Analysis of the Safety Impacts of the Left-In Left-Out Median Opening Treatment at Intersections/Driveways

Final Report

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1.0 INTRODUCTION AND BACKGROUND

The City of Scottsdale, Arizona contains numerous examples of left-in left-out (LILO) treatments at intersections and driveways where the minor street/driveway is stop-controlled and the major street is free-flowing. These treatments are typically applied on arterial roadways with medians and consist of a channelizing island in the median which helps direct vehicles turning left both on to and out of minor streets or driveways. Additionally, the treatment contains an exclusive left turn lane for vehicles turning left on to minor streets/driveways and left turn refuge with varying acceleration lane lengths for vehicles turning left out of minor streets/driveways (these left-turning vehicles then merge with major street traffic). Examples of aerial views of LILO treatments in Scottsdale are shown in Figure 2.1 and Figure 2.2.

The City of Scottsdale began installing the LILO treatment several decades ago as a potential alternative to signalized intersections (i.e. locations with high minor street left turn volumes but not meeting traffic signal warrants) and it was thought that these treatments make left turns easier for drivers and are relatively safer. The treatment is applied at locations that otherwise would have a standard median opening or two-way left-turn lane (TWLTL). The LILO treatment was originally installed on the Shea Blvd. corridor in Scottsdale and was expanded to other locations (approximately ~60 as of 2021) as they seemed to operate well. Although anecdotal evidence seems to indicate the LILO treatments in Scottsdale perform well with respect to operations and safety, a comprehensive analysis of this treatment has not been conducted. This lack of a concrete data-driven analysis provided the motivation for this study, which provides the first (to the authors' knowledge) comprehensive safety analysis of the LILO treatment.

Overall, the primary objectives of this study include the following:

- Conduct a crash analysis of LILO sites in Scottsdale, Arizona (along with identified control sites) to assess the overall safety performance of the LILO treatment trough development of crash modification factors.
- Analyze the potential impacts of different design features at LILO sites on crash frequencies.
- Analyze the potential impacts of the LILO treatment (along with design features) on crash severity.

1.1 POTENTIAL IMPACTS OF THE LILO TREATMENT

A comprehensive search of existing research literature yielded no results with respect analyses of the impacts of LILO treatments similar to those existing in Scottsdale (which strengthened the motivation for this study). That being said, LILO treatments have the potential to provide several benefits as compared with standard median openings or TWLTLs:

- Because an acceleration length is provided for vehicles turning left out of minor streets/driveways, drivers can focus on finding adequate gaps in traffic on the major street one direction at a time for the most part. This may reduce driver error and potentially prevent angle or left turn crash types which more often result in injuries or fatalities as compared with other crash types (e.g. rear ends, sideswipes, etc.).

- While LILO treatments have typically been applied at 3-leg intersections (i.e. "T-intersections"), some have been applied at 4-leg intersections as shown in Figure 2.1. In these cases, the application of the LILO treatment reduces the number of potential conflict points by preventing through movements on the minor street/driveway. It's important to note, however, that adequate access to adjacent properties should be considered in these cases.
- LILO treatments also have the potential to improve operations (i.e. reduce delay) for left turning vehicles by allowing motorists to focus more on one direction of traffic when determining whether gaps in major street traffic are adequate to complete the turn (thereby potentially accepting smaller but still safe gaps). It should be noted that potential impacts on operations are beyond the scope of this study, as only safety impacts are investigated.

Past research has shown that converting full turning movement operation to right-in right-out (RIRO) operation at stop-controlled 3-leg intersections results in 45%, 68%, and 80% reductions in total, intersection-related, and fatal/injury crashes, respectively (Le et al., 2018). Additionally, another reference reported that typical crash rates may be reduced from 0.3 crashes per million entering vehicles to 0.1 crashes per million entering vehicles when a full-access 3-leg intersection is converted to RIRO operation (MNDOT, 2011). While the RIRO treatment operates much differently than the LILO treatment, the results show that reducing potential conflict points can result in decreased crashes. Overall, there is no existing research literature assessing the performance of the LILO treatment, which as noted previously, provides motivation for this study.

1.2 EVALUATING THE SAFETY IMPACTS OF ROADWAY DESIGN FEATURES

According to the American Association of State Highway and Transportation Officials (AASHTO) Highway Safety Manuel (HSM), there are three primary types of study designs that can be used to perform safety effectiveness evaluations for roadway design features (HSM, 2010):

- Experimental before-after studies
- Observational cross-sectional studies
- Observational before-after studies

All of these types of studies have advantages, disadvantages, and limitations with respect to the types of data that are required and available. Experimental before-after studies require analysis of treatments specifically installed so that their effectiveness can be evaluated; a group of similar sites is selected and randomly assigned to be either a treatment site or control site. Since this is not the case with the LILO treatments in Scottsdale, the experimental before-after study type is not considered for evaluation of the LILO treatment.

Cross-sectional studies utilize data from both treatment and control sites and utilize statistical modeling techniques that consider the crash experience of sites with and without a particular treatment of interest during a time period after the treatment has been installed (HSM, 2010). The difference in crash experience between the treatment and control sites is measured using a statistical model and used to determine the effectiveness of the treatment. This type of study is well-suited to assess the safety impacts of the LILO treatments in Scottsdale since most of the treatments were installed before 2014, allowing a cross-sectional analysis to be conducted using LILO treatment and control sites utilizing data from 2014-2019. Further details regarding the cross-sectional analyses and results with respect to the LILO treatments in Scottsdale are provided in Chapter 3.0 of this report.

Within the category of observational before-after studies, the empirical-Bayes (EB) before-after study design is generally regarded as the most robust method. In this design, both before and after data for treatment sites are utilized along with crash prediction models developed from control sites to obtain an estimate of ‘expected’ crashes using a weighting factor. These ‘expected’ crash estimates are then compared with observed crashes at the treatment sites to estimate the safety effectiveness of the treatment. It is possible to use the EB before-after method to evaluate the safety impacts of the LILO treatments in Scottsdale, however, the installation dates for the LILO treatments vary widely. This limits the analysis to include only sites installed after 2000 since only data after this year were available. Despite this limitation, EB before-after analyses were conducted using a subset of the LILO treatment sites and further discussion on this method and results are provided in Chapter 4.0 of this report.

In both the cross-sectional and EB before-after studies described above, the primary goal was to develop crash modification factors (CMFs) for installation of the LILO treatment. A CMF is defined as “a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site” (Gross et al., 2010). As shown in Figure 1.1 which displays the concept of how CMFs can be interpreted, a CMF below 1.0 indicates that a treatment is expected reduce crashes, while a CMF greater than 1.0 indicates a treatment is expected to increase crashes. To calculate the expected percent change in crashes using a CMF, one would simply apply the following formula: Expected percent change = 100*(1-CMF). This expected percent change is also known as a crash reduction factor (CRF). It’s important to note that separate CMFs for total crashes, different crash types, and different crash severities can be developed for a single treatment.

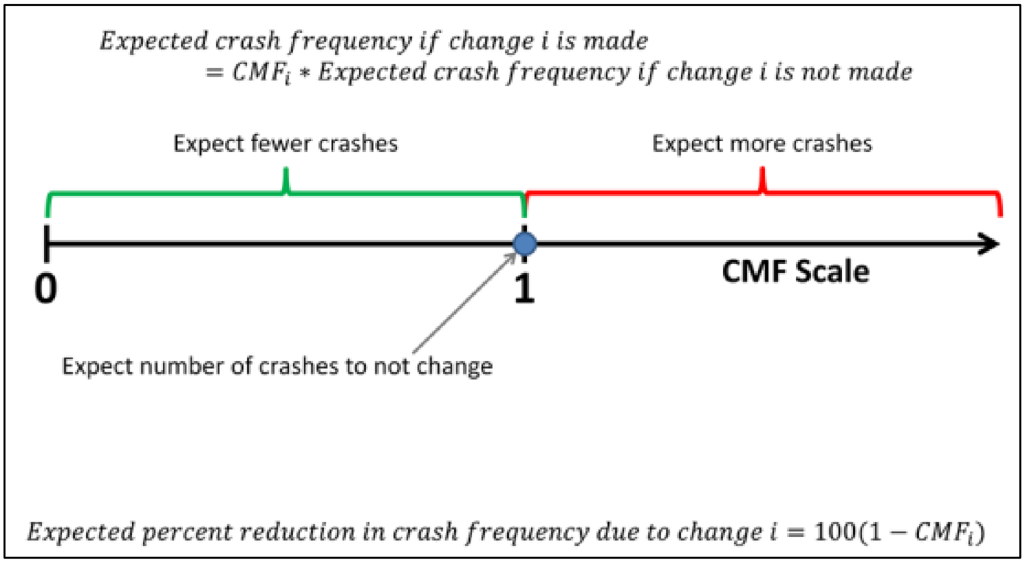

Figure 1.1: Concept of Crash Modification Factors (Gayah and Donnell, 2014)

One important consideration with respect to CMFs is whether they are determined to be statistically significant or not. Essentially, for a CMF to be statistically significant, it would need to be significantly different than 1.0 at a desired confidence level. Typically in traffic engineering, a 95% confidence level is desired to make strong conclusions about a certain statistical analysis. The standard error of a CMF can be used to determine whether it is statistically significant or not by calculating a 95% confidence interval using the following formula (Gross et al., 2010):

$$\text{Confidence Interval} = \text{CMF} \pm (\text{Cumulative Probability} * \text{Standard Error}) \quad (1)$$

Where the cumulative probability value is 1.960 for a 95% confidence interval. If 1.0 falls within this 95% confidence interval, then a CMF would not be considered statistically significant because one cannot conclude that it is significantly different than 1.0. It's important to note that although transportation agencies would desire to use statistically significant CMFs, even CMFs that are not statistically significant can show general expected crash trends for installation of a certain treatment, albeit with a lower level of confidence.

