



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

January 13, 2015  
TRB 94<sup>th</sup> Annual Meeting

# Presentation Overview

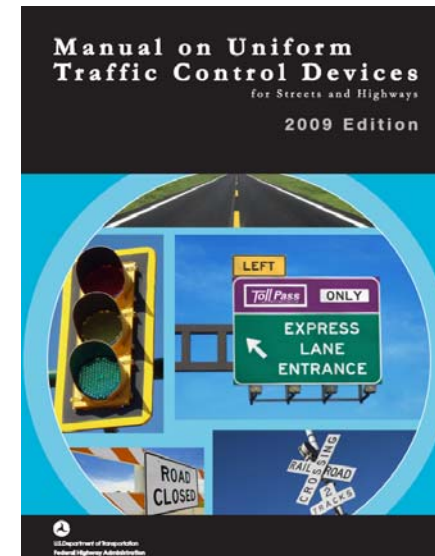
- Background
- Literature Review
- Project Scope
- Methodology
- Site Selection
- Results by Category
- Conclusions



# Background

## 2009 MUTCD

- FYA formally approved as recommended treatment for protective/permissive left turn (PPLT) displays
- NCDOT approved FYA as preferred installation for new PPLT installations



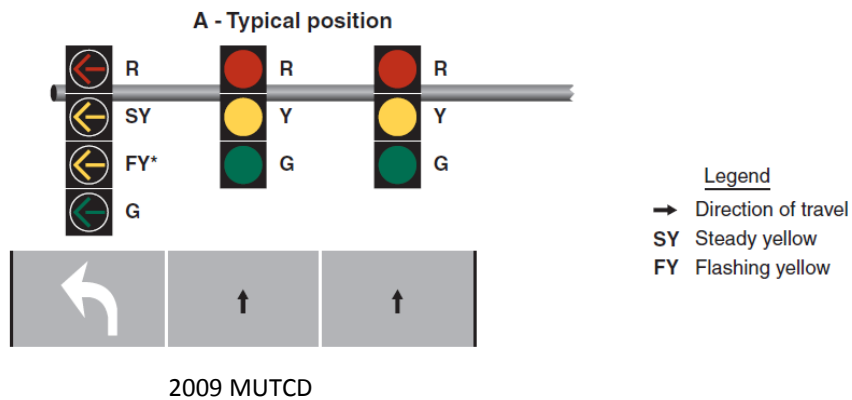
# Background

## Two Types of FYA in North Carolina:

### FYA-PPLT - 4 section

- Protected/Permissive Left Turn Mode
- Most Prevalent

Figure 4D-12. Typical Position and Arrangements of Separate Signal Faces with Flashing Yellow Arrow for Protected/Permissive Mode and Protected Only Mode Left Turns



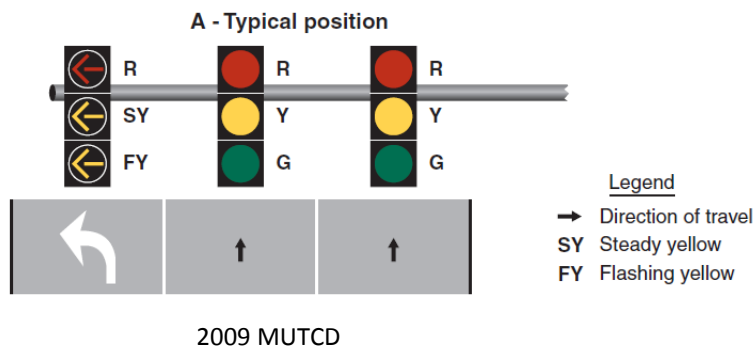
# Background

## Two Types of FYA in North Carolina:

### FYA-Permissive Only - 3 section

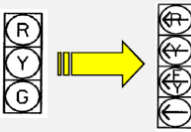
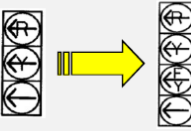
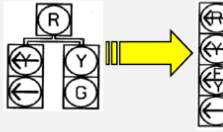
- Not Bimodal Use\* (No Green Arrow)
- Found at ~1/4 of intersections with FYA

Figure 4D-7. Typical Position and Arrangements of Separate Signal Faces with Flashing Yellow Arrow for Permissive Only Mode Left Turns



