MIAMIBEACH

NEIGHBORHOOD/COMMUNITY AFFAIRS COMMITTEE MEETING
SUPPLEMENTAL MATERIAL (12/10/2018)

City Hall, Commission Chambers, 3rd Floor, 1700 Convention Center Drive
December 14, 2018 – 9:00 AM

Commissioner Kristen Rosen Gonzalez, Chair
Commissioner Michael Góngora, Vice-Chair
Commissioner Mark Samuelian, Member
Commissioner Micky Steinberg, Alternate

SUPPLEMENTAL MATERIAL

NEW BUSINESS

6. **DISCUSSION REGARDING THE ASSESSMENT OF THE CITY OF MIAMI BEACH RED LIGHT CAMERA ENFORCEMENT PROGRAM CONDUCTED BY FLORIDA INTERNATIONAL UNIVERSITY LEHMAN CENTER FOR TRANSPORTATION RESEARCH**
   November 14, 2018 - C4 G

   Organizational Development Performance Initiatives

MIAMIBEACH

OFFICE OF THE CITY MANAGER

NO. LTC # 629-2018

LETTER TO COMMISSION

To: Mayor Dan Gelber and Members of the City Commission

From: Jimmy L. Morales, City Manager

Date: December 7, 2018

Subject: Evaluation of Photo Red Light Enforcement Program

The purpose of this Letter to Commission is to transmit the final report for the Evaluation of Photo Red Light (PRL) Enforcement Program in the City of Miami Beach submitted by Florida International University's Lehman Center for Transportation Research on December 7, 2018.

At the March 2018 Neighborhoods/Community Affairs Committee (NCAC) meeting, Committee members suggested the evaluation of the City's photo red light camera program data. Florida International University's Lehman Center for Transportation Research submitted a proposal specifying the assessment approach for the nine (9) intersections with photo red light cameras and the intersections to be used as the control group. The cost for the assessment was not to exceed $13,500 with funds from the police departments PRL program to fund the study.

The proposal was approved via Resolution No. 2018-30284 at the April 11, 2018 Commission meeting. Dr. Priyanka Alluri, Assistant Professor FIU Lehman Center for Transportation Research and primary contact for the study, worked with City staff in the Transportation Department, Police Department, and Organizational Development Department, to collect all required data. Dr. Alluri provided the completed evaluation to administration on December 7, 2018.

The main objectives of the study were to evaluate the safety and effectiveness of the PRL Enforcement Program in Miami Beach. The simple before-and-after analysis and the full Bayes (FB) before-and-after evaluation approach were used to quantify the safety effectiveness of the RLCs. The analysis was based on target crash type which includes angle/left-turn/right-turn, rear-end, and sideswipe crashes, and target crash severity which includes property damage (PDO) and fatal/injury crashes.

A total of of ten RLCs are operational at nine signalized intersections in Miami Beach. Due to the long period of construction activity, the intersection where Alton Road meets 17th Street was not included in the study. The simple before-and-after crash data analysis was conducted for the remaining eight signalized intersections. The advanced full Bayes before-and-after analysis was conducted only for the five four-legged signalized intersections. Only three treatment intersections are three-legged; the sample size is too small to yield reliable results from the FB statistical analysis.

The below are the findings from the simple before-and-after crash data analysis:

- Four-legged Intersections with RLCs
  - Reduction in target crashes after the installation of RLCs
  - Target crash types angle/left-turn/right-turn and sideswipe crashes usually decreased while rear-end crashes usually increased
  - Reduction in PDO target crashes
- Approaches with RLCs
  - At three of the five intersections, target crashes reduced after the installation of RLCs
  - At two of the five intersections, total crashes reduced after the installation of RLCs
  - At three of the five intersections, rear-end crashes increased after the installation of RLCs
- Three-legged Intersections with RLCs
  - Intersections with RLCs experienced a reduction in target crashes after the installation of RLCs
  - At all three intersections, rear-end and sideswipe crashes reduced after the installation of RLCs
  - Angle crashes reduced at two of the three intersections
  - Reduction in PDO target crashes
  - Approach with RLCs no target crashes after the installation of RLCs
- Safety Performance of Intersections with No RLCs
  - Average number of target crashes at the non-treatment intersections (i.e., signalized intersections with no RLCs) that are in the vicinity of treatment intersections reduced from 2011-2013 with fewer angle/left-turn and sideswipe crashes
  - Average number of target crashes at five signalized intersections that are far away from the intersections with RLCs was higher during 2011-2013 compared to 2008-2009 with an increase in angle/left-turn and sideswipe crashes

The below are the findings from the full Bayes before-and-after analysis:

- Crashes at the treatment intersections on an increasing trend similar to city, state, and national level crashes on an increasing trend
- Significant sudden drop in all types of target crashes immediately after the installation of RLCs
- Compared to the before-period, the after-period experienced fewer angle/left-turn/right-turn crashes, fewer sideswipe crashes, and more rear-end crashes
- Sideswipe and angle/left-turn/right-turn crashes dropped immediately after the installation of RLCs and then continued to increase, but are still lower than the before-period
- Rear-end crashes dropped immediately after the installation of the RLCs and then continue to increase

A discussion of the evaluation is on the December 14, 2018 Neighborhoods/Community Affairs Committee agenda.

Please contact me should you have any questions or concerns.

Attachment

KGB/LDR

Final Report

Evaluation of Photo Red Light Enforcement Program in the City of Miami Beach

Prepared for:

Prepared by:

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December 2018

DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the City of Miami Beach.

ACKNOWLEDGMENTS

This research was funded by the City of Miami Beach. The authors are grateful to Dr. Leslie Rosenfeld, Chief Learning and Development Officer, Organization Development Performance Initiatives, City of Miami Beach for her guidance and support throughout the project. A special thanks is due to the City of Miami Beach Police Department and the City of Miami Beach Transportation Department for providing the required data. The authors are also thankful to Mr. Hector Vargas and Ms. Liana Roque, undergraduate research assistants at Florida International University for assisting with the data collection.

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LIST OF ACRONYMS/ABBREVIATIONS

AADT	Annual Average Daily Traffic
BCI	Bayesian Credible Interval
DHSMV	Department of Highway Safety and Motor Vehicles (Florida)
EB	East Bound
FB	Full Bayes
FDOT	Florida Department of Transportation
NB	North Bound
PDO	Property Damage Only
PRL	Photo Red Light
RLC	Red Light Camera
RLR	Red-light Running
RTM	Regression-to-the-mean
SB	South Bound
WB	West Bound

EVALUATION OF PHOTO RED LIGHT ENFORCEMENT PROGRAM

This report summarizes the key findings of the safety evaluation of the Photo Red Light (PRL) Enforcement Program in the City of Miami Beach, Florida. The report is structured as follows.

- **Section 1** presents a brief introduction on the usage of red light cameras (RLCs) to improve safety at signalized intersections.
- **Section 2** presents the study objective.
- **Section 3** shows the results of the most recent studies on the safety effectiveness of RLCs.
- **Section 4** discusses the data used in this study and the data collection efforts.
- **Section 5** presents the methodology adopted to evaluate the safety performance of the PRL enforcement program in the City of Miami Beach.
- **Section 6** reflects on the main findings from the study.
- **Section 7** summarizes this research effort.

1. INTRODUCTION

Intersection-related crashes represent approximately 40% of all crashes (Decina et al., 2007). As such, intersection safety is a serious problem in the United States. Many of the crashes at signalized intersections can be attributed to red-light running (RLR), which "involves a driver entering an intersection after the traffic signal has turned red" (City of Fort Lauderdale, n.d.). The following crash types are commonly attributed to RLR: angle, left-turn, right-turn, and head-on crashes. These crashes are often severe and result in fatalities. For example, in 2015, on average, two people are killed every day due to RLR. From 2011 to 2015, 719 people died each year on an average from RLR crashes. In 2014, about 126,000 people were injured in RLR crashes. The estimated economic losses exceed $4 Billion annually (ATSOL, 2018). Interestingly, in RLR crashes, it was not the drivers who run red lights who sustain fatal injuries, but the occupants of other vehicles, pedestrians, and bicyclists who were hit by drivers who run red lights (IIHS-HLDI, 2016). In 2010, 61 people were killed in RLR crashes in Florida, making it the third deadliest state in the nation for RLR crashes (City of Miami Springs, n.d.).

Over the last decade, photo red light (PRL) cameras have been increasingly deployed to reduce the occurrence of RLR crashes. This automated enforcement method is used to discourage red light runners and decrease intersection crashes. Red light cameras (RLCs) are automated systems that photograph vehicles entering intersections after the traffic signals have turned red. The photographic evidence captured by the cameras allow camera operators to determine whether or not a ticket should be issued to the violating vehicle. In Florida, RLR tickets usually cost $158, but drivers could pay up to $262 if they fail to pay for the offence after the first notification (Florida Online Traffic School, 2018).

2. RESEARCH OBJECTIVE

The main objective of this study was to evaluate the safety effectiveness of the PRL Enforcement Program in the City of Miami Beach, Florida. The safety effectiveness of the RLCs was measured using the simple before-and-after analysis and the full Bayes before-and-after evaluation approach. The full Bayes method was implemented to take into account the regression-to-the-mean (RTM) phenomenon, which is observed due to the natural variability of crash data, to also consider the changes in traffic volume, geometric characteristics and driver behavior over time.

3. LITERATURE REVIEW

Table 1 summarizes recent studies that focused on the safety effectiveness of RLCs. The literature review revealed that most studies have compared data for the "before installation" and "after installation" periods for treatment and non-treatment intersections to quantify the safety effectiveness of RLCs. While most studies determined that signalized intersections equipped with RLCs experienced a considerably large reduction in RLR crash types and injuries, some studies determined that RLCs contribute only to a small reduction in crashes. Additionally, these studies found that RLCs have some negative safety impacts, i.e., they tend to increase specific crash types, such as rear-end and sideswipe collisions, by both number and severity. Understanding the methodology and findings of previous studies allowed the research team to adopt a methodology to overcome the past flaws and difficulties, such as, the RTM effect, and identify the right type of crashes to be evaluated.

Table 1: Summary of Recent Literature on the Safety Impacts of RLCs

Reference	Number of Study Intersections	Study Results	Method	Study Period	City, State
Ko et al. (2017)	• Treatment Sites: 48 • Comparison Sites: Not Available	• After the RLC activation: 37% crash reduction in all RLR crash types. • After the RLC deactivation: 20% increase in all RLR crash types.	Before-after (EB approach)	2008 - 2014	Houston, TX
Llau et al. (2015)	• Treatment Sites: 20 • Comparison Sites: 40	• 19% and 24% reduction in total injury, and RLR-related injury crashes. • 40% increase in rear-end crashes.	Before-after using comparison group (EB approach)	2008 – 2012	Miami-Dade County, FL
Claros et al. (2017)	• Treatment Sites: 24 • Comparison Sites: 35	• 12% reduction in angle crashes. • 10.5% increase in rear-end crashes. • Crash cost benefit of $47,000 per site per year.	Before-after (EB approach)	2006 – 2011	Missouri
Ahmed and Abdel-Aty (2014)	• Treatment Sites: 25 • Comparison Sites: Not Available	• Angle and left-turn crashes decreased by 24% and 26% for all severity and fatal and injury crashes, respectively, at approaches with RLCs. • Rear-end crashes increased by 32% and 41% for all severity level and fatal crashes.	Before-after (EB approach)	2006 – 2011	Orange County, FL
Shin and Washington (2007)	• Treatment Sites: 24 • Comparison Sites: 13	• Angle crashes decreased by 20% and left-turn crashes decreased by 45% at target approaches. • Rear-end crashes increased by 41%. • Similar results were found for non-target approaches, indicating a high spillover effect.	Before-after (Simple, with traffic flow correction, using comparison group, & EB approach)	1998 – 2003; 1990 – 2003	Phoenix and Scottsdale, AZ
Pulugurtha and Otturu (2013)	• Treatment Sites: 32 • Comparison Sites: Not Available	• Significant increase in sideswipe and rear-end crashes. • Significant reduction in total crashes.	Before-after (EB approach)	1997 – 2010	Charlotte, NC

Note: treatment sites are the signalized intersections with RLCs; while comparison (i.e., non-treatment) sites are the signalized intersections with no RLCs.

4. STUDY DATA

The study area included a total of 28 signalized intersections in the City of Miami Beach, Florida. The intersections were divided into two categories:

- signalized intersections with RLCs, termed as “treatment intersections”; and
- signalized intersections without RLCs, termed as “non-treatment intersections”.

As the name implies, treatment intersections are locations where RLCs were installed. On the other hand, non-treatment intersections, also known as comparison intersections, are those intersections that have similar traffic volume, roadway geometrics, and other site characteristics as the treatment intersections, but without the RLCs. These sites were manually selected after an extensive review of the City of Miami Beach’s roadway network.

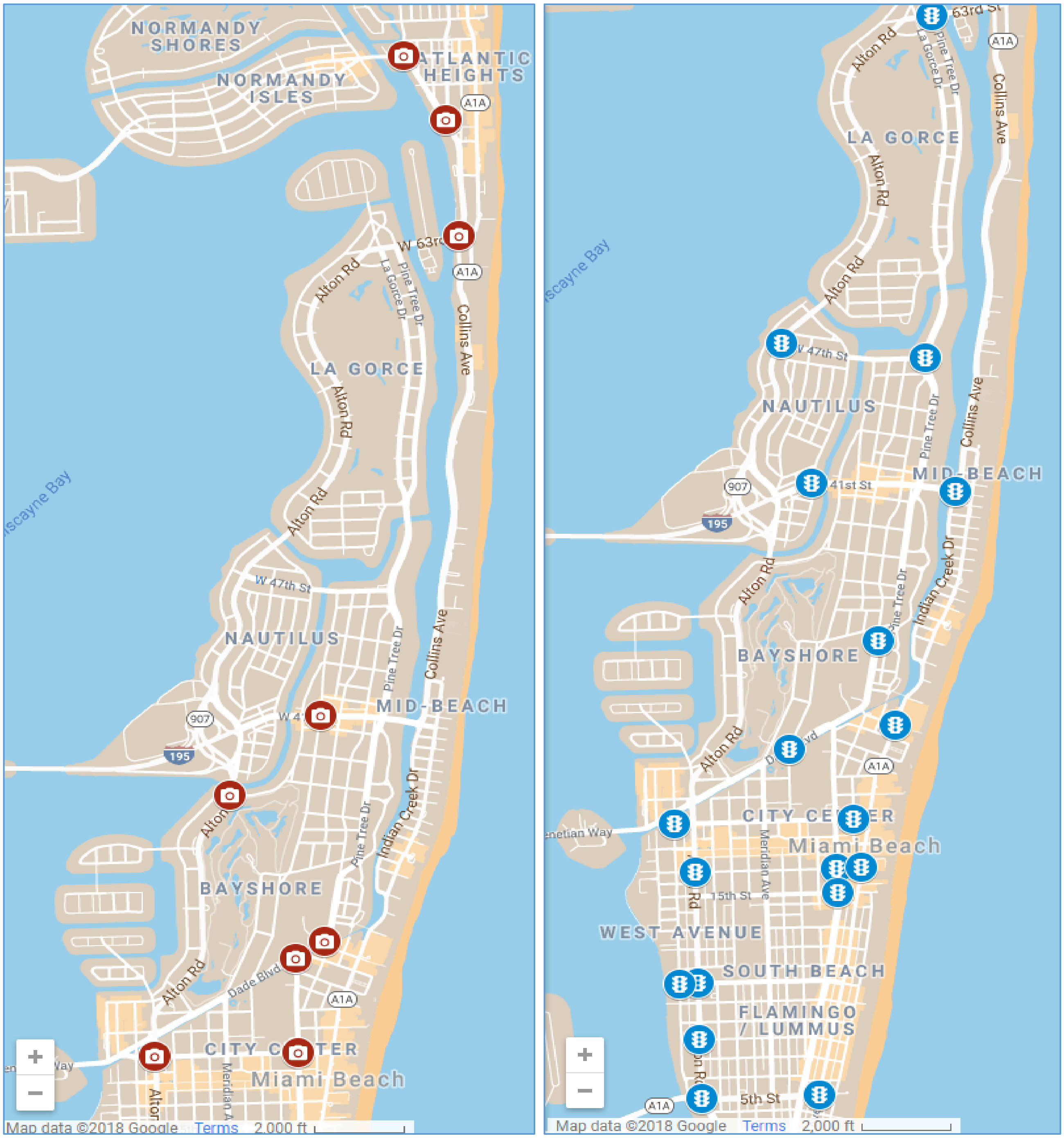
Figures 1(a) and 1(b) show the map of the treatment and non-treatment intersections, respectively. A total of nine signalized intersections were identified as “treatment intersections”. Of these nine, six are four-legged and the remaining three are three-legged intersections. A total of 19 signalized intersections were identified as “non-treatment intersections”, 14 of which are four-legged, and the remaining five are three-legged signalized intersections.

