Safety Effectiveness of Flashing Yellow Arrow: Evaluation of 222 Signalized Intersections in North Carolina

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ABSTRACT

The purpose of this project is to develop crash modification factors (CMFs) for the implementation of Flashing Yellow Arrow (FYA) based on the specific before and after period conditions of a signalized intersection. Although this countermeasure has been used for years in North Carolina and other States, none of the published studies to-date have provided CMFs for left turn crashes specific to the treated approaches, and none have provided CMFs for the three-section FYA for permissive only left turns.

Crash data from 222 intersections in North Carolina with FYA-protected/permissive left turn (FYA-PPLT) and/or three-section FYA-permissive only left turn installations were used to provide CMFs for five Category types: Category 1 (Permissive Only to FYA-PPLT), Category 2 (Protected Only to FYA-PPLT), Category 2A (Protected Only to FYA-PPLT with Time of Day Operation), Category 3 (5-Section PPLT to FYA-PPLT), and Category 4 (Permissive Only to FYA-Permissive Only). A before and after crash analysis with consideration for traffic increase was used to determine the safety estimates. Safety performance functions were used to account for the effect of traffic volume trends.

Readers may be most interested in Category 3 and 4, where the change is exclusive to the left turn display and not a change in phasing. All CMF results are statistically significant for Category 3, and target and injury CMF results are statistically significant for Category 4. Based on the results from our study sites, we find a statistically significant decrease in target left turn crashes and injury crashes when going from a solid green ball to a FYA for permissive left turns when phasing remains unchanged. This applies regardless of whether the left phasing is protected/permissive or fully permissive.

INTRODUCTION

Flashing Yellow Arrow (FYA) is one of many options used to indicate a permissive left turn movement. In 2003, National Cooperative Highway Research Program (NCHRP) Report 493 assessed the safety and operational characteristics of a variety of different displays to identify the "best" traffic signal display for protected/permissive left turn (PPLT) control (*1*). Photographic driver studies showed flashing indications were understood better than steady indications, and circular green indication had the lowest level of driver comprehension (nearly 50%) of all PPLT displays studied. The researchers performed field testing of the FYA at 15 intersections across the U.S. The results of before and after field conflict data showed no differences attributable to the change from the circular green indication to the FYA display. Based on all data collected, the researchers concluded the FYA has the most versatile characteristics and offers the highest level of safety. The report recommended FYA should be included in the Manual on Uniform Traffic Control Devices (MUTCD) as an allowable alternative display to the circular green indication when used in PPLT operation. Following the publication of the report, the Federal Highway Administration (FHWA) approved additional experimental FYA sites in numerous jurisdictions.

In the 2009 MUTCD, FYA was formally approved as the recommended configuration for protected/permissive and permissive left turn displays. Per Section 4D.13, circular green indications for permissive left turns should not be located over or in front of an exclusive left turn lane for new or reconstructed signal installations (*2*).

The FYA type more prevalently used in North Carolina is FYA for protected/permissive left turn mode (FYA-PPLT). It has four sections: a steady red arrow, a steady yellow arrow, a flashing yellow arrow, and a steady green arrow. The other type used in North Carolina is FYA for permissive only left turns (FYA-Permissive Only) which is used on approaches with no exclusive left turn phase. It has three sections: a steady red arrow, a steady yellow arrow, and a flashing yellow arrow. Figure 1 provides photographs of both display types at the intersection of Timber Drive and Grovemont Road in Garner, North Carolina. FYA has also been used in a limited number of right turn applications in North Carolina.

LITERATURE REVIEW

Studies have analyzed the operational impacts and other effects of FYA-PPLT but few studies have provided before and after crash analysis on more than a handful of sites. None of the published studies provide a target crash modification factor (CMF) for left turn crashes specific to the treated approaches, and none have provided CMFs for the three-section FYA-Permissive Only. The following summary of published literature to-date is specific to crash analysis studies on FYA.

NCHRP Web-Only Document 123 published in 2007 documents the follow-up safety study undertaken as recommended in NCHRP Report 493 (*3*). Crash data was obtained from over 50 intersections where FYA-PPLT was implemented in the U.S. The data was categorized based on conditions at the intersection before the FYA installation: PPLT, protected-only left turn, and permissive-only left turn. While the study provided new insight into the effectiveness of FYA, the authors note a couple shortcomings: limited after period data was available at the time and the evaluation of known changes other than the FYA implementation was not included. CMF results were not provided; however, the report provided the following general conclusions:

- Safety was improved at intersections that operated with PPLT phasing prior to and after the field implementation of the FYA.
- Safety was not improved at intersections that operated with protected only left-turn phasing prior to field implementation of the FYA-PPLT.
- No conclusions were made at intersections that operated with permissive only left turn phasing prior to implementation of the FYA-PPLT, due to a minimal number of implementation sites.

A 2011 study by Pulugurtha et.al evaluated the installations of FYA-PPLT at six signalized intersections in Charlotte, NC (*4*). Before period conditions on the approaches treated with FYA was not provided. The results showed improvements in safety at five of the six study sites. The study showed the number of total crashes at the treated sites would have generally increased had the FYA not been installed. The authors state that results considering larger sample sizes and considering only left-turn crashes need to be considered in future evaluations.

A 2012 study by Yi et.al studied crash data at intersections where FYA-PPLT was installed (*5*). The study included 12 intersections from Texas which all operated with PPLT phasing in the before period and 39 intersections from two cities in Washington State where the before left-turn control types included protected-only, permissive-only, and PPLT. The results indicated that the overall average left-turn crash rate decreased by 2 percent for the study sites in all three cities involved in the study. The study solely compared intersection crash rates, and CMFs were not provided.