# Literature Review

- NCHRP Web-Only Document 123 (2007)
  - Over 50 Sites across the US, including North Carolina
  - No CMFs
- NCDOT Unpublished Study (2011)
  - Preliminary data – 55 sites

		Total	Target
Permissive Only to FYA Protected-Permissive		-15%	-68%
Protected Only to FYA Protected-Permissive		+27%	+467%
5 Section "Doghouse" Protected-Permissive to FYA Protected-Permissive		0%	-37%

# Literature Review

- Charlotte, NC Safety Evaluation (2011)
  - Crash Analysis at 6 Intersections – No CMFs
- Safety Evaluation of FYA in Three Cities in WA and TX (2012)
  - Crash Rates at 51 intersections – No CMFs
- Crash Modification Factors for Changes to Left-Turn Phasing (2012)
  - Crash Analysis from NC, OR, WA - CMF Clearinghouse #s
  - All Left Turns included in “Target CMF”
  - No CMF for site with Permissive Only in Before Period
  - No CMF for sites with FYA-Permissive Only

# Project Scope

## Categories of FYA – Based on Before 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 PPLT to FYA-PPLT
- Category 4 – Permissive Only to FYA-Permissive Only

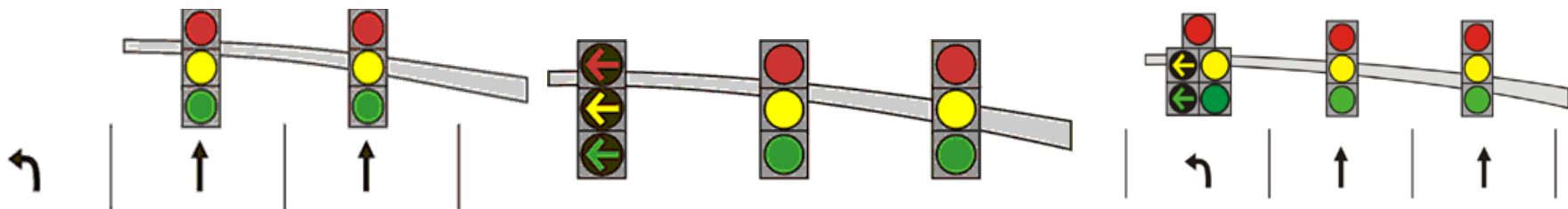


Image Source: Signalized Intersections: An Informational Guide



# Project Scope

## Measures of Effectiveness

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 for the total and target groups