2.0 DATA DESCRIPTION

2.1 TREATMENT AND CONTROL SITE IDENTIFICATION

As mentioned previously, there are approximately ~60 locations with the LILO treatment in Scottsdale, Arizona. However, the available budget for this study allowed for an analysis of 25 LILO treatment locations, along with 25 control site locations (without the LILO treatment). The LILO treatment sites included in this study were identified in consultation with City of Scottsdale staff, and were chosen such that they represented a typical application and had relatively higher turning movements compared with lower volume LILO sites. The control sites selected for this study represent locations similar to the LILO treatment sites in terms of roadway, crash, and traffic characteristics but without the LILO treatment and were also selected in consultation with City of Scottsdale staff. Example aerial images of LILO treatment sites are shown in Figure 2.1 and Figure 2.2 and an example aerial image of a control site is shown in Figure 2.3. Table 2.1 shows a list of the LILO treatment and control sites selected for this study which includes the unique site number, cross streets, site type, and the year in which the LILO treatment was installed (for LILO sites only).

Figure 2.1: Aerial view of Shea Blvd and 100th Street – LILO Site (#11) (Google, 2021)

Figure 2.2: Aerial view of Shea Blvd and 104th Street – LILO Site (#20) (Google, 2021)

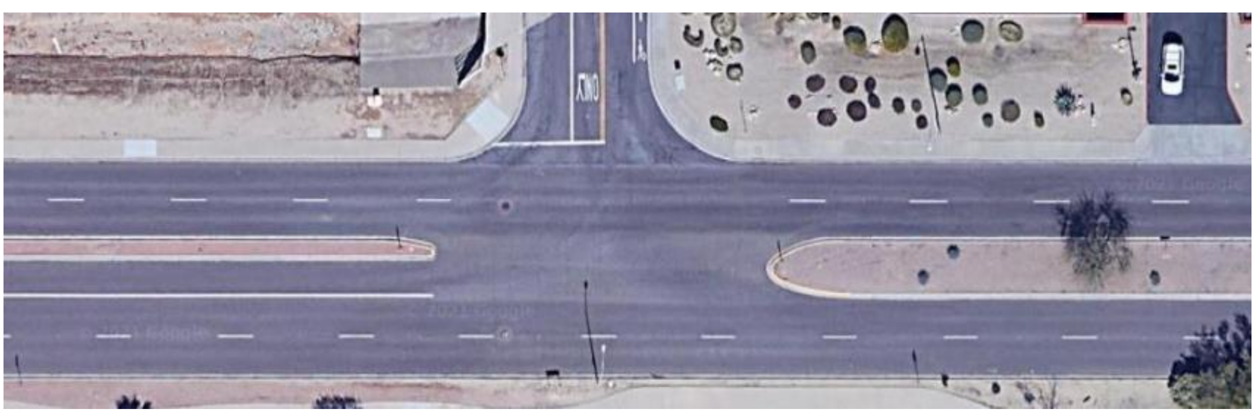

Figure 2.3: Aerial view of Via Linda and 108th Street – Control Site (#28) (Google, 2021)

Table 2.1: List of Treatment (LILO) and Control Study Sites

Site #	North/South Street	East/West Street	Site Type	Year LILO Installed
1	Pima	Paraiso	LILO	2012
2	Pima	DC Marketplace	LILO	2007
3	78th	Frank Lloyd Wright	LILO	2013
4	82nd	Frank Lloyd Wright	LILO	2016
5	Redfield	Frank Lloyd Wright	LILO	2013
6	Celtic	Frank Lloyd Wright	LILO	2016
7	Camino del Santo	Frank Lloyd Wright	LILO	2016
8	Sweetwater	Frank Lloyd Wright	LILO	2013
9	77th	Shea	LILO	2017
10	Becker Lane	Shea	LILO	2007
11	100th	Shea	LILO	1990
12	120th	Shea	LILO	1990
13	142nd	Shea	LILO	1999
14	Hayden	74th	LILO	2002
15	Scottsdale	Joshua Tree Lane	LILO	1997
16	Via Linda	94th	LILO	2018
17	104th	McDowell Mtn Ranch	LILO	2009
18	N Paradise View	Indian Bend	LILO	2009
19	Via De La Sendero	Indian Bend	LILO	2010
20	104th	Shea	LILO	1990
21	Access to Mountain View Park	Mountain View	LILO	2016
22	118th	Shea	LILO	1990
23	8180 Vintage Apts	Shea	LILO	2010
24	Access to Chaparral Plaza	Chaparral	LILO	2003
25	108th	Shea	LILO	1990
26	100th	Bell	Control	N/A
27	Via Linda	Cholla	Control	N/A
28	108th	Via Linda	Control	N/A
29	78th	Shea	Control	N/A
30	66th	Shea	Control	N/A
31	68th	Cactus	Control	N/A
32	70th	Cactus	Control	N/A
33	74th	Cactus	Control	N/A
34	Sundown	Cactus	Control	N/A
35	105th	McDowell Mountain Ranch	Control	N/A
36	90th	Bell	Control	N/A
37	Scottsdale	Cochise	Control	N/A
38	Scottsdale	Royal Palm	Control	N/A
39	84th	Indian Bend	Control	N/A
40	75th	Osborn	Control	N/A
41	70th	Goldwater	Control	N/A
42	Civic Center Plaza	Drinkwater	Control	N/A
43	75th	Thomas	Control	N/A
44	87th	McDowell	Control	N/A
45	64th	Osborn	Control	N/A
46	Scottsdale	Silverstone	Control	N/A
47	83rd	McDonald	Control	N/A
48	85th	McDowell	Control	N/A
49	Chase Bank d/w	Dynamite	Control	N/A
50	Pinnacle Peak	Alma School	Control	N/A

Once LILO treatment and control sites were identified, numerous roadway and traffic data were collected for each site. Geometric/roadway characteristic data were collected primarily via Google Earth aerial imagery and/or Street View (Google, 2021) for each site, and these data include:

- Number of lanes (including exclusive turn lanes) as well as total widths for both directions of the major road and the minor road/driveway.
- Type of median treatment on the roadway segment near the intersection (e.g. raised median, TWLTL, etc.) and width of median treatment.
- Speed limit on the major roadway.
- For the LILO treatment sites, additional data related specifically to the LILO treatment characteristics were collected including:
  - Presence of a raised vs. painted channelizing island.
  - Acceleration length provided for vehicles turning left from the minor street/driveway onto the major street.
  - Presence of signs related specifically to the LILO treatment. It should be noted that there is no 'typical' application of signs at these sites, and the combination of signs installed varied widely. Some sites did not have any LILO-specific signage and included only object markers (example shown in Figure 2.4), while some sites included combinations of a sign with a ''channelizing island' image, a yield sign, and a merge sign (example shown in Figure 2.5).

Traffic volume data were then obtained for each LILO treatment and control site. First, volume counts were collected in March, 2021 for each treatment and control site by approach for 48 hours and by turning movement for AM and PM peak periods in 15 minute increments. From these data, Average Daily Traffic (ADT) values were calculated for the major and minor street at each study intersection. Next, historical traffic volumes were provided by the City of Scottsdale dating back to the year 2000. ADT values for the major street segment for each intersection were identified, and since Scottsdale collected these data every other year historically, straight line interpolation was used to obtain an ADT value for the major street segment at each study intersection for every year from 2000-2019. Historical minor street ADTs counts did not exist, so these values were estimated based on the minor/major street ADT ratio observed in the 2021 counts and applied historically. Additionally, the 2021 counts were used to calculate the percentage of left turn volume on the minor road approach and major road approach, and these values were applied historically at each site for analysis in this study. It should be noted that the year 2020 is excluded from this study because the Covid-19 Pandemic drastically changed traffic volume and crash patterns and did not represent typical operating conditions. Table 2.2 shows a summary of roadway and traffic characteristics for each LILO treatment and control site including major road speed limit, mean major and minor street average ADT values, number of lanes, and LILO characteristics (at the treatment sites only). It should be noted that only ADT values for 2014-2019 (the means of which are presented in Table 2.2) are used in the cross-sectional analyses, though values dating back to 2000 are used at some sites in the empirical-Bayes before-after analyses depending on the year of LILO treatment installation.