The most comprehensive before and after safety study on FYA-PPLT to date was published in 2012 (*6*). "Crash Modification Factors for Changes to Left-Turn Phasing" provides CMFs for the implementation of FYA-PPLT based on data from 51 urban signalized intersections in Oregon, Washington State, and North Carolina. The empirical Bayes method was applied to the North Carolina sites but could not be applied to sites in the other States, although the statistical methodology combined some aspects of the empirical Bayes and the comparison group approaches. Crash data by treated approaches were not provided in North Carolina, so the analysis of these sites focused on intersection-level crashes. The results for all three States were combined at the intersection-level and reported for total crashes and total left-turn crashes. The CMF results are provided based on the before condition at the treated sites:

- Intersections at which the converted legs had protected-only phasing in the before period (29 Sites, 56 Legs Treated) – Total CMF: 1.338, Left Turn CMF: 2.242
- Intersections at which the converted legs had either permissive or protected–permissive phasing in the before period, and at least one of the converted legs had permissive phasing (9 Sites, 20 Legs Treated) – Total CMF: 0.753, Left Turn CMF: 0.635
- Intersections at which all of the converted legs had protected–permissive phasing in the before period (13 Sites, 27 Legs Treated) – Total CMF: 0.922, Left Turn CMF: 0.806

The results indicate a safety benefit at locations with some kind of permissive left-turn operation before and a disbenefit at locations with protected-only operation before. An overall CMF is not provided specifically for approaches with permissive only left-turn operation in the before period. The study offers CMF results for FYA-PPLT under three conditions but there are additional CMF values we want to determine for the FYA treatment, especially considering the wealth of additional data now available.

PROJECT SCOPE

The purpose of this project is to develop CMFs for the implementation of FYA-PPLT, FYA-PPLT with time of day (TOD) operation, and FYA-Permissive Only. Based on prior studies we recognize the immense impact of the before period left turn phasing conditions on the treatment effectiveness and have categorized the data to reflect this. We are most interested in Category 3 and 4, where the change is exclusive to the left turn display and not a change in phasing.

Category 1 – Permissive Only to FYA-PPLT
Category 2 – Protected Only to FYA-PPLT
Category 2A – Protected Only to FYA-PPLT with TOD Operation
Category 3 – 5-Section "Doghouse" PPLT to FYA-PPLT
Category 4 – Permissive Only to FYA-Permissive Only

The measures of effectiveness include:

1. Total crashes
2. Target crashes, specifically defined as left-turn same roadway crashes with the left-turner on an approach treated with FYA and occurring during the time of day when FYA is in operation
3. Injury crashes

METHODOLOGY

A before and after crash analysis with consideration for traffic increase was used to calculate the CMFs. Highway Safety Manual (HSM) safety performance functions (SPFs) for urban and suburban intersections were used to determine the effect of traffic volume trends on predicted crash frequency (*7*). SPFs provide an exponential form for relating volumes with expected crashes. The SPFs were used to create adjustment factors that incorporate the separate effects for Annual Average Daily Traffic (AADT) on the major and minor road legs in the before and after periods at each site. The before crash frequencies were multiplied by the ratio of after SPF predictions to before SPF predictions to obtain the expected number of after crashes.

The analysis does not account for selection bias or non-volume time trends, and does not address the threat of regression to the mean. Regression to the mean is the presumption that a site will return to its long-term mean crash frequency after an extraordinarily high or low period. Empirical Bayes before-and-after analysis, one of the techniques used to account for these potential deficiencies, was considered but not used for our study based on the following:

- Most sites were selected for treatment based on operational concerns or other non-safety issues. The average number of target crashes per year per intersection in the before period is small, only 1.08 crashes, which based on experience with urban signals in North Carolina suggests crash history was not a factor in treatment selection at many sites. Also, approximately 20 percent of signalized intersections in North Carolina currently use FYA or are planned for FYA in the near future. Therefore, we feel the bias due to regression to the mean was not evident in the selection of the treated locations.
- The Empirical Bayes approach requires the use of a reference group of sites similar to the treated ones but not receiving the treatment to account for changes in crashes unrelated to the treatment. Due to the large size of the treatment group, we decided the compilation

and analysis of an adequate reference group of similar intersections located within the vicinity of the treatment sites (but not affected by the treatment or undergoing changes in the study periods) was not feasible for our study. Also, it would be a feat to obtain target crashes from any potential reference group because it entails the manual review of crash reports to identify the "true" left turn targets (our efforts to assemble target crashes are explained later in this section).

The crash analysis was performed for each intersection using the North Carolina Traffic Records Database, which at the time of the study contained all reported crashes in the State from 1990 through November 30, 2013. The FYA installation dates varied from 2006 through 2011, so the period analyzed for each location varied according to when the treatment was installed. The before period consisted of three years of data, and the after period varied from two to three years at each site. The crash analyses were terminated before other known countermeasures were implemented. The data consisted of all crashes within 150 feet of the treated intersections. Injury crashes included fatal and nonfatal injury crashes combined. The current reporting threshold for crashes in North Carolina is $1,000.