The following data were included in the analysis: crash data, traffic volume, roadway geometric characteristics, and traffic control features. Note that these data were required for both treatment and non-treatment intersections. The following subsections discuss these data in detail.

4.1 Treatment and Non-treatment Intersections

A total of ten red-light cameras are operational at nine signalized intersections in the City of Miami Beach, as listed in Table 2 and shown in Figure 1(a). For all the intersections, Table 2 includes the number of intersection legs (i.e., three-legged or four-legged), and the major road and minor road names. For the treatment intersections, the table provides information on the RLC installation date and the approach with the RLC.

Due to the long period of construction activity, the intersection where Alton Road meets 17th Street was not included in the study. Temporary traffic controls, such as concrete barriers and traffic cones, tend to affect traffic patterns, traffic volumes, and the occurrence of crashes. Therefore, this intersection is expected to have an unusual crash frequency that cannot be associated with the operation of RLCs. The rest of the intersections (i.e., both treatment and non-treatment intersections) were manually reviewed to identify any major construction activity that might have taken place during the study period. However, no significant construction activity was found at the rest of the intersections. The review was also done to make sure that there were no other countermeasures during the study period other than the RLCs.



(a) Treatment Intersections **(b) Non-treatment Intersections**

Figure 1: Map of Treatment and Non-Treatment Intersections

Table 2: Treatment and Non-treatment Intersections

Intersection Type		Item	Major Road	Minor Road	Date of Operation	Approach with RLC
Treatment Intersections	4-legged	1	Washington Ave	17th St.	4/1/2010	SB
		2	Washington Ave	17th St.	4/1/2010	EB
		3*	Alton Road	17th St.	9/1/2015	WB
		4	41st St.	Prairie Ave	4/1/2010	NB
		5	Alton Road	Chase Ave	4/1/2010	NB
		6	Indian Creek Dr	W 63rd St.	4/1/2010	SB
		7	71st St.	Indian Creek Dr	4/1/2010	NB
	3-legged	8	Washington Ave	Dade Blvd.	4/1/2010	EB
		9	Pinetree Blvd	23rd St.	4/1/2010	WB
		10	Indian Creek Dr	Abbott Ave	4/1/2010	SB
Non-treatment Intersections	4-legged	11	Dade Blvd	Prairie Ave	Not Applicable	Not Applicable
		12	5th St.	Alton Road		
		13	Arthur Godfrey Rd.	Meridian Ave		
		14	Alton Road	16th St.		
		15	Alton Road	11th St.		
		16	Alton Road	8th St.		
		17	17th St.	James Ave		
		18	Alton Road	W 47th St.		
		19	Washington Ave	16th St.		
		20	41st St.	Indian Creek Dr		
		21	5th St.	Collins Ave		
		22	Collins Ave	16th St.		
		23	Collins Ave	23rd St.		
		24	63rd St.	Pine Tree Dr		
	3-legged	25	West Ave	17th St.		
		26	Pine Tree Dr	Sheridan Ave		
		27	Washington	15th St.		
		28	Pine Tree Dr	W 47th St.		
		29	West Avenue	11th St.		

* This location experienced major construction during the study period. Hence, it is not included in the analysis.

4.2 Crash Data

The analysis was based on five years of crash data. Since the RLCs were installed in April 2010, crash data from two years before the RLC installation (i.e., 2008-2009), and three years after the RLC installation (i.e., 2011-2013) were included in the analysis.

Signal Four Analytics, a statewide interactive web-based geospatial crash analytical tool developed by and hosted at the University of Florida, GeoPlan Center, was used to identify and extract crash data. All crashes that occurred within 300 ft from the center of the intersection were identified, and the police crash reports of all these crashes were downloaded and reviewed.

As is evident from the literature, RLCs impact only specific (and not all) crash types, commonly known as target crashes. The following crash types were considered to be associated with RLR and the operation of RLCs.

- Angle (side impact)
- Right-turn (vehicle turning)
- Left-turn (vehicle turning)
- Rear-end
- Sideswipe

The police reports of all crashes that occurred within 300 ft of the intersections were manually reviewed to identify intersection-related crashes and target crashes. The number of crashes extracted from Signal Four Analytics was 2,419. Of this total, only 1,080 target crashes were included in the analysis. A total of 389 target crashes were found to have occurred at treatment sites, and 691 target crashes were found to have occurred at non-treatment sites, during both the before and the after periods. Table 3 provides a summary of all observed crash frequencies for treatment and non-treatment intersections. In addition to crash type, crash severity was also considered in the analysis. Crashes were categorized into property damage only (PDO), and fatal/injury crashes. Note that all injury severity levels (i.e., incapacitating, non-incapacitating, and possible injury) were grouped in the fatal/injury crash category.

The following information was collected while reviewing the police reports:

- The approach the crash occurred
    - Major approach
    - Minor approach
    - Middle of the intersection
    - Not sure

- The crash occurred on the approach with a red light camera? (applicable only for treatment intersections)
    - Yes
    - No
    - Not sure

- Manner of collision
    - Rear-end
    - Angle/left-turn/right-turn
    - Head-on/front-to-front
    - Sideswipe
    - Backed into
    - Fixed object
    - Other
    - Not sure

- 1st vehicle maneuver action
    - Going straight
    - Making a left-turn
    - Making a U-turn
    - Making a right-turn

  - Not sure
  - Other

- 2nd vehicle maneuver action
  - Going straight
  - Making a left-turn
  - Making a U-turn
  - Making a right-turn
  - Not sure
  - Other

- Crash involving driveway/on-street parking
  - Yes
  - No
  - Not sure

- Crash involving a pedestrian/bicyclists
  - Yes
  - No
  - Not sure

- Crash involving a distracted driver
  - Yes
  - No
  - Not sure

To evaluate the direct impact of RLCs on crash frequency and severity, target crashes were excluded when one of the following conditions were present:

- Adverse weather condition
- Distraction
- Driving under the influence (DUI)
- Crashes related to emergency vehicles responding in emergency circumstances
- Sickness
- Sleep deprivation/fatigue

Table 3 provides the descriptive statistics of crashes at each of the treatment and non-treatment intersections.

Table 3: Descriptive Statistics of Crashes at Treatment and Non-treatment Intersections

Int. Type		Item	Major Road	Minor Road	Before-period							After-period						
					Target Crashes by Crash Type			Target Crashes by Severity		Total Target Crashes	Total Crashes	Target Crashes by Crash Type			Target Crashes by Severity		Total Target Crashes	Total Crashes
					Angle/ Left-turn/ Right-turn	Rear-end	Side-swipe	PDO	Fatal & Injury			Angle/ Left-turn/ Right-turn	Rear-end	Side-swipe	PDO	Fatal & Injury		
Treatment	4-legged	1	Washington Ave	17th St.	9	1.5	4.5	12	3	15	27	3.3	1.7	2.3	6.0	1.3	7.3	18.0
		2	Washington Ave	17th St.	9	1.5	4.5	12	3	15	27	3.3	1.7	2.3	6.0	1.3	7.3	18.0
		3*	Alton Road	17th St.	3.5	9	8	16	4.5	20.5	49	7.7	4.7	8.7	19.0	2.0	21.1	52.7
		4	41st St.	Prairie Ave	0.5	3.5	0.5	4	0.5	4.5	21	1.3	4.7	0.0	5.0	1.0	6	13.0
		5	Alton Road	Chase Ave	1	3	1.5	5	0.5	5.5	16	0.0	4.7	1.0	4.3	1.3	5.7	14.7
		6	Indian Creek Dr	W 63rd St.	1.5	5	3.5	9	1	10	19.5	1.0	3.7	2.7	6.3	1.0	7.4	25.0
		7	71st St.	Indian Creek Dr	3.5	11.5	4	16.5	2.5	19	23.5	2.7	8.3	3.3	11.0	3.3	14.3	18.7
	3-legged	8	Washington Ave	Dade Blvd.	1.5	2	1.5	4.5	0.5	5	10	2.7	1.0	0.7	3.3	1.0	4.4	10.3
		9	Pine Tree Blvd	23rd St.	1.5	1	1.5	4	0	4	12	0.7	0.0	1.3	1.7	0.3	2	7.3
		10	Indian Creek Dr	Abbott Ave	1	2.5	1.5	4	1	5	13	0.3	1.0	1.3	2.3	0.3	2.6	11.3
Non-treatment	4-legged	11	Dade Blvd.	Prairie Ave	1.5	1.5	1	3.5	0.5	4	6	2.0	1.0	0.3	2.7	0.7	3.3	5.7
		12	5th St.	Alton Road	2	35.5	8	39.5	6	45.5	55.5	2.0	26.0	9.7	31.7	6.0	37.7	51.3
		13	Arthur Godfrey Rd.	Meridian Ave	1.5	7	1	8.5	1	9.5	11.5	0.7	5.0	0.0	4.3	1.3	5.7	9.0
		14	Alton Road	16th St.	4.5	4	6.5	14	1	15	28.5	3.3	3.3	3.0	8.3	1.3	9.6	25.0
		15	Alton Road	11th St.	2	3	2	6.5	0.5	7	9	3.0	3.0	1.7	5.3	2.3	7.7	15.0
		16	Alton Road	8th St.	4	6.5	8.5	16	3	19	25.5	5.3	5.3	3.0	12.0	1.7	13.6	20.0
		17	17th St.	James Ave	2.5	1	0	2	1.5	3.5	5.5	1.0	0.7	2.0	3.7	0.0	3.7	6.7
		18	Alton Road	W 47th St.	0.5	1.5	0.5	2.5	0	2.5	4.5	0.7	1.0	0.3	2.0	0.0	2	4.0
		19	Washington Ave	16th St.	1.5	8	7	14	2.5	16.5	32.5	1.3	3.3	3.3	6.3	1.7	7.9	21.0
		20	41st St.	Indian Creek Dr	0.5	4.5	2	6	1	7	24	0.3	4.0	3.7	7.7	0.3	8	25.7
		21	5th St.	Collins Ave	3.5	2	1.5	6.5	0.5	7	26.5	0.3	0.7	2.3	3.0	0.3	3.3	16.3
		22	Collins Ave	16th St.	0	2	2	3	1	4	19.5	0.7	0.7	2.0	2.7	0.7	3.4	19.0
		23	Collins Ave	23rd St.	1.5	1	1	3	0.5	3.5	20	2.0	1.7	2.0	4.3	1.3	5.7	25.3
		24	63rd St.	Pine Tree Dr	0.5	1	0.5	2	0	2	10.5	0.3	0.0	0.7	1.0	0.0	1	9.0
	3-legged	25	West Ave	17th St.	1.5	2.5	1.5	4.5	1	5.5	8.5	0.3	1.7	0.3	2.0	0.3	2.3	4.7
		26	Pine Tree Dr	Sheridan Ave	0	1.5	0	1.5	0	1.5	4	0.7	0.7	0.3	1.3	0.3	1.7	4.5
		27	Washington Ave	15th St.	1	1.5	0	2	0.5	2.5	20.5	0.3	1.0	0.3	1.3	0.3	1.6	19.7
		28	Pine Tree Dr	W 47th St.	0.5	1	0	1	0.5	1.5	7	0.3	1.3	0.0	1.3	0.3	1.6	6.7
		29	West Avenue	11th St.	0	3.5	0.5	3.5	0.5	4	5.5	1.0	1.3	0.7	1.0	2.0	3	4.7

* This location experienced major construction during the study period, and is not included in the analysis.

Note: all the crashes are per year. Total target crashes include angle/left-turn/right-turn, sideswipe, and rear-end crashes. There is an approximation error of ±0.1 in total target crashes.

4.3 Traffic Volume

Traffic volume data is included in traffic safety models because it is proven to be the main contributor to what is called crash exposure, i.e., as traffic volume increases there is a higher likelihood for crashes to occur.

AADT were collected from the Florida Department of Transportation (FDOT) Traffic Online website, a web-based mapping application that provides traffic count site locations and historical traffic count data. It is managed by the FDOT Transportation Data and Analytics Office. AADT data were collected for every year of analysis, 2008, 2009, 2011, 2012, and 2013. However, it is important to note that traffic counts are not available for all years and all roads due to high data collection costs. As such, the research team made reasonable assumptions to estimate missing traffic counts. For the missing data, AADT was obtained from parallel roads with similar roadway geometric characteristics, and AADT for the missing years was extrapolated assuming that traffic volume increased by 3% each year.

4.4 Intersection Characteristics

Roadway geometric characteristics and traffic control features often influence the occurrence and severity of crashes at signalized intersections. Including these data in the analysis helps understand the relationship, if any, between the RLR behavior and the characteristics of the intersections. The following roadway geometric characteristics and traffic control features were collected for each of the study intersection:

- Roadway Geometric Characteristics
    - Number of through lanes
    - Approaches with left-turn lanes
    - Approaches with right-turn lanes
    - Length of the sidewalk

- Traffic Control Features
    - Yellow and all-red times
    - Presence of pedestrian phase
    - Type of left-turn signal phasing (i.e., protected, protected-permitted, or permitted)
    - Right-turn on red restriction

5. METHODOLOGY

5.1 Descriptive Statistics

The following 9 signalized intersections were installed with RLCs in the City of Miami Beach:

1. Washington Ave and 17th St.
2. Alton Road and 17th St.
3. 41st St. and Prairie Ave
4. Alton Road and Chase Ave
5. Indian Creek Dr and W 63rd St.
6. Indian Creek Dr and 71st St.
7. Washington Ave and Dade Blvd.
8. Pinetree Blvd and 23rd St.
9. Indian Creek Dr and Abbott Ave

Note that the intersection *Alton Road and 17th St.* experienced major construction during the study period, and hence excluded from the analysis. The following subsection discuss the safety performance of each of the remaining eight intersections.

