Final Report

Safety Evaluation of Signal Installation With and Without Left Turn Lanes on Two Lane Roads in Rural and Suburban Areas

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16. Abstract

Data from 117 intersections on two lane roads in rural and suburban areas in North Carolina were used to determine the safety effect of signalization with and without left turn lanes. This was a before-after study that was conducted using the empirical Bayes method. Before signalization, all the 117 intersections were controlled by stop signs on the minor legs. As part of implementing the empirical Bayes method, safety performance functions were estimated using data from a reference group of minor road stop controlled intersections. Results have been provided for three and four leg intersections separately. Five types of crashes were investigated: total, injury and fatal, rear end, frontal impact (type 1), and frontal impact (type 2).

It is clear that the introduction of signals without the addition of left turn lanes resulted in a reduction in total crashes, injury and fatal crashes, and frontal impact crashes (both types), and an increase in rear end crashes. When left turn lanes were added, rear end crashes decreased as well. Injury and fatal crashes and rear end crashes benefited the most from the addition of left turn lanes. Overall, frontal impact crashes did not benefit from the addition of the left turn lanes. These results along with information about the cost of adding left and right turn lanes could be used by NCDOT to determine the locations where these turn lanes would be most cost-effective.

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SUMMARY

When signals are installed at intersections on two lane roads in rural and suburban areas of North Carolina, there have been arguments for adding left turn lanes to prevent delays to the vehicles going straight through and to reduce the risk of collisions. Some districts in North Carolina have a policy of installing signals only if turn lanes are constructed as well. Other districts commonly install signals without turn lanes. This disparity makes it difficult to compare projects on a statewide basis for the use of spot safety funding. Additionally, installing turn lanes might not be necessary in certain locations, in terms of safety benefits, and adding the requirement unnecessarily results in significant delays in installing much-needed signals.

Adding left turn lanes can also substantially increase the cost of the project, since NCDOT will have to acquire new right-of-way and also possibly deal with the relocation of public and private utilities. The decision to implement a left turn lane with signalization should be based on the benefits and cost of the left turn lane. This project sought to quantify the potential benefits of preventing crashes by developing crash modification factors.

An empirical Bayes before-after study was conducted to evaluate the safety effect of signalization with and without left turn lanes. Data from 117 intersections on two lane roads in rural and suburban areas in North Carolina were investigated. Before signalization, all these intersections were controlled by stop signs on the minor road and did not have left turn lanes. Among these intersections, 50 of them were signalized without adding left turn lanes, and the remaining (67 intersections) were signalized along with the addition of at least one left turn lane. NCDOT provided basic information about these treatment locations. Further data were collected using NCDOT's GIS files and Google earth. Crash and AADT data were provided by NCDOT as well. As part of implementing the empirical Bayes method, safety performance functions (SPFs) were estimated using data from a reference group of minor road stop controlled intersections. Crash modification factors (CMFs) were developed for three- and four-leg intersections separately for both groups of treated sites: sites where left turn lanes were added and sites where left turns were not added during signalization. Five types of crashes were investigated: total, injury and fatal, rear-end, frontal impact (type 1), and frontal impact (type 2).

It is clear that the introduction of signals without the addition of left turn lanes resulted in a reduction in total crashes, injury and fatal crashes, and frontal impact crashes (both types), and an increase in rear end crashes. When left turn lanes were added, rear end crashes decreased as well. Injury and fatal crashes and rear end crashes benefited the most from the addition of left turn lanes. Overall, frontal impact crashes did not benefit from the addition of the left turn lanes. These results along with information about the cost of adding left and right turn lanes could be used by NCDOT to determine the locations where these turn lanes would be most cost-effective.

Contents

1. INTRODUCTION

When signals are installed at intersections on two lane roads in rural and suburban areas of North Carolina, there have been arguments for adding left turn lanes to prevent delays to the vehicles going straight through, and to reduce the risk of collisions. Some districts in North Carolina have a policy of installing signals only if turn lanes are constructed as well. Other districts commonly install signals without turn lanes. This disparity makes it difficult to compare projects on a statewide basis for the use of spot safety funding. Additionally, installing turn lanes might not be necessary in certain locations in terms of safety benefits, and adding the requirement unnecessarily results in significant delays in installing much-needed signals.

Adding left turn lanes can also substantially increase the cost of the project, since NCDOT will have to acquire new right-of-way and also possibly deal with the relocation of public and private utilities. In some cases, the cost of project could increase tenfold (e.g., installing a signal may cost $ 60,000, but adding a turn lane could increase the cost to $ 600,000)[1]. The decision to implement a left turn lane with signalization should be based on the benefits and cost associated with this change.

Review of the Literature

A detailed review was conducted to assemble knowledge from past studies on the safety effect of left turn lanes and signalization. The focus of this literature review was on results pertaining to rural or suburban intersections. However, other results are presented as well in the hopes of providing the larger picture.

Much of the guidance on adding exclusive left turn lanes to intersections focuses on the operational benefits. Additionally, much of the guidance for rural intersections focuses on unsignalized intersections. For example, NCHRP Report 457 (Bonneson and Fontaine, 1985) cites guidance by Neuman (1985) that suggests that a left turn lane on the major approach should be considered at any median crossover on a divided, high-speed road; when the intersecting road is an arterial or collector; and, when the combined intersection volumes are above a certain amount. Other research (Fitzpatrick and Wolff, 2003; Koepke, 1992; Harmelink, 1967) have provided guidance for installing left turn lanes based on critical gap, percent of left turn volume, and speed limit. Many of these were based on operational models.

The sections below provide the findings of this literature review for studies that used crash-based measures to determine the safety effect of signal installation, left turn lane installation, or both countermeasures installed together. The literature review is organized into the following sections:

- Safety Effects of Installing Signals

[1] Personal communication with Brian Mayhew, NCDOT.

- Safety Effects of Installing Left Turn Lanes at Signalized Intersections
- Safety Effects of Installing Signals and Left Turn Lanes Together

Safety Effects of Installing Signals

The following studies evaluated the safety impact of converting intersections from stop control to signal control.

Rural Intersections

NCHRP Project 17-25 evaluated the effect of converting rural stop-controlled intersections to signalized intersections (Harkey et al., 2008). The authors conducted an empirical Bayes before-after study on 45 converted intersections in California and Minnesota and used a reference group of approximately 3,500 intersections. They concluded that signalization caused a decrease in total crashes by 44% (crash modification factor, i.e., CMF 0.56), right-angle crashes by 77% (CMF 0.23), and left turn crashes by 60% (CMF 0.40). They also concluded that rear-end crashes increased by 58% (CMF 1.58). They did not observe much difference in the effect of signalization on three- vs. four-leg intersections. They conducted a benefit-cost analysis and noted that benefits were greater on higher volume intersections and greater where the ratio of expected right-angle crashes to rear-end crashes is higher.

Urban Intersections

McGee et al. (2003) conducted a study to establish crash-based warrants for signal installation or removal. They examined twenty-two 3-leg and one hundred 4-leg urban intersections from five U.S. states and Toronto that had been converted to signalized intersections. Their empirical Bayes analysis showed that converting a stop-controlled intersection to a signalized intersection resulted in decreases in all crashes, larger decreases in right-angle crashes, and increases in rear-end crashes. Table 1.1 shows the resulting CMF values (indicated as index of effectiveness). Their results show greater crash decreases at four-leg intersections when compared to three-leg intersections.

Table 1.1 Signal conversion CMFs from McGee et al. (2003)

	3-leg (22 conversions)			4-leg (100 conversions)		
	All	Right-angle	Rear-end	All	Right-angle	Rear-end
EB estimated after-period expected crashes without conversion (s.e.)	142.37 (11.32)	22.13 (3.62)	35.02 (3.87)	756.73 (31.77)	314.72 (19.84)	113.22 (8.20)
Injury crashes in the after period	123	15	53	585	105	157
Index of effectiveness θ	0.86	0.66	1.50	0.77	0.33	1.38
VAR{θ}	0.10	0.20	0.26	0.05	0.04	0.15

A study in Denmark evaluated the effects of installing signals at urban, yield-controlled intersections (Jensen, 2010). They conducted a before-after analysis of 54 intersections and accounted for changes in traffic volume, regression-to-the-mean, and physical changes to the sites during the study period. They reported that increases were seen in single-vehicle crashes, rear-end crashes, frontal crashes, and left- and right-turn crashes but were offset by large reductions in angle crashes and pedestrian and bicycle crashes. They determined that the conversion to signal resulted in a decrease in total crashes of 21% (CMF 0.79) at 3-leg intersections and 39% (CMF 0.61) at 4-leg intersections.

Unreported Area Type

Davis and Aul (2007) evaluated the effects of converting stop-controlled intersections to signal control, with an emphasis on the major left turn CMF. They studied 17 intersections in the Twin Cities Metro District of Minnesota which had four legs and were located on roads with speed limits at least 40 mph. The area type of the study sites was not reported. Their hierarchical Bayes analysis showed that signal installation caused increases in rear-end crashes and decreases in right-angle crashes. They found that there was no effect on left turn crashes as long as there was protected-only left turn phasing used on the major approaches.

The Highway Safety Manual (2010) provides CMFs related to signal installation in Chapter 14 (Table 14-7). It indicates that converting from stop control to signal control for rural three- and four-leg intersections results in a CMF of 0.56 for total crashes, 0.23 for right angle crashes, 0.40 for left turn crashes, and 1.58 for rear-end crashes. These CMFs are applicable for intersections where the major road AADT is 3,200 to 30,000 and the minor road AADT is 100 to 10,300.

Safety Effects of Installing Left Turn Lanes at Signalized Intersections

Harwood et al. (2002) evaluated the effects of turn lanes on intersection safety. Their study examined two treatments that are relevant to this project, adding left turn lanes to existing signalized intersections and adding left turn lanes to newly signalized intersections (e.g., signalized in conjunction with left turn installation). However, the group of treatment sites was mainly urban. They had no rural sites for which left turn lanes were added to existing signals and only two rural sites where left turn lanes were added to newly signalized intersections. Based on this very limited sample, they estimated a 35% decrease (CMF 0.65) in total crashes for adding one left turn lane at rural, four-leg, newly signalized intersections.

When presenting the results of Harwood et al. (2002), Harkey et al. (2008) recognized this gap in the research and filled it in with results from an analysis-driven expert panel. The expert panel results indicated that adding an exclusive left turn lane on one approach at rural signalized intersections results in a CMF for total crashes of 0.82 for four-leg intersections and 0.85 for three-leg intersections. The expert panel also listed a CMF of 0.67 for adding left turn lanes on both approaches at rural four-leg signalized intersections.

The Highway Safety Manual presents CMFs for exclusive left turn lanes in Part D, Chapter 14 (HSM Tables 14-10, 14-11, 14-12). For rural signalized intersections, the HSM lists the same CMFs as provided in Harkey et al. (2008). The HSM also provides CMFs for the installation of *channelized* left turn lanes but does not provide a breakdown according to traffic control type. Additionally, for the scenario addressed by this research project (turn lane installation on the major road), the CMFs provided by the HSM for channelized left turn lanes were not statistically significant.

The predictive process for rural 2-lane intersections in Part C of the HSM does include CMFs for left turn lanes. These CMFs are used to adjust the predictions of the safety performance function. There are no CMFs provided for three-leg signalized intersections. For four-leg signalized intersections, the HSM lists CMFs for total crashes according to how many approaches have left turn lanes installed:

- Left turn lane installed on one approach: CMF = 0.82
- Left turn lane installed on two approaches: CMF = 0.67
- Left turn lane installed on three approaches: CMF = 0.55
- Left turn lane installed on four approaches: CMF = 0.45

The 2004 Signalized Intersections: Informational Guide addresses the topic of left turn lanes at intersections (Rodegerdts, 2004). Much of the guidance is related to operational issues, with a view toward turning volumes and storage length. They list seven elements to consider when determining whether a left turn lane is warranted, including functional classification (consider left turn lanes for higher class facilities), prevailing approach speeds (consider left turn lanes for higher speed roads), capacity of an intersections (left turn lane increases capacity), proportion of left turning vehicles, volume of opposing through vehicles, design conditions (left turn lane may be needed for sight distance reasons), and crash history. To the last point, they indicate that a left turn lane may be needed if there is a significant problem with left turn related crashes. Some basic crash reduction factors (CRFs) were listed but were largely drawn from older compilations of CRFs based on surveys of state practices rather than research studies.

