake activation distances of before and after treatments. $\mu_1$and μ_2 were the population means which were assumed to be equal for both conditions so $\mu_1 - \mu_2$was equal to zero. S_1 and S_2 were the sample standard errors and n_1 and n_2 were the sample sizes.

With the same variables, degree of freedom (df) was calculated based on the equation listed below:

$$\mathrm{df} = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2 - 1}}$$

The null hypothesis (H_0) and alternative hypothesis (H_a) were set as shown below:

H_0: There was no significant difference for brake activation distance.

H_a: There was a significant difference for brake activation distance.

$H_0: \mu_1 - \mu_2 = 0$

$H_a: \mu_1 - \mu_2 \neq 0$

The confident interval was 95% and α was equal to 0.05 with a two sides Welch's t-Test. The results were shown in Table 13 based on different approaches:

Table 13: Two-Sample T-Test I

Location	Two Sample t-test Before vs. 1-month After		
	t Ratio	df	p-value
The North Approach of 21st Avenue and Lincoln Hwy	-0.663	1935	0.508
The South Approach of 21st Avenue and Lincoln Hwy	-33.157	2060	<0.001
The East Approach of 590th Street and 130th Avenue	-3.610	399	<0.001
The West Approach of 590th Street and 130th Avenue	-3.563	378	<0.001
The North Approach of 240th Avenue and 360th Street	-8.729	3289	<0.001
The South Approach of 240th Avenue and 360th Street	11.434	398	<0.001
The North Approach of W Avenue and 240th Street	2.845	399	0.005
The South Approach of W Avenue and 240th Street	-0.616	500	0.538
The West Approach of 140th Street and Hwy 1	3.836	399	<0.001

The brake activation distances between before and after treatments were significant different for all approaches except the north approach of 21st Avenue and Lincoln Hwy and the south approach of W Avenue and 240th Street for Before and 1-month After data based on their p-value were smaller than 0.025. It indicated the post mounted flashing beacons were having a significant impact on most of the county approaches.

4.4 Logistic Regression Model

Exploring the relationships between two or more variables could help to understand the potential transportation problem hidden behind the scene. In order to analyze the relationship between variables, a logistic regression analysis would be recommended as a statistical technique. Logistic regression analysis could be built as a model to predict the probability of certain outcome happens based on different factors.

The "logit" model was listed below:

$$\ln\left(\frac{P_i}{1-P_i}\right)$$

- P_i was the probability that an event occurs
- $P_i/(1- P_i)$ was the "odds ratio"
- In $[P_i/(1- P_i)]$ was the log odds ratio, or "logit"

The logistic distribution constrains estimated probabilities to lie between 0 and 1 and the estimated probability could be:

$$P_i = \frac{EXP[\beta X]}{1+EXP[\beta X]} \qquad P_i = \frac{1}{1+EXP[-\beta X]}$$

The natural logarithm of the odds ratio was a linear function of the regressor variable and the slope of any parameter (β_j) was the change in the "log odds". It indicated that the odds ratio changed by $e^{\beta j}$ when X_j increased by one unit.

The model likelihood ratio (LR) could be used to evaluate the performance of a single model based on the log of the likelihood function (LL). The equation was:

$$LR = -2\,[LL(\beta_R) - LL(\beta_U)]$$

The model was distributed chi-square with degrees of freedom equal to difference in the number of independent variable. It could be used to determine whether the model was statistically significant or not.

Ordinal probability models were derived by fitting a series of parallel binary logit/probit curves to the cumulative probabilities for each category:

$$P(y \leq j) = F\left(\alpha_j + XB\right)$$

- α_j was the slop for category/group j
- X was a vector of variables determining the discrete ordering
- B was a vector of estimable parameters that is common to each group