Table 2.2: Roadway and Traffic Characteristics for Treatment and Control Study Sites

Site #	Site Type	Major Road Speed Limit (mph)	Mean ADT (2014-2019)			Total Number of Lanes**		LILO Characteristics		
			Major Road	Minor Road	Minor Road Left Turn %	Major Road	Minor Road Approach	LILO Signs Present?	Accel. Length (ft.)	Raised vs. Painted Channelizing Island
1	LILO	45	28,243	297	66.1	8	1	Yes	190	Raised
2	LILO	45	44,028	1,666	34.8	8	2	Yes	315	Raised
3	LILO	45	36,420	1,352	23.7	8	2	Yes	265	Raised
4*	LILO	45	40,973	642	22.5	8	1	Yes	265	Raised
5	LILO	45	23,605	1,005	65.4	7	2	No	185	Raised
6*	LILO	45	28,528	259	80.0	6	1	No	115	Raised
7*	LILO	45	28,354	242	59.5	5	1	No	100	Painted
8	LILO	45	28,184	720	45.5	6	2	No	335	Raised
9*	LILO	45	41,089	377	32.7	7	1	No	90	Painted
10	LILO	45	44,488	1,039	50.8	8	2	Yes	250	Raised
11	LILO	45	41,083	841	60.4	7	1	Yes	285	Raised
12	LILO	50	41,891	818	77.5	8	2	Yes	285	Raised
13	LILO	50	30,153	230	78.4	8	2	Yes	315	Raised
14	LILO	45	16,200	604	37.4	6	2	Yes	300	Raised
15	LILO	45	46,584	177	37.5	7	1	Yes	230	Raised
16*	LILO	40	23,790	431	63.2	5	1	No	150	Raised
17	LILO	40	11,881	867	91.9	6	2	Yes	130	Raised
18	LILO	40	18,270	590	75.0	6	2	Yes	100	Raised
19	LILO	40	20,716	1,638	60.1	5	1	No	200	Raised
20	LILO	50	41,041	910	15.7	7	1	Yes	285	Raised
21*	LILO	40	12,946	633	44.9	5	1	No	160	Raised
22	LILO	50	41,925	612	72.9	7	2	Yes	290	Raised
23	LILO	45	45,277	557	55.0	8	1	Yes	185	Raised
24	LILO	30	16,810	1,252	29.8	5	1	No	125	Raised
25	LILO	50	37,588	64	100.0	7	1	Yes	300	Raised
26	Control	45	12,037	1,069	81.0	7	1	N/A	N/A	N/A
27	Control	40	11,902	422	83.3	5	2	N/A	N/A	N/A
28	Control	40	11,850	1,546	43.9	5	2	N/A	N/A	N/A
29	Control	40	39,687	692	11.4	8	2	N/A	N/A	N/A
30	Control	45	42,243	311	37.5	7	1	N/A	N/A	N/A
31	Control	45	29,863	252	59.5	4	1	N/A	N/A	N/A
32	Control	45	29,543	186	15.4	4	1	N/A	N/A	N/A
33	Control	45	35,260	364	14.0	4	1	N/A	N/A	N/A
34	Control	45	35,169	156	29.4	4	1	N/A	N/A	N/A
35	Control	40	2,910	219	11.1	5	1	N/A	N/A	N/A
36	Control	45	17,806	829	75.9	6	2	N/A	N/A	N/A
37	Control	40	37,179	845	38.0	7	2	N/A	N/A	N/A
38	Control	45	39,092	236	18.2	7	1	N/A	N/A	N/A
39	Control	40	20,636	203	64.5	5	1	N/A	N/A	N/A
40	Control	35	10,524	429	45.1	5	1	N/A	N/A	N/A
41	Control	35	11,828	1,524	72.2	6	2	N/A	N/A	N/A
42	Control	35	9,307	1,924	20.8	6	2	N/A	N/A	N/A
43	Control	40	28,352	196	41.1	4	1	N/A	N/A	N/A
44	Control	45	29,553	1,516	46.0	7	1	N/A	N/A	N/A
45	Control	40	11,200	1,566	48.5	5	2	N/A	N/A	N/A
46	Control	50	35,170	404	37.5	6	2	N/A	N/A	N/A
47	Control	40	21,191	372	52.2	4	1	N/A	N/A	N/A
48	Control	45	29,530	2,509	25.4	7	2	N/A	N/A	N/A
49	Control	50	14,635	273	57.6	8	1	N/A	N/A	N/A
50	Control	40	7,722	870	20.4	5	2	N/A	N/A	N/A

*ADT means based on years only after LILO installation

**Includes exclusive turn lanes

Figure 2.4: Street view of Frank Lloyd Wright Blvd. and Redfield Rd. – LILO Site (#5) (Google, 2021)

Figure 2.5: Street view of Shea Blvd. and 100th Street – LILO Site (#11) (Google, 2021)

2.2 CRASH DATA COLLECTION

City-wide crash data were obtained from the City of Scottsdale for the years 2000-2019 for use in this study. Using these data, all crashes occurring within 300 feet from the center of each intersection for LILO treatment and control sites (to account for crashes associated with the LILO refuge and acceleration areas) were identified for inclusion in this study. These crash data included numerous variables of interest, with crash type and severity being most relevant for this study. It was anticipated that angle, left-turn, and sideswipe-same crashes would be the types potentially most affected by installation of a LILO treatment, so crashes were summarized by these categories at each site (with angle and left-turn crashes combined because these are similar types) along with total crashes. It should be noted that the 'left-turn' crash category includes all crashes coded as such in the Scottsdale crash database and may involve a vehicle turning left onto or out of the minor road (it was not possible within the scope of this study to differentiate between the two using the crash database). Additionally, crashes were summarized by severity (i.e. injury severity of the most severely injured crash-involved person) in three different categories: all injury crashes (KABC), moderate/severe/fatal injury crashes (KAB) and severe/fatal injury crashes (KA). The definitions of the different severity levels are as follows: K = fatal injury, A = severe/serious injury, B = minor/non-severe injury C = possible injury, and O = no injury (property damage only). Table 2.3 shows average annual crashes by type and severity for each LILO treatment and control site. It should be noted that these annual average crash values are for the years 2014-2019 which are used in the cross-sectional analyses, though crash data dating back to 2000 are used at some sites in the empirical-Bayes before-after analyses depending on the year of LILO treatment installation.