Determination of target crashes required careful review of the crash data. We selected and reviewed every crash coded to four crash types: left turn same roadway (LTSR), left turn different roadway (LTDR), angle, and head on. Our target crash type is LTSR but it was necessary to include the additional crash types in our review because 45 percent of target crashes were comprised of crashes coded as LTDR, angle and head on when testing a subset of the sites. Had only the crashes coded as LTSR been selected to determine the target group, the results may have been very misleading. The selected crashes were reviewed to determine if they involved a left turning vehicle, if the vehicle was on an approach receiving the FYA, and if so, the category type on that approach. Also, if TOD operation was present, the day of the week and time of the crash were reviewed to determine if the crash occurred at a time when FYA was in operation.

Site Selection

As of late 2013, 1,625 FYA installations were in design, transmitted, or installed throughout North Carolina. Figure 2 shows the process we used for selecting our study sites. The number of sites in each group is listed in parenthesis. Over 600 sites were manually reviewed for inclusion in the study. All signal files dated within a site's study time periods were scanned to determine the category type and if major changes were made besides the FYA installation.

222 sites with no other documented changes and with readily accessible crash data were included in the study. A thorough review of signal plans was conducted to exclude sites where other treatments were implemented during the 'before' or 'after' period that may influence the results. We acknowledge that some changes (such as certain timing changes, system tweaks, or law enforcement programs) not documented in plans or maps may still have occurred. Keeping the before and after time periods to a maximum of three years may help minimize the number of other changes that generally happen over time.

Some of the reasons for excluding treatment sites include:

- Intersection geometry changes or roadway widening
- Offsetting left turn lanes
- Phasing changes (unrelated to the FYA)
- Speed limit changes

- Other countermeasures implemented
- No signal plans found

Sites were grouped based on whether or not a TOD plan was in operation. If alternate phasing plans were listed on a signal plan, the local traffic engineer was contacted to determine if TOD operation is utilized and to obtain the time periods of operation. Most sites with TOD operation employ FYA during off peak hours (generally 9 pm – 6 am) and operate fully protected the remainder of the day. Very few sites in the study utilize TOD operation, although this option is beginning to be used more frequently. The only category with sites using TOD operation was Category 2, and there was a sufficient sample to create Category 2A for this sub-group. The remainder of sites in the study use FYA 24-7.

Sites were further categorized based on the before and after period conditions of each approach. Intersections with only a single category type on one or more legs were separated from intersections where combinations of category types were employed across the legs. Figure 3 displays two example intersections, Site A and B, to illustrate site categorization. Site A has a single category type on one or more legs. This site is exclusive to Category 1 (Leg 1 is Category 1 FYA, Leg 2 is Category 1 FYA, and Legs 3 and 4 remain unchanged). Site A data is used on the intersection-level and the approach-level: intersection-level crashes are used to calculate a total CMF and an injury CMF for Category 1, while target left turn crashes from Legs 1 and 2 are used to calculate a target CMF and a target injury CMF for Category 1. Site B has a combination of category types across legs. This is a Category 1-3 site (Leg 1 is Category 1 FYA, Leg 2 is a Category 3 FYA, and Legs 3 and 4 remain unchanged). Site B data is used on the approach-level only: left turn crashes from Leg 1 are used to calculate a target CMF and a target injury CMF for Category 1, while left turn crashes from Leg 2 are used to calculate a target CMF and a target injury CMF for Category 3. This additional data proved helpful in backing up target CMF results in cases where limited sites were available.

RESULTS

The results are provided separately by category because each type is a separate countermeasure (some change phasing as well as left turn display) and result in varying crash outcomes.

Category 1 – Permissive Only to FYA-PPLT

Table 1 provides summary statistics for Category 1. Note that summary statistics are provided for the other categories as well to provide a fuller picture of the types of locations included in the study, as well as any variations between categories.

Table 2 presents the results of the crash analysis for Category 1. The parameter estimates are denoted as follows:

λ = actual number of after period crashes;
π = predicted number of after period crashes;
CMF = ratio of what safety was with treatment to what safety would have been without treatment, used as a multiplicative factor used to compute expected number of crashes after implementation of given countermeasure; and
CRF = crash reduction factor = estimate of percentage of reduction in crashes that might be expected after implementation of countermeasure, calculated as [(1-CMF) x 100] (*8*).

Conventional Hauer symbology and methodology were used in the countermeasure evaluation (*9*). The value after the plus-or-minus sign indicates the standard deviation of an estimated value.

Although the tables provide the results as both CMF and CRF estimates, the results here are reported as the CRF estimates for ease of consumption. For the 13 intersections (20 treated legs) exclusively receiving a Category 1 FYA, the results of the crash analysis yield a 7 percent reduction in total crashes, a 35 percent reduction in total injury crashes, and a 26 percent reduction in target crashes. For the 41 treated legs receiving a Category 1 FYA, the results yield a 40 percent reduction in target crashes.

Category 2 – Protected Only to FYA-PPLT

Table 3 provides summary statistics for Category 2. Table 4 presents the results of the crash analysis for Category 2. For the 20 intersections (43 treated legs) exclusively receiving a Category 2 FYA, the results of the crash analysis yield a 12 percent increase in total crashes, a 21 percent increase in total injury crashes, and a 244 percent increase in target crashes. For the 49 treated legs receiving a Category 2 FYA, the results yield a 268 percent increase in target crashes.