Safety Effects of Installing Left Turn Lanes and Signals Together

Thomas and Smith (2001) evaluated safety improvement projects conducted in Iowa. They examined 11 sites where new traffic signals were installed with the addition of one or more turn lanes. They did not specify whether the turn lanes were right- or left turn lanes. They also did not specify the area type of the intersections (urban or rural), but they did note that the sites were provided by Iowa DOT and were located throughout the state on primary, secondary, and city roads. They determined that installing a signal with one or more turn lanes resulted in an average 20% decrease in all crashes, although this value was not statistically significant at the 90% level. The treatment did show a statistically significant decrease in right angle crashes (63%) and left turn crashes (35%). However, their before-after analysis did not use a comparison or reference group. Hence, it is likely that changes in traffic volume, historical trends, and possible bias due to regression-to-the-mean may have affected their results.

The Highway Safety Manual (HSM) and the Crash Modification Factor (CMF) Clearinghouse (being maintained by the Highway Safety Research Center), provide CMFs for installation of signals and installation of left turn lanes at stop controlled and signalized intersections. However, very little information is available in these sources for signals that are installed in conjunction with left turn lanes in rural and suburban areas on two lane roads. This indicates the need for further research in this area using data from North Carolina.

2. OVERVIEW OF METHODOLOGY

There is general agreement in the safety community that before-after studies provide more reliable estimates of CMFs compared to cross-sectional studies. For example, Elvik (2011) argues that since in before-after studies, we are dealing with the same roadway unit located in a particular place used by probably the same users in the before and after period, they are less prone to confounding. However, since high accident locations are often selected for such treatments, before-after studies need to account for the possible bias due to regression to the mean (RTM). The empirical Bayes (EB) method has been accepted as one possible approach to account for the potential bias due to RTM. The before-after EB method was chosen for this evaluation.

Here is a brief overview of the approach that was used in this study:

1. Based on a before-after evaluation of data from sites where signals were installed without turn lanes, we determined the CMF for the effect of adding signals without turn lanes – we call this CMF_S.
2. Based on a before-after evaluation of data from sites where both signals and turn lanes were installed, we determined the CMF of the combined effect of signals and turn lanes - we call this CMF_{st}.
3. Based on the approach given in the HSM, the specific safety effect of adding turn lanes (when signals are installed) is the ratio CMF_{st} / CMF_S. For example, if installing signals with turn lanes is expected to reduce crashes by 40% (i.e., the CMF is 0.60), and installing signals without turn lanes is expected to reduce crashes by 25% (i.e, the CMF is 0.75), the specific safety effect of adding turn lanes (when signals are installed) will be about 0.60/0.75 = 0.80 (i.e., about a 20% reduction in crashes specifically due to the turn lanes). The reason that the specific safety effect would be not exactly 0.8 is because it is a ratio of CMFs, and ratios lead to biased estimates. A correction is needed to address this bias. Usually, this bias is usually quite small, and the specific safety effect is typically very close to 0.8 (Hauer, 1997).

The steps involved in estimating CMF_{st} and CMF_S are similar and have been used by the authors in many prior studies (for instance, pages 43 through 47 of Section 5 from a recent NCDOT Report by Srinivasan and Carter, 2011, discuss these steps with an example). The steps are outlined below:

1. Identified a group of reference sites that were otherwise similar to the treatment sites, but without the treatment (i.e., stop controlled intersections on two lane rural and suburban roads without a left turn lane)
2. Used the crash data and the characteristics of the intersections (e.g., traffic volume, minimum intersection angle, speed limit on the major road) in the reference group to estimate safety performance functions (SPFs) relating crash frequency with the site characteristics. The SPFs were estimated using negative binomial regression. The SPFs were also used to estimate annual calibration factors (ACFs) for each year. The ACFs are defined as the ratio of the total observed crash frequency to the total predicted crash frequency from the SPF for each year. The ACFs are estimated to account for trends due to changes in crash reporting, weather, driver population, vehicle population, etc.

3. Used the SPFs, ACFs, and the characteristics of the each treatment site (including traffic volume) to estimate the predicted number of crashes in the before period for each treatment site. For the before and after periods, we considered three options. Option 1 used all the data that we had for a particular treatment site; option 2 limited the before period to a maximum of 10 years (median of the before periods) and the after period to a maximum of 9 years (median of the after periods); option 3 limited the before and after periods to a maximum of 5 years. After discussing this with NCDOT, we limited to our analysis to option 3. We call the predicted number of crashes in the before period as P_b.
4. Used a weighted average of the observed crashes in the before period (A_b) and the predicted crashes from the previous step to estimate the EB expected crashes in the before period (EB_b). The weights are based on P_b and the overdispersion parameter that was estimated as part of the SPF development.
5. Used the SPFs, ACFs, and the characteristics of each treatment site to estimate the predicted number of crashes in the after period at each treatment site (P_a). The EB expected crashes in the after period (π) was estimates as follows:

$$\pi = EB_b \left(\frac{P_a}{P_b} \right)$$

6. The sum of π (π_{sum}) and the variance of this sum was used along with the sum of the actual reported number of crashes in the after period (λ_{sum}) to estimate the crash modification factors (and the standard error of the CMFs) associated with the treatment. The formula for the CMF and the standard error of the CMF is as follows:

$$CMF = \frac{\dfrac{\lambda_{sum}}{\pi_{sum}}}{1 + \dfrac{Var(\pi_{sum})}{\pi_{sum}^2}}$$

Standard error of CMF= $\sqrt{\dfrac{CMF^2 \left(\dfrac{Var(\lambda_{sum})}{\lambda_{sum}^2} + \dfrac{Var(\pi_{sum})}{\pi_{sum}^2} \right)}{\left(1 + \dfrac{Var(\pi_{sum})}{\pi_{sum}^2} \right)^2}}$

These steps were repeated for intersections that were signalized without adding left turn lanes (to obtain CMF_s) and for intersections that were signalized while adding at least one left turn lane (to obtain CMF_{st}).

As mentioned earlier, to identify the specific effect of adding a left turn lane (to a signalized intersections) (let us call this CMF_t), it is necessary to take the ratio of CMF_{st} and CMF_s and correct for the bias that can arise when ratios of random variables are estimated. CMF_t and its standard error was estimated as follows:

$$CMF_t = \frac{\dfrac{CMF_{st}}{CMF_s}}{1 + \dfrac{Var(CMF_s)}{CMF_s^2}}$$

Standard error of CMF_t= $\sqrt{\dfrac{CMF_t^{\,2}\left(\dfrac{Var(CMF_{st})}{CMF_{st}^2}+\dfrac{Var(CMF_s)}{CMF_s^2}\right)}{\left(1+\dfrac{Var(CMF_s)}{CMF_s^2}\right)^2}}$

The formulas are based on a Taylor series approximation and based on the work by Hauer (1997) and Papanicolaou (2009). Papanicolaou's work was in-turn based on the book by Casella and Berger (2001).

The CMFs were estimated for five different crash types:

- Total crashes
- Total injury and fatal crashes
- Total rear end crashes
- Frontal impact crashes (type 1) that included the following crash types:
    - Left turn same roadway
    - Left turn different roadway
    - Angle
- Frontal impact crashes (type 2) that included the following crash types:
    - Left turn same roadway
    - Left turn different roadway
    - Angle
    - Right turn same roadway
    - Right turn different roadway
    - Sideswipe opposite direction
    - Head-on

3. DATA COLLECTION

Determining Treatment and Reference Locations

The site selection process began with obtaining the treatment sites for data collection. Based on information from NCDOT, the team used intersections from a database of Spot Safety Project Evaluations and Hazard Elimination Project Evaluations from the Traffic Safety Evaluation Group at NCDOT. The database documented simple before and after evaluations of intersections receiving new traffic signals. The data team identified sites from the database that were on two lane roads in rural and suburban areas. These intersections were organized into sites that received traffic signals without the installation of new left turn lanes and sites that received left turn lanes with the new traffic signals. Sites were chosen for both 4-leg and 3-leg intersections.

The selection of reference sites was done in such a way as to ensure that the eventual reference group would be as similar as possible to the treatment group. After locating and collecting data for each treatment site, the data collector looked in the surrounding area to identify up to three reference sites. Intersections were selected to be reference sites only if they were intersections of two-lane roads that did not have traffic signals or flashing beacons and were located in rural and suburban areas. These sites were stop-controlled on the minor road and had no left turn lanes on the major road. The legs that were not stop-controlled were deemed the major road. Additionally, a reference site was required to have the same number of legs as the treatment site (either 3 or 4 legs). No public street intersections were allowed within 100 feet of the intersection. Finally, no changes were allowed during the study period, such as new development, the addition of flashing beacons, or the addition of a second through lane.

During the process, the team identified reference sites near the treatment sites and, if needed, gradually increased the distance from treatment sites to identify appropriate reference sites. The study site major and minor roads, as well as other nearby roads, were followed several miles until appropriate reference sites were found. Sometimes in low density rural areas, references sites were located some distance away in the same county or in nearby counties of the treatment sites.

Data Elements Collected

NCDOT provided much data in their Spot Safety Evaluation reports, such as number of lanes, intersection geometry, speed limits, description of intersection installation, and date of installation. The data collection task involved having a data collector manually collect various roadway features not covered by the NCDOT report, including mileposts for both major and minor roads at the intersection, coordinates of the intersection, and measurement of skew angles. The data collector also noted left turn lane offsets on major roads, the number of right turn lanes on major roads, and the number of large volume driveways on major roads within 100 feet of the intersection. Using aerial imagery, horizontal curves within 250 feet of the intersection were noted on major and minor roads. The data collector used Google Street View to note vertical curves in minor and major roads. The presence and types of medians were noted on major roads. Some elements such as left turn phasing and year of phasing were only noted for treatment sites, since reference sites were stop-controlled. Speed limit and year the image was taken on Street View was recorded. Finally, if the treatment site had any noticeable changes over the years, such as road widening, turn lane additions, or other major changes, the description of the change was noted along with the year of the change. The Highway Safety Information System (HSIS) was used to collect supplemental information that was not available from other sources (See Table 3.1).

Table 3.1: Data Sources for Intersection Elements on Treatment Sites

Data Element	**Source**
Name(s) of Major Roads and Minor Roads	Evaluation Reports (NCDOT), GIS (NCDOT), Aerial/Street View Imagery
Lane Width	HSIS
Shoulder Type	HSIS
Shoulder Width	HSIS
AADT and Year	GIS (NCDOT), HSIS
County Location	GIS (NCDOT)
Speed Limit and Year of Image (Major)	Street View Imagery
Speed Limit (Minor)	HSIS
Coordinates of Intersection	Aerial/Street View Imagery, GIS (NCDOT)
Left turn Lane Offset (Major)	Aerial/Street View Imagery
Left Turn Lane Installed on Minor Road When Signal Installed	Evaluation Reports (NCDOT)
Large Volume Driveways Within 100 feet (Major)	Aerial/Street View Imagery
Horizontal Curves and Type Within 250 feet	Aerial Imagery
Vertical Curves and Type Within 250 feet	Street View Imagery
Left turn Phasing and Year of Phasing	Street View Imagery
Milepost at Intersection	GIS (NCDOT)
Measurement of Skew Angle	GIS (NCDOT)
Right Turn Lanes (Major)	Aerial/Street View Imagery
Median Type and Width (Major)	Aerial/Street View Imagery

References sites had the same elements collected as treatment sites except the following:

- Left turn Phasing and Year of Phasing
- Left turn Lane Offset (Major)
- Left Turn Lane Installed on Minor Road When Signal Installed

Figure 3.1 and Figure 3.2 show the satellite and street views of an intersection. In the Satellite View, one can obtain much information about the treatment site. The information present includes the lack of a dedicated right turn lane on the major road, what also appears to be a lack of large volume driveways on the major road, and a painted median that appears to be slightly narrower than a travel lane. The intersection appears not to have a horizontal curve in its immediate proximity, but the distance to any nearby curve was fully determined using Map View and the "distance measurement tool".