Table 2.3: Crash Data Summary for Treatment (LILO) and Control Study Sites

Site #	Site Type	Year LILO Installed	Average Annual Crashes (2014-2019)					
			Total Crashes	Angle-LT Crashes	Sideswipe Crashes	Injury (KABC)	Injury (KAB)	Injury (KA)
1	LILO	2012	1.0	0.0	0.2	0.2	0.2	0.2
2	LILO	2007	3.0	1.7	0.5	1.7	1.3	0.3
3	LILO	2013	2.7	1.0	0.8	0.2	0.0	0.0
4*	LILO	2016	7.3	1.3	0.7	1.7	0.3	0.3
5	LILO	2013	2.8	2.0	0.2	1.2	0.8	0.2
6*	LILO	2016	1.0	0.7	0.3	0.3	0.3	0.0
7*	LILO	2016	1.3	0.0	0.3	0.3	0.3	0.0
8	LILO	2013	3.0	0.3	0.3	1.0	0.5	0.0
9*	LILO	2017	2.5	1.0	0.0	1.5	0.5	0.0
10	LILO	2007	3.2	0.5	0.5	0.5	0.0	0.0
11	LILO	1990	2.3	0.3	0.5	0.8	0.3	0.0
12	LILO	1990	2.5	0.5	0.7	0.8	0.5	0.0
13	LILO	1999	4.0	0.2	0.3	1.8	0.8	0.0
14	LILO	2002	0.5	0.2	0.0	0.2	0.2	0.0
15	LILO	1997	0.5	0.0	0.3	0.0	0.0	0.0
16*	LILO	2018	1.0	0.0	0.0	0.0	0.0	0.0
17	LILO	2009	1.7	1.5	0.0	1.0	0.7	0.0
18	LILO	2009	1.2	0.5	0.3	0.3	0.2	0.0
19	LILO	2010	2.8	1.3	0.3	0.7	0.5	0.0
20	LILO	1990	2.5	0.7	0.0	1.5	0.5	0.3
21*	LILO	2016	0.0	0.0	0.0	0.0	0.0	0.0
22	LILO	1990	1.5	0.5	0.5	0.3	0.2	0.0
23	LILO	2010	1.5	0.2	0.0	0.5	0.0	0.0
24	LILO	2003	1.5	0.5	0.2	0.5	0.5	0.0
25	LILO	1990	0.7	0.0	0.2	0.3	0.3	0.2
		LILO Site Mean	**2.1**	**0.6**	**0.3**	**0.7**	**0.4**	**0.1**
26	Control	N/A	1.5	1.2	0.0	0.5	0.3	0.0
27	Control	N/A	0.8	0.7	0.0	0.2	0.2	0.0
28	Control	N/A	1.2	0.2	0.0	0.7	0.5	0.0
29	Control	N/A	1.3	0.3	0.3	0.7	0.2	0.0
30	Control	N/A	2.0	0.8	0.3	1.0	0.5	0.0
31	Control	N/A	3.2	0.7	0.3	1.5	0.8	0.2
32	Control	N/A	2.0	0.0	0.3	0.8	0.7	0.0
33	Control	N/A	3.2	0.7	0.2	0.7	0.2	0.0
34	Control	N/A	0.8	0.2	0.3	0.2	0.2	0.0
35	Control	N/A	1.7	1.0	0.0	0.8	0.5	0.0
36	Control	N/A	1.2	0.8	0.0	0.2	0.0	0.0
37	Control	N/A	4.2	2.8	0.3	1.2	0.8	0.0
38	Control	N/A	1.7	0.2	0.0	1.2	0.7	0.2
39	Control	N/A	0.7	0.2	0.2	0.5	0.2	0.0
40	Control	N/A	1.3	0.2	0.0	0.3	0.2	0.0
41	Control	N/A	0.8	0.3	0.5	0.5	0.2	0.0
42	Control	N/A	0.7	0.3	0.2	0.2	0.2	0.0
43	Control	N/A	3.2	0.8	0.3	1.0	0.3	0.2
44	Control	N/A	4.3	3.0	0.0	1.5	1.2	0.5
45	Control	N/A	5.0	2.8	0.0	1.7	1.0	0.2
46	Control	N/A	1.0	0.2	0.0	0.2	0.0	0.0
47	Control	N/A	0.8	0.7	0.0	0.3	0.2	0.0
48	Control	N/A	3.0	1.7	0.2	1.3	0.8	0.0
49	Control	N/A	0.0	0.0	0.0	0.0	0.0	0.0
50	Control	N/A	0.5	0.2	0.0	0.2	0.0	0.0
		Control Site Mean	**1.8**	**0.8**	**0.1**	**0.7**	**0.4**	**0.1**

*Means based on years only after LILO installation

3.0 CROSS-SECTIONAL SAFETY ANALYSES

As noted in previously in Chapter 1.2, cross-sectional analyses can utilize statistical modelling to determine the safety effectiveness of a roadway treatment. In this study, that modelling framework involves development of annual crash prediction models, also known as safety performance functions (SPFs). Essentially, these models are developed to predict annual crash frequencies as a function of exposure variables (in this case major and minor road ADT), and site characteristics (in this case, an indicator variable for presence of the LILO treatment). The parameter estimates for the LILO treatment variable in the model output can then be used to determine the safety effectiveness of the treatment compared with the control sites. Given the non-negative integer nature of crash frequency data (i.e. discrete count data), negative binomial (NB) regression is used to develop these crash prediction models. The NB modelling framework is extremely common in this application (HSM, 2010), and takes the following form in this study:

Predicted Annual Crash Frequency = $e\hat{}(\beta_1 X_1 + \beta_2 X_2 + \beta_i X_i\ )$ (2)

Where β_i are model estimated parameters and the X_i are values of independent variables (e.g. major road ADT, minor road ADT, and LILO treatment indicator (LILO = 1, control site = 0)). It should be noted that the p-value associated with each β_i parameter estimate can be used to determine statistical significance; if the p-value is less than 0.05, that parameter would be considered statically significant at the 95% confidence level. Annual crash frequency would be considered the dependent variable in this modelling framework. Given the relative overdispersion of crash data (i.e. variance is greater than the mean), the NB modelling framework also estimates an 'overdispersion parameter' which is not especially relevant for the cross-sectional analyses, but is utilized for the EB before-after analyses which will be discussed in Chapter 4.0 of this report. Further more detailed discussion of the NB modelling framework can be found elsewhere (Washington et al., 2011).

To assemble the modelling dataset for the cross-sectional analyses, the number of crashes, major street ADT, and minor street ADT were summarized for each site (both treatment and control) and each year from 2014-2019. It should be noted that for the LILO treatment sites, six locations had LILO installation dates after 2013, and only years after installation were included in this data set (with the year of installation also excluded). This resulted in a total of 279 site-years of observations for this modeling (129 site-years for treatment sites and 150 site-years for control sites). With this dataset, six different NB models were estimated for different crash types/severities including:

- Total crashes
- Angle/Left-Turn (LT) crashes
- Sideswipe-same direction crashes
- All injury (KABC) crashes
- KAB injury crashes
- KA injury crashes

It should also be noted that for modelling purposes, the natural log (Ln) of ADT values were used just to improve interpretability of results (if ADT is used directly, the parameter estimates are extremely small decimal values).

Table 3.1 shows the results of the six NB regression models estimated for the cross-sectional analyses including β_i parameter estimates, p-values, and overdispersion parameter. Of most importance are the parameter estimates for the LILO treatment indicator in each model. A negative parameter estimate indicates that parameter would tend to reduce annual crash frequencies, while a positive parameter estimate indicates that parameter would tend to increase annual crash frequencies. The parameter estimates for the LILO treatment can be converted to CMFs by simply taking e^($\beta_{LILO\ Treatment}$). For example, the CMF for total crashes is calculated to be: $CMF_{total\ crashes}$ = e^(-1.106) = 0.899 which translates to an expected crash reduction of 100*(1-0.899) = 10.1%.

Table 3.1: Negative Binomial Regression Models Developed for Cross-Sectional Analyses

Crash Type	Parameter Estimates									
	Intercept		Ln Major Road ADT		Ln Minor Road ADT		**LILO Treatment Indicator**			Over-dispersion Parameter
	β	P-value	β	P-value	β	P-value	**β**	**Std. Error**	**P-value**	
Total Crashes	-6.128	<0.001	0.483	<0.001	0.305	<0.001	**-0.106**	**0.118**	**0.368**	0.305
Angle/Left-Turn Crashes	-7.030	<0.001	0.174	0.283	0.780	<0.001	**-0.404**	**0.185**	**0.029**	0.492
Sideswipe Crashes	-13.265	<0.001	1.029	0.002	0.156	0.345	**0.399**	**0.288**	**0.166**	<0.001
All Injury Crashes	-5.903	0.001	0.405	0.011	0.237	0.019	**-0.160**	**0.170**	**0.346**	0.289
KAB Injury Crashes	-5.817	0.011	0.287	0.145	0.318	0.014	**-0.167**	**0.216**	**0.439**	0.185
KA Injury Crashes	-21.571	0.013	1.585	0.042	0.399	0.270	**-0.288**	**0.618**	**0.641**	3.116

*Note: Underlined text indicates β parameter estimate is significant at 95% confidence level

As shown in Table 3.1, the parameter estimates for the LILO treatment indicator are negative for total crashes, angle/left-turn crashes, all injury crashes, KAB injury crashes, and KA injury crashes, indicating the LILO treatment would tend to decrease crashes for all of these crash types/severities as compared to the control sites. However, only the estimate for angle/left-turn crashes is statistically significant at the 95% confidence level. The parameter estimate for sideswipe crashes is positive, indicating the LILO treatment may tend to increase this crash type compared to the control sites, though the estimate is not statistically significant. These results indicate that the LILO treatment is promising in terms of crash reduction compared with control sites, as the benefits of the expected reduction in total, angle-left turn (particularly since this is a statistically significant finding), and crashes in all severity categories is likely to outweigh potential increases in sideswipe crashes (which tend to be lower severity compared with other crash types). It is likely the potential increase in sideswipe crashes is associated with the merging action associated with the refuge and acceleration length provided with the LILO treatment.

Table 3.2 shows the CMFs, CRFs, standard error, and statistical significance for each crash type/severity obtained from the cross-sectional analyses. Most notably, the LILO treatment CMF for angle/left-turn crashes is 0.688 (33.2% reduction) and is statistically significant at the 95% confidence level. To help visualize the model-predicted crashes for LILO treatment vs. control sites, Figure 3.1 shows model-predicted annual total crashes and Figure 3.2 shows model-predicted annual angle/left-turn crashes across a range of major street ADTs with minor street ADT set to the overall average of 758 vehicles per day.