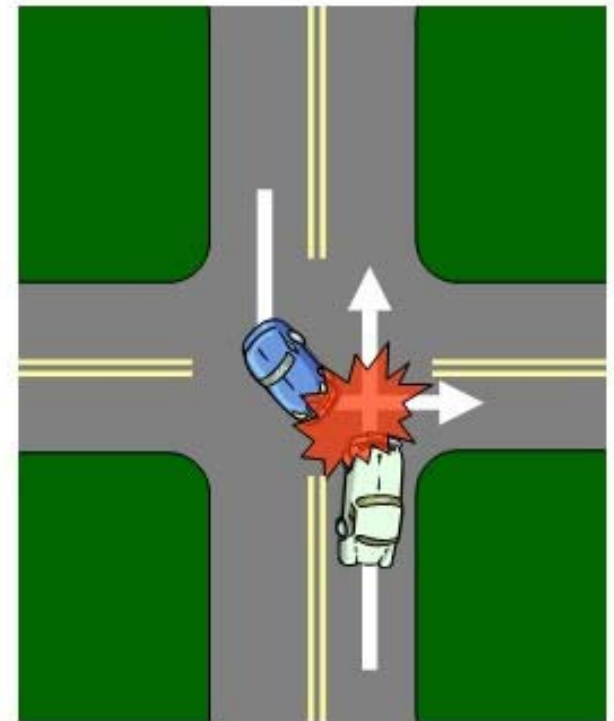
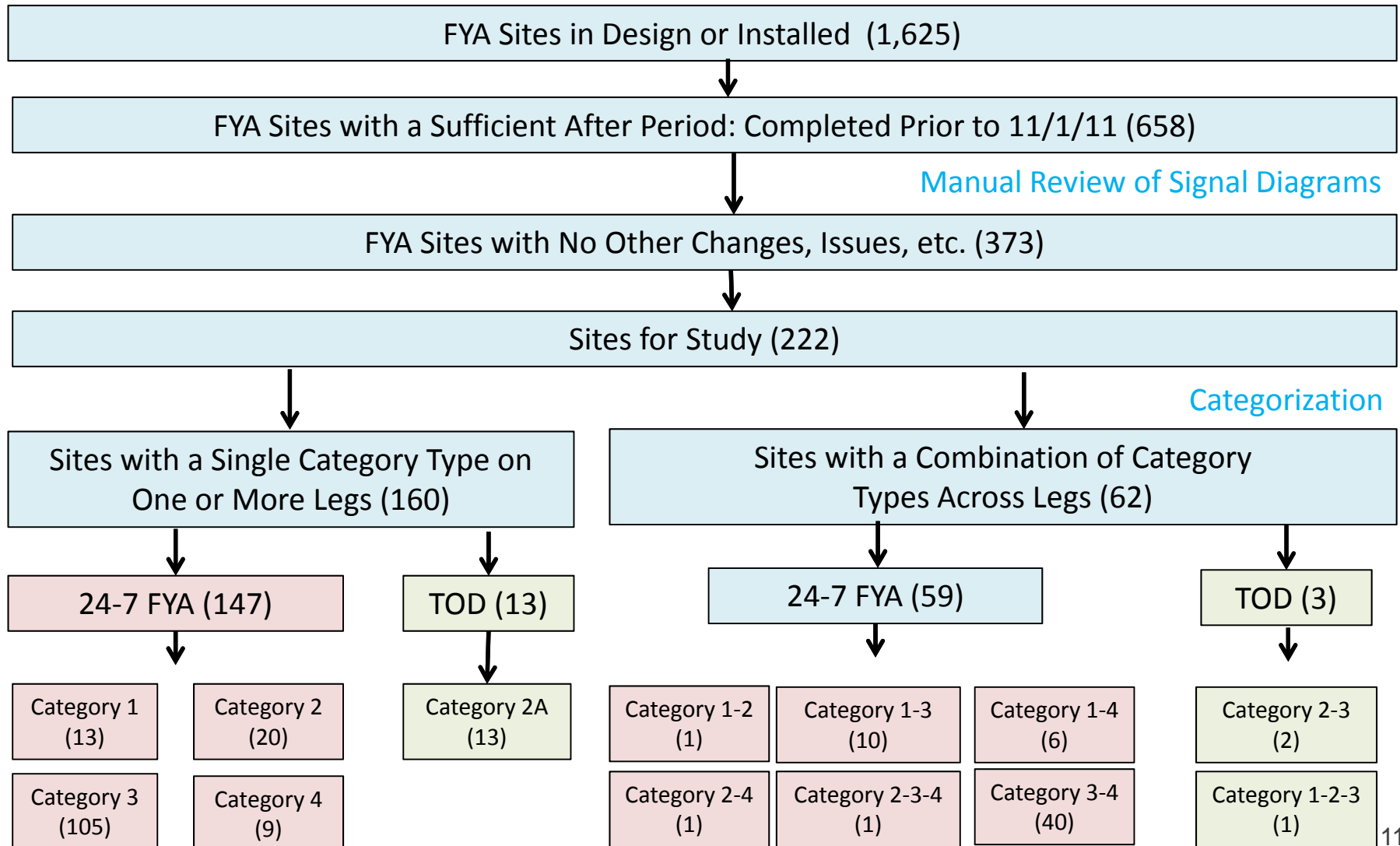