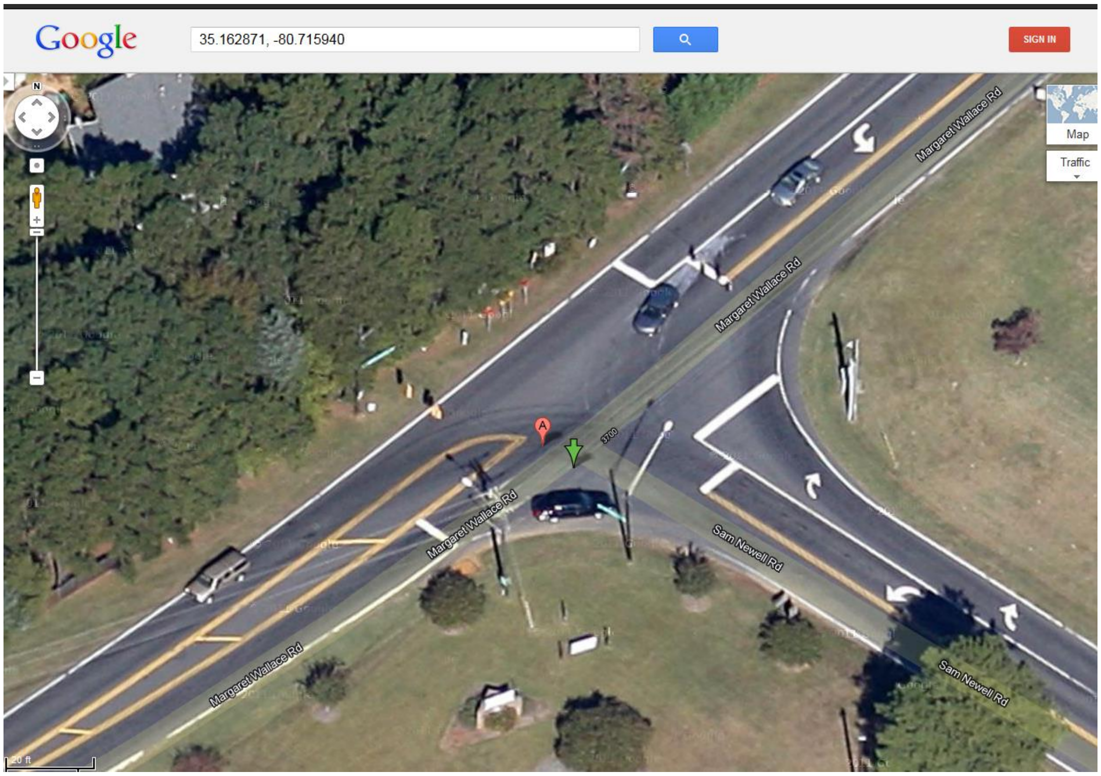

Figure 3.1: Satellite View

In the Street View of the same intersection (Figure 3.2), there appears to be a doghouse signal head configuration for the left turn lane of this leg of the intersection. Although not very visible due to the small size of the image, there is a date in the lower left corner when the photograph was taken. Somewhat visible from this view is lack of median on this leg and the median and its width on the opposite leg in the distance. It also appears that there is no vertical curve at the intersection on the major road.

Figure 3.2: Street View

Data Collection Process

The data collection step involved obtaining data on geometric and cross-sectional characteristics and traffic volumes. The sources of characteristics and volume data were the HSIS, NCDOT GIS layers of the road network and traffic volume points, and Google aerial and Street View imagery. At times, Google Earth was used to determine historical changes in road geometry and years of change. The GIS layers contained street names, milepost data, and AADT data. The layers did not have local street names so Google imagery was used to extract this information. The milepost information for the intersection was extracted from GIS to be used in obtaining data from HSIS. A more in-depth explanation of the following data collection procedures can be found in Appendix A.

To locate the intersection for treatment sites, the team used NCDOT information to obtain the name of the intersection. The intersection was then brought into Google Maps. Once on Google Maps, Maps Labs and the LatLng Marker tool were used to find the coordinates of the intersection and transfer them to GIS.

In order to get the skew angle, the editor tool in ArcGIS and the COGO Report icon were used to find the smallest angle. When editing is turned on, the data collector clicked on COGO Report, then the icon marked “angle between two lines” which started the tool. Previously, a 50-foot buffer was created around the roads and the team began measuring the angle starting at the edge of the buffers. More detailed information is contained in Appendix A.

Left lane offsets, which only applied to treatment sites, were determined using Google satellite imagery. Intersections that did not have left turn lanes were noted as such. Right turn lanes were also determined if imagery was available.

The data collector counted the number of large volume driveways within 100 feet of the intersection using the “distance measurement tool” on Google Maps Labs. Lines originated at the intersection and had a 100 foot radius. Once a line 100 feet long line was drawn, the view was changed from aerial to Street View and the view was moved along the area that was formed to confirm or deny assumptions from aerial view.

The same “distance measurement tool” was used to determine whether any horizontal curves were within 250 feet of the intersection. Using the Map aerial view, a 250 foot long line was extended from the intersection. If this line in the center of the street originating from the intersection touched a side of a street along the 250 foot span while the end of the line maintained its location at the center of the street, then that road was considered to have a horizontal curve. This was also applied to minor streets. Vertical curves were determined using Street View. Looking at the legs of a major road, the data collector determined whether the road appeared to crest at the intersection, sag, or neither. If it appeared that one leg changed elevation (up or down) and this same pattern (up or down) continued to the opposite leg through the intersection and down the road, then this was not considered to have a vertical curve (it was simply considered a straight inclined grade). Minor legs were also analyzed to determine if they had vertical curves.

Medians were determined using Street View and Satellite views and if present, both views were used to determine the median width.

Left turn phasing was determined using Street View and the year was also captured by Street View. The NCDOT Evaluation Reports provided speed limits for treatment sites. The year the evaluation report was written was used as the year of the speed limit for the major road on the intersection. For reference sites, speed limits were determined by traveling on both legs of the major road for about a quarter mile, and if still not located, the search continued at locations where the major road met a high traffic road. Sometimes this would be an opportune location to find a speed limit sign.

AADT was determined using information from the NCDOT GIS layers and was also obtained from HSIS data. If one leg did not have AADT data, then the information from the opposite leg was assumed to apply. If there were two different numbers of a major or minor road were present, then the numbers were averaged.

Crash Data

Crash data were provided by NCDOT for both reference and treatment sites. Using the information obtained from the crash data, the project team was able to determine the counts for the five different types of crashes for each reference and treatment site for each year.

Traffic Volume (AADT)

The proposed analysis approach required AADT data for each year in the study period. Based on the mileposts of the major and minor roads at the intersections, AADT data from 1992 to 2012 were obtained from HSIS (the AADT data in HSIS are based on information provided by NCDOT every year). When the AADT data were examined, large changes were found in the AADT (usually reductions) around 2009. Some of this could be attributed to the recession. However, some of the changes were quite dramatic, e.g., more than a 50 percent reduction in AADT at some locations. Further discussion with NCDOT revealed that the AADT provided by NCDOT to HSIS were not accurate for many locations because they were based on counts from traffic counters that were far away from the roadway segments under consideration. Since the AADT from HSIS was not accurate enough to be used in this project, NCDOT compiled the traffic counts from the nearest count station for the major and minor road for each intersection, and provided this information to the project team. If AADT counts were not available for a particular year, they were filled based on a method developed by Lord (2000).

4. RESULTS AND DISCUSSION

NCDOT provided information on 130 intersections on two lane roads in rural and suburban areas that had been signalized in the last 21 years. None of these intersections had left turn lanes before signalization. However, not all these intersections could be used in the evaluation for a few reasons. For example, some of the intersections also had other significant improvements, such as significant roadway realignment. Other intersections were part of loops which made it difficult to determine if a crash occurred at that intersection or a nearby intersection that was part of the same loop. In other cases, there were no AADT counts near the major or minor road of the intersections. This reduced the sample of intersections to 117. Among this group, left turn lanes were not added at 50 of the intersections, and at least one left turn lane was added in the remaining 67 intersections. Among the 50 intersections where left turn lanes were not added, 17 were 3-leg intersections and 33 were 4-leg intersections. Among the 67 intersections where at least one left turn lane was added, 19 were 3-leg intersections and 48 were 4-leg intersections.

Summary Statistics

Following are summary statistics for the treatment and reference sites. Separate tables are provided for 3 and 4 leg intersections. Two of the treatment intersections had no crashes in the before period. Among the 67 intersections where at least one left turn was added, one had negative offset left turn lanes. None of them had positive offsets. Among the 50 intersections where a left turn was not added, protected-permissive left turn phasing was implemented on the major approaches at four intersections, and permissive left turn phasing was implemented at the remaining 46 intersections. Among the 67 intersections where a left turn lane was not added, permissive left turn phasing was implemented on the major approaches at 36 intersections, protected-permissive left turn phasing was implemented at 30 intersections, and protected left turn phasing was implemented at one intersection.

Table 4.1: Summary statistics for 3 leg treatment sites (36 intersections)

Variable	Signalization without addition of left turn lanes (17 sites)			Signalization with addition of at least one left turn lane (19 sites)		
	Min.	Max.	Mean	Min.	Max.	Mean
Years before	5	5	5	5	5	5
Years after	4	5	4.88	3	5	4.79
Total Crashes/site-year before	0	4.4	2.38	0.6	10.4	3.94
Total Crashes/site-year after	0	5.4	1.86	0.6	7.4	2.55
Injury & Fatal Crashes/site-year before (KABC)	0	2.2	1.05	0.2	4.2	1.8
Injury & Fatal Crashes/site-year after (KABC)	0	1.8	0.76	0	2.6	0.81
Rear End Crashes/site-year before	0	1.4	0.64	0	5	1.61
Rear End Crashes/site-year after	0	3.2	1.01	0.2	3.2	1.16
Type 1 Frontal Impact Crashes/site-year before	0	1.8	1.01	0.4	5.8	1.65
Type 1 Frontal Impact Crashes/site-year after	0	1.2	0.43	0	3.8	0.82
Type 2 Frontal Impact Crashes/site-year before	0	2	1.12	0.6	6	1.77
Type 2 Frontal Impact Crashes/site-year after	0	1.2	0.51	0.2	4.4	0.98
Major road AADT before	3475	14539	8150	2981	15107	9518
Major road AADT after	3907	18025	8307	3870	18248	10820
Minor road AADT before	986	5871	3671	1852	13880	5686
Minor road AADT after	972	6829	3777	3104	13880	6255
Intersection AADT before	6130	16336	11821	8341	25421	15204
Intersection AADT after	6110	20247	12084	8880	32129	17075

Table 4.2: Summary statistics for 3 leg reference sites (129 intersections)

Variable	Minimum	Maximum	Mean
Years	21	21	21
Total Crashes/site-year	0	3.29	0.69
Injured Crashes/site-year (KABC)	0	1.19	0.27
Rear End Crashes/site-year	0	1.33	0.21
Type 1 Frontal Impact Crashes/site-year	0	1.14	0.2
Type 2 Frontal Impact Crashes/site-year	0	1.24	0.23
Major road AADT	511	10619	4101
Minor road AADT	73	6519	1211
Intersection AADT	570	13050	4706

Table 4.3: Summary statistics for 4 leg treatment sites (81 intersections)

Variable	Signalization without addition of left turn lanes (33 sites)			Signalization with addition of at least one left turn lane (48 sites)		
	Min.	Max.	Mean	Min.	Max.	Mean
Years before	2	5	4.79	4	5	4.96
Years after	2	5	4.76	1	5	4.75
Total Crashes/site-year before	0.2	8.6	4.41	0	10.2	4.6
Total Crashes/site-year after	0	6.6	2.64	0	7.4	2.78
Injury & Fatal Crashes/site-year before (KABC)	0	4.6	2.33	0	6	2.42
Injury & Fatal Crashes/site-year after (KABC)	0	2.6	1.19	0	4	1.13
Rear End Crashes/site-year before	0	2	0.59	0	3	0.95
Rear End Crashes/site-year after	0	2.4	0.93	0	4	1
Type 1 Frontal Impact Crashes/site-year before	0.2	7.2	3.22	0	8.2	3.07
Type 1 Frontal Impact Crashes/site-year after	0	2.8	1.25	0	4.6	1.13
Type 2 Frontal Impact Crashes/site-year before	0.2	7.4	3.35	0	8.2	3.2
Type 2 Frontal Impact Crashes/site-year after	0	3	1.32	0	5	1.38
Major road AADT before	2480	14805	5947	1360	14309	7869
Major road AADT after	2680	17566	6729	1467	15500	9241
Minor road AADT before	746	5463	2823	1036	8884	3633
Minor road AADT after	1014	5803	3295	1063	8537	4360
Intersection AADT before	4624	17412	8770	5325	18906	11502
Intersection AADT after	4394	19573	10023	5770	22392	13601

Table 4.4: Summary statistics for 4 leg reference sites (276 intersections)

Variable	Minimum	Maximum	Mean
Years	21	21	21
Total Crashes/site-year	0	4.29	1.03
Injured Crashes/site-year (KABC)	0	2.57	0.55
Rear End Crashes/site-year	0	1.29	0.12
Type 1 Frontal Impact Crashes/site-year	0	3.29	0.66
Type 2 Frontal Impact Crashes/site-year	0	3.33	0.7
Major road AADT	167	15352	2919
Minor road AADT	87	3813	945
Intersection AADT	317	17054	3864

Discussion of Results

As presented in Section 2, the first step in the evaluation was to estimate safety performance functions (SPFs) using data from the reference sites. These SPFs are documented in Appendix B.