Ordered logit could be presented as following where Λ (.) is the cumulative logistic distribution is:

$$P(y = 1) = \Lambda\,(\alpha_1 + XB)$$

$$P(y = 2) = \Lambda\,(\alpha_2 + XB) - \Lambda\,(\alpha_1 + XB)$$

$$P(y = 3) = \Lambda\,(\alpha_3 + XB) - \Lambda\,(\alpha_2 + XB)$$

$$P(y = j) = 1 - \Lambda\,(\alpha_j + XB)$$

The brake activation distances were categorized into a series order of 500 feet, 450 feet, 400 feet, 350 feet, 300 feet, 250 feet, 200 feet, 150 feet, 100 feet, 50 feet, and 0 foot as discussed in the coding process of chapter 4.1 (50 feet intervals). The stop location and type of stop were independent variables and separated into binary variables for further analysis. The ordinal logistic model was used to estimate the probabilities of each categories of brake activation distances occurred under different type of stop location.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Brake Activation Distances and Stop Locations

The study area only covered the north and south approaches of 21st Avenue and Lincoln Hwy because those approaches contains a larger sample size. The parameter estimates of the model was not presented due to there was no meaning of the parameter of each variable. Model Chi-Square and the probability of different brake activation distances were listed below.

The result for before and after treatments for the north approach of 21st Avenue and Lincoln Hwy were shown from Table 14 to Table 17:

Table 14: Probability (%) of Different Brake Activation Distances for Before Treatments

Stop Location	Brake Activation Distance (Foot)										
	0	50	100	150	200	250	300	350	400	450	500
Non-Stop	0.0	0.1	0.3	0.2	0.5	0.7	1.8	2.1	16.3	2.8	75.2
After Stop Bar	0.0	0.0	0.1	0.1	0.1	0.2	0.6	0.7	6.1	1.2	91.0
At Stop Bar	0.0	0.1	0.5	0.4	0.9	1.3	3.5	3.8	25.4	3.7	60.3
Before Stop Bar	0.0	0.0	0.2	0.1	0.3	0.5	1.3	1.5	12.6	2.3	81.0

Table 15: Probability (%) of Different Brake Activation Distances for After Treatments

Stop Location	Brake Activation Distance (Foot)										
	0	50	100	150	200	250	300	350	400	450	500
Non-Stop	0.4	0.0	0.4	0.0	5.2	4.9	24.6	18.3	15.2	8.1	22.9
After Stop Bar	0.2	0.0	0.2	0.0	2.1	2.1	13.0	13.5	15.2	10.3	43.5
At Stop Bar	0.2	0.0	0.2	0.0	2.6	2.6	15.3	14.9	15.8	10.1	38.3
Before Stop Bar	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.7	0.8	97.7

Table 16: Model Chi-Square

Term	Model	-LogLikelilhood	DF	ChiSquare	Prob>ChiSq
Before	Difference	17.6	3	35.1	<.0001
	Full	934.3			
	Reduced	951.9			
After	Difference	256.7	3	513.4	<.0001
	Full	875.8			
	Reduced	1132.5			

Table 17: Differences (%) Between After and Before Treatments

Stop Location	Brake Activation Distance (Foot)										
	0	50	100	150	200	250	300	350	400	450	500
Non-Stop	0.4	-0.1	0.1	-0.2	4.7	4.2	22.7	16.2	-1.1	5.3	-52.3
After Stop Bar	0.2	0.0	0.1	-0.1	2.0	1.9	12.4	12.8	9.2	9.1	-47.5
At Stop Bar	0.2	-0.1	-0.3	-0.4	1.6	1.2	11.8	11.1	-9.5	6.5	-21.9
Before Stop Bar	0.0	0.0	-0.2	-0.1	-0.3	-0.5	-1.0	-1.1	-11.9	-1.5	16.7

The model described 97% chances that vehicles braked at 500 feet would stop before stop bar for after installations and it increased around 16.7% comparing to before treatments. There was normally a higher chance for driver stopping after stop bar even though they started to brake at 500 feet. There were 75% chances when vehicle braked at 500 feet but did not stop in the end, and 91% chances when vehicles braked at 500 feet and stopped after stop bar for before treatments. The percentage of those two movements dropped to 22.9% and 43.5% for after installations. The 52.3% and 47.5% decreases on non-stop and after stop bar indicated people braked at 500 feet would have a higher chance to stop at a designated area (before or at stop bar). There were 20% to 2% increases of vehicles that stopped at or after stop bar or did not stop when they braked between 350 feet to 200 feet. The probabilities changed less than 1% when vehicle braked at a distance that was equal or less than 150 feet and stopped at either location or did not stop.