Category 2A – Protected Only to FYA-PPLT with TOD Operation

Table 5 provides summary statistics for Category 2A. Table 6 presents the results of the crash analysis for Category 2A. As mentioned earlier, when TOD operation was present, the day of the week and time of the crash were reviewed. Only left turn crashes that occurred at a time when FYA was in operation were included as target crashes. Results which are not statistical significant at the 5% level, but are statistically significant at the 10% level are shown in italic. For these results, a larger sample is required to detect the same level of effect with 95 percent certainty.

For the 13 intersections (28 treated legs) exclusively receiving a Category 2A FYA, the results of the crash analysis yield a 10 percent reduction in total crashes, a 7 percent reduction in total injury crashes, and a 173 percent increase in target crashes. For the 34 treated legs exclusively receiving a Category 2A FYA, the results yield a 173 percent increase in target crashes.

Category 3 – 5-Section PPLT to FYA-PPLT

Table 7 provides summary statistics for Category 3. Table 8 presents the results of the crash analysis for Category 3. For the 105 intersections (193 treated legs) exclusively receiving a Category 3 FYA, the results of the crash analysis yield a 7 percent reduction in total crashes, a 15 percent reduction in total injury crashes, and a 22 percent reduction in target crashes. For the 254 treated legs receiving a Category 3 FYA, the results yield a 16 percent reduction in target crashes. All results are statistically significant at the 5% level.

Category 4 – Permissive Only to FYA-Permissive Only

Table 9 provides summary statistics for Category 4. Table 10 presents the results of the crash analysis for Category 4. For the 9 intersections (14 treated legs) exclusively receiving a Category 4 FYA, the results of the crash analysis yield an 11 percent reduction in total crashes, a 31 percent reduction in total injury crashes, and a 59 percent reduction in target crashes. For the 64 treated legs receiving a Category 4 FYA, the results yield a 50 percent reduction in target crashes. All results except total crashes are statistically significant at the 5% level.

CONCLUSION

The ample number of FYA sites that have been employed in North Carolina allowed us to analyze a large amount of crash data. All CMF results are statistically significant for Category 3 (5-Section PPLT to FYA-PPLT) and target and injury CMF results are statistically significant for Category 4 (Permissive Only to FYA-Permissive Only). Finding meaningful results from these two groups was a main objective of our study. Based on the results from the Category 3 and 4 sites, we find a statistically significant decrease in target left turn crashes and injury crashes when going from a solid green ball to a FYA for permissive left turns when phasing remains unchanged. This applies regardless of whether the left phasing is protected/permissive or fully permissive. The Category 4 target crash results are larger than expected and may be related to an additional signal head being installed for the permissive left turn.

Many of the Category 1 (Permissive Only to FYA-PPLT), Category 2 (Protected Only to FYA-PPLT), and Category 2A (Protected Only to FYA-PPLT with TOD) results, which involve a change in left turn phasing as well as the FYA, are not as robust, which suggests variability in performance and a need for more samples in these groups. Target crash frequency is so small at most sites (and comprises such a small percentage of total crashes) that a very large number of treated approaches are necessary to determine more reliable target CMFs. It may be difficult to add many more sites to Category 2. Due to higher levels of scrutiny we rarely choose to change the left turn mode from fully protected to protected/permissive.

We plan to look more into the safety effects of TOD operation as more sites come online. It appears that the safety of sites changed from fully protected to FYA-PPLT only during off-peak hours (Category 2A) may not be degraded as much as sites changed from fully protected to FYA-PPLT 24-7 (Category 2). Also, there may be real benefits in using TOD operation at locations where target crashes are occurring at specific times of day. The left turn signal may be operated in fully protected mode only during the hours identified as having peak crash frequency.

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FIGURE 1 Photographs of FYA-PPLT (Left) and FYA-Permissive Only (Right) left turn displays