5.1.1 Washington Ave and 17th Street

This intersection is a four-legged signalized intersection. Figure 2 shows the aerial view of this intersection. The RLCs on the SB and EB approaches were installed on April 1, 2010. Figure 3 shows the number of target crashes by crash type and crash severity at this intersection before and after the RLC installation. Figure 4 shows the number of target crashes and total crashes at the approaches with RLCs. Note that target crashes include angle/left-turn/right-turn, rear-end, and sideswipe crashes. Some of the key findings include:

- This intersection experienced a total of 108 crashes during the study period (i.e., 2008-2009 and 2011-2013). The before-period had 27 crashes per year, and the after-period had 18 crashes per year.

- Overall, there was a reduction in target crashes after the installation of the RLCs at this intersection.

- After the RLC installation, both the PDO and fatal/injury crashes decreased by half.

- Both total crashes and total target crashes decreased at the approaches with RLCs. Angle/left-turn/right-turn crashes decreased, rear-end crashes increased, while sideswipe crashes didn’t change after the installation of RLCs.

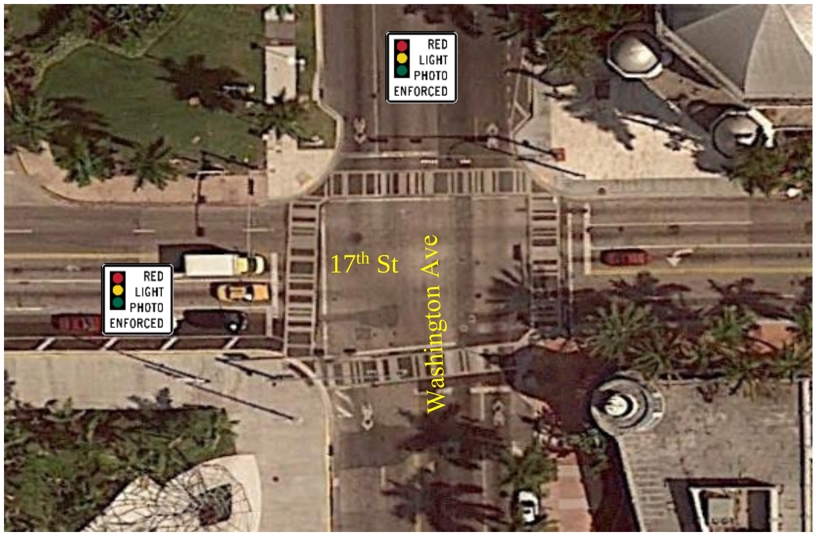
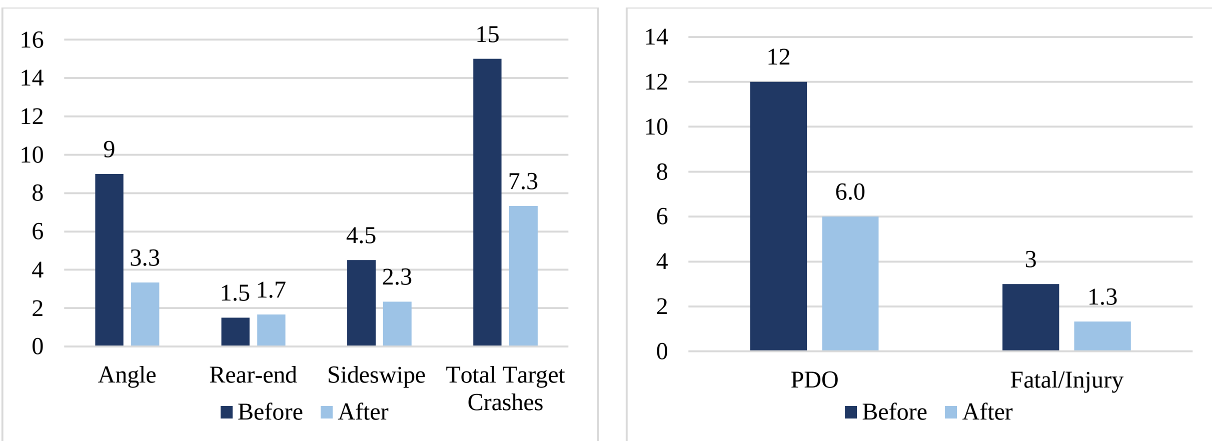
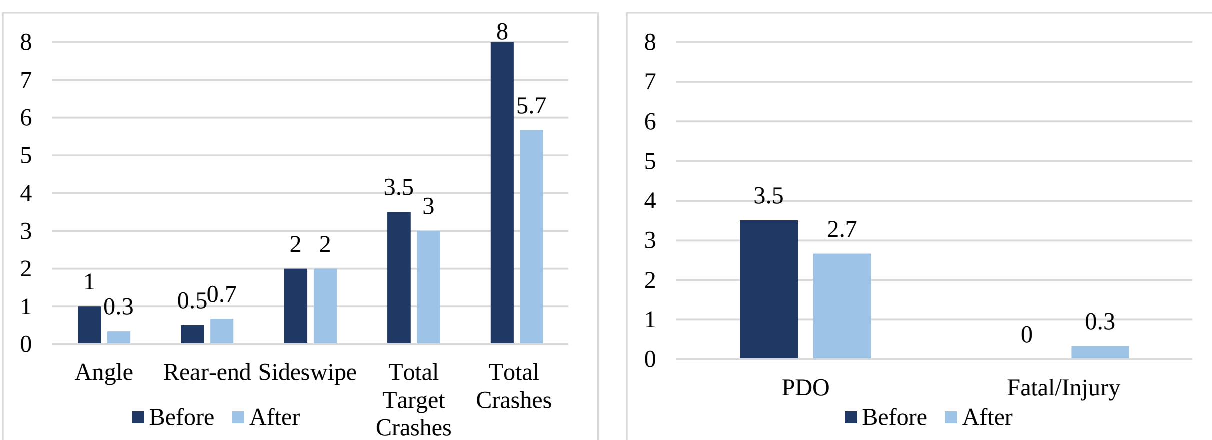


Figure 2: Aerial View of Washington Ave and 17th St. Intersection



(a) Target Crashes by Crash Type (b) Target Crashes by Crash Severity

Figure 3: Overview of Target Crashes at Washington Ave and 17th St Intersection



(a) Target Crashes by Crash Type (b) Target Crashes by Crash Severity

Figure 4: Washington Ave and 17th St Intersection - Overview of Target Crashes at Approaches with RLCs

5.1.2 41st St. and Prairie Ave

This intersection is a four-legged signalized intersection. Figure 5 shows the aerial view of this intersection. The RLC on the NB approach was installed on April 1, 2010. Figure 6 shows the number of target crashes by crash type and crash severity at this intersection before and after the RLC installation. Figure 7 shows the number of target crashes and total crashes at the approach with RLC. Note that target crashes include angle/left-turn/right-turn, rear-end, and sideswipe crashes. Some of the key findings include:

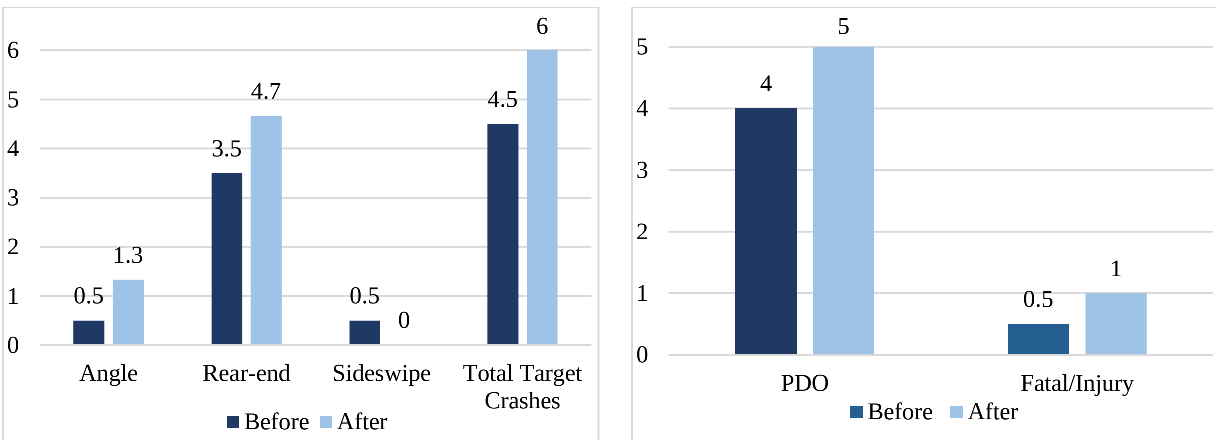
- This intersection experienced a total of 81 crashes during the study period (i.e., 2008-2009 and 2011-2013). The before-period had 21 crashes per year, and the after-period had 13 crashes per year.

- Overall, the number of target crashes at this intersection increased after installing the RLC. Angle/left-turn/right-turn and rear-end crashes increased after the RLC installation. No sideswipe crashes were reported after the RLC installation.

- Even though there was an increase in target crashes, the total crashes at the intersection decreased.

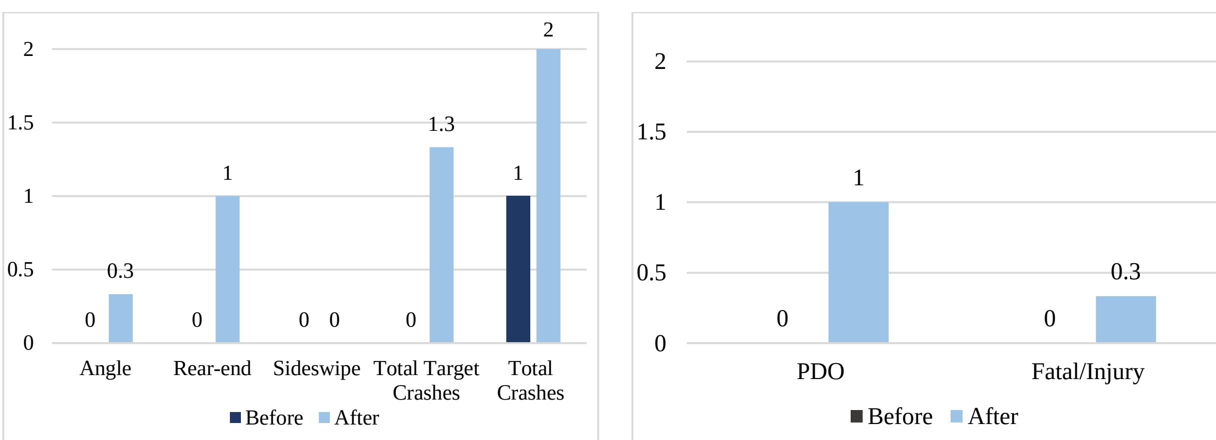
- At the approach with the RLC, the before-period did not have any target crashes, however, the approach experienced three target crashes after the RLC installation.

Figure 5: Aerial View of W 41st St and Prairie Ave Intersection



(a) Target Crashes by Crash Type (b) Target Crashes by Crash Severity

Figure 6: Overview of Target Crashes at W 41st St and Prairie Ave Intersection



(a) Target Crashes by Crash Type (b) Target Crashes by Crash Severity

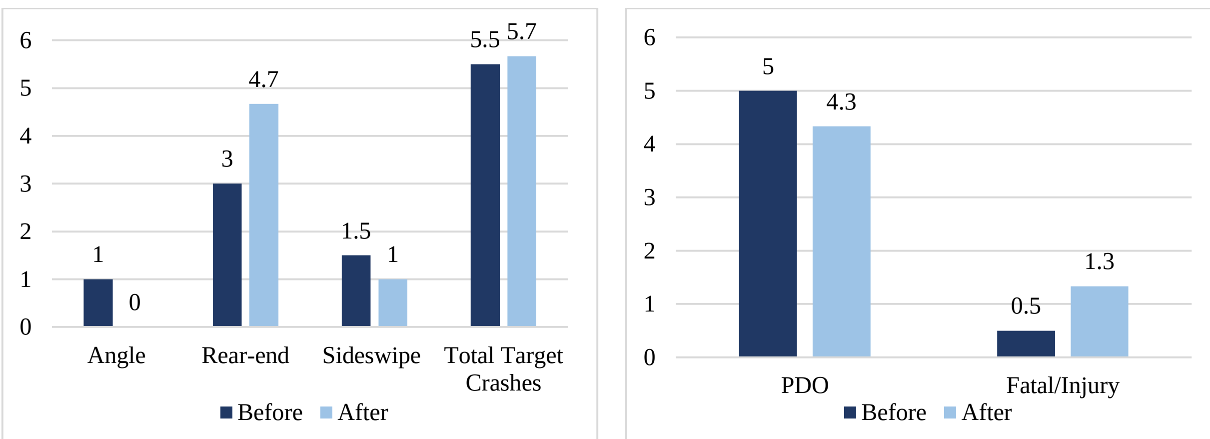
Figure 7: W 41st St and Prairie Ave Intersection - Overview of Target Crashes at Approach with RLC

5.1.3 Alton Rd and Chase Ave

This intersection is a four-legged signalized intersection. Figure 8 shows the aerial view of this intersection. The RLC on the NB approach was installed on April 1, 2010. Figure 9 shows the number of target crashes by crash type and crash severity at this intersection before and after the RLC installation. Figure 10 shows the number of target crashes and total crashes at the approach with RLC. Note that target crashes include angle/left-turn/right-turn, rear-end, and sideswipe crashes. Some of the key findings include:

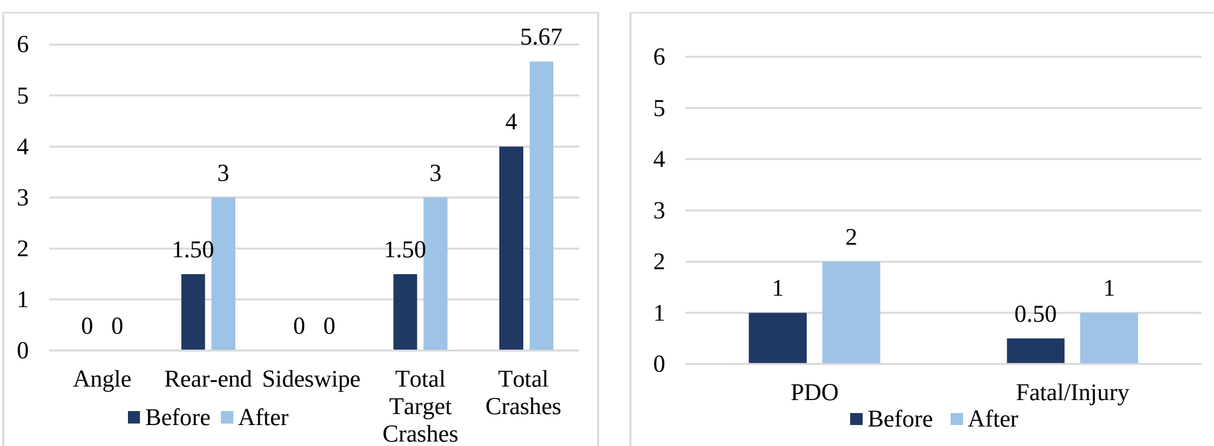
- This intersection experienced a total of 76 crashes during the study period (i.e., 2008-2009 and 2011-2013). The before-period had 16 crashes per year, and the after-period had 14.7 crashes per year.
- The results show that while angle/left-turn/right-turn and sideswipe crashes decreased, rear-end crashes increased after the RLC installation.
- Overall, this intersection experienced similar crash trend after the RLC installation.
- The approach with RLC did not experience any angle/left-turn/right-turn or sideswipe crashes during the study period. However, multiple rear-end crashes were reported. Rear-end crashes doubled after the RLC installation.