Image Source: Safety at Unsignalized Intersections

## Methodology

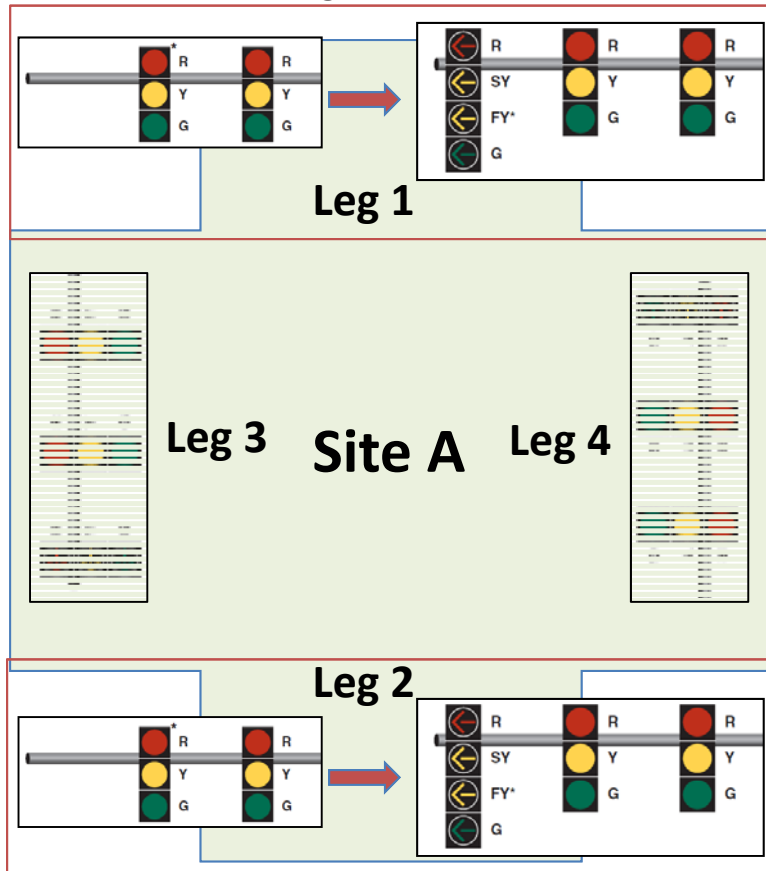
- Before and After Crash Analysis with consideration for traffic increase
- Data comprised 3 years before & minimum 2 years after
- Installation Dates varied from 2006-2011, but many in 2010
- Target Crashes – required careful review

# Site Selection

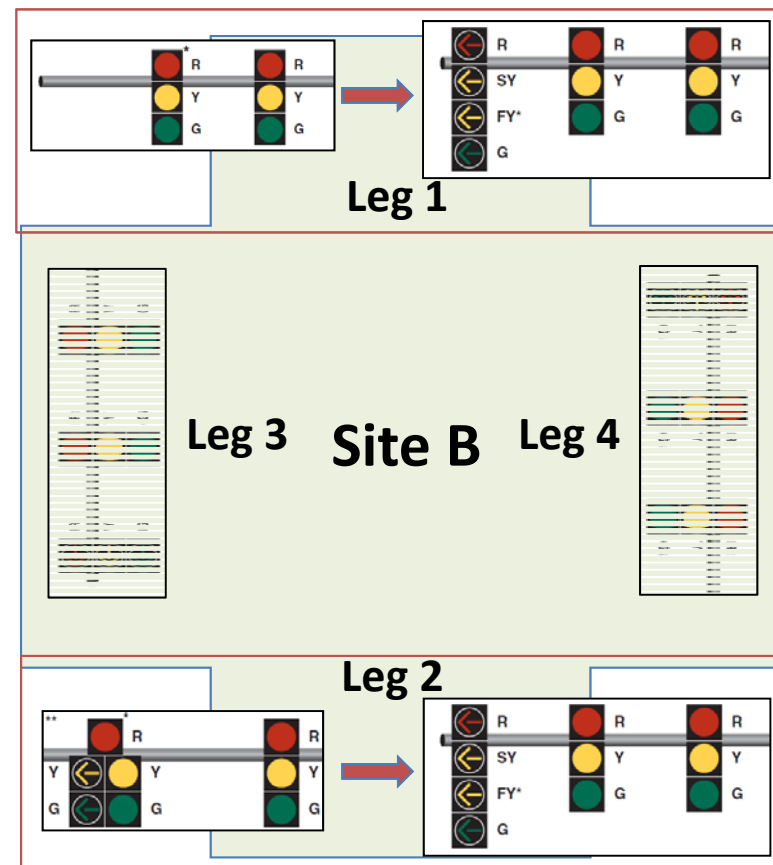


# Site Selection

Example 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).