Table 3.2: CMFs and CRFs Developed from Cross-Sectional Analyses

Crash Type	Crash Modfication Factor (CMF)	Crash Reduction Factor (CRF) %	Standard Error	Statistically Significant at 95% Confidence?
Total Crashes	0.899	10.1%	0.118	No
Angle/Left-Turn Crashes	0.668	33.2%	0.185	Yes
Sideswipe Crashes	1.490	-49.0%	0.288	No
All Injury Crashes	0.852	14.8%	0.170	No
KAB Injury Crashes	0.846	15.4%	0.216	No
KA Injury Crashes	0.750	25.0%	0.618	No

It should be noted that several variables related to left-turn volumes were tested as part of the cross-sectional analyses. The following variables were tested for inclusion in the NB regression models and all were found to be **not** statistically significantly associated with crash frequencies:

- Minor road left turn percentage
- Major road left turn percentage
- Cross-product of left-turn volume and conflicting major road through volume.

In addition to testing statistical significance for inclusion in the NB regression models, scatterplots summarizing average annual crash frequencies vs. minor road left-turn percentage were developed using data from years 2014-2019 for both LILO and control sites. Separate scatterplots were developed for both total crash frequency and angle/left-turn crash frequency and they are shown in Figure 3.3 and Figure 3.4, respectively. Although the LILO sites have a slightly higher average minor road left-turn percentage than the control sites (55.2% and 42.0%, respectively), it is clear from examining these scatterplots that minor road left-turn percentage does not appear to be strongly correlated with total or angle/left turn crash frequencies.

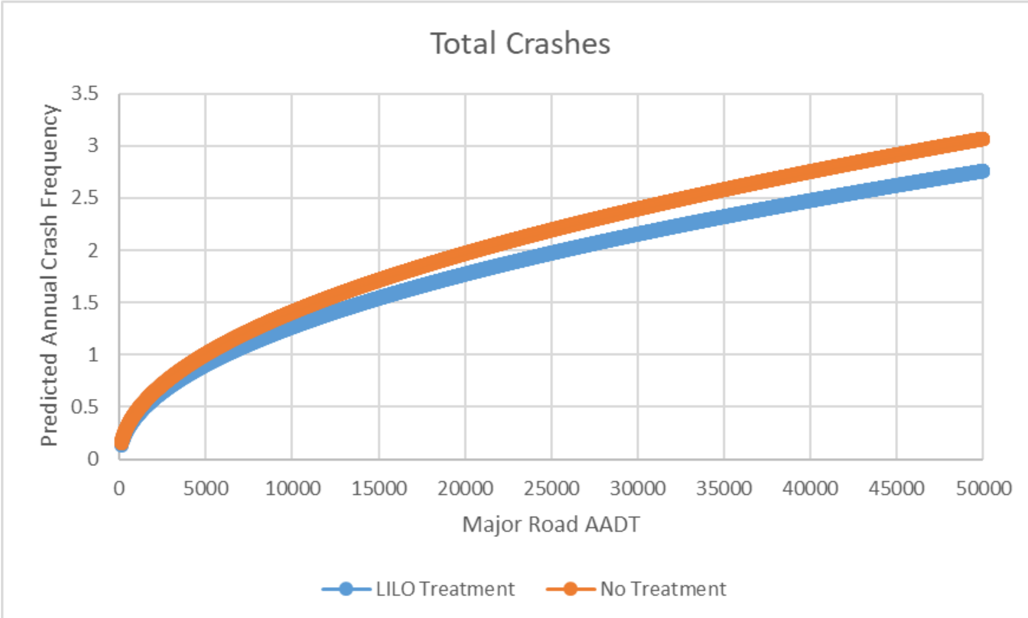

Figure 3.1: Model-Predicted Annual Total Crash Frequency for LILO and Control Sites

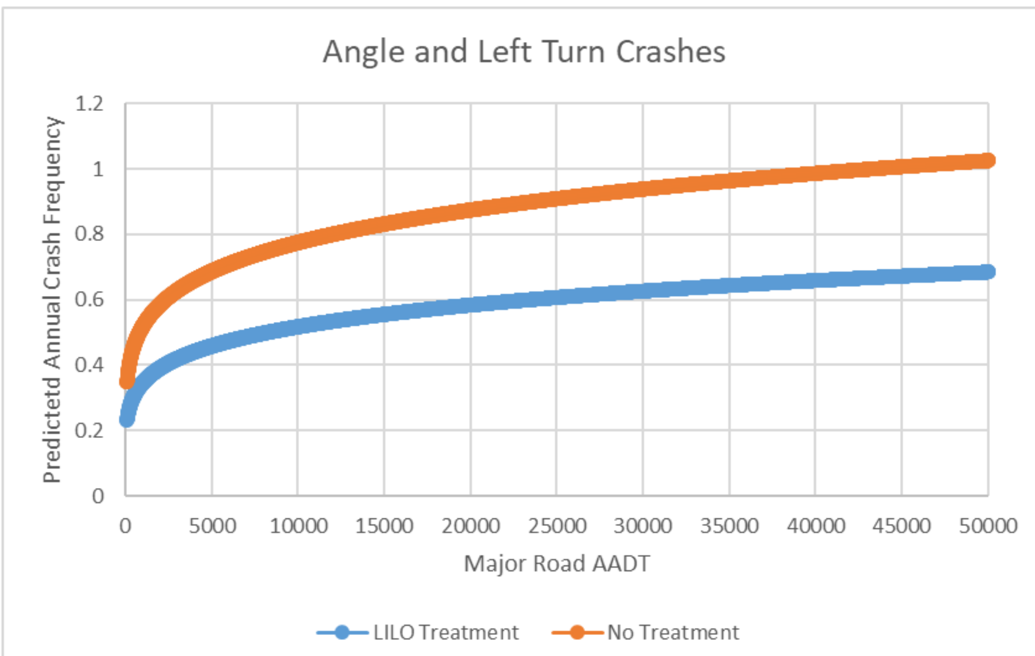

Figure 3.2: Model-Predicted Annual Angle/Left-Turn Crash Frequency for LILO and Control Sites

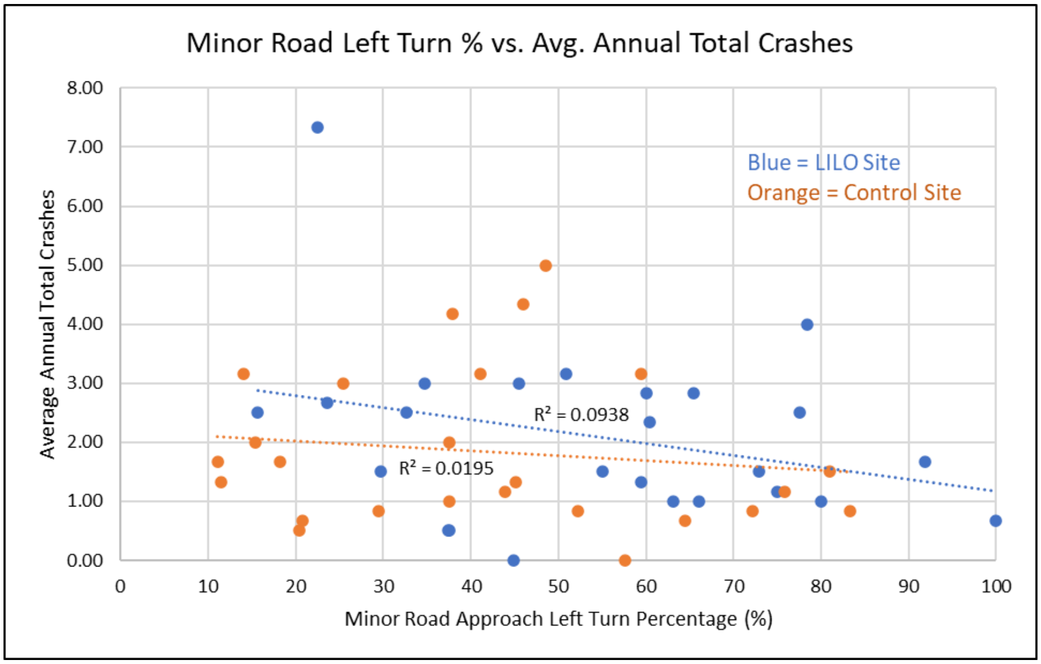

Figure 3.3: Summary of Minor Road Left-turn Percentage vs. Average Annual Total Crash Frequency for LILO and Control Sites