Figure 8: Aerial View of Alton Rd and Chase Ave Intersection



(a) Target Crashes by Crash Type
(b) Target Crashes by Crash Severity

Figure 9: Overview of Target Crashes at Alton Rd and Chase Ave Intersection



(a) Target Crashes by Crash Type
(b) Target Crashes by Crash Severity

Figure 10: Alton Rd and Chase Ave Intersection - Overview of Target Crashes at Approach with RLC

5.1.4 Indian Creek Dr and W 63rd Street

This intersection is a four-legged signalized intersection. Figure 11 shows the aerial view of this intersection. The RLC on the SB approach was installed on April 1, 2010. Figure 12 shows the number of target crashes by crash type and crash severity at this intersection before and after the RLC installation. Figure 13 shows the number of target crashes and total crashes at the approach with RLC. Note that target crashes include angle/left-turn/right-turn, rear-end, and sideswipe crashes. Some of the key findings include:

- This intersection experienced a total of 114 crashes during the study period (i.e., 2008-2009 and 2011-2013). The before-period had 19.5 crashes per year, and the after-period had 25 crashes per year.

- This intersection experienced a reduction in all target crashes (i.e., angle/left-turn/right-turn, rear-end, and sideswipe crashes) after the RLC installation.

- There was a reduction in PDO target crashes; while the target crashes resulting in injuries experienced similar crash trend after the RLC installation.

- The approach with RLC experienced a positive effect; angle/left-turn/right-turn, rear-end, and sideswipe crashes decreased after the RLC installation.

- The approach with RLC experienced a reduction in PDO crashes. No fatal/injury crashes were reported on this approach during the study period.

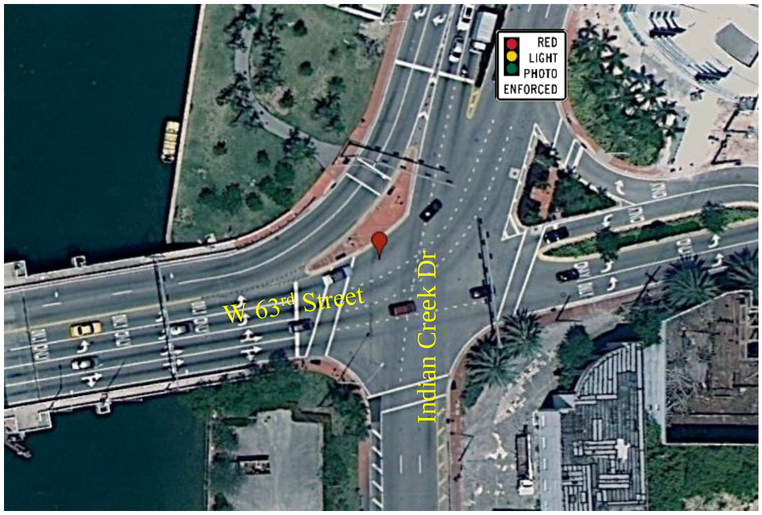
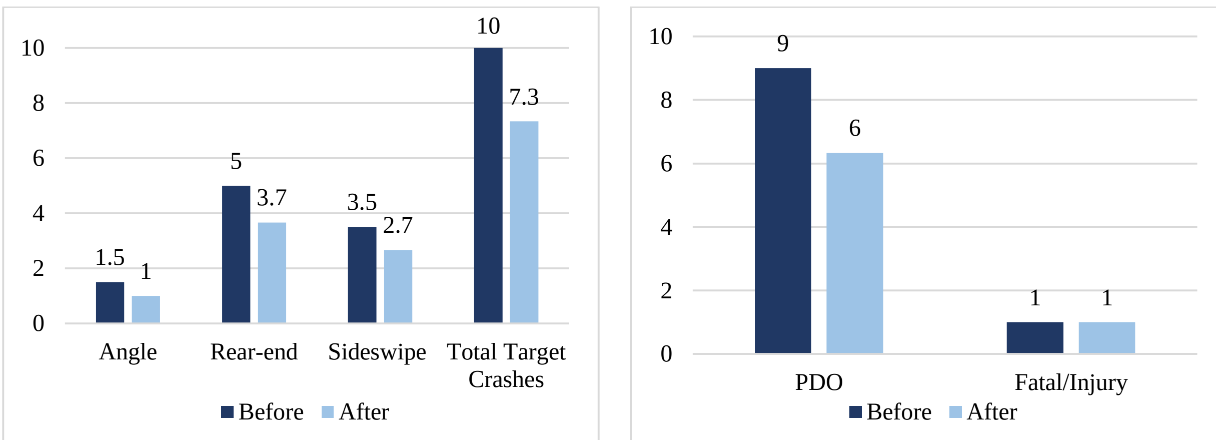


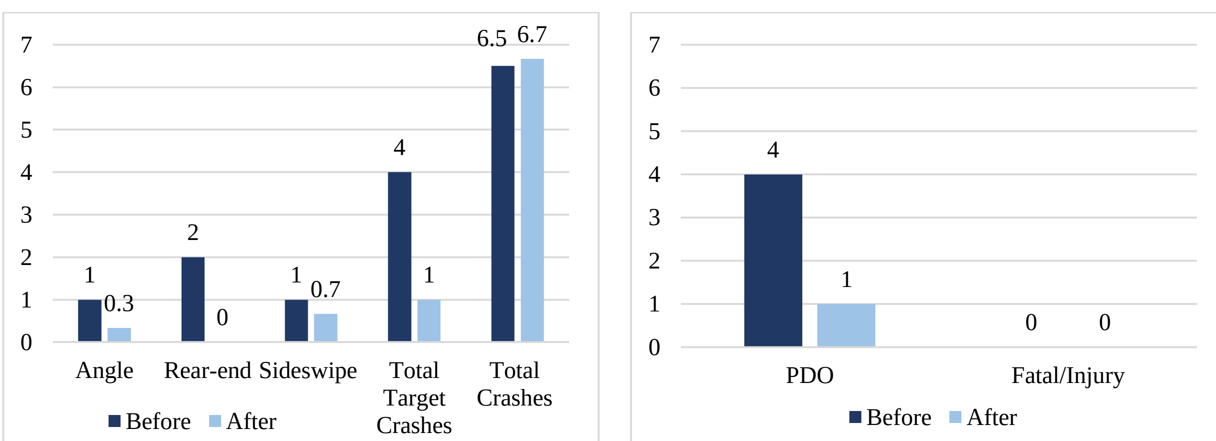
Figure 11: Aerial View of Indian Creek Dr and W 63rd St. Intersection



(a) Target Crashes by Crash Type

(b) Target Crashes by Crash Severity

Figure 12: Overview of Target Crashes at Indian Creek Dr and W 63rd St. Intersection



(a) Target Crashes by Crash Type

(b) Target Crashes by Crash Severity

Figure 13: Indian Creek Dr and W 63rd St. Intersection - Overview of Target Crashes at Approach with RLC

5.1.5 Indian Creek Dr and 71st Street

This intersection is a four-legged signalized intersection. Figure 14 shows the aerial view of this intersection. The RLC on the NB approach was installed on April 1, 2010. Figure 15 shows the number of target crashes by crash type and crash severity at this intersection before and after the RLC installation. Figure 16 shows the number of target crashes and total crashes at the approach with RLC. Note that target crashes include angle/left-turn/right-turn, rear-end, and sideswipe crashes. Some of the key findings include:

- This intersection experienced a total of 103 crashes during the study period (i.e., 2008-2009 and 2011-2013). The before-period had 23.5 crashes per year, and the after-period had 18.7 crashes per year.

- This intersection experienced a reduction in all target crashes (i.e., angle/left-turn/right-turn, rear-end, and sideswipe crashes) after the RLC installation.

- There was a reduction in PDO target crashes, but target crashes resulting in injuries slightly increased.

- The approach with RLC experienced a positive effect; angle/left-turn/right-turn, rear-end, and sideswipe crashes decreased after the RLC installation. The total number of crashes also decreased at this approach.

- While PDO target crashes decreased by more than half, fatal/injury target crashes increased. It is important to note that no fatal/injury target crashes were reported in the before-period.

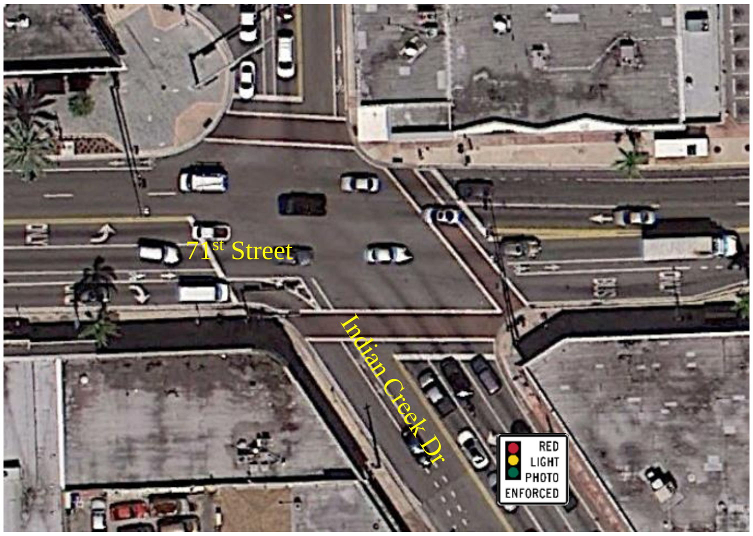
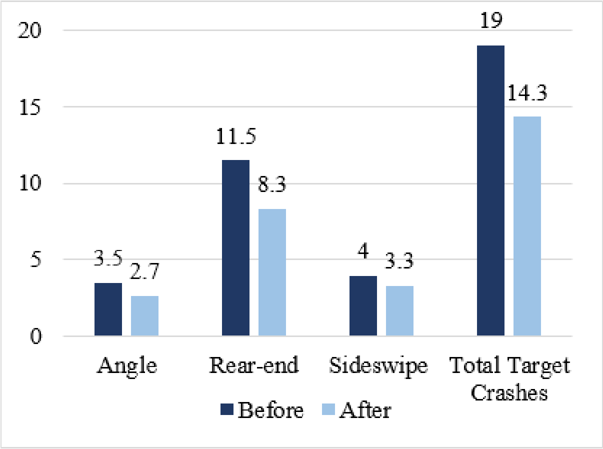
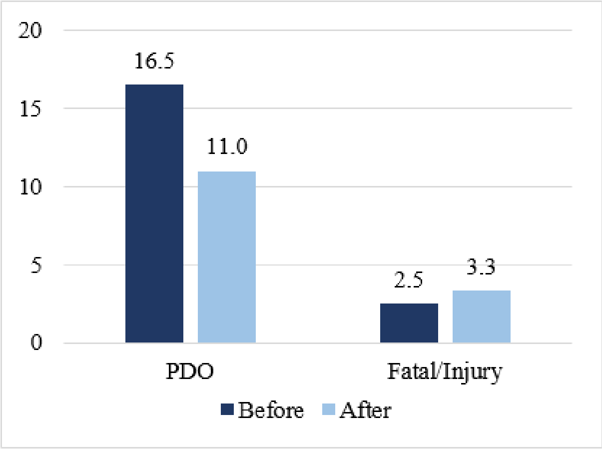


Figure 14: Aerial View of Indian Creek Dr and 71st St. Intersection

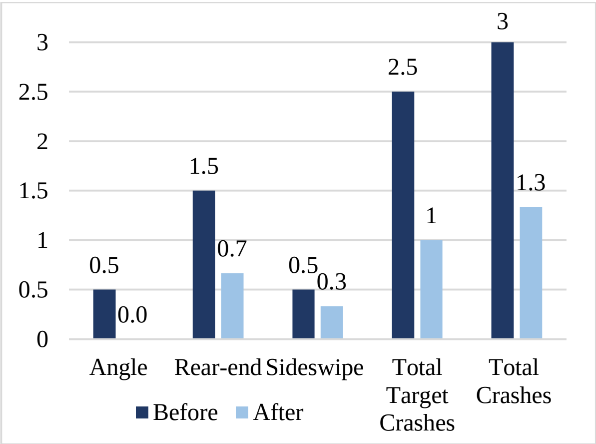


(a) Target Crashes by Crash Type

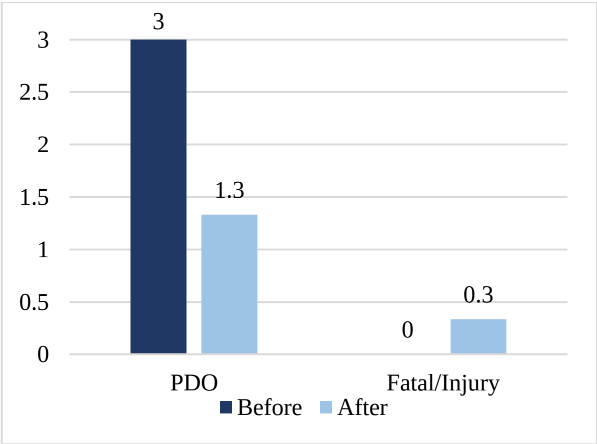


(b) Target Crashes by Crash Severity

Figure 15: Overview of Target Crashes at Indian Creek Dr and 71st St. Intersection



(a) Target Crashes by Crash Type



(b) Target Crashes by Crash Severity

Figure 16: Indian Creek Dr and 71st St. Intersection - Overview of Target Crashes at Approach with RLC

5.1.6 Washington Ave and Dade Blvd

This intersection is a three-legged signalized intersection. Figure 17 shows the aerial view of this intersection. The RLC on the EB approach was installed on April 01, 2010. Figure 18 shows the number of target crashes by crash type and crash severity at this intersection before and after the RLC installation. Figure 19 shows the number of target crashes and total crashes at the approach with RLC. Note that target crashes include angle/left-turn/right-turn, rear-end, and sideswipe crashes. Some of the key findings include:

- This intersection experienced a total of 51 crashes during the study period (i.e., 2008-2009 and 2011-2013). The before-period had 10 crashes per year, and the after-period had 10.3 crashes per year.

- Overall, target crashes slightly decreased at this intersection after the RLC installation.

- After the RLC installation, this intersection experienced an increase in angle/left-turn/right-turn crashes but a decrease in rear-end and sideswipe crashes.