Example 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).



# Category 1: Permissive Only to FYA-PPLT

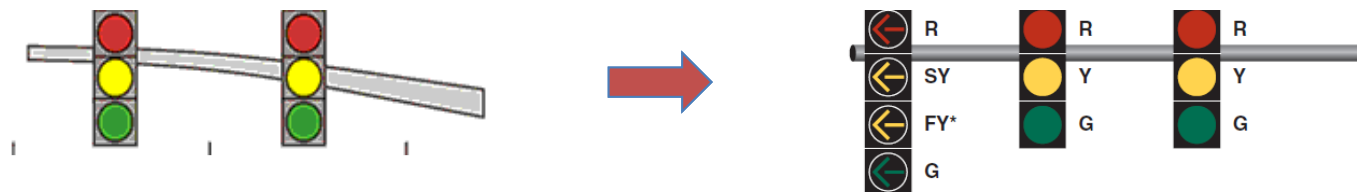
## Results

Average Target Crashes/Year/Site After: 0.6

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

Source	Crash Type	$\pi$	$\lambda$	CMF	CRF
<b>13 Sites (20 Treated Legs)</b>					
	Total	171.3 ± 12.7	161 ± 12.7	<b>0.935 ± 0.100</b>	6.5% ± 10.0%
	Total Injury	61.7 ± 7.6	41 ± 6.4	<b>0.654 ± 0.128</b>	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%
<b>30 Sites (41 Treated Legs)</b>					
	Target	84.2 ± 9.2	51 ± 7.1	<b>0.598 ± 0.105</b>	40.2% ± 10.5%
	Target Injury	41.2 ± 6.3	25 ± 5.0	<b>0.592 ± 0.146</b>	40.8% ± 14.6%

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



# Category 2: Protected Only to FYA-PPLT

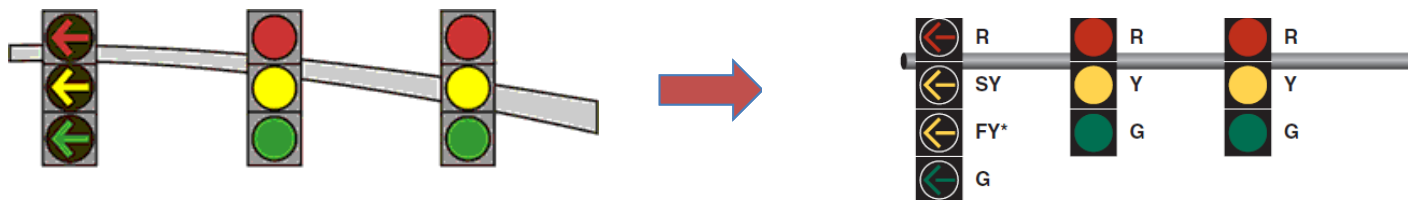
## Results

Average Target Crashes/Year/Site After: 1.6

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

Source	Crash Type	$\pi$	$\lambda$	CMF	CRF
<b>20 Sites (43 Treated Legs)</b>					
	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	<b>3.440 ± 0.727</b>	-244.0% ± 72.7%
	Target Injury	11.8 ± 3.4	55 ± 7.4	<b>4.308 ± 1.270</b>	-330.8% ± 127.0%
<b>23 Sites (49 Treated Legs)</b>					
	Target	28.1 ± 5.2	107 ± 10.3	<b>3.684 ± 0.748</b>	-268.4% ± 74.8%
	Target Injury	11.8 ± 3.4	61 ± 7.8	<b>4.778 ± 1.397</b>	-377.8% ± 139.7%