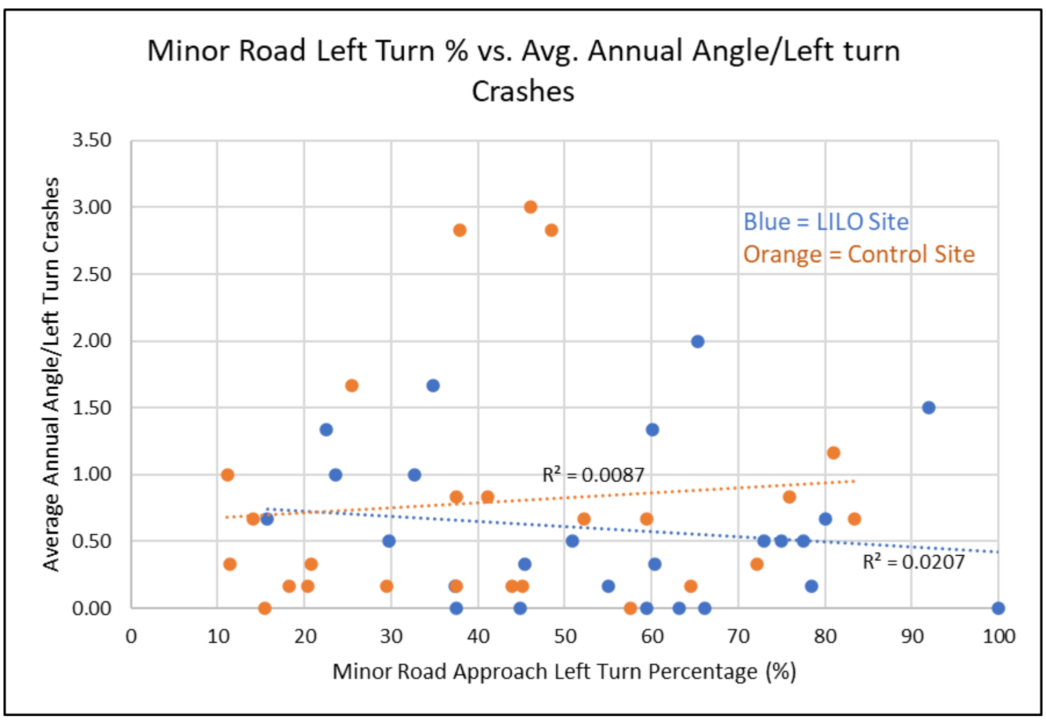

Figure 3.4: Summary of Minor Road Left-turn Percentage vs. Average Annual Angle/Left-turn Crash Frequency for LILO and Control Sites

4.0 EMPRICIAL BAYES BEFORE-AFTER ANALYSES

As mentioned previously in Chapter 1.2, an EB before-after analysis was also conducted on a subset of the LILO treatment sites. At sites # 11,12,13,15, 20, 22, and 25, the LILO treatment was installed before the year 2000, and at site # 2, the roadway did not exist before the LILO treatment was installed. Therefore, these sites were excluded from the EB before-after analysis as ‘before’ data was not available, and the remaining subset included 17 LILO treatment sites (which is still within the HSM recommendation of using a minimum of 10-20 sites for EB before-after analyses).

In contrast to the cross-sectional analyses, the EB before-after method uses up to 5 years of crash data both before and after LILO installation (with the installation year excluded) at the treatment sites along with predicted crashes based on models developed with the data from control sites. A weighted combination of the observed and model-predicted crashes is used to determine an ‘expected’ number of crashes at each treatment site and these estimates are compared with observed ‘after’ crashes to determine the safety effectiveness of the treatment. The EB method requires a 14-step process which is shown in Figure 4.1, and further details of each step can be found elsewhere (HSM, 2010).

It’s important to note there are a few limitations with respect to the EB before-after method in this study. First, as already noted, the analyses can only be conducted on a subset of the LILO treatment sites which reduces the sample size. Second, the installation dates for LILO sites in the remaining subset vary widely from 2002 to 2018. In these cases, only 1 or 2 years of before or after data can be included in the study. That being said, EB before-after analyses were conducted for the same crash types/severities as the cross-sectional analyses:

- Total crashes
- Angle/Left-Turn (LT) crashes
- Sideswipe-same direction crashes
- All injury (KABC) crashes
- KAB injury crashes
- KA injury crashes

Before conducting the EB before-after analyses, crash prediction models (SPFs) were estimated using data only from the control sites which estimate the predicted annual crash frequency as a function of major and minor street ADTs. These models were developed using the same NB regression framework previously described in Chapter 3.0, and the results of these models are presented in Table 4.1 and are utilized in the EB before-after analyses.

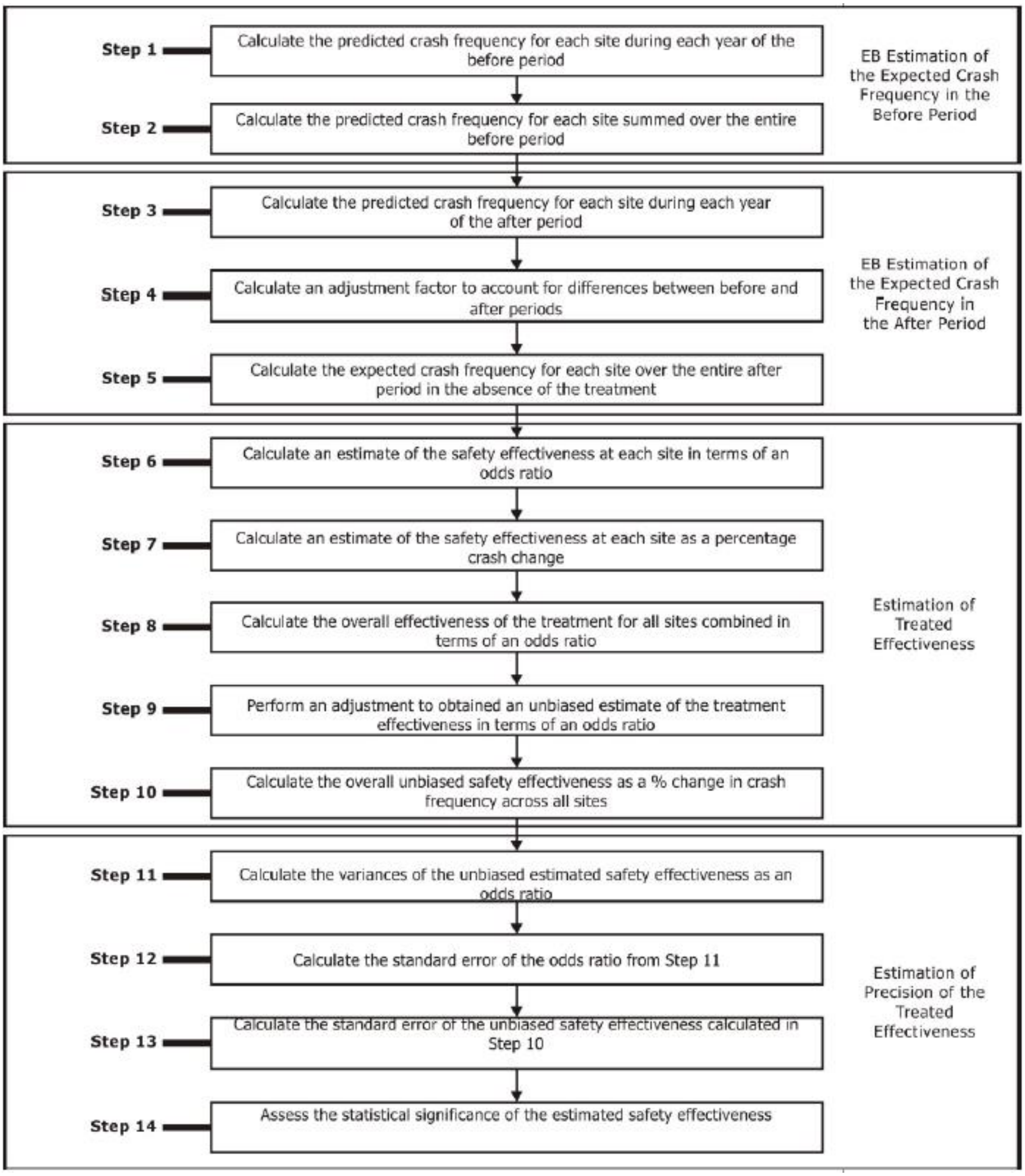

Figure 4.1: Empirical Bayes Before-After Evaluation Process (HSM, 2010)

Table 4.1: Negative Binomial Regression Models Developed for Empirical Bayes Before-After Analyses (Control Sites Only)