The crash modification factors (CMFs) and standard errors are shown in Table 4.5. CMFs that are statistically different from 1.0 at the 0.05 significance level are shown in bold. Results are shown for 3 leg and 4 leg intersections separately. For each category, the EB expected crashes in the after period[2] is shown along with the actual crashes in the after period, the CMF, and the standard error of the CMF. The table shows separate results for the two treatment groups: signal without addition of left turn lane (which provides CMF_s), and signal with addition of at least one left turn lane (which provides CMF_{st}). The last part of the table shows the additional safety effect of adding left turn lanes (i.e., CMF_t).

It is clear that the introduction of signals without the addition of left turn lanes resulted in a reduction in total crashes, injury and fatal crashes, and frontal impact crashes (both types), and an increase in rear end crashes. When left turn lanes were added, rear end crashes decreased as well.

Compared to 3-leg intersections, 4-leg intersections experienced a larger reduction in frontal impact crashes. At the same time, 4-leg intersections experienced a larger increase in rear end crashes when left turn lanes were not added, and a smaller reduction in rear end crashes when at least one left turn was added. Based on the last two columns of the table, it is clear that injury and fatal and rear end crashes benefited the most from the addition of left turn lanes. Overall, frontal impact crashes did not benefit by the addition of the left turn lanes.

Appendix C shows the results of disaggregate analysis where the results are broken down by the number of left and right turn lanes and left turn phasing on the major road. Since the number of sites in the different categories of turn lanes and left turn phasing were limited, definite conclusions could not be made based on the disaggregate analysis. Previous research using data from Toronto and North Carolina has shown that the change from permissive to protected-permissive phasing can be effective in reducing left turn opposing through crashes by about 15 to 25 percent, with very little effect on total and injury and fatal crashes at an intersection (Srinivasan et al., 2012). Left turn opposing through crashes were not separately investigated in this study, although they were part of the two frontal impact crash types.

[2] This is the estimate of the expected number of crashes in the after period had the treatment not been implemented

Table 4.5: Crash Modification Factors

Crash Type	Legs	Signalization without addition of left turn lanes					Signalization with addition of at least one left turn lane					Effect due to left turn Lanes	
		Sites	Actual After	EB Expected After	CMF_s	S.E. of CMF	Sites	Actual After	EB Expected After	CMF_{st}	S.E. of CMF	CMF_t	S.E. of CMF
Total	3 legs	17	154	214.3	**0.716**	0.073	19	234	431.2	**0.541**	0.044	**0.748**	0.095
	4 legs	33	421	685.1	**0.614**	0.037	48	606	1064.9	**0.569**	0.028	0.924	0.070
	3 & 4 legs	50	575	899.4	**0.639**	0.033	67	840	1496.2	**0.561**	0.024	0.876	0.066
Injury & fatal	3 legs	17	63	77.8	0.803	0.123	19	75	160.4	**0.465**	0.062	**0.566**	0.113
	4 legs	33	192	318.9	**0.601**	0.052	48	242	499.7	**0.484**	0.036	**0.799**	0.089
	3 & 4 legs	50	255	396.7	**0.642**	0.048	67	317	660.2	**0.480**	0.031	**0.744**	0.071
Rear end	3 legs	17	83	68.5	1.198	0.182	19	105	206.8	**0.505**	0.062	**0.412**	0.079
	4 legs	33	149	93.3	**1.586**	0.183	48	208	232.3	0.892	0.080	**0.555**	0.079
	3 & 4 legs	50	232	161.8	**1.427**	0.132	67	313	439.1	**0.711**	0.052	**0.494**	0.059
Frontal impact type 1	3 legs	17	36	77.6	**0.460**	0.087	19	76	155.3	**0.487**	0.066	1.020	0.230
	4 legs	33	198	478.3	**0.413**	0.034	48	254	695.9	**0.365**	0.026	0.879	0.101
	3 & 4 legs	50	234	555.8	**0.420**	0.032	67	330	851.2	**0.387**	0.025	0.916	0.101
Frontal impact type 2	3 legs	17	42	84.7	**0.492**	0.086	19	91	164.7	**0.550**	0.069	1.086	0.225
	4 legs	33	210	505.5	**0.415**	0.033	48	310	729.9	**0.424**	0.028	1.016	0.108
	3 & 4 legs	50	252	590.2	**0.426**	0.031	67	401	894.6	**0.448**	0.026	1.046	0.107

Note: CMFs is bold are statistically different from 1.0 at the 0.05 significance level

5. CONCLUSIONS AND IMPLEMENTATION

Data from 117 intersections on two lane roads in rural and suburban areas in North Carolina were investigated to determine the safety effect of signalization with and without left turn lanes. This was a before-after study that was conducted using the empirical Bayes method. As part of implementing the empirical Bayes method, safety performance functions were estimated using data from a reference group of minor road stop controlled intersections. CMFs were estimated for three and four leg intersections separately. Five types of crashes were investigated: frontal impact (type 1), frontal impact (type 2), injury and fatal, rear end, and total.

It is clear that the introduction of signals without the addition of left turn lanes resulted in a reduction in total crashes, injury and fatal crashes, and frontal impact crashes (both types), and an increase in rear end crashes. When left turn lanes were added, rear end crashes decreased as well. Compared to 3-leg intersections, 4-leg intersections experienced a larger reduction in frontal impact crashes. At the same time, 4-leg intersections experienced a larger increase in rear end crashes when left turn lanes were not added, and a smaller reduction in rear end crashes when at least one left turn was added. It is clear that injury and fatal and rear end crashes benefited the most from the addition of left turn lanes. Overall, frontal impact crashes did not benefit by the addition of the left turn lanes. These results along with information about the cost of adding left and right turn lanes could be used by NCDOT to determine the locations where these turn lanes would be most cost-effective.

Future research could investigate the development of crash modification functions that may provide further insight into the specific conditions under which certain treatments are most effective. Ongoing NCHRP Project 17-63 (*Guidance for the Development and Application of Crash Modification Factors*) is expected to provide guidance on the most effective ways to estimate crash modification functions.

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APPENDIX A: DATA COLLECTION PLAN

This document was developed to guide the data collector in the collection and coding of intersection features for the treatment and reference sites. It also serves as the documentation on how the data were coded for each field in the database.

Site Identification

NCDOT provided a list of intersections where signals were installed on 2-lane roads, including signals installed with left turn lanes and signals installed without left turn lanes. This group constituted the treatment sites for this study.

To conduct the empirical Bayes before-after study, it will be necessary to identify a group of reference sites. After getting information about each treatment site, get three reference sites. If not enough reference sites can be found using the major street, other streets can be used as long as they meet the criteria. The reference sites shall be directly underneath the treatment site in the spreadsheet and will be labeled with the same File Number but with an R1, R2, or R3. Use GIS layer to find minor roads that have AADT information. Do not use sites from from GIS layer that do not have AADT for at least one minor and major road leg of each intersection.
Reference sites should be:

- Intersections of 2-lane road with 2-lane road
- Stop-controlled on the minor road
- Same number of legs as the associated treatment site (3 or 4)
- No left turn lanes on major road
- No public street intersection within 100 feet
- No rail grade crossing within 500 feet
- No changes during study period (new development nearby, addition of flashing beacon, etc.)

Reference sites will be identified by the person doing the data collection for the treatment sites. This person will look for suitable reference sites near each treatment site, aiming for an identification of three reference sites for each treatment site. This will be done by examining several miles on the major road on either side of the treatment site and expanded if no appropriate sites found. Data collection for the reference sites will be conducted in the same way as for treatment sites.
Procedure for Data Collector:

1. Locate treatment site intersection (use evaluation report, Google Maps, GIS)
2. Get Coordinates in degrees from Google Maps
3. Gather all data elements of treatment site (If Google Streetview is not available for site, get as much information as possible. Use U if unknown.)
4. Identify three reference sites on adjacent sections of major road

5. Gather all data elements for reference sites

Flag if any of these criteria are met (use the bolded word):

- **Urban** - Appears to be urban (moderately high development density, frequent driveways)
- **Int** - Public street intersection within 100 feet
- **PCU** Potential change unknown- If do not know what or when possible change occurred
- **Rail** Rail grade crossing within 500 feet

If OK is given to drop the site, put "Yes" in Dropped Site Column and give a reason.
Put in Change Columns

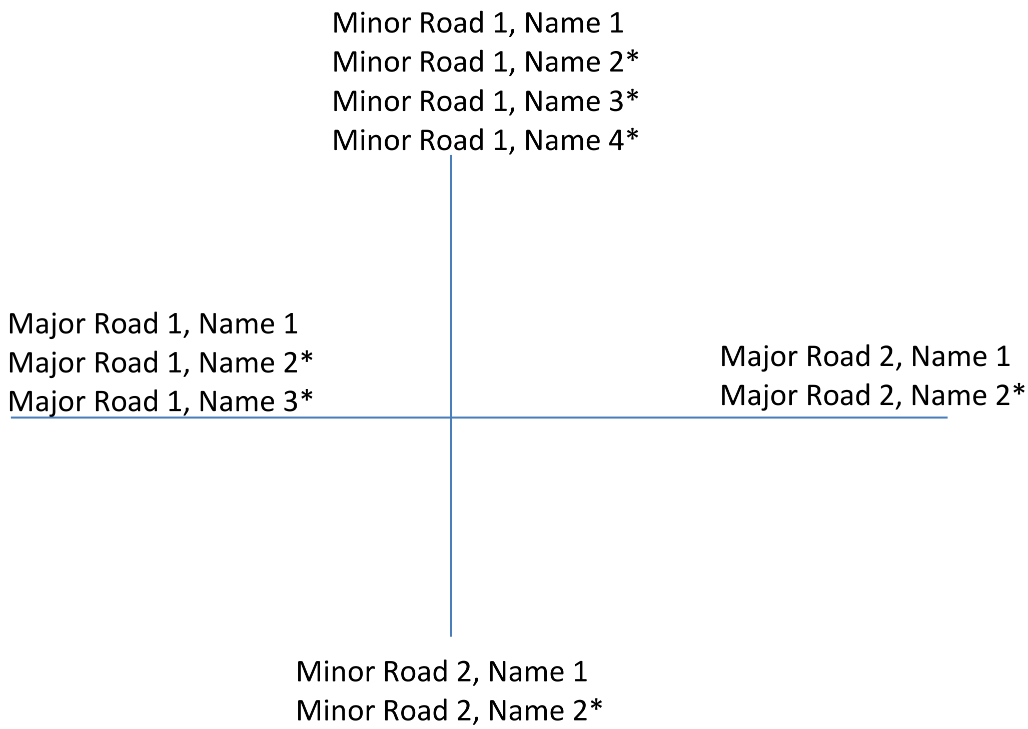
- **Change** - Obvious changes (new development, flashers, etc.)
- **Lanes** – Intersection is no longer two through lanes on all legs

Data Collection

Data collection in this task will consist of investigating each intersection to obtain the necessary site characteristics, traffic volume, and crash data to conduct the safety analysis. The NCDOT data provided information on some basic site elements, such as number of lanes, description of the installation, and date of installation. The data collection to be performed by HSRC will add to this data. Below are the data elements to be collected by the HSRC data collector and how each one should be coded.

Name/route of major road

All names and routes of the major and minor roads shall be included. There are extra columns if there is more than one name for major roads. Spaces are OK between words of each street such as Main Street or NC 54. This is important for the understanding of later elements that are coded as major roads. The major road is typically the road with a higher route designation (e.g., NC route is higher than SR route) and was not previously stop controlled according to evaluation reports, is obviously functioning as the major road of the intersection, is the continuous road of a T-intersection, or is the road with the higher traffic volume (AADT). Often the roads with the higher route designation and those that were not previously stop controlled based on evaluation reports were the main elements for determining the major road. A major road with more than one name will begin with the highest order (Such as US 301) in the Major Road 1, Name 1 column and will continue in descending order to Major Road 1, Name 2, and so on until all names are entered. If a road has different names for each leg at the intersection, put the first name in the Major Road 1, Name 1 column, and the second name in Major Road 2, Name 1. When this occurs, gather milepost information for this second leg as well. See the figure below for an illustration.