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



# Category 2A: Protected Only to FYA-PPLT with TOD

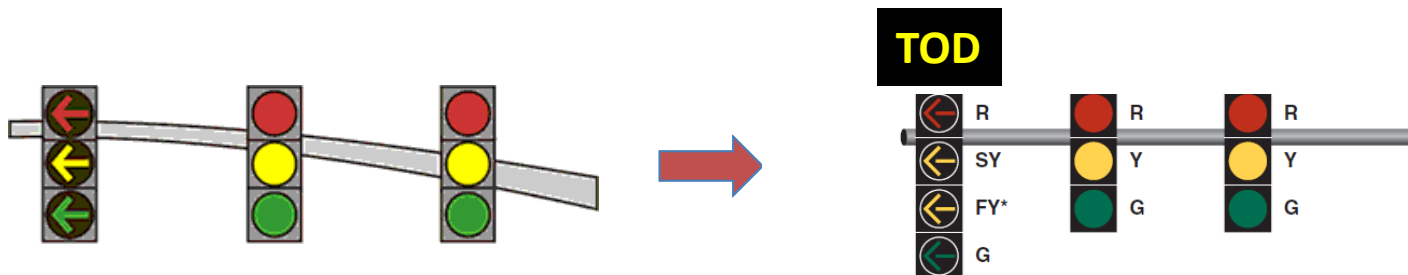
## Results

Average Target Crashes/Year/Site After: 0.5

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

Source	Crash Type	$\pi$	$\lambda$	CMF	CRF
<b>13 Sites (28 Treated Legs)</b>					
	Total	692.0 ± 25.0	624 ± 25.0	<b>0.901 ± 0.048</b>	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%
<b>16 Sites (34 Treated Legs)</b>					
	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