<table>
<tr><th rowspan="3">Crash Type</th><th colspan="7">Parameter Estimates</th></tr>
<tr><th colspan="2">Intercept</th><th colspan="2">Ln Major Road ADT</th><th colspan="2">Ln Minor Road ADT</th><th rowspan="2">Over-dispersion Parameter</th></tr>
<tr><th>β</th><th>P-value</th><th>β</th><th>P-value</th><th>β</th><th>P-value</th></tr>
<tr><td>Total Crashes</td><td><u>-5.444</u></td><td>0.001</td><td><u>0.444</u></td><td>0.001</td><td><u>0.258</u></td><td>0.007</td><td>0.372</td></tr>
<tr><td>Angle/Left-Turn Crashes</td><td><u>-6.982</u></td><td>0.003</td><td><u>0.257</u></td><td>0.200</td><td><u>0.647</u></td><td><0.001</td><td>0.733</td></tr>
<tr><td>Sideswipe Crashes</td><td><u>-10.845</u></td><td>0.049</td><td><u>0.928</u></td><td>0.047</td><td>-0.069</td><td>0.807</td><td><0.001</td></tr>
<tr><td>All Injury Crashes</td><td><u>-6.308</u></td><td>0.004</td><td><u>0.454</u></td><td>0.013</td><td>0.225</td><td>0.068</td><td>0.071</td></tr>
<tr><td>KAB Injury Crashes</td><td><u>-8.087</u></td><td>0.006</td><td><u>0.491</u></td><td>0.047</td><td><u>0.353</u></td><td>0.032</td><td>0.162</td></tr>
<tr><td>KA Injury Crashes</td><td><u>-22.329</u></td><td>0.039</td><td>1.512</td><td>0.102</td><td>0.631</td><td>0.187</td><td>1.000</td></tr>
<tr><td colspan="8">*Note: Underlined text indicates β parameter estimate is significant at 95% confidence level</td></tr>
</table>

The results of the six EB before-after analyses are presented in Table 4.2, which includes the CMF, CRF, standard error and whether the CMF is statistically significant for the six different crash types/severities. The results for total crashes and sideswipe crashes are quite similar to those of the cross-sectional analysis – a modest decrease in total crashes and increase in sideswipe crashes, neither being statistically significant. The results for angle/sideswipe crashes differ from those in the cross-sectional analysis in that the EB before-after analysis shows a slight increase in these crash types, though it's not statistically significant. This is an unexpected result, but a more careful examination shows that this result is driven by sites # 3,4, and 5 (all on the Frank Lloyd Wright corridor) which experienced a total of 6, 4 and 11 angle/left-turn crashes, respectively, in the 5-year after period after LILO installation. This is not completely surprising given crashes tend to be rare and somewhat random events which are influenced by both deterministic factors and stochastic (random and unpredictable) factors (HSM, 2010). If these three sites (#3, 4, and 5) are removed from the analysis, the CMF for angle/left-turn crashes becomes 0.650 (35.0% reduction) and is statistically significant at the 90% confidence level – results much closer to those observed in the cross-sectional analysis. Because of this finding, it's recommended that the CMF obtained in the cross-sectional analysis be treated as the recommended finding (especially given the result was statistically significant at 95% confidence in the cross-sectional analysis).

Table 4.2: CMFs and CRFs Developed from Empirical Bayes Before-After Analyses

Crash Type	Crash Modfication Factor (CMF)	Crash Reduction Factor (CRF) %	Standard Error	Statistically Significant at 95% Confidence?
Total Crashes	0.935	6.5%	0.105	No
Angle/Left-Turn Crashes	1.158	-15.8%	0.263	No
Sideswipe Crashes	1.427	-42.7%	0.357	No
All Injury Crashes	0.735	26.5%	0.124	Yes
KAB Injury Crashes	0.586	41.4%	0.149	Yes
KA Injury Crashes	0.599	40.1%	0.384	No

Turning to the EB before-after results for the different injury categories, as shown in Table 4.2, crash frequencies for all three injury categories showed a reduction after the LILO treatment (similar to the findings in the cross sectional analyses but with different magnitudes). However, the CMFs for all injury crashes and KAB injury crashes (0.735 and 0.586, respectively) were found to be statistically significant at 95% confidence in the EB before-after analysis (they were not statistically significant in the cross-sectional analyses). This result shows that the LILO treatment does seem to be consistent in reducing more severe crashes, and the statistically significant CMFs obtained from the EB before-after analysis should be considered the more conclusive finding.

5.0 POTENTIAL SAFETY IMPACTS OF LILO DESIGN FEATURES

While the previous two chapters of this report presented analyses of the overall safety impacts of LILO treatments through development of CMFs, another objective of this study was to assess the potential impacts of different design features specifically at LILO sites on crash frequencies. As such, a NB regression model was estimated for total crashes using the same framework described previously in Chapter 3.0, but using only data from LILO treatment sites (2014-2019) and considering additional variables beyond major and minor street ADT. The results of this model are presented in Table 5.1 which include variables related to the LILO channelizing island design, signage, acceleration length, speed limit, and the cross product of peak hour minor road left turn traffic and major road traffic, among others. In examining the p-values in Table 5.1, it is apparent that none of the variables are significant at the 95% confidence level (or even a 90% confidence level for that matter). Based on these results, a strong conclusion cannot be made with respect to the performance of different LILO design features with the available data set. Further research and monitoring over time may be warranted to further explore potential impacts of specific LILO design features.

Table 5.1: Negative Binomial Model to Assess LILO Design Features

Parameter	β	Standard Error	P-value
Intercept	-3.360	3.279	0.305
Ln Major ADT	0.123	0.335	0.714
Ln Minor ADT	0.235	0.183	0.197
LILO - Raised channelizing island	-0.389	0.439	0.376
LILO - No signs present	0.235	0.225	0.296
LILO - Accel. length less than 200 ft	-0.310	0.213	0.144
Speed Limit 45-50mph	0.226	0.315	0.472
Raised Median	0.046	0.475	0.922
Ln Cross Product LT Minor-Major Volume	0.112	0.126	0.374
Overdispersion parameter	0.209	0.090	- -

6.0 CRASH SEVERITY ANALYSIS

While the previous described analyses have focused on crash frequencies, it's also important to investigate how installation of the LILO treatment may impact injury severity outcomes given a crash has occurred. To assess the potential impacts of the LILO treatment on crash severity (i.e. most severely injured crash-involved person) at the crash-level, a series of binary logistic (logit) regression models were estimated to analyze factors associated with crash severity. In these analyses, the dependent variable is a binary indicator (1= injury of any severity (KABC) and 0=no injury). The binary logit model is appropriate given this binary nature of the dependent variable, and in this framework, the probability of a crash resulting in any level of injury is estimated as (Washington et al., 2011):

$$P_i = \frac{EXP[\beta_o+\beta_1 X_{1,i}+\beta_2 X_{2,i}+\cdots+\beta_K X_{K,i}]}{1+EXP[\beta_o+\beta_1 X_{1,i}+\beta_2 X_{2,i}+\cdots+\beta_K X_{K,i}]} \quad (3)$$

where: P_i is the probability of crash i resulting in any level of injury, β_0 is the model constant, and $\beta_1,.. \beta_K$ are estimable parameters corresponding with explanatory site and crash variables X_K. In interpreting model results, a negative β estimate indicates that variable is associated with a decrease in injury probability, and the opposite is true for a positive β estimate. Additionally, odds ratios are estimated with the models which can be used to determine the expected percent change in the probability of a crash resulting in an injury for that particular independent variable.

First, a model was estimated using all crashes occurring at LILO treatment and control sites for years 2014-2019 (note for the few LILO sites installed after 2013, only crashes occurring in the years after installation were included in this dataset). This dataset consisted of 268 crashes occurring at LILO sites and 276 crashes occurring at control sites (544 total). This model includes only an indicator for the LILO treatment as the independent variable which results in an estimate of the probability of a crash resulting in an injury at a LILO site vs. a control site, all else being equal. The results of this model are shown in Table 6.1, and the LILO treatment indicator variable has a negative parameter estimate (which implies a reduction in injury probability). The odds ratio for the LILO binary indicator is 0.864, which translates to a 13.6% reduction in probability of injury for crashes occurring at a LILO site compared to a control site, all else being equal. However, it's important to note that this result is not statistically significant given the p-value for the LILO indicator (0.413) is greater than 0.05.

Table 6.1: Binary Logit Severity Model with Only LILO Treatment Indicator Variable

Parameter	β	Standard Error	P-value	Odds Ratio
Constant	-0.519	0.124	<0.001	0.595
LILO Treatment Indicator	-0.147	0.179	0.413	0.864

While the results in Table 6.1 show that in general it seems crashes occurring at LILO sites have a lower probability of injuries occurring (although it was not a statistically significant result), there are many other crash and roadway characteristics which may be associated with crash severity. Therefore, another model was estimated which includes additional variables related to time of day, crash type, roadway width, and speed limit. The results of this model are shown in Table 6.2. The results show that the LILO treatment indicator still indicates a reduction in probability of injury even when accounting for crash type and other variables, though it is still not statistically significant. Estimates for time-of-day variables (compared with off-peak times), roadway width, and speed limit variables are not statistically significant predictors of crash severity. However, several crash type variables were statistically significant (compared with sideswipe and other crash types). It was found that left-turn crashes exhibited the highest probability of injury, followed by single-vehicle and angle crashes. This is a notable result because the cross-sectional analysis presented in Chapter 3.0 showed a statistically significant reduction in angle/left-turn crash frequency associated with the LILO treatment, indicating the LILO treatment may be successful in preventing these relatively more severe crash types.