FIGURE 2 Site Selection and Categorization Process

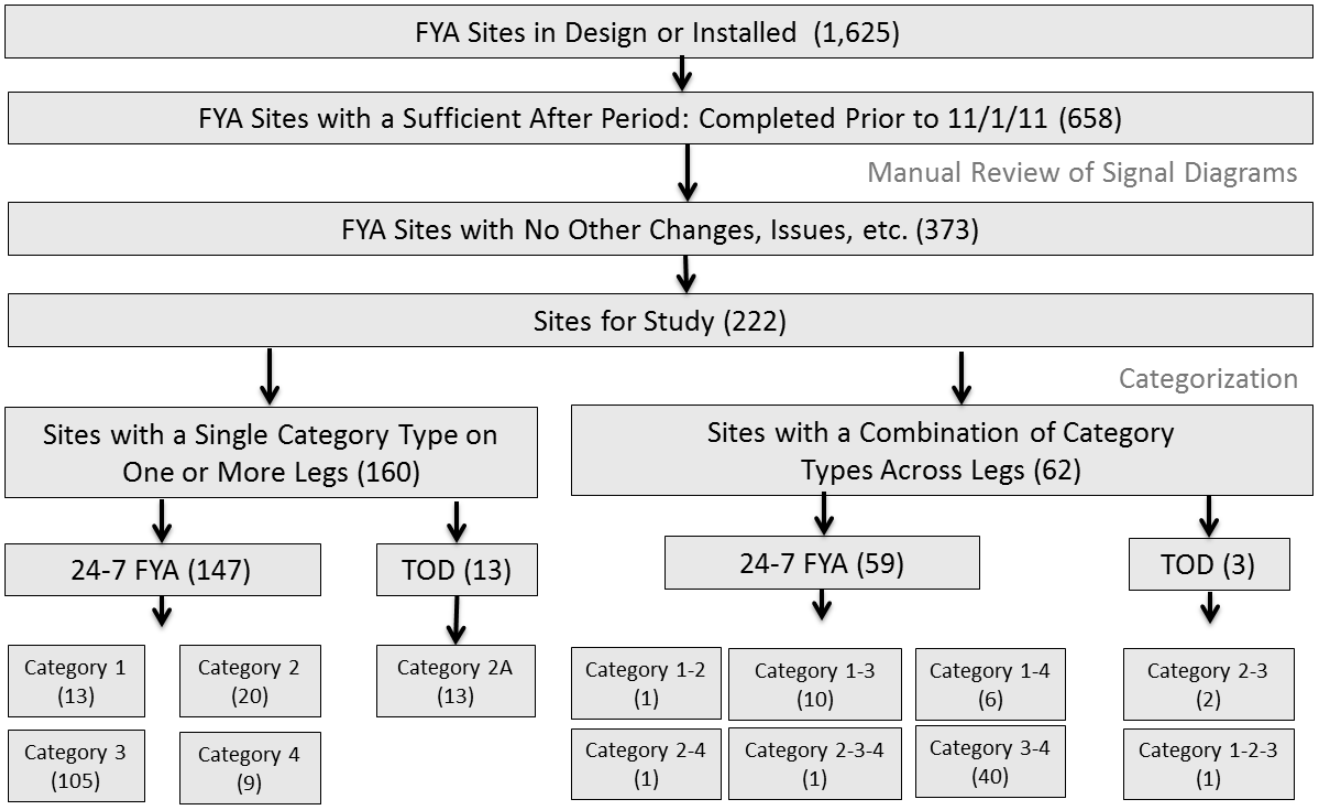

FIGURE 3 Site Categorization at the Approach Level

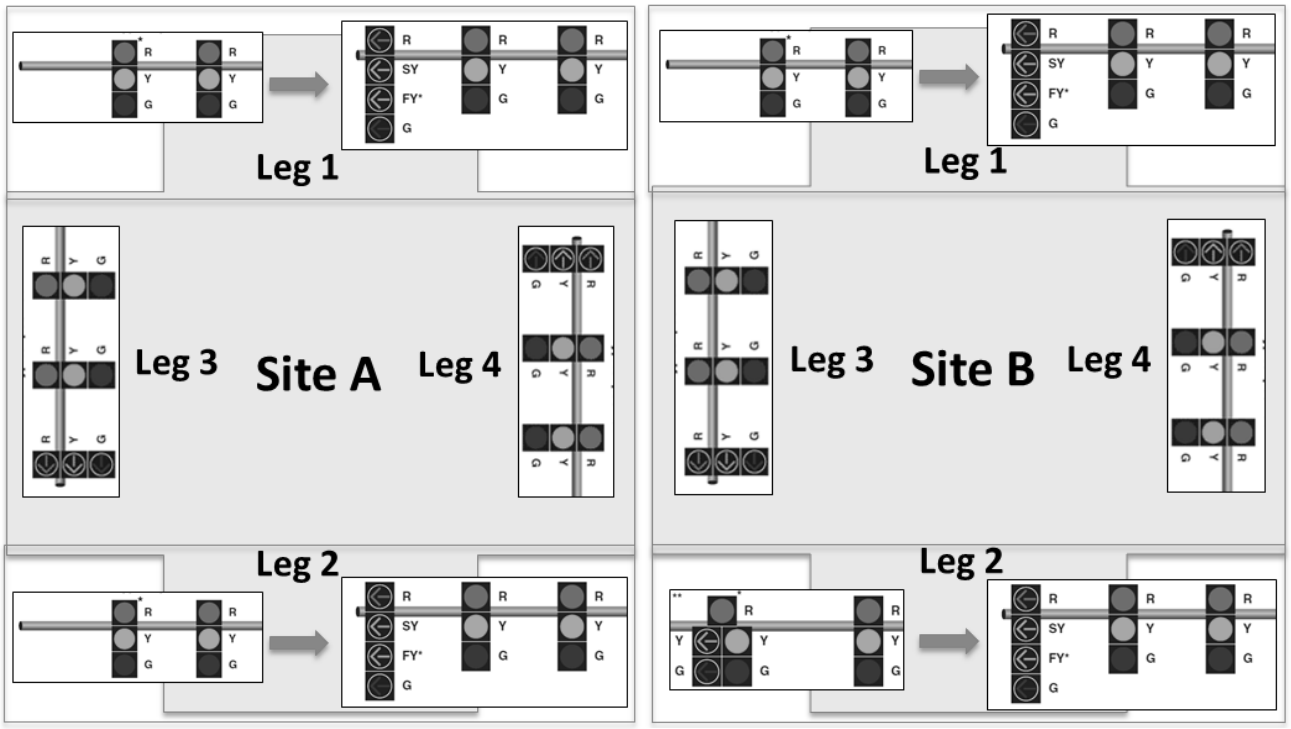

TABLE 1 Summary Statistics for Category 1 (Permissive Only to FYA-PPLT)