# Category 3: 5-Section PPLT to FYA-PPLT

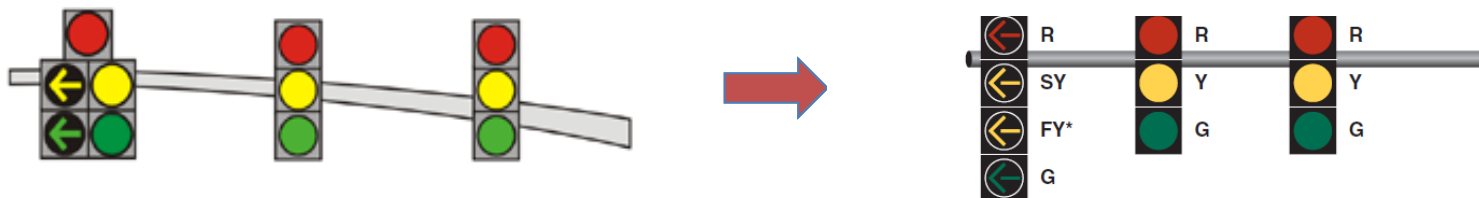
## Results

Average Target Crashes/Year/Site After: 1.0

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

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

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





# Category 4: Permissive Only to FYA-Permissive Only

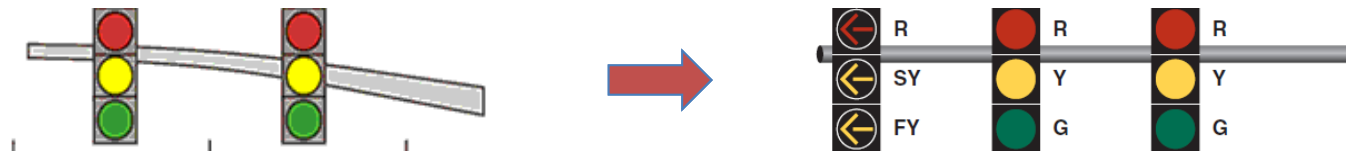
## Results

Average Target Crashes/Year/Site After: 0.1

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

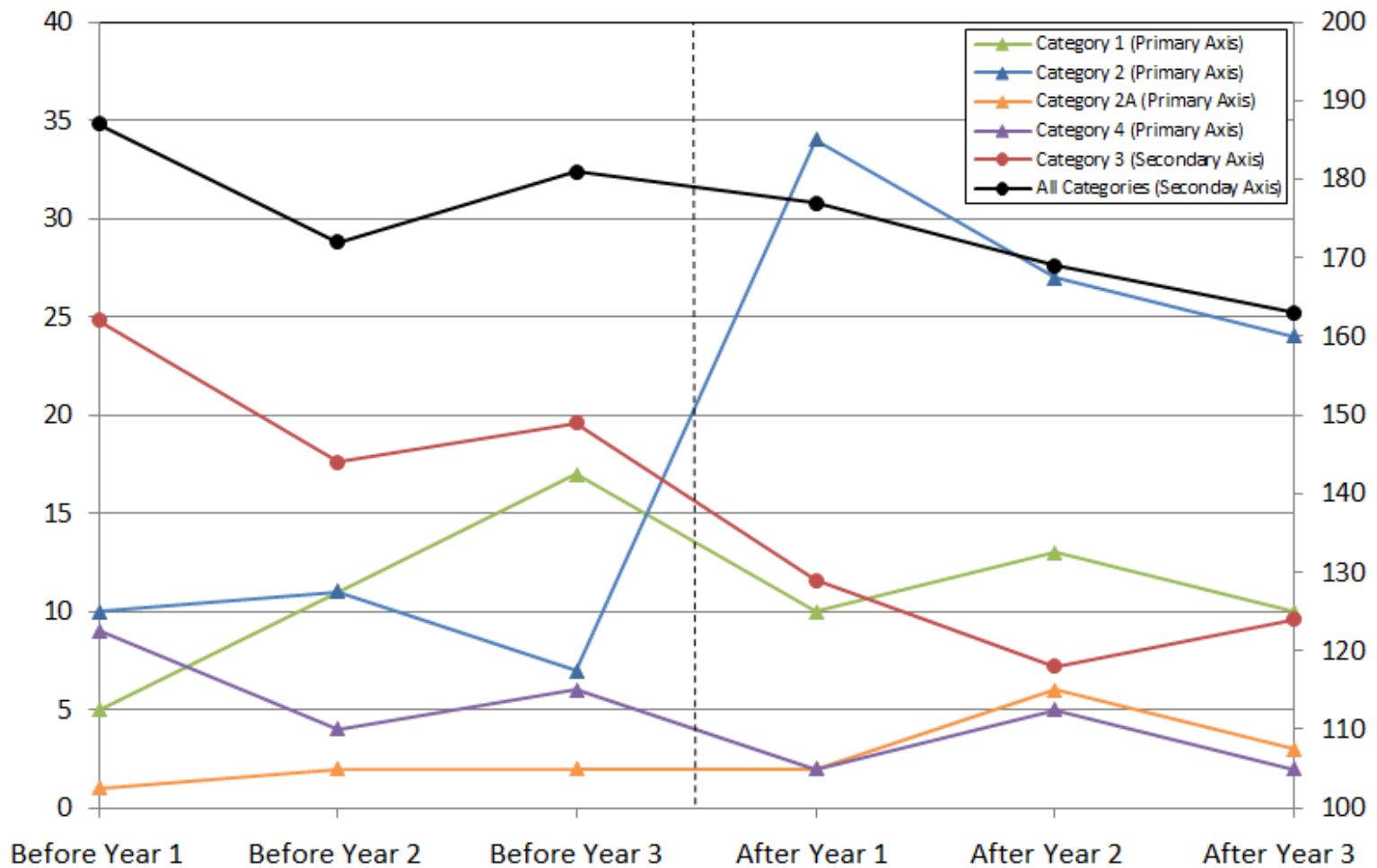
Source	Crash Type	$\pi$	$\lambda$	CMF	CRF
<b>9 Sites (14 Treated Legs)</b>					
	Total	140.1 ± 12.8	126 ± 11.2	0.892 ± 0.113	10.8% ± 11.3%
	Total Injury	59.7 ± 8.4	42 ± 6.5	<b>0.689 ± 0.141</b>	31.1% ± 14.1%
	Target	15.9 ± 4.3	7 ± 2.6	<b>0.410 ± 0.177</b>	59.0% ± 17.7%
	Target Injury	11.9 ± 3.7	4 ± 2.0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

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



# Additional Analysis

## Target Crash Trends By Category



# Additional Analysis

- What role do site characteristics play (Category 3)?