The result for before and after treatments for the south approach of 21st Avenue and Lincoln Hwy were shown from Table 18 to Table 21:

Table 18: Probability (%) of Different Brake Activation Distances for Before Treatments

Stop Location	Brake Activation Distance (Foot)										
	0	50	100	150	200	250	300	350	400	450	500
Non-Stop	0.4	4.6	20.0	15.6	16.1	7.7	7.4	4.1	8.5	0.9	14.7
After Stop Bar	0.2	2.9	14.0	12.6	15.1	8.1	8.3	4.9	10.9	1.2	21.8
At Stop Bar	0.4	5.5	22.6	16.4	16.1	7.4	6.9	3.7	7.6	0.8	12.6
Before Stop Bar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 19: Probability (%) of Different Brake Activation Distances for After Treatments

Stop Location	Brake Activation Distance (Foot)										
	0	50	100	150	200	250	300	350	400	450	500
Non-Stop	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
After Stop Bar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
At Stop Bar	0.0	0.0	0.4	0.9	3.4	5.2	7.2	12.2	7.1	6.5	57.1
Before Stop Bar	0.0	0.0	0.1	0.3	1.2	2.0	3.0	5.8	3.9	4.0	79.7

Table 20: Model Chi-Square

Term	Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Before	Difference	4.2	2	8.4	0.0152
	Full	1158.5			
	Reduced	1162.7			
After	Difference	0.6	1	1.2	0.2795
	Full	2211.9			
	Reduced	2212.5			

Table 21: Differences (%) Between After and Before Treatments

Stop Location	Brake Activation Distance (Foot)										
	0	50	100	150	200	250	300	350	400	450	500
Non-Stop	-0.4	-4.6	-20.0	-15.6	-16.1	-7.7	-7.4	-4.1	-8.5	-0.9	-14.7
After Stop Bar	-0.2	-2.9	-14.0	-12.6	-15.1	-8.1	-8.3	-4.9	-10.9	-1.2	-21.8
At Stop Bar	-0.4	-5.5	-22.2	-15.6	-12.7	-2.1	0.3	8.5	-0.5	5.7	44.5
Before Stop Bar	0.0	0.0	0.1	0.3	1.2	2.0	3.0	5.8	3.9	4.0	79.7

Due to there was no vehicle stopping after stop bar or non-stopping in the end after installation; and there was no vehicle stopping before stop bar before installation, the model describes there was a significant increased on vehicles braked at 500 feet and stopped before stop bar after installation. There were 79.7% more vehicles that stopped before stop bar when they braked at 500 feet comparing to before installations when there was a 14.7% reduction on vehicles braking at 500 feet and non-stopping in the end. There were a 21.8% reduction on vehicles stopping after stop bar and braking at 500 feet and a 44.5% increase on vehicles stopping at stop bar while braking at 500 feet. The reductions were continuous throughout the whole brake activation distances for vehicle did not stop and stopped before stop bar. There were 10% to 20% reductions on vehicles that braked between 100 feet to 200 feet and stopped at stop bar. Instead there were continuous increases on vehicles stopped before stop bar and braked earlier.

5.2 Brake Activation Distance and Type of Stop

The following tables shows the results of the relationships between brake activation distances and type of stop. The result for before and after treatments for the north approach of 21st Avenue and Lincoln Hwy were shown from Table 22 to Table 25:

Table 22: Probability (%) of Different Brake Activation Distances for Before Treatments

Type of Stop	Brake Activation Distance (Foot)										
	0	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
No Slow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Fast Rolling	0.0	0.2	0.7	0.5	1.2	1.7	4.4	4.7	28.0	3.7	54.9
Slow Rolling	0.0	0.1	0.4	0.3	0.7	1.0	2.6	2.9	20.4	3.1	68.5
Complete Stop	0.0	0.1	0.5	0.3	0.8	1.1	3.0	3.3	22.3	3.3	65.1