Variable	Minimum	Maximum	Average
13 Sites exclusive to Category 1 (20 Category 1 Legs)			
Years Before	3.0	3.0	3.0
Years After	2.1	3.0	2.8
Number of Legs	3	4	3.8
Number of Category 1 Treated Legs	1	4	1.5
Number of Category 1 Major Road Treated Legs	1	2	1.2
Number of Category 1 Minor Road Treated Legs	0	2	0.3
Major Road Speed Limit	35	45	41.2
Number of Signal Phases After	2*	8	4.5
Major Road AADT Before	7,000	24,000	12,300
Major Road AADT After	7,800	23,000	12,900
Minor Road AADT Before	1,100	9,300	4,700
Minor Road AADT After	1,100	9,000	4,800
Total Crashes/Year Before	0.7	14.0	4.8
Total Crashes/Year After	0.7	12.5	4.6
Total Injury Crashes/Year Before	0.3	6.3	1.7
Total Injury Crashes/Year After	0.0	3.4	1.1
Target Crashes/Year Before	0.0	3.3	0.8
Target Crashes/Year After	0.0	1.7	0.6
Target Injury Crashes/Year Before	0.0	2.3	0.5
Target Injury Crashes/Year After	0.0	1.1	0.3
17 Sites with multiple category types including at least one Category 1 leg (21 Category 1 Legs)			
Years Before	3.0	3.0	3.0
Years After	2.3	3.0	2.8
Number of Legs	4	4	4.0
Number of Category 1 Treated Legs	1	2	1.2
Number of Category 1 Major Road Treated Legs	0	1	0.7
Number of Category 1 Minor Road Treated Legs	0	2	0.5
Major Road Speed Limit	35	55	44.1
Number of Signal Phases After	3	8	5.4
Major Road AADT Before	7,700	49,000	19,800
Major Road AADT After	7,600	47,000	20,000
Minor Road AADT Before	600	17,000	6,400
Minor Road AADT After	600	13,500	6,900
Target Crashes/Year Before	0.0	9.7	1.0
Target Crashes/Year After	0.0	2.3	0.6
Target Injury Crashes/Year Before	0.0	5.7	0.5
Target Injury Crashes/Year After	0.0	1.4	0.3

*Two phase signal is a 3 leg intersection with right turns only allowed from the stem.

TABLE 2 Evaluation Results for Category 1 (Permissive Only to FYA-PPLT)

Source	Crash Type	π	λ	CMF	CRF
13 Sites (20 Category 1 Legs)					
	Total	171.3 ± 12.7	161 ± 12.7	0.935 ± 0.100	6.5% ± 10.0%
	Total Injury	61.7 ± 7.6	41 ± 6.4	**0.654** ± 0.128	34.6% ± 12.8%
	Target	30.2 ± 5.3	23 ± 4.8	0.738 ± 0.195	26.2% ± 19.5%
	Target Injury	16.7 ± 3.9	12 ± 3.5	0.683 ± 0.240	31.7% ± 24.0%
30 Sites (41 Category 1 Legs)					
	Target	84.2 ± 9.2	51 ± 7.1	**0.598** ± 0.105	40.2% ± 10.5%
	Target Injury	41.2 ± 6.3	25 ± 5.0	**0.592** ± 0.146	40.8% ± 14.6%

Note: CMFs in bold are statistically different from 1.0 at the 5% level.

TABLE 3 Summary Statistics for Category 2 (Protected Only to FYA-PPLT)

Variable	Minimum	Maximum	Average
20 Sites exclusive to Category 2 (43 Category 2 Legs)			
Years Before	3.0	3.0	3.0
Years After	3.0	2.3	2.9
Number of Legs	3	4	3.9
Number of Category 2 Treated Legs	1	4	2.2
Number of Category 2 Major Road Treated Legs	1	2	1.8
Number of Category 2 Minor Road Treated Legs	0	2	0.4
Major Road Speed Limit	35	55	43.5
Number of Signal Phases After	3	8	5.5
Major Road AADT Before	12,000	40,500	24,300
Major Road AADT After	12,000	38,000	24,800
Minor Road AADT Before	1,100	16,500	5,700
Minor Road AADT After	900	17,000	5,800
Total Crashes/Year Before	2.3	18.7	6.8
Total Crashes/Year After	0.7	18.0	7.5
Total Injury Crashes/Year Before	0.3	6.3	2.4
Total Injury Crashes/Year After	0.0	7.1	2.9
Target Crashes/Year Before	0.0	6.3	0.45
Target Crashes/Year After	0.0	5.7	1.6
Target Injury Crashes/Year Before	0.0	3.0	0.2
Target Injury Crashes/Year After	0.0	3.0	0.9
3 Sites with multiple category types including at least one Category 2 leg (6 Category 2 Legs)			
Years Before	3.0	3.0	3.0
Years After	2.4	3.0	2.8
Number of Legs	4	4	4.0
Number of Category 2 Treated Legs	2	2	2.0
Number of Category 2 Major Road Treated Legs	2	2	2.0
Number of Category 2 Minor Road Treated Legs	0	0	0.0
Major Road Speed Limit	45	50	46.7
Number of Signal Phases After	5	8	6.3
Major Road AADT Before	9,100	49,000	25,000
Major Road AADT After	10,000	47,000	25,300
Minor Road AADT Before	3,300	5,400	4,300
Minor Road AADT After	3,100	4,900	4,200
Target Crashes/Year Before	0.0	0.3	0.2
Target Crashes/Year After	0.4	3.7	1.6
Target Injury Crashes/Year Before	0.0	0.0	0.0
Target Injury Crashes/Year After	0.3	1.3	0.7

TABLE 4 Evaluation Results for Category 2 (Protected Only to FYA-PPLT)

Source	Crash Type	π	λ	CMF	CRF
20 Sites (43 Category 2 Legs)					
	Total	390.4 ± 19.5	440 ± 21.0	1.124 ± 0.077	-12.4% ± 7.7%
	Total Injury	139.9 ± 11.7	170 ± 13.0	1.206 ± 0.136	-20.6% ± 13.6%
	Target	26.1 ± 5.0	93 ± 9.6	**3.440** ± 0.727	-244.0% ± 72.7%
	Target Injury	11.8 ± 3.4	55 ± 7.4	**4.308** ± 1.270	-330.8% ± 127.0%
23 Sites (49 Category 2 Legs)					
	Target	28.1 ± 5.2	107 ± 10.3	**3.684** ± 0.748	-268.4% ± 74.8%
	Target Injury	11.8 ± 3.4	61 ± 7.8	**4.778** ± 1.397	-377.8% ± 139.7%

Note: CMFs in bold are statistically different from 1.0 at the 5% level.