Mainline Characteristics	Sites	Average AADT	Target	Total
Low Speeds - 2-3 Lane	11	22,000	68.9 +/- 13.8	5.7 +/- 11.3
Low Speed - 4-5 Lane	15	25,000	50.7 +/- 12.4	5.5 +/- 7.8
High Speed - 2-3 Lane	18	17,200	27.1 +/- 19.8	13.7 +/- 8.8
High Speed - 4-5 Lane	56	27,700	16.3 +/- 7.1	6.6 +/- 3.9
All Speeds - 6-7 Lane	5	36,700	12.4 +/- 22.9	2.2 +/- 10.9

Mainline Characteristics	Sites	Average AADT	Target	Total
Low Speed - 2-3 Lane (< 25,000 AADT)	7	14,200	69.2 +/- 18.4	4.2 +/- 15.8
Low Speed - 2-3 Lane (> 25,000 AADT)	4	35,800	71.3 +/- 17.1	8.5 +/- 15.8
Low Speed - 4-5 Lane (< 25,000 AADT)	8	19,200	83.4 +/- 11.7	-4.4 +/- 13.6
Low Speed - 4-5 Lane (> 25,000 AADT)	7	31,700	40.9 +/- 16.0	11.7 +/- 9.4
High Speed - 2-3 Lane (< 25,000 AADT)	14	13,800	70.3 +/- 17.8	8.9 +/- 13.3
High Speed - 2-3 Lane (> 25,000 AADT)	4	29,300	10.9 +/- 27.3	18.3 +/- 11.5
High Speed - 4-5 Lane (< 25,000 AADT)	25	20,200	28.4 +/- 11.2	11.5 +/- 7.1
High Speed - 4-5 Lane (> 25,000 AADT)	31	33,800	11.1 +/- 9.0	4.9 +/- 4.6

# Conclusions

## Category 3 & 4

- Category 3 - main objective of study
- Statistically significant decrease in target & injury crashes when going from a solid green ball to a FYA for permissive left turns when phasing remains unchanged
- Applies regardless of whether the left phasing is protected/permissive or fully permissive

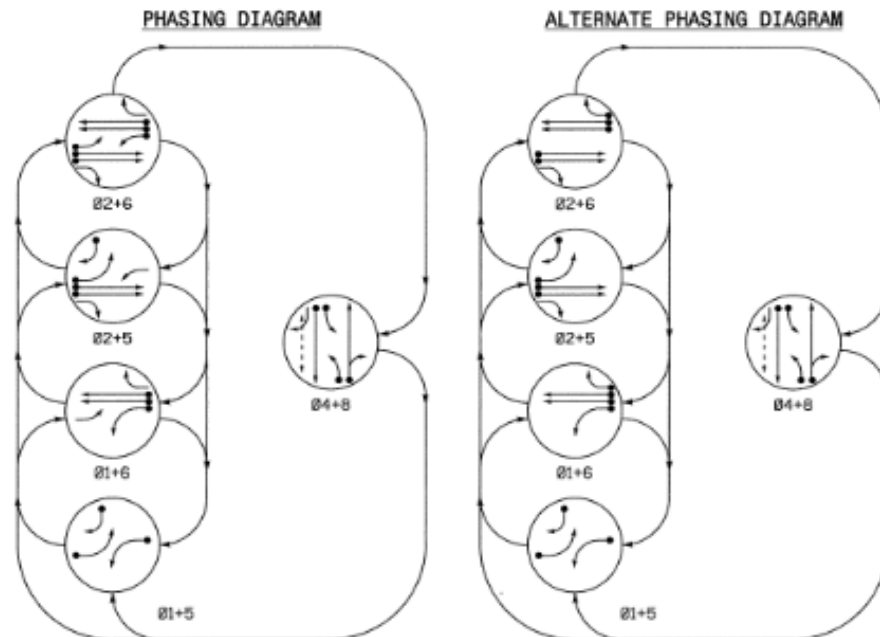
## Other Categories

- Results not surprising – changes in crashes are likely a factor of phase-change in addition to the FYA
- Results are not as robust, which suggests variability in performance and a need for more samples

# Conclusions

## TOD Operation

- May be real benefits in using TOD operation at locations where target crashes are occurring at specific times of day. Operate in fully protected mode only during hours of peak crash frequency.
- We plan to look more into this as more sites come online.



# Questions?

Carrie L. Simpson, PE  
[clsimpson@ncdot.gov](mailto:clsimpson@ncdot.gov)

Shawn A. Troy, PE  
[stroy@ncdot.gov](mailto:stroy@ncdot.gov)

<https://connect.ncdot.gov/resources/safety/Pages/Safety-Evaluation.aspx>