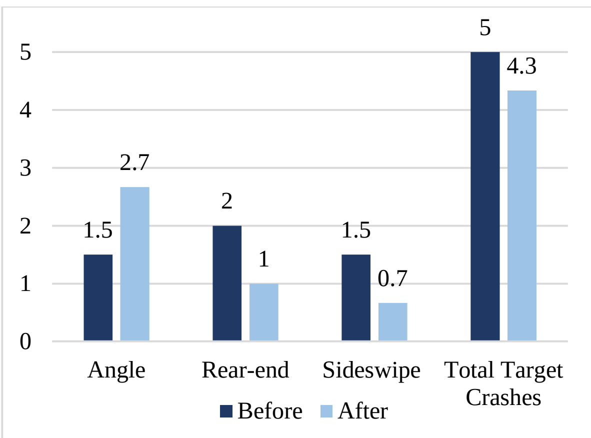
- PDO target crashes decreased while fatal/injury target crashes increased.

- It is important to note that the approach with RLC did not experience any angle/left-turn/right-turn or rear-end crashes. There were only two target crashes (sideswipe) reported during the before-period.

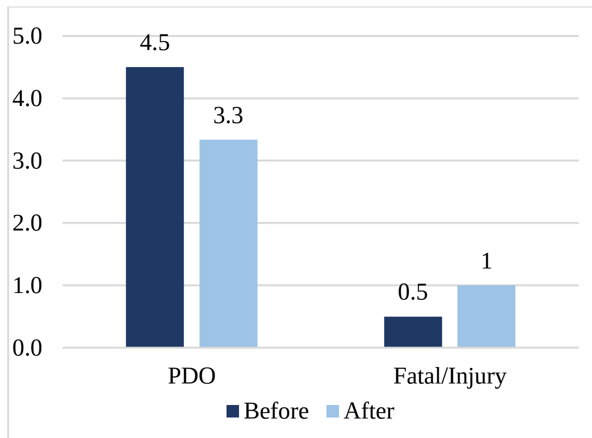
- At the approach with RLC, no target crashes were reported after the RLC installation. Total crashes decreased at this approach.

- The approach with RLC experienced a reduction in PDO crashes after the RLC installation. It is important to note that there were no observed fatal/injury crashes during the study period.

Figure 17: Aerial View of Washington Ave and Dade Blvd Intersection

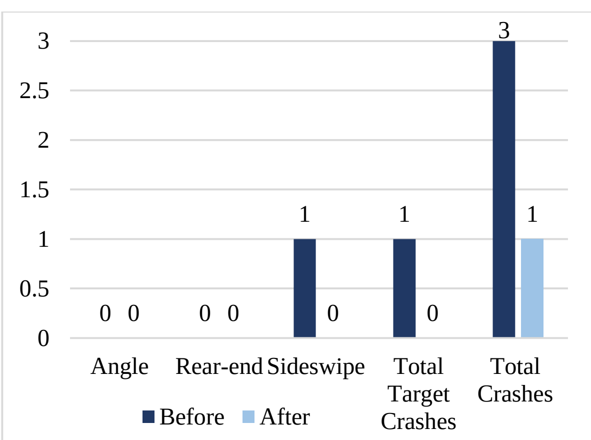


(a) Target Crashes by Crash Type

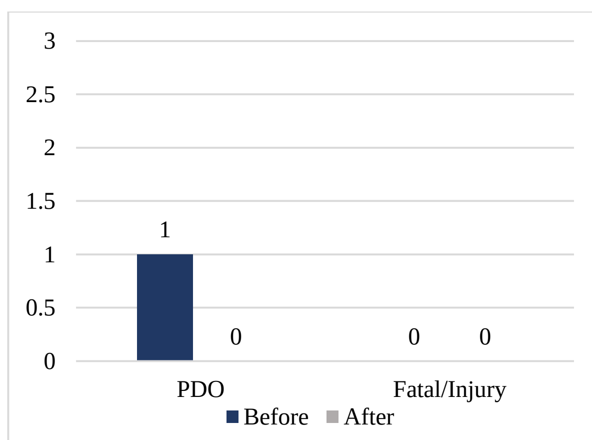


(b) Target Crashes by Crash Severity

Figure 18: Overview of Target Crashes at Washington Ave and Dade Blvd. Intersection



(a) Target Crashes by Crash Type



(b) Target Crashes by Crash Severity

Figure 19: Washington Ave and Dade Blvd. Intersection - Overview of Target Crashes at Approach with RLC

5.1.7 Pine Tree Blvd and 23rd Street

This intersection is a three-legged signalized intersection. Figure 20 shows the aerial view of this intersection. The RLC on the WB approach was installed on April 01, 2010. Figure 21 shows the number of target crashes by crash type and crash severity at this intersection before and after the RLC installation. Figure 22 shows the number of target crashes and total crashes at the approach with RLC. Note that target crashes include angle/left-turn/right-turn, rear-end, and sideswipe crashes. Some of the key findings include:

- This intersection experienced a total of 46 crashes during the study period (i.e., 2008-2009 and 2011-2013). The before-period had 12 crashes per year, and the after-period had 7.3 crashes per year.
- Overall, target crashes decreased by half after the RLC installation.
- This intersection experienced a reduction in angle/left-turn/right-turn, rear-end, and sideswipe crashes after the RLC installation.
- After the RLC installation, there was a reduction in PDO target crashes at the intersection, but there was a slight increase in fatal/injury target crashes.
- It is important to note that the approach with RLC did not experience any angle/left-turn/right-turn or rear-end crashes during the study period. Similarly, there were no observed fatal/injury crashes during the study period.
- PDO target crashes decreased at the approach with RLC after its installation.

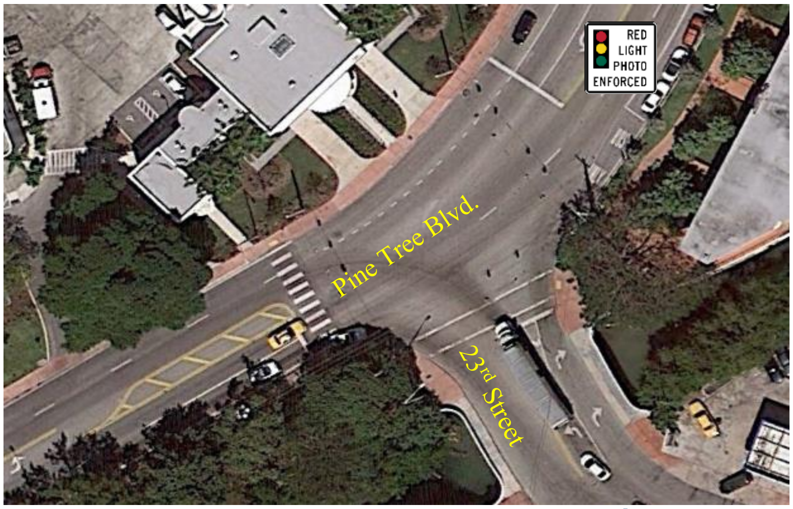
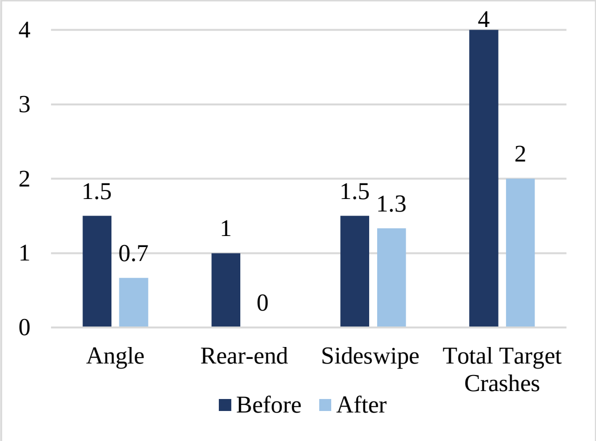
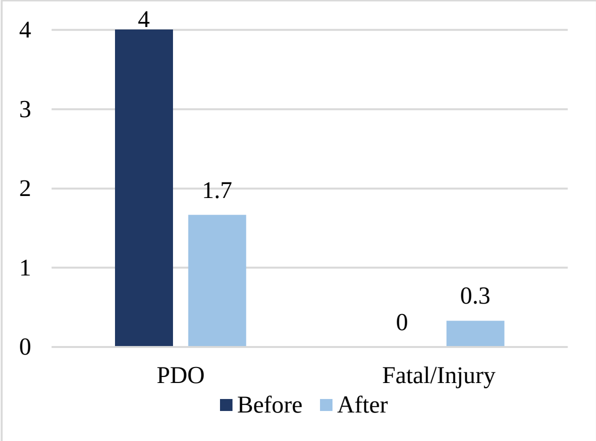


Figure 20: Aerial View of Pine Tree Blvd and 23rd St. Intersection

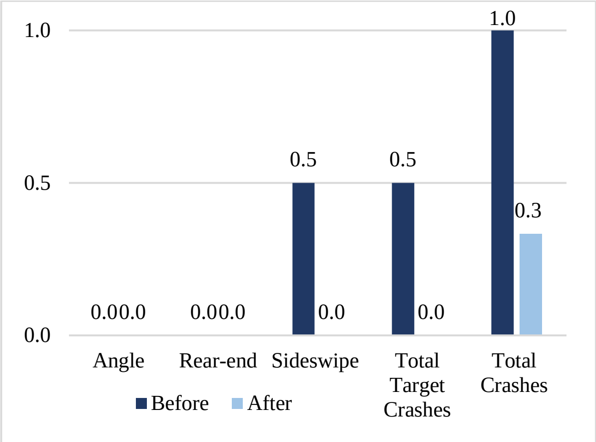


(a) Target Crashes by Crash Type

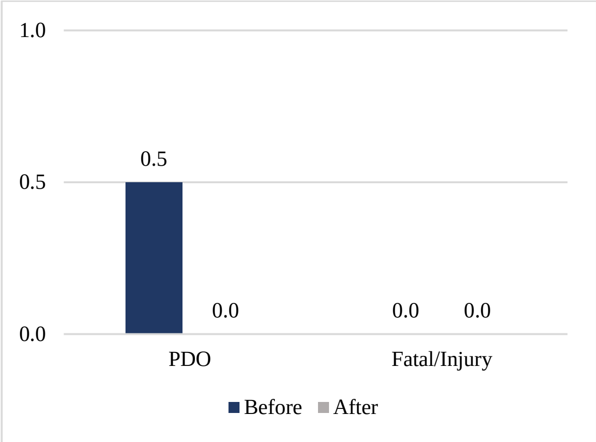


(b) Target Crashes by Crash Severity

Figure 21: Overview of Target Crashes at Pine Tree Blvd and 23rd St. Intersection



(a) Target Crashes by Crash Type



(b) Target Crashes by Crash Severity

Figure 22: Pine Tree Blvd and 23rd St. Intersection - Overview of Target Crashes at Approach with RLC

5.1.8 Indian Creek Dr and Abbott Ave

This intersection is a three-legged signalized intersection. Figure 23 shows the aerial view of this intersection. The RLC on the SB approach was installed on April 1, 2010. Figure 24 shows the number of target crashes by crash type and crash severity at this intersection before and after the RLC installation. Figure 25 shows the number of target crashes and total crashes at the approach with RLC. Note that target crashes include angle/left-turn/right-turn, rear-end, and sideswipe crashes. Some of the key findings include:

- This intersection experienced a total of 60 crashes during the study period (i.e., 2008-2009 and 2011-2013). The before-period had 13 crashes per year, and the after-period had 11.3 crashes per year.

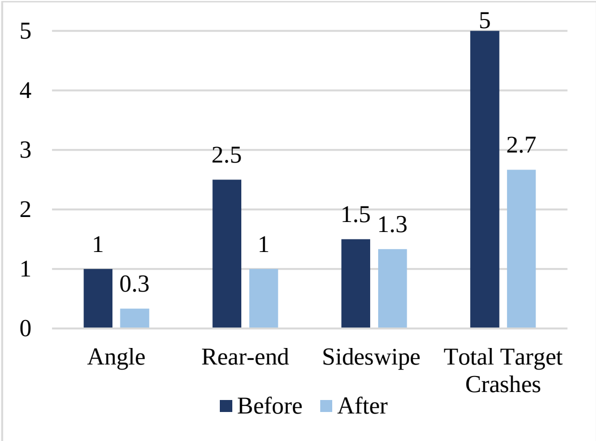
- This intersection experienced a reduction in all target crashes (i.e., angle/left-turn/right-turn, rear-end, and sideswipe crashes) after the RLC installation.

- Similarly, both PDO and fatal/injury target crashes decreased after the RLC installation.

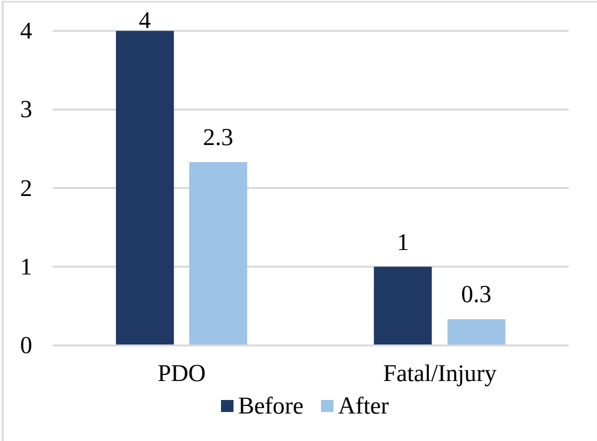
- The approach with RLC did not experience any angle/left-turn/right-turn, rear-end or sideswipe crashes after the RLC installation. There were no observed target crashes on this approach after the RLC installation.

- Even though the approach with RLC didn’t experience any target crashes after the RLC installation, the total number of crashes at the approach with RLC increased slightly.

Figure 23: Aerial View of Indian Creek Dr and Abbott Ave Intersection

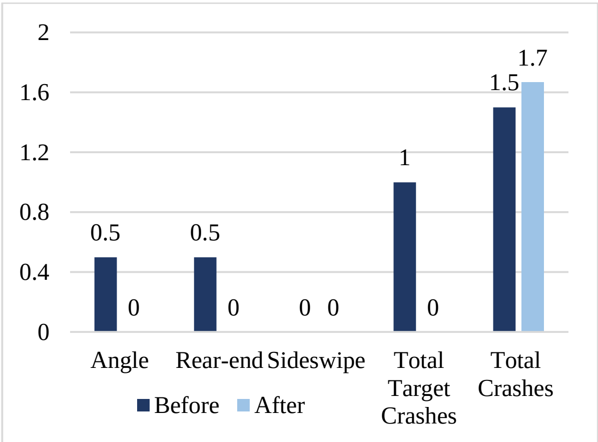


(a) Target Crashes by Crash Type

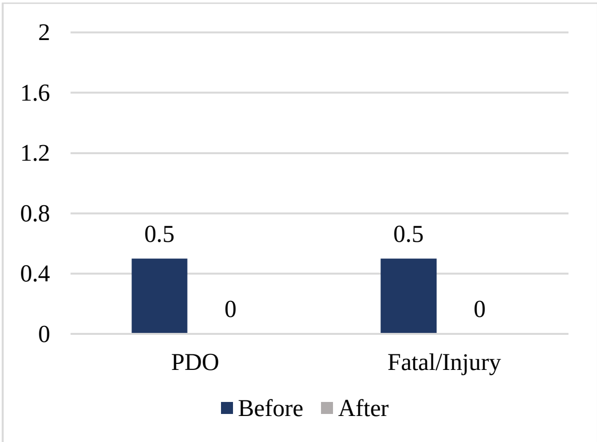


(b) Target Crashes by Crash Severity

Figure 24: Overview of Target Crashes at Indian Creek Dr and Abbott Ave Intersection



(a) Target Crashes by Crash Type



(b) Target Crashes by Crash Severity

Figure 25: Indian Creek Dr and Abbott Ave Intersection - Overview of Target Crashes at Approach with RLC

5.2 Statistical Models

Traditionally, naïve statistical methods have been used to quantify the safety performance of roadway countermeasures. In these approaches, the long-term safety effectiveness of the roadway countermeasure – in this case intersections with RLC – is quantified based on estimated crash rate. The estimated crash rates in this case are obtained by averaging observed crash rates over a few years on sites where the countermeasure have been installed. Despite being the most used technique for evaluating safety effectiveness of roadway countermeasures, this approach however, suffers from methodological and statistical limitations, including but not limited to:

- Failure to estimate reliable estimates when there is scarcity of sample size. The estimated long-term crash rate obtained by averaging observed crash rates over a few years can be unduly influenced by a single year with an unusually high (or low) number of crashes.
- Inability to account for the uncertainty of the crash data.
- Failure to account for the regression-to-the-mean bias, which is often predominant when the treatment sites are identified based on prior crash experience.