TABLE 5 Summary Statistics for Category 2A (Protected Only to FYA-PPLT with TOD Operation)

Variable	Minimum	Maximum	Average
13 Sites exclusive to Category 2A (28 Category 2A Legs)			
Years Before	3.0	3.0	3.0
Years After	2.0	3.0	2.7
Number of Legs	4	4	4.0
Number of Category 2A Treated Legs	1	4	2.2
Number of Category 2A Major Road Treated Legs	0	2	1.5
Number of Category 2A Minor Road Treated Legs	0	2	0.6
Major Road Speed Limit	35	45	43.5
Number of Signal Phases After	4	8	7.2
Major Road AADT Before	19,000	41,000	30,400
Major Road AADT After	19,000	40,000	29,200
Minor Road AADT Before	3,000	32,000	20,400
Minor Road AADT After	3,000	27,000	18,600
Total Crashes/Year Before	1.7	60.7	20.0
Total Crashes/Year After	1	43.3	17.8
Total Injury Crashes/Year Before	1.3	17.0	6.4
Total Injury Crashes/Year After	0.0	13.7	5.9
Target Crashes/Year Before	0.0	1.0	0.2
Target Crashes/Year After	0.0	2.8	0.6
Target Injury Crashes/Year Before	0.0	1.0	0.1
Target Injury Crashes/Year After	0.0	2.3	0.4
3 Sites with multiple category types including at least one Category 2A leg (6 Category 2A Legs)			
Years Before	3.0	3.0	3.0
Years After	2.1	2.4	2.3
Number of Legs	4	4	4.0
Number of Category 2A Treated Legs	2	2	2.0
Number of Category 2A Major Road Treated Legs	0	2	1.3
Number of Category 2A Minor Road Treated Legs	0	2	0.7
Major Road Speed Limit	35	45	38.3
Number of Signal Phases After	6	8	6.7
Major Road AADT Before	18,500	24,000	22,000
Major Road AADT After	18,000	25,000	22,700
Minor Road AADT Before	6,000	21,000	14,000
Minor Road AADT After	5,600	20,000	13,200
Target Crashes/Year Before	0.0	0.0	0.0
Target Crashes/Year After	0.0	0	0
Target Injury Crashes/Year Before	0.0	0.0	0.0
Target Injury Crashes/Year After	0.0	0.0	0.0

TABLE 6 Evaluation Results for Category 2A (Protected Only to FYA-PPLT with TOD Operation)

Source	Crash Type	π	λ	CMF	CRF
13 Sites (28 Category 2A Legs)					
	Total	692.0 ± 25.0	624 ± 25.0	**0.901** ± 0.048	9.9% ± 4.8%
	Total Injury	218.4 ± 14.0	203 ± 14.2	0.926 ± 0.088	7.4% ± 8.8%
	Target	6.4 ± 2.4	20 ± 4.5	*2.732* ± 1.053	-173.2% ± 105.3%
	Target Injury	4.6 ± 2.1	13 ± 3.6	2.371 ± 1.043	-137.1% ± 104.3%
16 Sites (34 Category 2A Legs)					
	Target	6.4 ± 2.4	20 ± 4.5	*2.732* ± 1.053	-173.2% ± 105.3%
	Target Injury	4.6 ± 2.1	13 ± 3.6	2.371 ± 1.043	-137.1% ± 104.3%

Note: CMFs in bold are statistically different from 1.0 at the 5% level. CMFs in italic are statistically different from 1.0 at the 10% level

TABLE 7 Summary Statistics for Category 3 (5-Section PPLT to FYA-PPLT)

Variable	Minimum	Maximum	Average
105 Sites exclusive to Category 3 (193 Treated Legs)			
Years Before	3.0	3.0	3.0
Years After	2.1	3.0	2.9
Number of Legs	3	4	3.7
Number of Category 3 Treated Legs	1	4	1.8
Number of Category 3 Major Road Treated Legs	0	2	1.6
Number of Category 3 Minor Road Treated Legs	0	2	0.2
Major Road Speed Limit	20	55	43.3
Number of Signal Phases After	3	8	4.9
Major Road AADT Before	5,500	52,000	19,800
Major Road AADT After	5,300	51,000	19,500
Minor Road AADT Before	400	26,500	6,000
Minor Road AADT After	300	24,000	5,900
Total Crashes/Year Before	0.0	24.3	6.6
Total Crashes/Year After	0.3	24.7	6.0
Total Injury Crashes/Year Before	0.0	9.3	2.3
Total Injury Crashes/Year After	0.0	10.3	1.9
Target Crashes/Year Before	0.0	7.7	1.4
Target Crashes/Year After	0.0	8.3	1.1
Target Injury Crashes/Year Before	0.0	4.3	0.7
Target Injury Crashes/Year After	0.0	4.0	0.5
51 Sites with multiple category types including at least one Category 3 leg (61 Treated Legs)			
Years Before	3.0	3.0	3.0
Years After	2.2	3.0	2.9
Number of Legs	4	4	4.0
Number of Category 3 Treated Legs	1	3	1.2
Number of Category 3 Major Road Treated Legs	0	2	1.0
Number of Category 3 Minor Road Treated Legs	0	1	0.2
Major Road Speed Limit	20	55	42.1
Number of Signal Phases After	3	8	4.2
Major Road AADT Before	4,100	38,000	17,400
Major Road AADT After	3,500	39,000	17,700
Minor Road AADT Before	500	17,000	5,400
Minor Road AADT After	500	14,500	5,300
Target Crashes/Year Before	0.0	5.7	0.8
Target Crashes/Year After	0.0	5.3	0.8
Target Injury Crashes/Year Before	0.0	3.0	0.4
Target Injury Crashes/Year After	0.0	3.0	0.4