Table 23: Probability (%) of Different Brake Activation Distances for After Treatments

Type of Stop	Brake Activation Distance (Foot)										
	0	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
No Slow	0.7	0.0	0.7	0.0	8.1	7.1	28.6	15.8	10.7	5.0	23.3
Fast Rolling	0.7	0.0	0.7	0.0	8.1	7.1	28.6	15.8	10.7	5.0	23.3
Slow Rolling	0.5	0.0	0.5	0.0	6.2	5.7	25.3	15.8	11.5	5.6	28.9
Complete Stop	0.1	0.0	0.1	0.0	1.1	1.1	6.7	6.8	7.5	5.0	71.7

Table 24: Model Chi-Square

Term	Model	-LogLikelilhood	DF	ChiSquare	Prob>ChiSq
Before	Difference	1.7	3	3.4	0.3327
	Full	950.2			
	Reduced	951.9			
After	Difference	18.9	3	37.9	<.0001
	Full	1113.5			
	Reduced	1132.5			

Table 25: Differences (%) Between After and Before Treatments

Type of Stop	Brake Activation Distance (Foot)										
	0	50	100	150	200	250	300	350	400	450	500
No Slow	0.7	0.0	0.7	0.0	8.1	7.1	28.6	15.8	10.7	5.0	-76.7
Fast Rolling	0.7	-0.2	0.0	-0.5	6.9	5.4	24.3	11.1	-17.3	1.3	-31.5
Slow Rolling	0.5	-0.1	0.1	-0.3	5.6	4.7	22.7	12.9	-8.9	2.5	-39.6
Complete Stop	0.1	-0.1	-0.4	-0.3	0.3	-0.1	3.7	3.5	-14.8	1.6	6.6

Vehicles that started to brake at 500 feet had a 65.1% chance to stop completely; a 68.5% chance to roll slowly; a 54.9% chance to roll fast; and a 100% to keep going without continues braking in the end for before treatments. It indicated a higher chance of getting into angle crash if a vehicle did not stop in the intersection properly. In the after treatments regression model, it showed there were 71.7% vehicles that braked at 500 feet and stopped completely; 28.9% vehicles that braked at 500 feet and roll slowly; 23.3% vehicles that braked at 500 feet and rolled fast or did not stop in the end. On the 500 feet brake activation distance, there were 6.6% increases of vehicles stopping completely and around 30% to 40% reductions on fast and slow rolling. Also, A 76.7% reduction on vehicles that did not come to a stop in the end. However, there were around 30% to 10% increases for vehicles that braked at a distance of 400 feet to 200 feet and rolled slowly or fast or did not stop in the end. There was a 14.8% reduction on vehicles stopping completely if they braked at 400 feet. Probabilities of type of stop changed less than 1% if the brake activation distance was less or equal to 150 feet.

The result for before and after treatments for the south approach of 21st Avenue and Lincoln Hwy were shown from Table 26 to Table 29:

Table 26: Probability (%) of Different Brake Activation Distances for Before Treatments

Type of Stop	Brake Activation Distance (Foot)										
	0	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
No Slow	0.7	9.2	31.2	17.6	14.4	5.8	5.1	2.6	5.1	0.5	7.7
Fast Rolling	0.5	6.4	25.0	16.9	15.8	7.0	6.3	3.4	6.8	0.7	11.1
Slow Rolling	0.3	4.5	19.5	15.2	16.1	7.7	7.4	4.1	8.7	0.9	15.4
Complete Stop	0.4	4.7	20.2	15.5	16.1	7.7	7.3	4.0	8.4	0.9	14.8

Table 27: Probability (%) of Different Brake Activation Distances for After Treatments