**Names 2, 3, or 4 were used for any coinciding routes on the same leg.*

<u>Milepost of intersection – major</u>

Major road milepost value for the location of the intersection (e.g., milepost 27.25). Find the milepost using the identify route locations icon. The **measure value** is the number of the exact location clicked when using the GIS tool - Identify Route Locations. The minimum and maximum measures show the total length of the route.

<u>Name/route of minor road</u>

All names and routes of the minor road will be entered following the example of major roads. This is important for the understanding of later elements that are coded as major or minor.

<u>Milepost of intersection – minor</u>

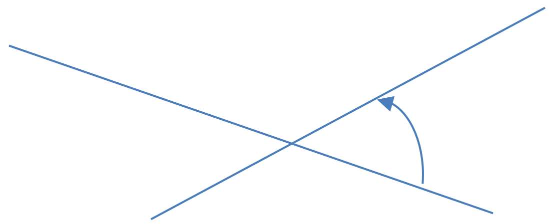
Minor road milepost value for the location of the intersection (e.g., milepost 27.25). If there is no minor leg in GIS, label "U" for unknown.

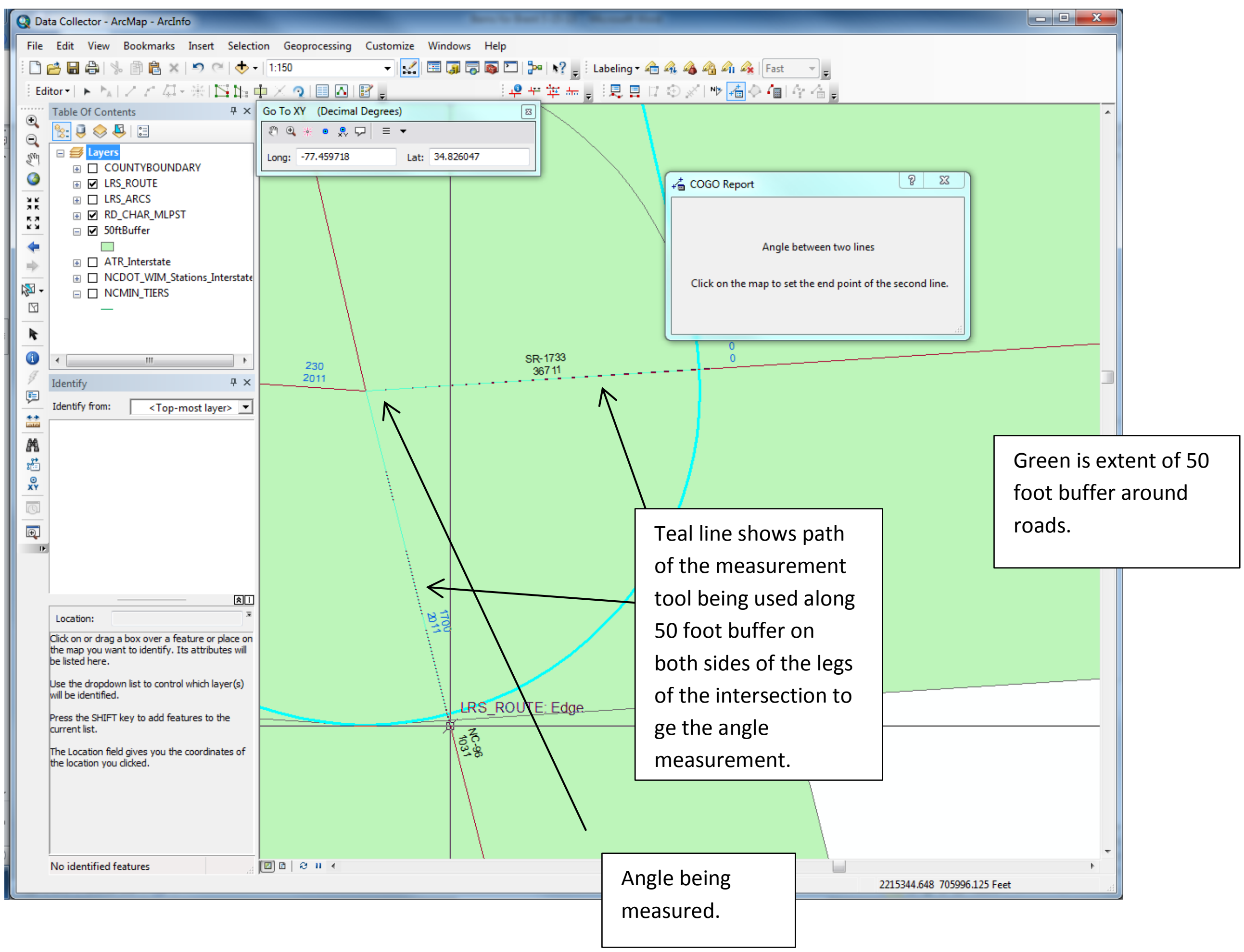
<u>Coordinates of intersection</u>

Coordinates of the intersection in decimal form and latitude/longitude (e.g., 34.826047, -77.459718).

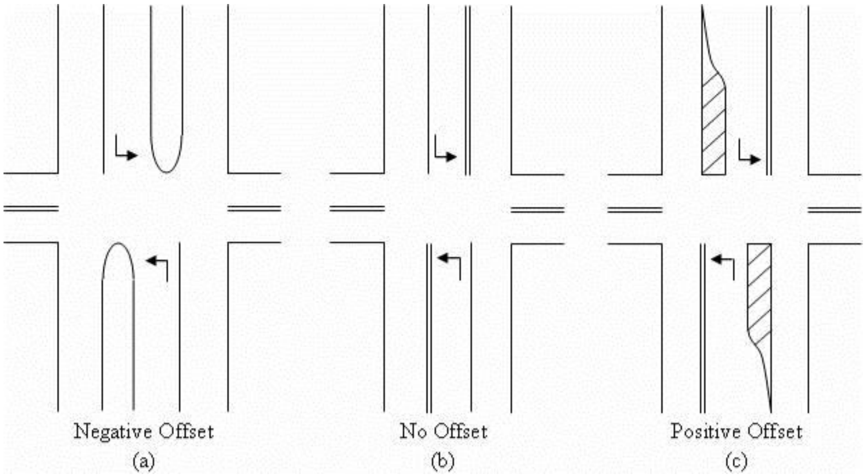
<u>Intersection Skew Angle (smallest angle)</u>

Measurement in degrees of the <u>**smallest**</u> angle between any two of the intersection approaches. If the intersection looks square to the eye, code it as "S" and do not measure with COGO. If it does not look square, use **Editor** in GIS and click start editing. Click on the COGO Report icon and use the second icon, the angle between two lines. Measure 50 feet away from the intersection for consistency by using a 50 foot buffer. With the buffer activated, zoom into the intersection and start using the COGO tool. Move the cross hashes near one side of the angle on one road until it says “50footbuffer: Vertex or 50footbuffer: Edge”. Now move the hash just outside of the “50footbuffer: Vertex or 50footbuffer: Edge”marks along the road until it says “LRS_Route:Edge” and click on it. This should be a very small move. Now click on the vertex and then move to the other side of the angle using the same process as the first side until you obtain an angle reading. See figure below for illustration.





Left turn lane offset on major rd



a = negative offset

b = no offset

c = positive offset

NA= No left turn lane or is a three-leg intersection

Right turn lane presence on **Major** rd

Example of right turn lane

U= Unknown (Satellite view is too old or from Google Earth historical imagery and it is not possible to determine if there are/were right turn lanes)

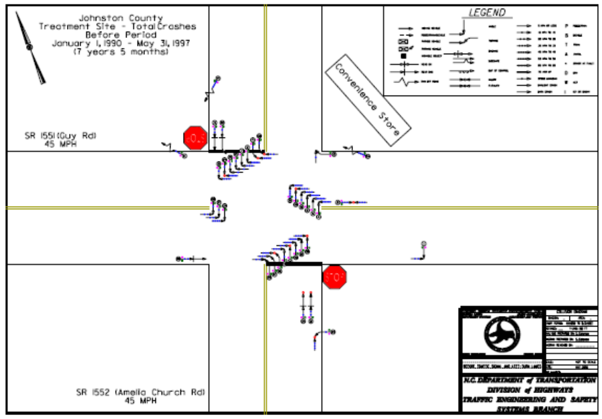
0 = no exclusive right turn lane present on either major road approach

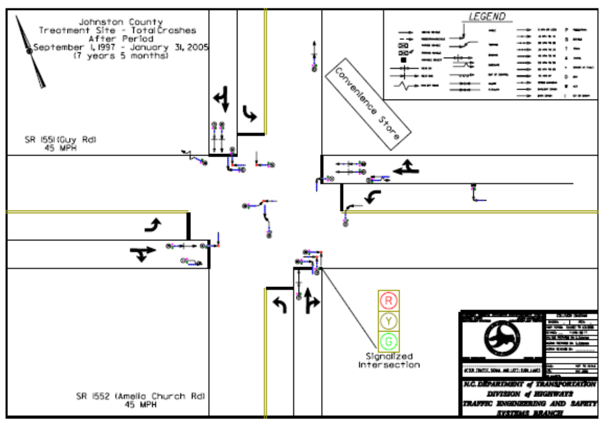
1 = exclusive right turn lane present on one major road approach

2 = exclusive right turn lane present on both major road approaches

Left turn lane installed on minor road when signal installed

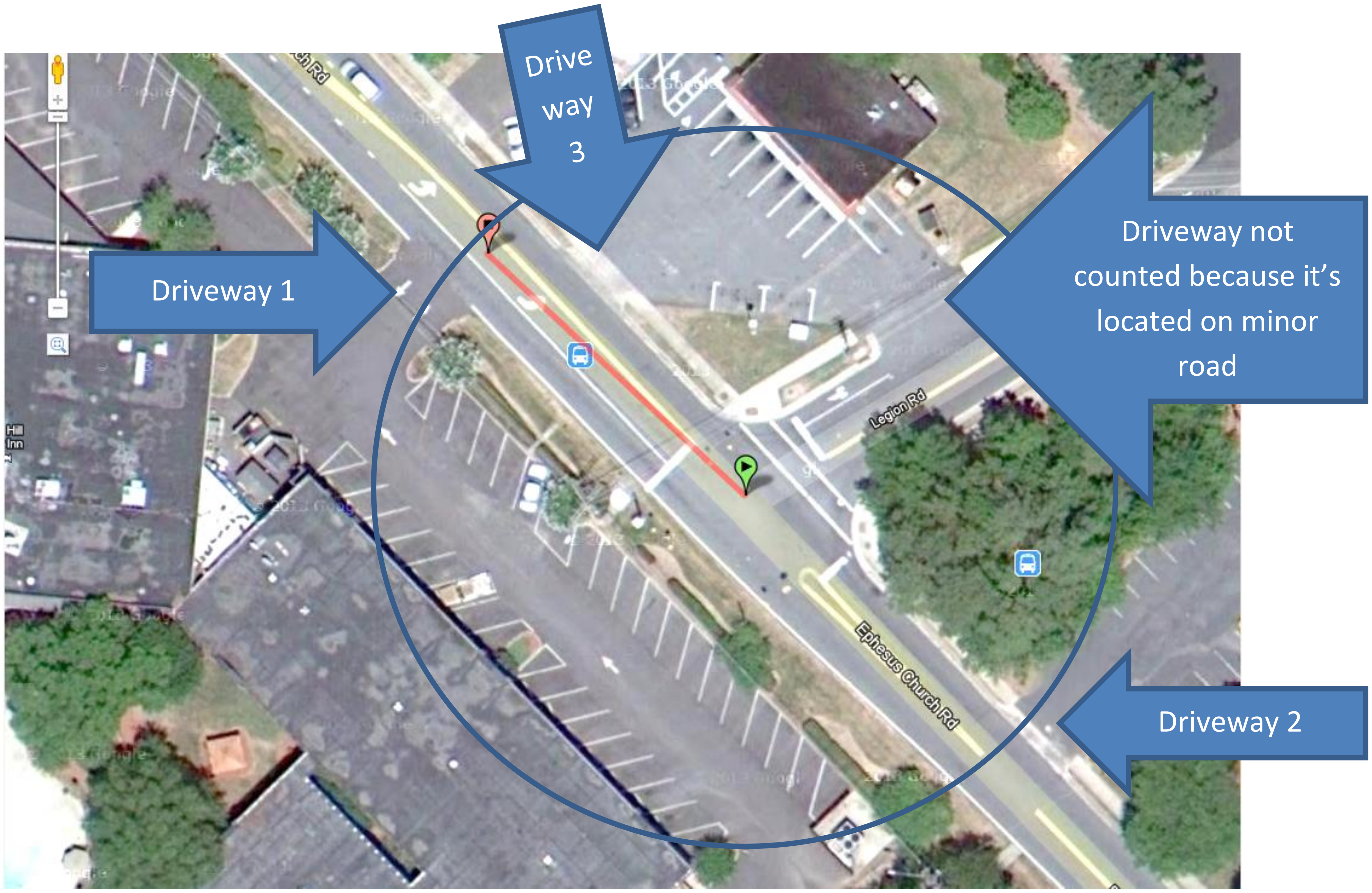
Using the signal plans in the evaluation report, determine if new left turn lanes were installed on the minor road when signal installation occurred on the treatment site. The example below demonstrates such a change with the top diagram demonstrating the before configuration and the bottom diagram being the configuration after signal installation.