TABLE 8 Evaluation Results for Category 3 (5-Section PPLT to FYA-PPLT)

Source	Crash Type	π	λ	CMF	CRF
105 Sites (193 Treated Legs)					
	Total	1964.9 ± 43.6	1836 ± 42.8	**0.934** ± 0.030	6.6% ± 3.0%
	Total Injury	683.4 ± 25.6	584 ± 24.2	**0.853** ± 0.048	14.7% ± 4.8%
	Target	417.2 ± 20.1	325 ± 18.0	**0.777** ± 0.057	22.3% ± 5.7%
	Target Injury	220.9 ± 14.6	150 ± 12.2	**0.676** ± 0.071	32.4% ± 7.1%
156 Sites (254 Treated Legs)					
	Target	528.8 ± 22.6	444 ± 21.1	**0.838** ± 0.053	16.2% ± 5.3%
	Target Injury	282.9 ± 16.5	212 ± 14.6	**0.747** ± 0.067	25.3% ± 6.7%

Note: CMFs in bold are statistically different from 1.0 at the 5% level.

TABLE 9 Summary Statistics for Category 4 (Permissive Only to FYA-Permissive Only)

Variable	Minimum	Maximum	Average
9 Sites exclusive to Category 4 (14 Treated Legs)			
Years Before	3.0	3.0	3.0
Years After	2.0	3.0	2.7
Number of Legs	3	4	3.9
Number of Category 4 Treated Legs	1	2	1.6
Number of Category 4 Major Road Treated Legs	1	2	1.6
Number of Category 4 Minor Road Treated Legs	0	0	0.0
Major Road Speed Limit	35	55	48.3
Number of Signal Phases After	2	4	2.7
Major Road AADT Before	7,300	25,000	13,800
Major Road AADT After	7,100	25,000	15,000
Minor Road AADT Before	900	13,300	5,300
Minor Road AADT After	900	12,000	5,200
Total Crashes/Year Before	0.7	15.3	4.6
Total Crashes/Year After	0.0	16.7	5.0
Total Injury Crashes/Year Before	0.0	6.7	2.0
Total Injury Crashes/Year After	0.0	6.7	1.7
Target Crashes/Year Before	0.0	1.7	0.6
Target Crashes/Year After	0.0	1.0	0.3
Target Injury Crashes/Year Before	0.0	1.3	0.4
Target Injury Crashes/Year After	0.0	0.5	0.2
48 Sites with multiple category types including at least one Category 4 leg (50 Treated Legs)			
Years Before	3.0	3.0	3.0
Years After	2.2	3.0	2.8
Number of Legs	4	4	4.0
Number of Category 4 Treated Legs	1	2	1.0
Number of Category 4 Major Road Treated Legs	0	1	0.9
Number of Category 4 Minor Road Treated Legs	0	2	0.2
Major Road Speed Limit	20	55	41.9
Number of Signal Phases After	3	6	3.6
Major Road AADT Before	4,100	38,000	16,900
Major Road AADT After	3,500	39,000	17,400
Minor Road AADT Before	500	13,000	5,000
Minor Road AADT After	500	14,500	5,100
Target Crashes/Year Before	0.00	0.67	0.13
Target Crashes/Year After	0.00	0.89	0.08
Target Injury Crashes/Year Before	0.00	0.67	0.08
Target Injury Crashes/Year After	0.00	0.36	0.03

TABLE 10 Evaluation Results for Category 4 (Permissive Only to FYA-Permissive Only)

Source	Crash Type	π	λ	CMF	CRF
9 Sites (14 Treated Legs)					
	Total	140.1 ± 12.8	126 ± 11.2	0.892 ± 0.113	10.8% ± 11.3%
	Total Injury	59.7 ± 8.4	42 ± 6.5	**0.689** ± 0.141	31.1% ± 14.1%
	Target	15.9 ± 4.3	7 ± 2.6	**0.410** ± 0.177	59.0% ± 17.7%
	Target Injury	11.9 ± 3.7	4 ± 2.0	**0.306** ± 0.164	69.4% ± 16.4%
57 Sites (64 Treated Legs)					
	Target	33.1 ± 5.8	17 ± 4.1	**0.498** ± 0.145	50.2% ± 14.5%
	Target Injury	21.9 ± 4.8	8 ± 2.8	**0.349** ± 0.139	65.1% ± 13.9%

Note: CMFs in bold are statistically different from 1.0 at the 5% level.