These limitations can be potentially addressed by employing a more reliable approach such as a full Bayes (FB) method in lieu of a crash rate approach. The FB method uses the data from the intersections of interest in combination with information from similar sites to complement the limited data. A FB approach has the ability to account for most of the uncertainties in the dataset and model parameters (Park et al., 2016). This method is also independent of sample size, yielding robust results even when used with small sample size (Li et al., 2013). Additionally, the FB approach divides the periods into time intervals (yearly in this case) and models each time interval as a separate data point to account for time variations, unlike the crash rate methodology which averages the data into a single data point. Detailed discussion about the FB method is presented in Carriquiry & Pawlovich (2004).

This study evaluated the safety effectiveness of RLCs at signalized intersections. The study employed the FB methodology to evaluate the overall safety effectiveness in terms of the effectiveness for target crashes by crash type (angle/left-turn/right-turn, rear-end, and sideswipe), and crash severity (PDO and fatal/injury crashes). Note that the models were developed only for four-legged signalized intersections. Only three treatment intersections are three-legged; the sample size is too small to yield reliable results from the FB statistical analysis.

5.2.1 Data Variables Considered

In this study, the FB before-and-after with comparison sites approach was used to assess the effectiveness of RLCs at signalized intersections. The RLCs were installed in 2010. The before-period included two years (2008 and 2009) before the installation of the RLCs; and the after-period included three years after the installation of RLCs (2011-2013). As mentioned earlier, treatment intersections are those where RLCs were installed. Comparison (i.e., non-treatment) intersections, on the other hand, include intersections similar to treatment intersections but without RLCs. Independent variables included in this study are listed below (see Table 4):

- Treatment indicator. It represents the countermeasure effectiveness (i.e., RLCs in this case). It measures the difference in crash count between treatment and comparison intersections.
    - comparison intersections (code 0)
    - treatment intersections (code 1)
- Time indicator. It accounts for the changes in crash frequency due to the intervention.
    - before period (code 0)
    - after period (code 1)
- Treatment by time indicator. It accounts for different time trends across treatment and comparison intersections.
- Jump parameter. It accounts for a sudden drop or increase in crash frequency upon installation of RLCs.
- Average annual daily traffic (AADT) on the major street (Major AADT).
- AADT on the minor street (Minor AADT).
- Speed limit on the major approach (Major speed)
    - ≤ 30 mph (code 0)
    - > 30 mph (code 1)
- Speed limit on the minor approach (Minor AADT)
    - ≤ 30 mph (code 0)
    - > 30 mph (code 1)
- Yellow time
    - < 4 seconds (code 0)
    - ≥ 4 seconds (code 1)
- All red time
    - ≤ 2 seconds (code 0)
    - > 2 seconds (code 1)
- Length of the pedestrian crosswalk
- Number of through lanes on the major approach (Major through lanes)
    - ≤ 2 lanes (code 0)
    - > 2 lanes (code 1)
- Number of lanes on the minor approach (Minor through lanes)
    - ≤ 1 lanes (code 0)
    - > 1 lanes (code 1)
- Number of driveways within 250 feet from the center of the intersection (Number of driveways)
    - ≤ 3 (code 0)
    - > 3 (code 1)

Table 4: Descriptive Statistics of the Data Used in the full Bayes Models

Variable	Units	Mean	Std. Dev.	Minimum	Median	Maximum
Major AADT	Vehicles per day	31,721	13,674.06	4,900	35,000	83,500
Minor AADT	Vehicles per day	9,581	8,802.09	2,700	5,500	39,500
Major speed	Miles per hour	32.13	2.48	30	30	35
Minor speed	Miles per hour	30.38	2.35	20	30	35
Yellow time	Seconds	3.94	0.20	3.06	4	4.3
All red time	Seconds	2.36	0.55	2	2	4
Length of pedestrian crosswalk	Feet	72.27	18.7	48	67.3	120
Major through lanes	Count	2.15	0.53	1	2	4
Minor through lanes	Count	1.225	0.47	0	1	2
Number of driveways	Count	3.325	1.53	0	3	8

5.2.2 Poisson-gamma Model

The Poisson-gamma statistical model was considered to assess the safety effectiveness of RLCs. In all cases, Y_{it} in Equation 1 denotes the crash count observed at intersection $i(i = 1,2,3, \dots, n)$ during year t $(t = 1,2,3, \dots,5)$ and can be modeled with a Poisson distribution with mean and variance equal to θ_{it}.

$$Y_{it}|\theta_{it} \sim Poisson\ (\theta_{it}), \qquad (1)$$

The Poisson mean θ_{it} can be written as shown in Equation 2.

$$ln(\theta_{it}) = ln(\mu_{it}) + \varepsilon_i \qquad (2)$$

Using the Poisson-gamma, the random effect ε_i is assumed to follow a Gamma distribution as presented in Equation 3.

$$\varepsilon_i \sim Gamma\left(\varphi, \frac{1}{\varphi}\right)\ \ where \quad \varphi \sim Gamma(1,1) \qquad (3)$$

The log-gamma model for crash density is described as a piecewise linear function (Equation 4) of predictor variables, such that the function is continuous at the change point t_{0i}. t_{0i} represent the interventions year (2010) for the i^{th} treatment intersections. The piecewise linear function is defined by at least two equations, each of which applies to a different part of the domain, i.e., before-and-after installation of the RLCs in this case. The linear-intervention model allows for different slopes of crash frequency on time before and after the installation of the RLCs and also across the treatment and comparison intersections.

$$\ln(\theta_{it}) = \alpha_0 + \alpha_1 T_i + \alpha_2 I_{t>t_{0i}} + \alpha_3 T_i t + \alpha_4 T_i I_{t>t_{0i}} + \beta_1 X_{1it} + \beta_2 X_{2it} + \cdots + \beta_{10} X_{10} \qquad (4)$$

5.2.3 Model Results and Discussion

To obtain the FB estimates of the unknown parameters, it is required to specify prior distributions for the hyper-parameters. The most commonly used priors are vague normal distributions (with zero mean and large variance) for the regression parameters. The posterior estimates of the model's parameters for the FB methods were obtained via four independent chains with 25,000 iterations whereby the first 25,000 were used as a burn-in sample. The posterior means and the 80^{th} percentile Bayesian Credible Intervals (BCIs) of the posterior distributions for each crash type and crash severity are shown in Tables 5 and 6, respectively. The predictor variable is considered to be significant at 80% BCI if the values of the 10% and 90% percentiles do not include zero (0), i.e., they are both negative or positive. The findings from the analyses are summarized below by target crash type and target crash severity.

Total Target Crashes

For both treatment and non-treatment four-legged signalized intersections,

- In general, major and minor approach AADT, speed limit of over 30 mph, amber time ≥ 4 seconds, length of pedestrian crossing, and number of driveways ≥ 3 within the intersection influence area increase the target crash probability.
- Longer all red interval has a positive impact in reducing the target crash probability; however, it is not significant at 80% BCI.
- Major approach with more than two through lanes and minor approach with more than one lane result in reduced target crash probabilities.

For four-legged signalized intersections with RLC,

- Compared to the before-period, the after-period experienced fewer target crashes.
- Fewer target crashes are expected at the treatment intersections compared to the non-treatment intersections; however, it is not significant at 80% interval.
- There is a significant drop in target crashes immediately after the installation of RLCs.
- The target crashes dropped immediately after the installation of RLCs, and then continued to increase, but they are still lower than the target crashes in the before-period.

Angle/Left-Turn/Right-Turn Crashes

- Compared to the before-period, the after-period experienced fewer angle/left-turn/right-turn crashes. This observation is significant at 70% BCI.
- Fewer angle/left-turn/right-turn crashes are expected at the treatment intersections compared to the non-treatment intersections; however, it is not significant at 80% interval.
- There is a significant drop in angle/left-turn/right-turn crashes immediately after the installation of RLCs.
- The angle/left-turn/right-turn crashes dropped immediately after the installation of RLCs, and then continued to increase, but they are still lower than the before-period.

Rear-end Crashes

- Compared to the before-period, the after-period experienced fewer rear-end crashes.
- More rear-end crashes are expected at the treatment intersections compared to the non-treatment intersections. This observation is significant at 70% BCI.
- There is a drop in rear-end crashes immediately after the installation of RLCs; however, this drop is not significant at 80% BCI.
- The rear-end crashes dropped immediately after the installation of RLCs, and they continued to increase at a steeper rate.

Sideswipe Crashes

- Compared to the before-period, the after-period experienced fewer sideswipe crashes.
- Fewer sideswipe crashes are expected at the treatment intersections compared to the non-treatment intersections.
- There is a significant drop in sideswipe crashes immediately after the installation of RLCs.
- The sideswipe crashes dropped immediately after the installation of RLCs, and then continued to increase, but they are still lower than the before-period.

Target PDO Crashes

- Compared to the before-period, the after-period experienced fewer target PDO crashes.
- Fewer target PDO crashes are expected at the treatment intersections compared to the non-treatment intersections; however, it is not significant at 80% BCI.
- There is a significant drop in target PDO crashes immediately after the installation of RLCs.
- The target PDO crashes dropped immediately after the installation of RLCs, and then continued to increase, but they are still lower than the before-period.

Target Fatal/Injury Crashes

- Compared to the before-period, the after-period experienced fewer target fatal/injury crashes; but it is not significant at 80% BCI.
- Fewer target fatal/injury crashes are expected at the treatment intersections compared to the non-treatment intersections; however, it is also not significant at 80% BCI.
- There is a significant drop in target fatal/injury crashes immediately after the installation of RLCs.
- The target fatal/injury crashes dropped immediately after the installation of RLCs, and they continued to increase, but they are still lower than the before-period.

Table 5: Model Results for Different Target Crash Types

Variable/ Parameter	Total Target Crashes			Angle/Left-turn/Right-turn Crashes			Rear-end Crashes			Sideswipe Crashes		
	Mean	10%	90%	Mean	10%	90%	Mean	10%	90%	Mean	10%	90%
Intercept	**-13.371**	**-15.039**	**-11.719**	**-8.508**	**-11.573**	**-5.461**	**-17.916**	**-20.354**	**-15.498**	**-15.539**	**-18.477**	**-12.634**
ln(major AADT)	**0.239**	**0.129**	**0.35**	-0.092	-0.29	0.106	**0.548**	**0.393**	**0.704**	0.017	-0.172	0.207
ln(minor AADT)	**0.607**	**0.455**	**0.76**	-0.1	-0.38	0.182	**0.95**	**0.711**	**1.193**	**0.779**	**0.507**	**1.053**
Major approach posted speed > 30 mph	**0.072**	**0.039**	**0.105**	**0.202**	**0.132**	**0.272**	-0.029	-0.076	0.019	**0.124**	**0.065**	**0.185**
Minor approach posted speed > 30 mph	**0.117**	**0.078**	**0.156**	**0.104**	**0.033**	**0.176**	**0.101**	**0.041**	**0.16**	**0.086**	**0.018**	**0.154**
Yellow time ≥ 4 seconds	**0.485**	**0.278**	**0.692**	**0.982**	**0.538**	**1.434**	0.233	-0.045	0.511	**1.294**	**0.884**	**1.714**
All red time > 2 seconds	-0.084	-0.238	0.069	-0.191	-0.524	0.139	**-0.309**	**-0.501**	**-0.117**	**0.806**	**0.466**	**1.148**
Length of pedestrian crossing	**0.012**	**0.005**	**0.019**	-0.009	-0.021	0.003	**0.037**	**0.026**	**0.048**	0.011	-0.001	0.024
Major approach through lanes > 2	**-1.282**	**-1.793**	**-0.776**	-0.465	-1.408	0.484	**-2.247**	**-3.068**	**-1.441**	-0.917	-1.889	0.048
Minor approach through lanes > 1	**-0.535**	**-0.766**	**-0.304**	**0.775**	**0.331**	**1.219**	**-1.55**	**-1.893**	**-1.209**	**-0.755**	**-1.162**	**-0.352**
Number of driveways within 250 ft of the intersection	**0.219**	**0.173**	**0.265**	**0.325**	**0.242**	**0.409**	**0.192**	**0.13**	**0.255**	**0.254**	**0.171**	**0.337**
Time indicator (after treatment)	**-0.347**	**-0.472**	**-0.224**	**-0.188***	**-0.365***	**-0.011***	**-0.455**	**-0.626**	**-0.286**	**-0.335**	**-0.538**	**-0.133**
Treatment indicator (treated intersection)	-0.081	-0.311	0.148	-0.085	-0.484	0.317	**0.272***	**0.001***	**0.545***	**-1.006**	**-1.436**	**-0.58**
Jump parameter (Interaction of Time & Treatment indicator)	**-0.552**	**-0.827**	**-0.276**	**-0.622**	**-1.114**	**-0.13**	-0.202	-0.563	0.159	**-1.082**	**-1.623**	**-0.544**
Treatment effect over time	**0.243**	**0.158**	**0.328**	0.127	-0.025	0.279	**0.25**	**0.141**	**0.359**	**0.329**	**0.161**	**0.498**

Note: bold values are significant at 80% Bayesian Credible Interval (BCI); * values are significant at 70% BCI instead of 80% BCI.