Type of Stop	Brake Activation Distance (Foot)										
	0	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
No Slow	0.0	0.0	0.3	0.6	2.2	3.6	5.2	9.4	5.9	5.7	67.2
Fast Rolling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Slow Rolling	0.0	0.0	0.3	0.6	2.2	3.6	5.2	9.4	5.9	5.7	67.2
Complete Stop	0.0	0.0	0.4	0.9	3.4	5.2	7.2	12.2	7.1	6.5	57.1

Table 28: Differences (%) Between After and Before Treatments

Term	Model	-LogLikelilhood	DF	ChiSquare	Prob>ChiSq
Before	Difference	0.8	3	1.5	0.6748
	Full	1161.9			
	Reduced	1162.7			
After	Difference	0.3	2	0.5	0.7641
	Full	2212.2			
	Reduced	2212.5			

Table 29: Differences (%) Between After and Before Treatments

Type of Stop	Brake Activation Distance (Foot) 0	50	100	150	200	250	300	350	400	450	500
No Slow	-0.7	-9.2	-30.9	-17.0	-12.2	-2.3	0.1	6.8	0.8	5.2	59.4
Fast Rolling	-0.5	-6.4	-25.0	-16.9	-15.8	-7.0	-6.3	-3.4	-6.8	-0.7	-11.1
Slow Rolling	-0.3	-4.5	-19.2	-14.7	-13.8	-4.2	-2.3	5.3	-2.8	4.7	51.8
Complete Stop	-0.4	-4.7	-19.8	-14.6	-12.7	-2.4	-0.1	8.2	-1.3	5.6	42.3

There were 15.4% and 14.8% chances of vehicles that rolled slowly or came to a completely stop if they braked at 500 feet for before treatment. There were around 15% chances for vehicles to do any type of stop when they braked at 150 feet to 200 feet. When vehicles braked at 100 feet, there were 31.2%, 25%, 19.5%, and 20.2% chances for not slow, fast rolling, slow rolling, or complete stop. There were 67.2% vehicles that were slow rolling and no slow, and 57.1% vehicles that was complete stop if a vehicle braked at 500 feet for after treatments. The percentages of no slow and slow rolling were the same throughout every brake activation distance categories and they were all around 5%. There were 42.3%, 51.8%, and 59.4% increases when vehicles stopped completely, rolled slowly, and did not come to a fully stop in the end and braked at 500 feet. An 11.1% reduction on vehicles braking at 500 feet and rolling fast. There were less than 10% changes on all types of stop when vehicles braked between 450 feet to 250 feet. There were around 15% to 30% reductions on all types of stop when vehicles braked between 200 feet to 100 feet. There were less than 10% reductions on all types of stop when vehicles braked after 50 feet. However, both p-values in Model Chi-Square for before and after treatments were 0.67 and 0.76, which indicated a lot of expected values were different than the observed values and changes were not statistically significant.

CHAPTER 6: CONCLUSION

Stop sign mounted beacons effect driver behaviors. The brake activation distances were significant different between before and after treatments for most county approaches. Brake activation distances had significant increases for all county approaches except the south approach of 240th Avenue and 360th Street, the north approach of W Avenue and 240th Street, and the west approach of 140th Street and Hwy 1 while comparing "Before" and "1-month After". Drivers stopped completely more often when post mounted flashing beacons have been installed for a while. The percentage of fast rolling and no slow in type of stop decreased. It showed an improvement on nearly zero percentage of drivers who did not stop at the intersection.

Improvements can be made on future study. Limitations exist in additional to data collection and data reduction processes. Brake activation distance and driver behaviors such as stop locations and type of stop are subjective due to the distance between the cameras to the intersection. Also, cameras could not capture night time video. It is recommended to install a better camera to record at night so night time data could be accessible.

Ultimately, the results of this study can be used as a reference for future investments. Agencies can use the result to decide which countermeasures will fit better for problematic rural intersections. The effectiveness of stop sign mounted beacons can be observed in the short term and target future deployments to make a better decision on improving safety issue in rural intersection. The measures of effectiveness (MOEs) can be evaluated to determine the impact of the countermeasures by comparing conditions of before and after installation. Future study can be done on long term to observe if there is any significant decrease on crash rate due to there was no accident during study period.

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