Number of large volume driveways on **Major** rd within 100 ft

The purpose of this variable is to capture the number of large volume driveways that exist along the major road within 100 feet of the intersection. This would not include driveways serving single family residences. It would include any type of commercial driveway and any driveway serving more than one residence (e.g., entrance to an apartment complex). Using Maps Labs from Google Maps, use the Distance Measurement Tool to measure distance from intersection. See figure below for illustration.



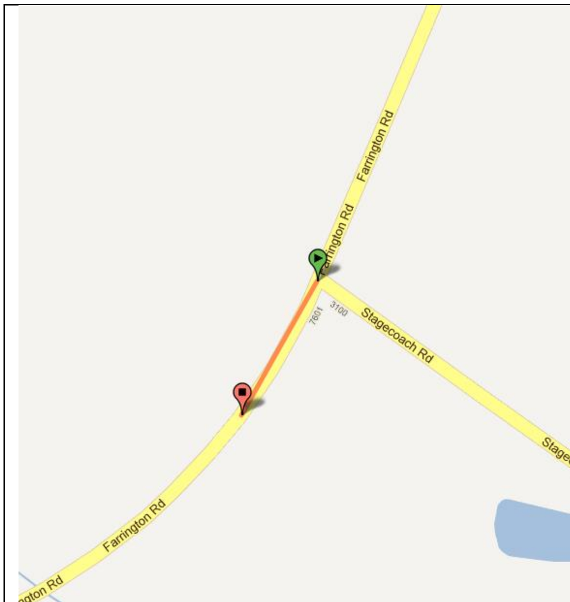
This intersection would be coded as having **<u>three</u>** large volume driveways on the major road within 100 feet (distance measured with Google tool, circle drawn by eye with Word tool for illustration purposes). If the Google Maps Streetview is not available and Google satellite view does not have accurate enough resolution to determine the number of large driveways, use "U" for unknown.

<u>Horizontal curve within 250 ft – major</u>

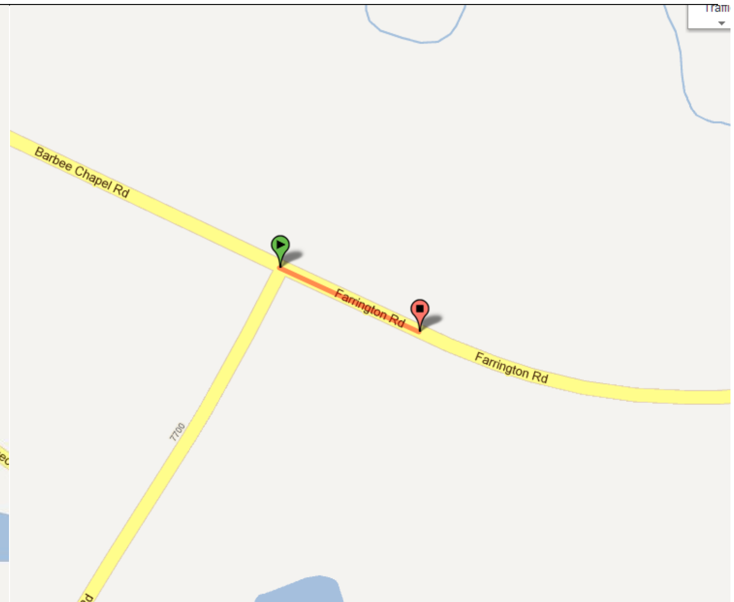
The road must be part of the curve and not part of a straight section.

0 = no horizontal curve on the major road within 250 feet of the center of the intersection

1 = horizontal curve (any piece of the curve) located on the major road within 250 feet of the center of the intersection. This is determined visually. See figure below for illustration.



This intersection would be coded as having a curve within 250 feet (250 ft distance shown by Google measurement)



This intersection would NOT be coded as having a curve within 250 feet (250 ft distance shown by Google measurement)

Horizontal curve within 250 ft – minor

See coding for major road variable.

Vertical curve at intersection - major

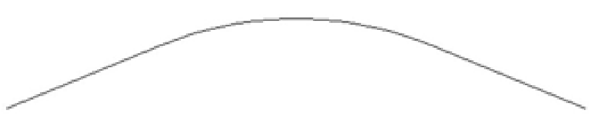
N = intersection is not located on a vertical curve of the major road (is either straight flat, straight uphill, or straight downhill)

C = intersection is located on a crest vertical curve of the major road

S = intersection is located on a sag vertical curve of the major road

U= Unknown

See figure below showing crest and sag curves.



Crest

Sag

Vertical curve at intersection – minor

See coding for major road variable.

Median at intersection on major rd

Median is defined as anything wider than a double yellow.

N = no median present on the major road at the intersection
D = depressed (typically grass)
R = raised (typically concrete or decorative grass)
P = painted (paved area flush with the travel lanes, typically painted in a hash diagonal pattern)
R/P = Raised on one leg of road and painted on other leg of same road
F = flexible dividers (individual post-like dividers that bend when hit by cars)

Median width on major rd
0 = median is narrower than one travel lane
1 = median width is equal to or greater than one travel lane
NA= not applicable (no median present)

Left turn phasing on major
0 = only permissive left turn phasing on both major road approaches
1 = permissive/protected phasing on one major road approach or if is a 3-legged intersection (protected is green arrow)
2 = permissive/protected phasing on both major road approaches
3 = protected phasing on one major road approach
4 = protected phasing on both major road approaches
5= permissive/protected phasing on one major road approach and protected phasing on other major road approach
NA= Not applicable (no signal heads present)
U= Unknown. Satellite view may be only one available and one cannot make out signal head from this satellite view.
If there is a 4-section vertical signal head, consider it permissive/protected. If there is a doghouse configuration with a single red bulb and 4 bulbs beneath it, consider it permissive/protected. The example below demonstrates both configurations. In this case, the doghouse configuration is being used for the right lane of traffic but for the study, the doghouse configuration must be used for the left lane.

Left turn phasing year

Year of the information on left turn phasing. This essentially tells us how current the information on the left turn phasing is. This can be obtained based on the source of the left turn phasing information, such as the year of the signal plan, year of the aerial photograph, or year of the evaluation report. If unknown, put "U". If no signal heads are present, put "NA" for not applicable.

Speed limit – major

Speed limt in mph on the major road. This can be obtained from the "Statement of Existing Physical Condition" field, or from the evaluation report for treatment sites. If unknown after quick search or after not finding any information in Evaluation Report, enter "U" in the cell. For reference sites, look on the major road for about ¼ mile in each direction. If the major roads crosses other high traffic roads within about 3 miles, look for speed limit signs at those locations. If there is a different speed limit that is visible in Google Streetview than in the Evaluation Report, use the Streetview speed limit.

Speed limit- year

Put in the year that the speed limit was last known. If not known, put in "U".

AADT Major

Enter AADT using RD_CHAR_MLPST layer. Enter "U" if unknown. If there are two different AADT counts on the different approaches of the same street, average the two. If one side has a number but the other has a zero, use the number for both sections of the road.

AADT Major Year

Enter year which is also found using RD_CHAR_MLPST layer. Put "U" if unknown.

AADT Minor

See instructions for AADT Major.

AADT Minor Year

See instructions for AADT Major.

Change 1

Use this field to note any significant change that occurred at the intersection. This may be seen in the evaluation report, or obtained by some other means (observations from aerial photos, etc). Example: Major road was widened to 4 lanes.

Change 1 Year

Year of the Change 1 modification. Example: 2004

Change 2

Use this field to note any additional change which is different than Change 1 or which occurred at a different time. Same coding as Change 1.

Change 2 Year

Year of the Change 2 modification. Example: 2007

Data Elements Obtained from HSIS

The following elements were obtained from HSIS.

Lane width – major

Lane width – minor

Shoulder type – major

Shoulder type – minor

Shoulder width – major

Shoulder width – minor

Speed limit – minor

APPENDIX B: SAFETY PERFORMANCE FUNCTIONS

SPFs were estimated for 3 leg and 4 leg stop controlled intersections separately for each of the five crash types. The parameter estimates along with the standard errors are shown in the following pages. The relationship between crash frequency and the independent variables are as follows:

$$Y = \exp\{\alpha + \beta_1 * f_1(AADT) + \beta_2 f_2(X_2) + \beta_3 f_3(X_3) + \beta_4 f_4(X_4) + ...\} \quad (8)$$

Where f_1, f_2, f_3, and f_4, represent functions of the independent variables AADT, X_2, X_3, and X_4. SPFs were estimated using negative binomial regression. Here are the variables that were included in the SPFs:

Variable	**Description**
lgma_aadt	ln(major road AADT)
lgmi_aadt	ln(minor road AADT)
lgcos_ma	ln[(1+cos(minimum intersection angle))(major road AADT)]
lgcos_mi	ln[(1+cos(minimum intersection angle))(minor road AADT)]
drwys_ma100	Number of driveways within 100 of the intersection on the major road
Min angle > 85	Indicator variable which was defined as 1 if the minimum intersection angle was greater than 85 degrees (0, otherwise).
Minimum Angle	Minimum intersection angle
Hcurve250_ma (No)	Indicator variable which was defined as 1 if there are no curves on the major road within 250 feet of the intersection, 0 otherwise
ln(1+cos_min_angle)	ln[(1+cos(minimum intersection angle)]
Terrain (flat)	Indicator variable which was defined as 1 for flat terrain, 0 otherwise
Terrain (rolling)	Indicator variable which was defined as 1 for rolling terrain, 0 otherwise
ma_spd_limt > 50	Indicator variable which was defined as 1 if the speed limit on the major road was greater than 50, 0 otherwise
Vcurve_mi (crest)	Indicator variable which was defined as 1 if there was a vertical curve on the minor road and it was a crest, 0 otherwise
Vcurve_mi (no curve)	Indicator variable which was defined as 1 if there was no vertical curve on the minor road, 0 otherwise

Table B.1: SPFs for 4 leg intersections

Parameter	Total Crashes		Injury and Fatal (KABC)		Frontal Impact (Type 1)		Frontal Impact (Type 2)		Rear end	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Intercept	-8.4813	0.6017	-10.2189	0.8223	-9.4163	0.7524	-9.2838	0.7362	-13.9074	0.6602
lgma_aadt	0.3913	0.0221	0.3490	0.0291	0.2414	0.0274	0.2643	0.0267	1.2825	0.0675
lgmi_aadt	0.5212	0.0210	0.5331	0.0282	0.6585	0.0267	0.6388	0.0261	0.3846	0.0548
ln(1+cos_min_angle)	2.0498	0.5112	2.8561	0.7039	2.5752	0.6391	2.5312	0.6256	-0.0126	0.0027
Minimum Angle	0.0164	0.0059	0.0294	0.0082	0.0236	0.0074	0.0228	0.0072		
Terrain (flat)	0.2900	0.0766	0.4723	0.1025	0.3768	0.0990	0.3084	0.0952		
Terrain (rolling)	0.1679	0.0654	0.2464	0.0897	0.2458	0.0857	0.1910	0.0818		
Terrain (mountainous)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		
Hcurve250_ma (No)	0.1042	0.0308	0.1205	0.0407	0.1392	0.0383	0.1309	0.0375		
Hcurve250_ma (Yes)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		
ma_spd_limt > 50			0.1493	0.0626						
ma_spd_limt ≤ 50			0.0000	0.0000						
Vcurve_mi (crest)									-0.8041	0.1937
Vcurve_mi (no curve)									-0.2514	0.1332
Vcurve_mi (sag)									0.0000	0.0000
Over-dispersion	0.2262	0.0228	0.2721	0.0400	0.3425	0.0368	0.3414	0.0353	0.4069	0.1455

Table B.2: SPFs for 3 leg intersections

Parameter	Total Crashes		Injury and Fatal (KABC)		Frontal Impact (Type 1)		Frontal Impact (Type 2)		Rear-end	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Intercept	-8.3878	0.4763	-10.1958	0.6047	-10.4885	0.6567	-10.1940	0.6120	-15.2874	0.9697
lgma_aadt	0.7637	0.0465	0.7298	0.0702					1.4000	0.0933
lgmi_aadt	0.3717	0.0333	0.4064	0.0496					0.4124	0.0597
lgcos_ma					0.6273	0.0784	0.6347	0.0731		
lgcos_mi					0.4878	0.0560	0.4597	0.0521		
drwys_ma100					0.2010	0.0789	0.1453	0.0755		
Min angle > 85	0.3740	0.0854							0.5258	0.1552
Min angle ≤ 85	0.0000	0.0000							0.0000	0.0000
Minimum Angle	-0.0131	0.0028							-0.0157	0.0049
Hcurve250_ma (No)	-0.1205	0.0539								
Hcurve250_ma (Yes)	0.0000	0.0000								
Over-dispersion	0.2818	0.0476	0.4125	0.1163	0.4114	0.1384	0.3712	0.1220	0.3917	0.1259

Appendix C: Results of Disaggregate Analysis

This appendix shows the results of the disaggregate analysis where speed limit, the number of legs where left and right turn lanes were added, and left turn phasing on the major legs, were investigated.