Table 6.2: Binary Logit Severity Model with LILO Treatment Indictor plus Other Variables

Parameter	β	Standard Error	P-value	Odds Ratio
Constant	-1.378	0.630	0.029	0.252
LILO Treatment Indicator	-0.270	0.239	0.260	0.764
Night time 11pm-6am	0.211	0.465	0.650	1.234
AM Peak 6-10am	0.272	0.254	0.283	1.313
PM Peak 3-7pm	0.105	0.217	0.630	1.110
Single vehicle crash	<u>1.010</u>	<u>0.371</u>	<u>0.006</u>	<u>2.746</u>
Angle crash	<u>0.827</u>	<u>0.325</u>	<u>0.011</u>	<u>2.287</u>
Left Turn crash	<u>1.152</u>	<u>0.337</u>	<u>0.001</u>	<u>3.164</u>
Rear end crash	<u>0.700</u>	<u>0.296</u>	<u>0.018</u>	<u>2.013</u>
Main Street N/E bound total width	-0.014	0.014	0.299	0.986
Main Street S/W bound total width	0.007	0.013	0.579	1.007
Center treatment width	0.031	0.031	0.328	1.031
Speed limit 40mph	-0.278	0.475	0.558	0.757
Speed limit 45mph	-0.200	0.462	0.666	0.819
Speed limit 50mph	0.258	0.539	0.632	1.294
Note: underlined text indicates statistically significant variables at 95% confidence				

Finally, a binary logit model was estimated with only LILO treatment site data in an attempt to determine whether certain LILO-specific features (e.g. signage, acceleration length, etc.) might be associated with crash severity. The results of this model are shown in Table 6.3. While several parameter estimates change slightly compared with the model results presented previously in Table 6.2, of primary interest are the LILO-specific variables. The presence of a raised channelizing island (as opposed to painted) and a LILO site having no signs present (compared with some combination of signs present) were not statistically significantly associated with crash severity. Sites with acceleration lengths of 200 ft. or less (compared to acceleration lengths of more than 200 ft.) were associated with an increased probability of injury, though this result is only marginally significant (at the 90% confidence level, but not 95%). However, an additional model was run with acceleration length of 200 ft. or less as the only predictor, and this variable became even less significant (p-value = 0.398), which indicates there may be some unobserved correlation with other variables, and strong conclusions should not be drawn regarding this acceleration length result.

Table 6.3: Binary Logit Severity Model with LILO Treatment Characteristics (LILO Treatment Sites Only)

Parameter	β	Standard Error	P-value	Odds Ratio
Constant	-3.458	1.621	0.033	0.031
Night time 11pm-6am	-1.030	0.895	0.250	0.357
AM Peak 6-10am	0.309	0.384	0.421	1.362
PM Peak 3-7pm	0.154	0.326	0.638	1.166
Single vehicle crash	<u>1.474</u>	<u>0.527</u>	<u>0.005</u>	<u>4.365</u>
Angle crash	0.811	0.501	0.106	2.250
Left Turn crash	0.585	0.539	0.278	1.795
Rear end crash	<u>1.064</u>	<u>0.432</u>	<u>0.014</u>	<u>2.899</u>
Main Street N/E bound total width	-0.004	0.028	0.872	0.996
Main Street S/W bound total width	0.006	0.035	0.862	1.006
Center treatment width	<u>0.152</u>	<u>0.063</u>	<u>0.015</u>	<u>1.165</u>
Speed limit 40mph	-1.060	1.082	0.327	0.346
Speed limit 45mph	-1.430	1.176	0.224	0.239
Speed limit 50mph	-0.526	1.119	0.638	0.591
LILO - Raised channelizing island	-0.209	1.044	0.841	0.811
LILO - No signs present	0.401	0.754	0.595	1.493
LILO - Accel. length less than 200 ft	0.736	0.406	0.070	2.087
Note: underlined text indicates statistically significant variables at 95% confidence				

7.0 SUMMARY AND CONCLUSIONS

This study presented an analysis of the potential safety impacts of LILO treatments in Scottsdale, Arizona. Crash, traffic, and roadway data were collected for 25 LILO treatment sites and 25 control sites (similar sites but without the LILO treatment) to complete the analyses. CMFs and CRFs were developed for different crash types and severities using both cross-sectional and EB before-after study designs. Additionally, the potential impacts of specific LILO design features on crash frequencies were assessed, and factors associated with crash severity in terms of the overall LILO treatment and specific LILO design features were evaluated. To the authors' knowledge, this study presents the first analysis of the potential safety impacts of the LILO treatment. The primary conclusions of this study include the following:

- The CMFs developed through cross-sectional analyses indicated that the LILO treatment was associated with a reduction in total crashes, angle/left-turn crashes, all injury crashes, KAB injury crashes, and KA injury crashes, though only <u>the CMF for angle/left-turn crashes (CMF=0.668, 33.2% reduction) was statistically significant at the 95% confidence level</u>. Additionally, the CMF for sideswipe-same direction crashes indicated the LILO treatment was associated with an increase of this crash type, though the result was not statistically significant.

- The CMFs developed through EB before-after analyses using a subset of the LILO treatment sites (17 sites) indicated that the LILO treatment was associated with a reduction in total crashes, all injury crashes, KAB injury crashes, and KA injury crashes. Most notably, the CMFs for all injury crashes (CMF=0.735, 26.5% reduction) and KAB injury crashes (CMF=0.586, 41.4% reduction) were statistically significant at the 95% confidence level. The CMFs for angle/left-turn and sideswipe-same crashes indicated the LILO treatment was associated with an increase of these crash types, though neither result was statistically significant. An inspection of the angle/left turn crash analysis revealed this result was driven largely by three sites, and this result should not be considered a strong conclusion.

- An analysis of the potential impacts of specific LILO design features on crash frequency showed that no variables (e.g. channelizing island type, signage, acceleration length) were significantly associated with crash frequency. These results may have been limited by sample size, and further research and monitoring over time may be warranted to further explore these potential impacts.

- An analysis of factors associated with crash severity showed that the LILO treatment was associated with a reduced probability of injury in the event of a crash occurrence compared with control sites, though this result was not statistically significant. Finally, in an analysis using only LILO treatment site data, it was found that LILO-specific design features were not significantly associated with crash severity, though again, this could due to sample size limitations and further investigation may be warranted.

7.1 PRACTICAL IMPLICATIONS FOR THE CITY OF SCOTTSDALE

Overall, the findings of this study indicate that the LILO is a promising treatment, as it was found to significantly reduce (at the 95% confidence level) angle/left-turn crashes, all injury crashes, and KAB injury crashes through analyses using two different types of statistical analyses. This indicates that the City of Scottsdale is warranted in considering subsequent applications of the LILO treatment at locations which are generally similar to the sites assessed in this study in terms of volumes, speeds, geometry, etc.

In terms of the potential safety impacts of specific LILO design features, based on the data assembled in this study for the 25 LILO treatment sites, there were no significant associations found between crashes and the signage present, acceleration length, speed limit of the major road, or median type. Of these findings, perhaps most notably, the varying application of signage at the LILO treatment sites does not appear to impact safety. In fact, there was no difference in safety performance found between LILO sites with signs vs. no signs (object marker only), indicating that future installations may not require specialized signage. Finally, it should be noted that these results are based only on the 25 LILO sites analyzed as part of this study. Subsequent analyses of other existing or future LILO treatments may provide additional guidance as to the potential impacts of specific LILO design features.

8.0 REFERENCES

Gayah, V. and E. Donnell (2014). “Establishing Crash Modification Factors and Their Use”, FHWA-PA-2014-005-PSU WO 6, Pennsylvania Department of Transportation, Harrisburg, PA.

Google LLC (2021). Google Maps and Street View. https://www.google.com/maps.

Gross, F., Persaud, B., and C. Lyon (2010). “A Guide to Developing Quality Crash Modification Factors”, FHWA-SA-10-032, Federal Highway Administration, Washington, DC.

Highway Safety Manual (HSM) (2010). 1st Edition. American Association of State Highway and Transportation Officials (AASHTO), Washington, DC.

Le. T, Gross, F., and T. Harmon (2018). "Safety Effects of Turning Movement Restrictions at Stop-Controlled Intersections". Presented at the 97th Annual Meeting of the Transportation Research Board, Paper No. 18-03753, Washington, D.C.

Minnesota Department of Transportation (MNDOT) (2011). “Minnesota’s Best Practices and Policies for Safety Strategies on Highways and Local Roads – Intersection Treatments” https://www.dot.state.mn.us/stateaid/trafficsafety/safety/intersection-treatments.pdf

Washington, S., Karlaftis, M., and F. Mannering (2011). “Statistical and Econometric Methods for Transportation Data Analysis (2nd ed.)”, Boca Raton, FL.: Chapman and Hall/CRC..