Table 6: Model Results for Different Target Crash Severities

Variable/ Parameter	Total Target Crashes			PDO Crashes			Fatal/Injury Crashes		
	Mean	10%	90%	Mean	10%	90%	Mean	10%	90%
Intercept	**-13.371**	**-15.039**	**-11.719**	**-13.699**	**-15.435**	**-11.974**	**-15.349**	**-18.84**	**-11.892**
ln(major AADT)	**0.239**	**0.129**	**0.35**	**0.271**	**0.155**	**0.388**	0.083	-0.148	0.316
ln(minor AADT)	**0.607**	**0.455**	**0.76**	**0.627**	**0.469**	**0.787**	**0.478**	**0.123**	**0.836**
Major approach posted speed > 30 mph	**0.072**	**0.039**	**0.105**	**0.064**	**0.03**	**0.099**	**0.139**	**0.058**	**0.221**
Minor approach posted speed > 30 mph	**0.117**	**0.078**	**0.156**	**0.11**	**0.07**	**0.151**	**0.164**	**0.075**	**0.252**
Yellow time ≥ 4 seconds	**0.485**	**0.278**	**0.692**	**0.475**	**0.261**	**0.691**	**0.514**	**0.025**	**1.013**
All red time > 2 seconds	-0.084	-0.238	0.069	-0.124	-0.289	0.039	0.092	-0.250	0.431
Length of pedestrian crossing	**0.012**	**0.005**	**0.019**	**0.014**	**0.007**	**0.021**	-0.001	-0.016	0.015
Major approach through lanes > 2	**-1.282**	**-1.793**	**-0.776**	**-1.353**	**-1.887**	**-0.821**	-0.803	-2.026	0.411
Minor approach through lanes > 1	**-0.535**	**-0.766**	**-0.304**	**-0.507**	**-0.748**	**-0.266**	**-0.735**	**-1.265**	**-0.214**
Number of driveways within 250 ft of the intersection	**0.219**	**0.173**	**0.265**	**0.224**	**0.176**	**0.273**	**0.186**	**0.088**	**0.286**
Time indicator (after treatment)	**-0.347**	**-0.472**	**-0.224**	**-0.376**	**-0.504**	**-0.247**	-0.154	-0.416	0.11
Treatment indicator (treated intersection)	-0.081	-0.311	0.148	-0.011	-0.253	0.228	-0.272	-0.766	0.227
Jump parameter (Interaction of Time & Treatment indicator)	**-0.552**	**-0.827**	**-0.276**	**-0.494**	**-0.784**	**-0.205**	**-0.902**	**-1.48**	**-0.328**
Treatment effect over time	**0.243**	**0.158**	**0.328**	**0.206**	**0.116**	**0.296**	**0.409**	**0.238**	**0.583**

Note: bold values are significant at 80% Bayesian Credible Interval (BCI).

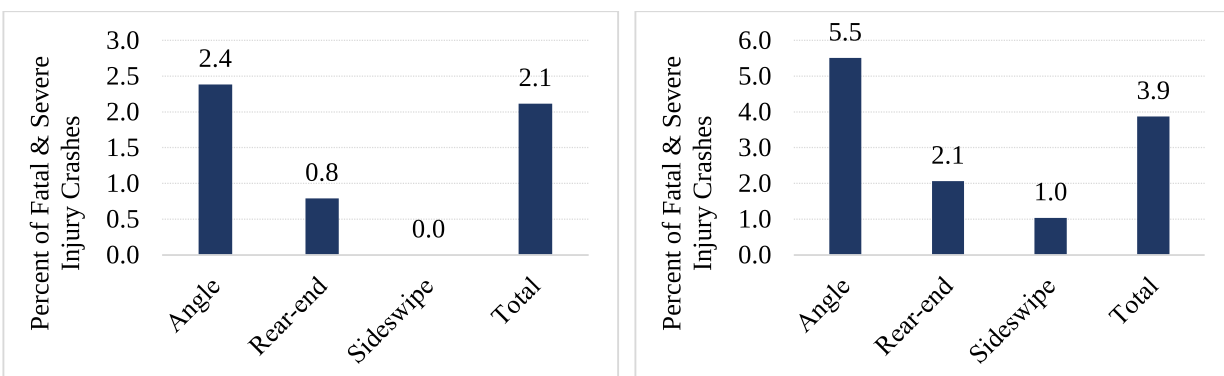
6. REFLECTION

The main objective of this study was to evaluate the safety effectiveness of the PRL Enforcement Program in the City of Miami Beach, Florida. The simple before-and-after analysis and the full Bayes before-and-after evaluation approach were used to quantify the safety effectiveness of the RLCs. The analysis was based on target crash type which includes angle/left-turn/right-turn, rear-end, and sideswipe crashes, and target crash severity which includes PDO and fatal/injury crashes. In general, three main inferences could be drawn from the analysis results.

6.1 Target Crash Type and Target Crash Severity

The presence of RLCs at the study intersections tend to increase rear-end crashes and decrease angle/left-turn/right-turn and sideswipe crashes. This observation is consistent with several other previous studies that have focused on analyzing the effectiveness of RLCs at intersections (Høye, 2013; Ahmed and Abdel-Aty, 2015; Llau et al., 2015; Claros et al., 2017).

Rear-end crashes are often less severe compared to angle crashes. For example, Figures 26 (a) and (b) show the proportion of fatal and severe injury crashes by these crash types in the City of Miami Beach and statewide, respectively. Note that these figures are for the year 2013 and for all crashes that occurred on non-limited access facilities. It can be inferred from Figure 26 that in the City of Miami Beach, about 2.4% of all angle/left-turn/right-turn crashes result in fatal or incapacitating injury, while a relatively lower 0.8% of all rear-end crashes are fatal and incapacitating injury crashes. A similar trend, nonetheless at a higher magnitude, is observed in Florida (Figure 26 (b)).

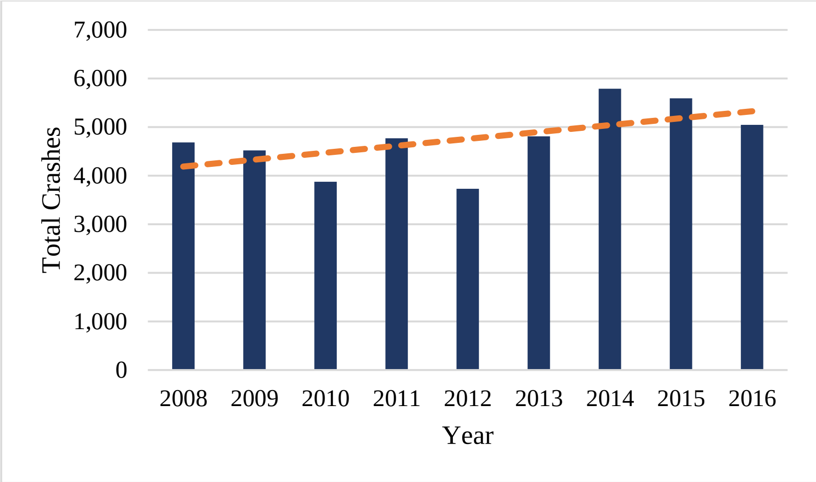


(a) City of Miami Beach (b) State of Florida

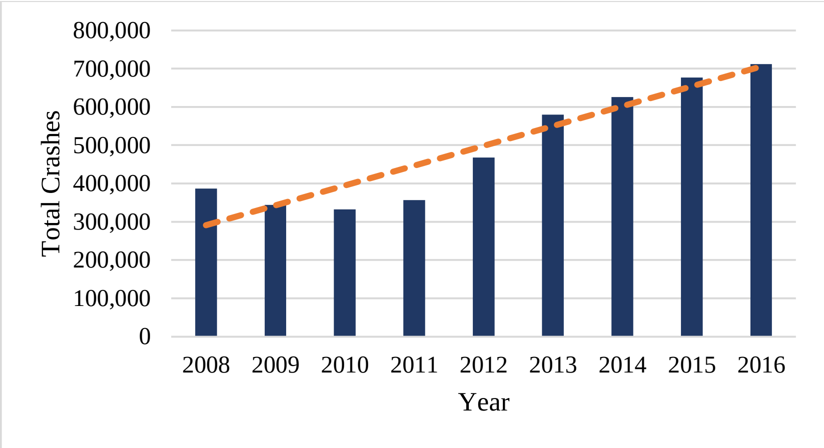
Figure 26: Percent of Fatal and Severe Injury Crashes by Target Crash Type

6.2 General Crash Trend

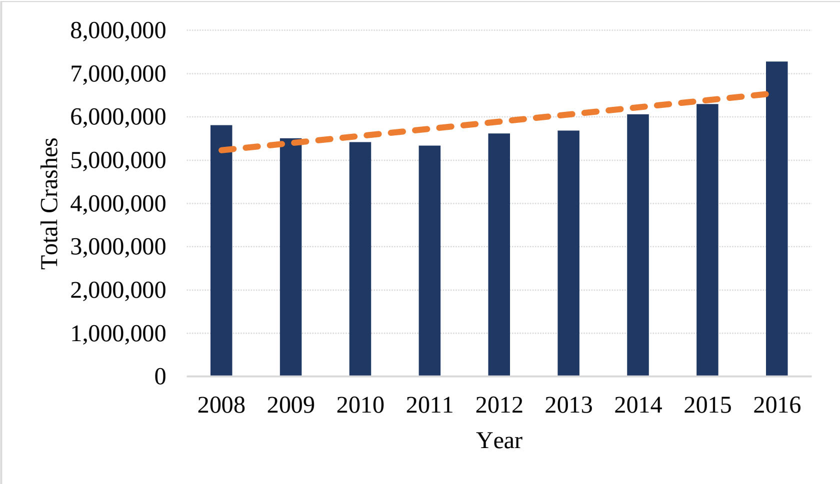
From the full Bayes model results, it can be inferred that crashes at the treatment intersections were on an increasing trend. However, this trend may not be attributed to the presence of RLCs. In general, recent years have seen an increasing trend in crashes. At the city, state, and the national level, crashes are generally on an increasing trend, especially since 2011. Figure 27 gives the annual crash trends from 2008-2016 in the City of Miami Beach, the State of Florida, and the United States.



(a) Annual Crash Trend in the City of Miami Beach (Source: Signal Four Analytics, 2018)



(b) Annual Crash Trend in Florida (Source: Signal Four Analytics, 2018)



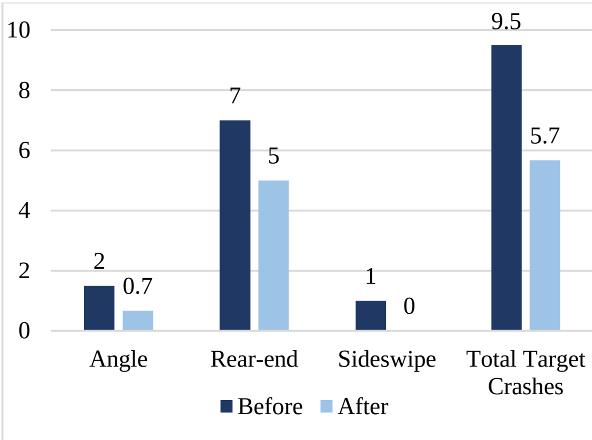
(c) Annual Crash Trend in the U.S. (Source: NHTSA, 2018)

Figure 27: Annual Crash Trend

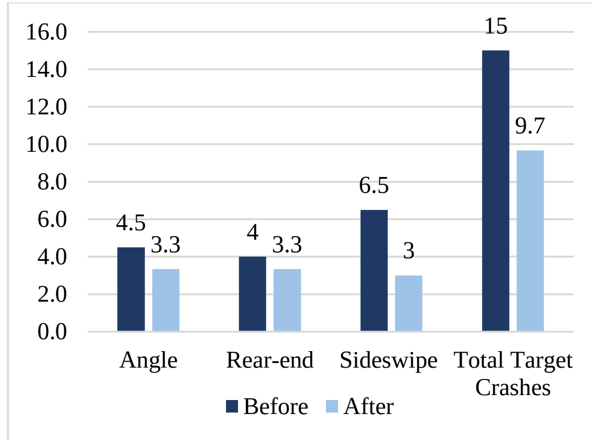
6.3 Safety Performance of Non-treatment Intersections

The simple before-and-after study revealed that most of the treatment intersections experienced fewer target crashes after the installation of RLCs. The average number of target crashes at the non-treatment (i.e., comparison) intersections have also reduced in the after-period (i.e., from 2011-2013). Drivers, when they encounter a RLC at an intersection, may anticipate RLCs at other intersections within the region, and as a result drive more cautiously. This behavior may result in a reduction in target crashes at non-treatment intersections as well. Moreover, jurisdiction-wide publicity of RLCs and the general public's lack of knowledge on the exact installation locations of RLCs may result in fewer target crashes within the region. Figure 28 shows the average number of target crashes at non-treatment intersections during the before- and after- periods. Note that target crashes include angle/left-turn/right-turn, rear-end, and sideswipe crashes.

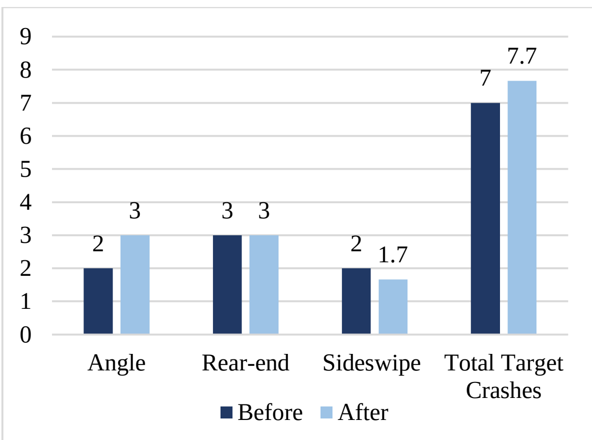
A total of five signalized intersections that are far away from the intersections with RLCs were identified. The average number of target crashes at these far-away intersections was found to be higher during 2011-2013 (i.e., after RLC installation) compared to 2008-2009 (i.e., before RLC installation). In general, angle/left-turn/right-turn and sideswipe crashes increased in 2011-2013, while rear-end crashes reduced. In other words, the intersections in the vicinity of RLCs, in general, were found to experience fewer angle/left-turn/right-turn and sideswipe crashes, while the intersections far away from the treatment sites were found to experience an increase in angle/left-turn/right-turn and sideswipe crashes in 2011-2013 compared to 2008-2009.



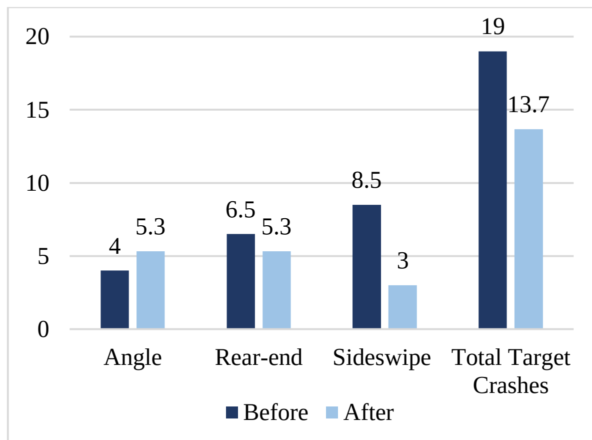
Arthur Godfrey Rd. and Meridian Ave Intersection



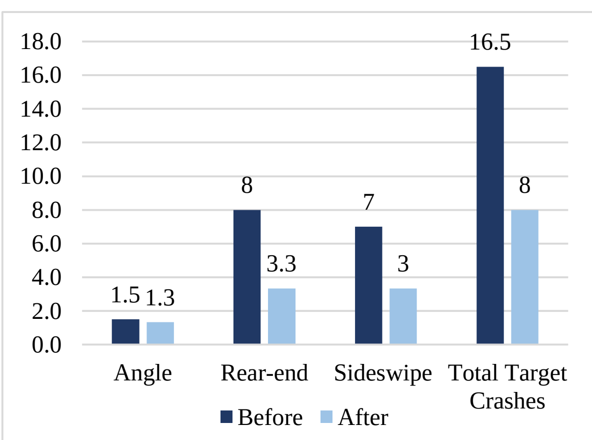
Alton Rd. and 16th St.