Tables C.1 through C.5 show the CMFs based on speed limit, number of legs at the intersection, and the number of legs where left and right turn lanes were added. Results are shown for 3 leg and 4 leg intersections separately. For each category, the EB expected crashes in the after period is shown along with the actual crashes in the after period, the CMF, and the standard error of the CMF. The top table shows separate results for the two treatment groups: signal without addition of left turn lane (which provides CMF_s), and signal with addition of at least one left turn lane (which provides CMF_{st}). The last part of the top table shows the additional safety effect of adding left turn lanes (i.e., CMF_t). The bottom table shows CMFs based on the number of left and right turn lanes that were added during signalization. The CMFs highlighted in bold are statistically different from 1.0 at the 0.05 significance level.

Table C.6 shows the CMFs based on the number of legs and left turn phasing on the major road for those intersections where signals were installed without addition of a left turn lane. Tables C.7 through C.11 show the CMFs based on the number of legs, number of legs where left and right turn lanes were added, and left turn phasing on the major road, for those intersections where signals were installed along with the addition of at least one left turn lane.

Due to the limited number of intersections in different categories, it was not possible to make definitive conclusions based on phasing or the number of turn lanes that were added. However, there is one category of intersections that deserves a note. Based on the results from tables C.4, C.5, C.10, and C.11, intersections where 3 to 4 left turn lanes and 1 to 2 right turn lanes were added during signalization seem to have experienced a significant reduction in frontal impact crashes – the CMFs are close to 0.2 or lower. Among the 7 intersections that belong to this category, 1 had permissive left turn phasing on the major road, 5 had protected-permissive left turn phasing on the major road, and 1 had protected left turn phasing on the major road. Since the sample of intersections is limited to 7, it is unclear if definitive conclusions can be made based on these results.

Table C.1: CMFs for Total Crashes

		Signalization without addition of left turn lanes					Signalization with addition of at least one left turn lane					Effect due to Left Turn Lanes	
Legs	Speed Limit (mph)	Sites	Actual After	EB Expected After	CMF_s	S.E. of CMF	Sites	Actual After	EB Expected After	CMF_{st}	S.E. of CMF	CMF_t	S.E. of CMF
3 legs	35-45	9	92	115.9	**0.788**	0.106	10	118	259.6	**0.453**	0.050	**0.565**	0.100
4 legs	35-45	17	191	371.2	**0.513**	0.045	16	203	392.1	**0.517**	0.044	1.000	0.122
3 & 4 legs	35-45	26	283	487.1	**0.580**	0.042	26	321	651.7	**0.492**	0.033	0.843	0.084
3 legs	50-55	8	62	98.4	**0.625**	0.097	9	116	171.6	**0.672**	0.081	1.051	0.202
4 legs	50-55	16	230	313.9	**0.731**	0.062	32	403	672.9	**0.598**	0.037	**0.812**	0.082
3 & 4 legs	50-55	24	292	412.3	**0.707**	0.052	41	519	844.5	**0.614**	0.033	0.863	0.080
3 legs	35-55	17	154	214.3	**0.716**	0.073	19	234	431.2	**0.541**	0.044	**0.748**	0.095
4 legs	35-55	33	421	685.1	**0.614**	0.037	48	606	1064.9	**0.569**	0.028	0.924	0.070
3 & 4 legs	35-55	50	575	899.4	**0.639**	0.033	67	840	1496.2	**0.561**	0.024	0.876	0.066

Legs	Speed Limit (mph)	Sites	# of left turn lanes added	# of right turn lanes added	Actual After	EB Expected After	CMF	S.E. of CMF
3 legs	35-55	6	1	0	71	125.8	**0.560**	0.082
3 legs	35-55	2	1	1 or 2	41	38.3	1.043	0.227
3 legs	35-55	11	2	1 or 2	122	267.1	**0.455**	0.050
4 legs	35-55	24	1 or 2	0	353	535.8	**0.658**	0.044
4 legs	35-55	6	1 or 2	1 or 2	60	89.3	**0.666**	0.106
4 legs	35-55	11	3 or 4	0	139	280.2	**0.494**	0.051
4 legs	35-55	7	3 or 4	1 or 2	54	159.6	**0.337**	0.052

Table C.2: CMFs for Injury and Fatal Crashes

Legs	Speed Limit (mph)	Signalization without addition of left turn lanes					Signalization with addition of at least one left turn lane					Effect due to Left Turn Lanes	
		Sites	Actual After	EB Expected After	CMF_s	S.E. of CMF	Sites	Actual After	EB Expected After	CMF_{st}	S.E. of CMF	CMF_t	S.E. of CMF
3 legs	35-45	9	36	43.9	0.808	0.164	10	37	99.1	**0.371**	0.069	**0.441**	0.118
4 legs	35-45	17	86	160.2	**0.535**	0.067	16	70	174.2	**0.400**	0.054	0.735	0.137
3 & 4 legs	35-45	26	122	204.1	**0.596**	0.064	26	107	273.3	**0.390**	0.043	**0.647**	0.100
3 legs	50-55	8	27	33.9	0.783	0.181	9	38	61.4	**0.612**	0.119	0.742	0.213
4 legs	50-55	16	106	158.8	**0.665**	0.079	32	172	325.5	**0.527**	0.047	**0.782**	0.111
3 & 4 legs	50-55	24	133	192.6	**0.688**	0.073	41	210	386.9	**0.542**	0.044	**0.780**	0.102
3 legs	35-55	17	63	77.8	0.803	0.123	19	75	160.4	**0.465**	0.062	**0.566**	0.113
4 legs	35-55	33	192	318.9	**0.601**	0.052	48	242	499.7	**0.484**	0.036	**0.799**	0.089
3 & 4 legs	35-55	50	255	396.7	**0.642**	0.048	67	317	660.2	**0.480**	0.031	**0.744**	0.071

Legs	Speed Limit (mph)	Sites	# of left turn lanes added	# of right turn lanes added	Actual After	EB Expected After	CMF	S.E. of CMF
3 legs	35-55	6	1	0	20	51.5	**0.383**	0.096
3 legs	35-55	2	1	1 or 2	15	11.4	1.232	0.420
3 legs	35-55	11	2	1 or 2	40	97.5	**0.407**	0.073
4 legs	35-55	24	1 or 2	0	145	257.1	**0.562**	0.055
4 legs	35-55	6	1 or 2	1 or 2	25	41.2	**0.597**	0.139
4 legs	35-55	11	3 or 4	0	52	130.4	**0.397**	0.062
4 legs	35-55	7	3 or 4	1 or 2	20	71.0	**0.279**	0.068

Table C.3: CMFs for Rear End Crashes

Legs	Speed Limit (mph)	Signalization without addition of left turn lanes					Signalization with addition of at least one left turn lane					Effect due to Left Turn Lanes	
		Sites	Actual After	EB Expected After	CMF_s	S.E. of CMF	Sites	Actual After	EB Expected After	CMF_{st}	S.E. of CMF	CMF_t	S.E. of CMF
3 legs	35-45	9	49	38.2	1.255	0.251	10	63	129.3	**0.483**	0.076	**0.370**	0.091
4 legs	35-45	17	68	53.4	1.257	0.206	16	70	74.7	0.926	0.147	0.717	0.159
3 & 4 legs	35-45	26	117	91.7	1.266	0.162	26	133	204.0	**0.648**	0.073	**0.504**	0.083
3 legs	50-55	8	34	30.3	1.096	0.250	9	42	77.5	**0.535**	0.101	**0.464**	0.130
4 legs	50-55	16	81	39.9	**2.002**	0.319	32	138	157.6	0.872	0.095	**0.425**	0.080
3 & 4 legs	50-55	24	115	70.2	**1.624**	0.215	41	180	235.1	**0.763**	0.073	**0.462**	0.073
3 legs	35-55	17	83	68.5	1.198	0.182	19	105	206.8	**0.505**	0.062	**0.412**	0.079
4 legs	35-55	33	149	93.3	**1.586**	0.183	48	208	232.3	0.892	0.080	**0.555**	0.079
3 & 4 legs	35-55	50	232	161.8	**1.427**	0.132	67	313	439.1	**0.711**	0.052	**0.494**	0.059

Legs	Speed Limit (mph)	Sites	# of left turn lanes added	# of right turn lanes added	Actual After	EB Expected After	CMF	S.E. of CMF
3 legs	35-55	6	1	0	27	53.1	**0.498**	0.118
3 legs	35-55	2	1	1 or 2	16	21.6	0.711	0.222
3 legs	35-55	11	2	1 or 2	62	132.2	**0.465**	0.073
4 legs	35-55	24	1 or 2	0	147	131.7	1.109	0.125
4 legs	35-55	6	1 or 2	1 or 2	16	25.9	**0.601**	0.174
4 legs	35-55	11	3 or 4	0	25	42.9	**0.573**	0.136
4 legs	35-55	7	3 or 4	1 or 2	20	31.7	**0.616**	0.162

Table C.4: CMFs for frontal impact crashes (Type 1)

Legs	Speed Limit (mph)	Signalization without addition of left turn lanes					Signalization with addition of at least one left turn lane					Effect due to Left Turn Lanes	
		Sites	Actual After	EB Expected After	CMF_s	S.E. of CMF	Sites	Actual After	EB Expected After	CMF_{st}	S.E. of CMF	CMF_t	S.E. of CMF
3 legs	35-45	9	23	40.9	**0.554**	0.132	10	29	95.6	**0.301**	0.062	**0.515**	0.154
4 legs	35-45	17	87	254.2	**0.341**	0.041	16	82	265.3	**0.308**	0.038	0.888	0.145
3 & 4 legs	35-45	26	110	295.1	**0.372**	0.040	26	111	361.0	**0.307**	0.033	0.814	0.127
3 legs	50-55	8	13	36.6	**0.349**	0.106	9	47	59.6	0.777	0.145	2.042	0.662
4 legs	50-55	16	111	224.0	**0.494**	0.056	32	172	430.6	**0.399**	0.035	0.798	0.107
3 & 4 legs	50-55	24	124	260.7	**0.474**	0.050	41	219	490.2	**0.446**	0.035	0.929	0.124
3 legs	35-55	17	36	77.6	**0.460**	0.087	19	76	155.3	**0.487**	0.066	1.020	0.230
4 legs	35-55	33	198	478.3	**0.413**	0.034	48	254	695.9	**0.365**	0.026	0.879	0.101
3 & 4 legs	35-55	50	234	555.8	**0.420**	0.032	67	330	851.2	**0.387**	0.025	0.916	0.101

Legs	Speed Limit (mph)	Sites	# of left turn lanes added	# of right turn lanes added	Actual After	EB Expected After	CMF	S.E. of CMF
3 legs	35-55	6	1	0	22	41.8	**0.519**	0.126
3 legs	35-55	2	1	1 or 2	20	13.3	1.420	0.443
3 legs	35-55	11	2	1 or 2	34	100.2	**0.336**	0.065
4 legs	35-55	24	1 or 2	0	131	342.8	**0.381**	0.038
4 legs	35-55	6	1 or 2	1 or 2	25	52.5	**0.468**	0.109
4 legs	35-55	11	3 or 4	0	79	191.0	**0.412**	0.054
4 legs	35-55	7	3 or 4	1 or 2	19	109.5	**0.172**	0.042

Table C.5: CMFs for Frontal Impact Crashes (Type 2)

		Signalization without addition of left turn lanes					Signalization with addition of at least one left turn lane					Effect due to Left Turn Lanes	
Legs	Speed Limit (mph)	Sites	Actual After	EB Expected After	CMF_s	S.E. of CMF	Sites	Actual After	EB Expected After	CMF_{st}	S.E. of CMF	CMF_t	S.E. of CMF
3 legs	35-45	9	24	42.5	**0.557**	0.130	10	33	100.1	**0.327**	0.063	**0.557**	0.160
4 legs	35-45	17	92	265.8	**0.345**	0.041	16	105	283.3	**0.369**	0.042	1.052	0.184
3 & 4 legs	35-45	26	116	308.3	**0.375**	0.040	26	138	383.5	**0.359**	0.035	0.944	0.138
3 legs	50-55	8	18	42.2	**0.420**	0.110	9	58	64.6	0.887	0.152	1.977	0.577
4 legs	50-55	16	118	239.7	**0.491**	0.054	32	205	446.5	**0.458**	0.038	0.921	0.119
3 & 4 legs	50-55	24	136	281.9	**0.481**	0.049	41	263	511.1	**0.514**	0.038	1.059	0.117
3 legs	35-55	17	42	84.7	**0.492**	0.086	19	91	164.7	**0.550**	0.069	1.086	0.225
4 legs	35-55	33	210	505.5	**0.415**	0.033	48	310	729.9	**0.424**	0.028	1.016	0.108
3 & 4 legs	35-55	50	252	590.2	**0.426**	0.031	67	401	894.6	**0.448**	0.026	1.046	0.107

Legs	Speed Limit (mph)	Sites	# of left turn lanes added	# of right turn lanes added	Actual After	EB Expected After	CMF	S.E. of CMF
3 legs	35-55	6	1	0	28	43.5	**0.635**	0.141
3 legs	35-55	2	1	1 or 2	23	13.6	1.598	0.480
3 legs	35-55	11	2	1 or 2	40	107.6	**0.369**	0.067
4 legs	35-55	24	1 or 2	0	159	360.5	**0.440**	0.041
4 legs	35-55	6	1 or 2	1 or 2	32	55.9	**0.564**	0.120
4 legs	35-55	11	3 or 4	0	95	200.0	**0.473**	0.058
4 legs	35-55	7	3 or 4	1 or 2	24	113.5	**0.210**	0.046

Table C.6: CMFs based on number of legs and left turn phasing (no left turn lanes added during signalization)

Crash Type	Legs	Sites	Left turn Phasing on Major Road	Actual After	EB Expected After	CMF	S.E. of CMF
Total	3-Leg	15	Permissive	136	184.8	**0.732**	0.080
	3-Leg	2	Protected - Permissive	18	29.5	**0.595**	0.167
	4-Leg	31	Permissive	402	659.3	**0.609**	0.038
	4-Leg	2	Protected - Permissive	19	25.8	0.716	0.197
Injury & Fatal	3-Leg	15	Permissive	57	69.1	0.817	0.132
	3-Leg	2	Protected - Permissive	6	8.7	0.650	0.294
	4-Leg	31	Permissive	187	305.0	**0.612**	0.054
	4-Leg	2	Protected - Permissive	5	13.9	**0.346**	0.163
Rear-end	3-Leg	15	Permissive	79	61.0	1.278	0.204
	3-Leg	2	Protected - Permissive	4	7.5	0.493	0.263
	4-Leg	31	Permissive	139	88.5	**1.560**	0.186
	4-Leg	2	Protected - Permissive	10	4.9	1.869	0.762
Frontal Impact (type 1)	3-Leg	15	Permissive	29	68.5	**0.420**	0.087
	3-Leg	2	Protected - Permissive	7	9.1	0.729	0.308
	4-Leg	31	Permissive	191	459.1	**0.415**	0.035
	4-Leg	2	Protected - Permissive	7	19.1	**0.353**	0.144
Frontal Impact (type 2)	3-Leg	15	Permissive	35	75.0	**0.463**	0.088
	3-Leg	2	Protected - Permissive	7	9.7	0.688	0.289
	4-Leg	31	Permissive	202	485.9	**0.415**	0.034
	4-Leg	2	Protected - Permissive	8	19.6	**0.395**	0.153

Table C.7: CMFs based on number of legs, number of legs where turn lanes were added, and left turn phasing (total crashes)

Legs	Sites	# of left turn lanes added	# of right turn lanes added	Left turn Phasing on Major Road	Actual After	EB Expected After	CMF	S.E. of CMF
3-Leg	3	1	0	Permissive	35	61.3	**0.561**	0.117
3-Leg	3	1	0	Protected - Permissive	36	64.4	**0.551**	0.112
3-Leg	2	1	1 or 2	Protected - Permissive	41	38.3	1.043	0.227
3-Leg	3	2	1 or 2	Permissive	18	40.7	**0.434**	0.117
3-Leg	8	2	1 or 2	Protected - Permissive	104	226.5	**0.457**	0.055
4-Leg	17	1 or 2	0	Permissive	225	348.0	**0.645**	0.054
4-Leg	7	1 or 2	0	Protected - Permissive	128	187.7	**0.679**	0.076
4-Leg	3	2	1 or 2	Permissive	25	46.2	**0.533**	0.124
4-Leg	3	2	1 or 2	Protected - Permissive	35	43.1	0.795	0.176
4-Leg	9	3 or 4	0	Permissive	97	213.2	**0.453**	0.055
4-Leg	2	3 or 4	0	Protected - Permissive	42	67.1	**0.617**	0.120
4-Leg	1	4	1	Permissive	5	20.7	**0.237**	0.109
4-Leg	5	3 or 4	1 or 2	Protected - Permissive	38	104.9	**0.359**	0.067
4-Leg	1	4	2	Protected	11	34.0	**0.315**	0.105

Table C.8: CMFs based on number of legs, number of legs where turn lanes were added, and left turn phasing (injury and fatal crashes)

Legs	Sites	# of left turn lanes added	# of right turn lanes added	Left turn Phasing on Major Road	Actual After	EB Expected After	CMF	S.E. of CMF
3-Leg	3	1	0	Permissive	10	25.6	**0.379**	0.133
3-Leg	3	1	0	Protected - Permissive	10	25.9	**0.376**	0.131
3-Leg	2	1	1 or 2	Protected - Permissive	15	11.4	1.232	0.420
3-Leg	3	2	1 or 2	Permissive	7	11.9	0.562	0.235
3-Leg	8	2	1 or 2	Protected - Permissive	33	85.7	**0.382**	0.075
4-Leg	17	1 or 2	0	Permissive	98	170.9	**0.571**	0.068
4-Leg	7	1 or 2	0	Protected - Permissive	47	86.3	**0.540**	0.092
4-Leg	3	2	1 or 2	Permissive	13	21.1	**0.598**	0.189
4-Leg	3	2	1 or 2	Protected - Permissive	12	20.1	**0.576**	0.193
4-Leg	9	3 or 4	0	Permissive	35	100.6	**0.346**	0.065
4-Leg	2	3 or 4	0	Protected - Permissive	17	29.8	**0.555**	0.159
4-Leg	1	4	1	Permissive	3	9.3	**0.311**	0.182
4-Leg	5	3 or 4	1 or 2	Protected - Permissive	14	44.0	**0.313**	0.092
4-Leg	1	4	2	Protected	3	17.7	**0.163**	0.096

Table C.9: CMFs based on number of legs, number of legs where turn lanes were added, and left turn phasing (rear-end crashes)

Legs	Sites	# of left turn lanes added	# of right turn lanes added	Phasing on Major Road	Actual After	EB Expected After	CMF	S.E. of CMF
3-Leg	3	1	0	Permissive	15	35.6	**0.408**	0.125
3-Leg	3	1	0	Protected - Permissive	12	17.5	0.649	0.230
3-Leg	2	1	1 or 2	Protected - Permissive	16	21.6	0.711	0.222
3-Leg	3	2	1 or 2	Permissive	7	19.8	**0.340**	0.140
3-Leg	8	2	1 or 2	Protected - Permissive	55	112.4	**0.484**	0.082
4-Leg	17	1 or 2	0	Permissive	87	75.6	1.140	0.163
4-Leg	7	1 or 2	0	Protected - Permissive	60	56.1	1.051	0.190
4-Leg	3	2	1 or 2	Permissive	4	9.8	**0.390**	0.203
4-Leg	3	2	1 or 2	Protected - Permissive	12	16.1	0.708	0.247
4-Leg	9	3 or 4	0	Permissive	15	25.2	**0.581**	0.171
4-Leg	2	3 or 4	0	Protected - Permissive	10	17.7	**0.535**	0.201
4-Leg	1	4	1	Permissive	1	0.6	1.483	1.365
4-Leg	5	3 or 4	1 or 2	Protected - Permissive	15	27.6	**0.529**	0.157
4-Leg	1	4	2	Protected	4	3.6	0.952	0.530

Table C.10: CMFs based on number of legs, number of legs where turn lanes were added, and left turn phasing (frontal impact crashes – type 1)

Legs	Sites	# of left turn lanes added	# of right turn lanes added	Phasing on Major Road	Actual After	EB Expected After	CMF	S.E. of CMF
3-Leg	3	1	0	Permissive	11	12.9	0.809	0.290
3-Leg	3	1	0	Protected - Permissive	11	28.8	**0.373**	0.123
3-Leg	2	1	1 or 2	Protected - Permissive	20	13.3	1.420	0.443
3-Leg	3	2	1 or 2	Permissive	4	11.3	**0.337**	0.176
3-Leg	8	2	1 or 2	Protected - Permissive	30	88.9	**0.334**	0.069
4-Leg	17	1 or 2	0	Permissive	91	222.2	**0.408**	0.049
4-Leg	7	1 or 2	0	Protected - Permissive	40	120.6	**0.329**	0.059
4-Leg	3	2	1 or 2	Permissive	12	28.8	**0.407**	0.130
4-Leg	3	2	1 or 2	Protected - Permissive	13	23.8	**0.524**	0.174
4-Leg	9	3 or 4	0	Permissive	52	146.4	**0.353**	0.056
4-Leg	2	3 or 4	0	Protected - Permissive	27	44.7	**0.591**	0.141
4-Leg	1	4	1	Permissive	2	19.6	**0.100**	0.071
4-Leg	5	3 or 4	1 or 2	Protected - Permissive	13	63.5	**0.202**	0.060
4-Leg	1	4	2	Protected	4	26.4	**0.147**	0.075

Table C.11: CMFs based on number of legs, number of legs where turn lanes were added, and left turn phasing (frontal impact crashes – type 2)

Legs	Sites	# of left turn lanes added	# of right turn lanes added	Phasing on Major Road	Actual After	EB Expected After	CMF	S.E. of CMF
3-Leg	3	1	0	Permissive	15	13.8	1.041	0.335
3-Leg	3	1	0	Protected - Permissive	13	29.7	**0.429**	0.132
3-Leg	2	1	1 or 2	Protected - Permissive	23	13.6	1.598	0.480
3-Leg	3	2	1 or 2	Permissive	5	13.3	**0.360**	0.171
3-Leg	8	2	1 or 2	Protected - Permissive	35	94.3	**0.367**	0.071
4-Leg	17	1 or 2	0	Permissive	109	233.5	**0.465**	0.053
4-Leg	7	1 or 2	0	Protected - Permissive	50	127.0	**0.391**	0.064
4-Leg	3	2	1 or 2	Permissive	14	29.9	**0.457**	0.138
4-Leg	3	2	1 or 2	Protected - Permissive	18	26.0	0.667	0.198
4-Leg	9	3 or 4	0	Permissive	65	155.1	**0.416**	0.060
4-Leg	2	3 or 4	0	Protected - Permissive	30	44.8	**0.655**	0.151
4-Leg	1	4	1	Permissive	3	19.6	**0.149**	0.087
4-Leg	5	3 or 4	1 or 2	Protected - Permissive	16	67.0	**0.235**	0.064
4-Leg	1	4	2	Protected	5	26.8	**0.181**	0.084