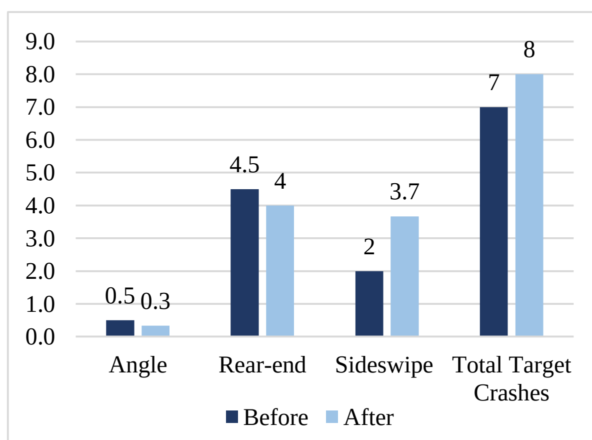
Alton Rd. and 11th St.



Alton Rd. and 8th St.

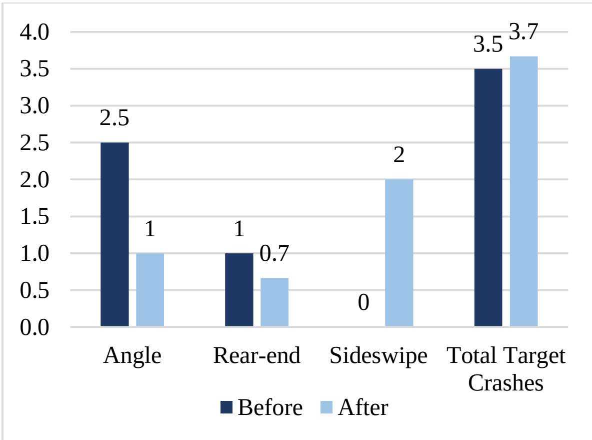


Washington Ave and 16th St.

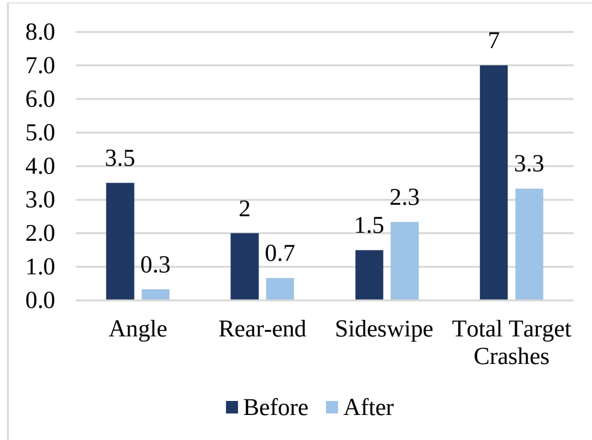


41st St. and Indian Creek Dr

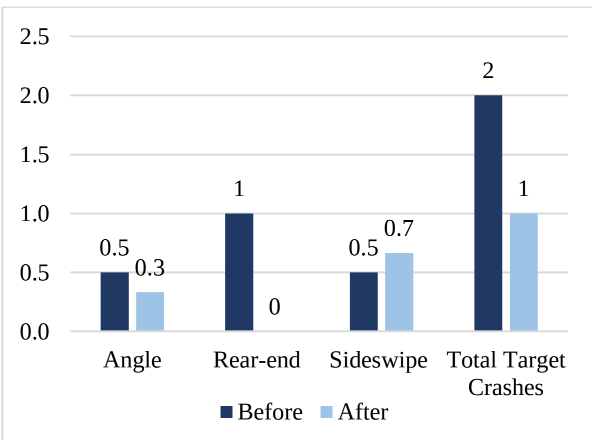
Figure 28: Target Crashes by Crash Type at Comparison Intersections



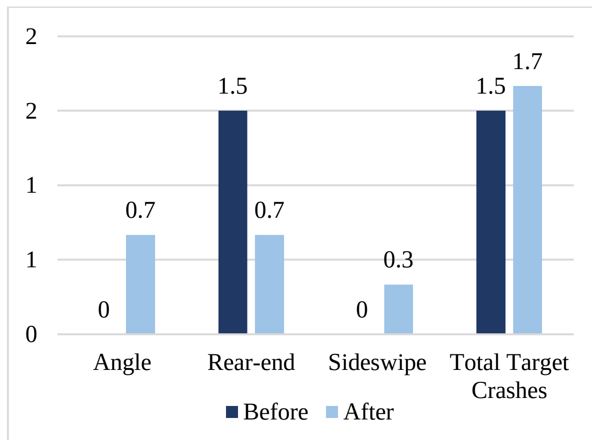
17th St. and James Ave



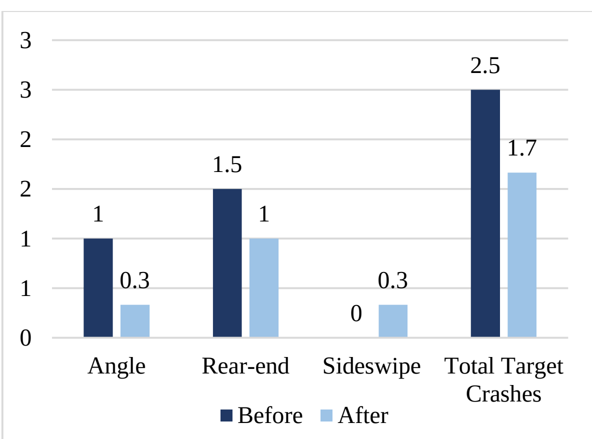
5th St. and Collins Ave



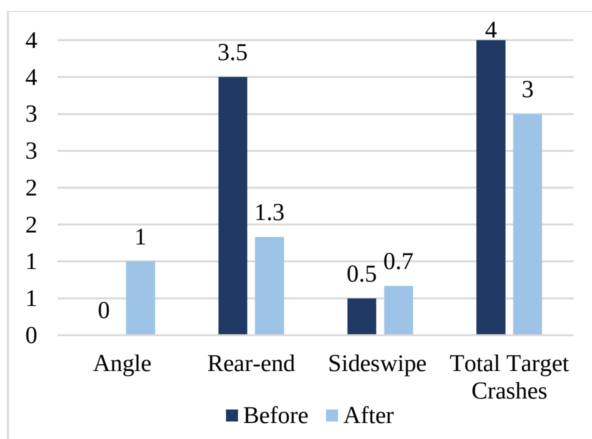
63rd St. and Pine Tree Dr



Pine Tree Dr and Sheridan Ave (3-legged)

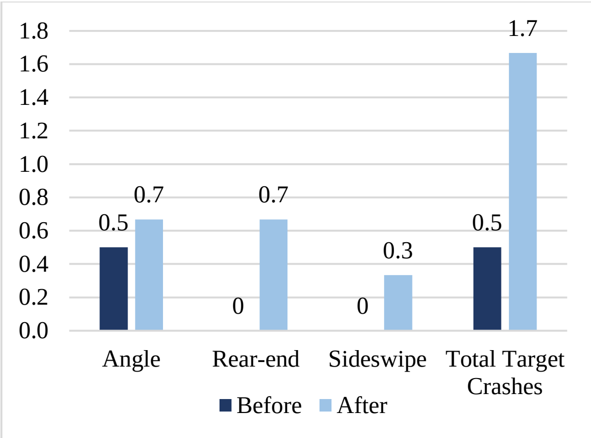


Washington Ave and 15th St. (3-legged)

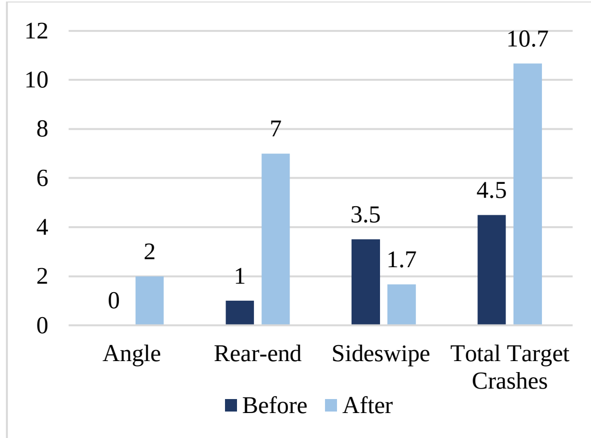


West Ave and 11th St. (3-legged)

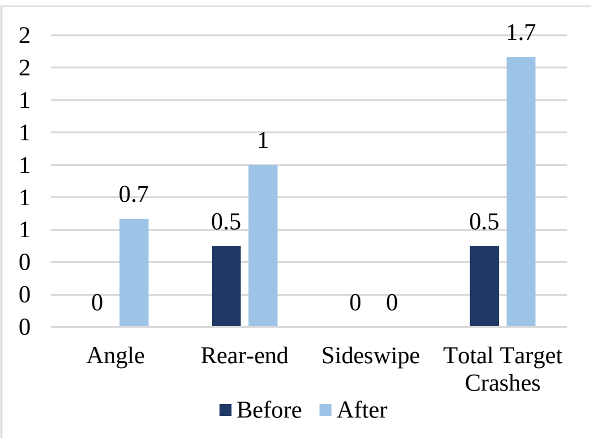
Figure 28 (cont'd): Target Crashes by Crash Type at Comparison Intersections



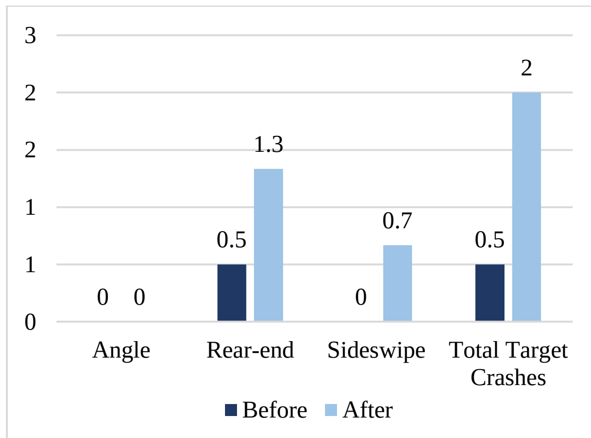
Meridian Ave and 8th St.



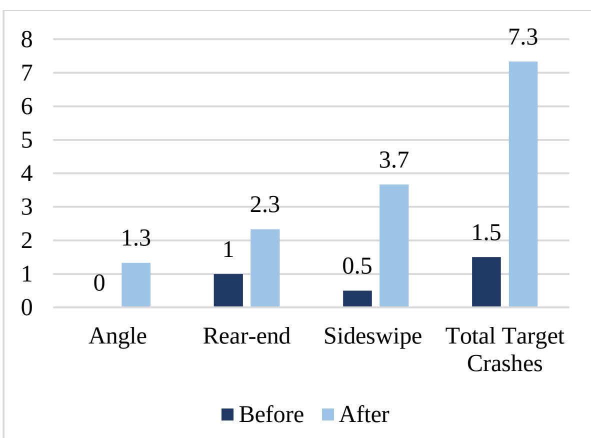
Washington Ave and 11th St.



Meridian Ave and 11th St.



5th St. and Ocean Dr (3-legged)



Washington Ave and 6th St. (3-legged)

Figure 29: Target Crashes at Intersections Far Away from the Treatment Sites

7. SUMMARY

The main objective of this study was to evaluate the safety effectiveness of the PRL Enforcement Program in the City of Miami Beach, Florida. The simple before-and-after analysis and the full Bayes before-and-after evaluation approach were used to quantify the safety effectiveness of the RLCs. The analysis was based on target crash type which includes angle/left-turn/right-turn, rear-end, and sideswipe crashes, and target crash severity which includes PDO and fatal/injury crashes.

A total of ten RLCs are operational at nine signalized intersections in the City of Miami Beach. Due to the long period of construction activity, the intersection where Alton Road meets 17th Street was not included in the study. The simple before-and-after crash data analysis was conducted for the remaining eight signalized intersections. The advanced full Bayes before-and-after analysis was conducted only for the five four-legged signalized intersections. Only three treatment intersections are three-legged; the sample size is too small to yield reliable results from the FB statistical analysis.

7.1 Simple Before-and-after Crash Data Analysis

7.1.1 Four-legged Intersections

At four-legged intersections with RLCs,

- In general, there was a reduction in target crashes after the installation of RLCs.
- Among the target crash types, angle/left-turn/right-turn and sideswipe crashes usually decreased while rear-end crashes usually increased. In other words, the presence of RLCs at the study intersections were found to increase rear-end crashes and decrease angle/left-turn/right-turn and sideswipe crashes. However, rear-end crashes are often considered to be less severe compared to angle/left-turn/right-turn crashes.
- In general, there was a reduction in PDO target crashes, but target crashes resulting in injuries slightly increased.

At approaches with RLCs,

- At three of the five intersections, target crashes reduced after the installation of RLCs.
- At two of the five intersections, total crashes reduced after the installation of RLCs.
- At three of the five intersections, rear-end crashes increased after the installation of RLCs.

7.1.2 Three-legged Intersections

- Overall, the intersections with RLCs experienced a reduction in target crashes after the installation of RLCs.
- At all the three intersections, rear-end and sideswipe crashes reduced after the installation of RLCs.
- Angle crashes reduced at two of the three intersections.
- In general, there was a reduction in PDO target crashes, but target crashes resulting in injuries slightly increased.
- At approaches with RLCs, there were no target crashes after the installation of RLCs.

7.1.3 Safety Performance of Intersections with No RLCs

The average number of target crashes at the non-treatment intersections (i.e., signalized intersections with no RLCs) that are in the vicinity of treatment intersections have also reduced in the after-period (i.e., from 2011-2013). Drivers, when they encounter a RLC at an intersection, may anticipate RLCs at other intersections within the region, and as a result drive more cautiously. This behavior may result in a reduction in target crashes at intersections with no RLCs as well. Moreover, jurisdiction-wide publicity of RLCs and the general public's lack of knowledge on the exact installation locations of RLCs may result in fewer target crashes within the region.

The average number of target crashes at five signalized intersections that are far away from the intersections with RLCs was found to be higher during 2011-2013 (i.e., after RLC installation) compared to 2008-2009 (i.e., before RLC installation). The intersections in the vicinity of RLCs, in general, were found to experience fewer angle/left-turn/right-turn and sideswipe crashes, while the intersections far away from the treatment sites were found to experience an increase in angle/left-turn/right-turn and sideswipe crashes in 2011-2013 compared to 2008-2009.

7.2 FB Before-and-after Analysis

- In general, crashes at the treatment intersections were on an increasing trend. However, this trend may not be attributed to the presence of RLCs. Recent years have seen an increasing trend in crashes. At the city, state, and the national level, crashes are generally on an increasing trend, especially since 2011.

- There is a significant sudden drop in all types of target crashes immediately after the installation of RLCs.

- Compared to the before-period, the after-period experienced:
  - Fewer target crashes
  - Fewer angle/left-turn/right-turn crashes
  - Fewer sideswipe crashes
  - More rear-end crashes

- The sideswipe and angle/left-turn/right-turn crashes dropped immediately after the installation of RLCs, and then continued to increase, but they are still lower than the before-period.

- The rear-end crashes dropped immediately after the installation of RLCs, and then continued to increase, but they increased at a steeper rate.

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