NORTH CAROLINA
Department of Transportation

# Implementation of a Dynamic All Red Extension at Signalized Intersections

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# Introduction

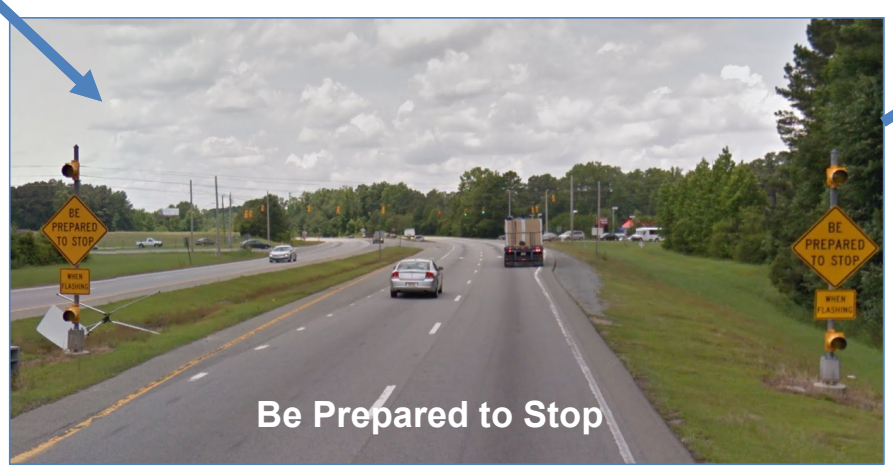




Grade Separation

# Introduction



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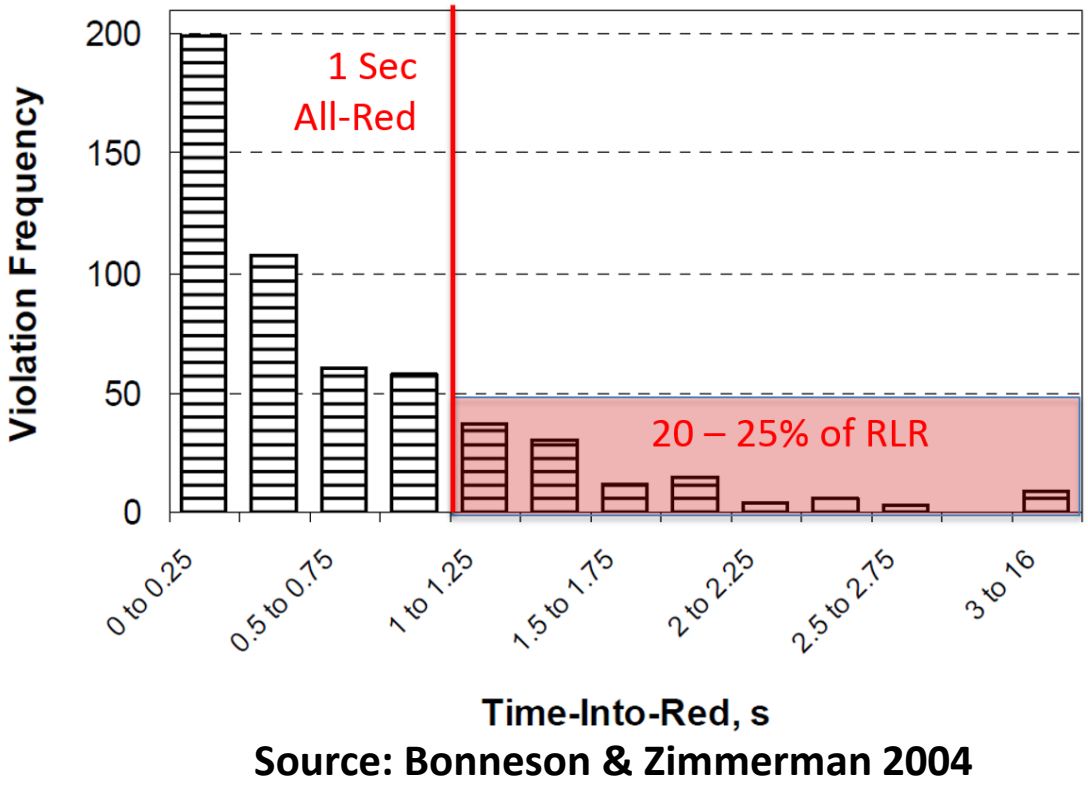
# Introduction

## Frequency of Red-Light Violations as a Function of Time-Into-Red



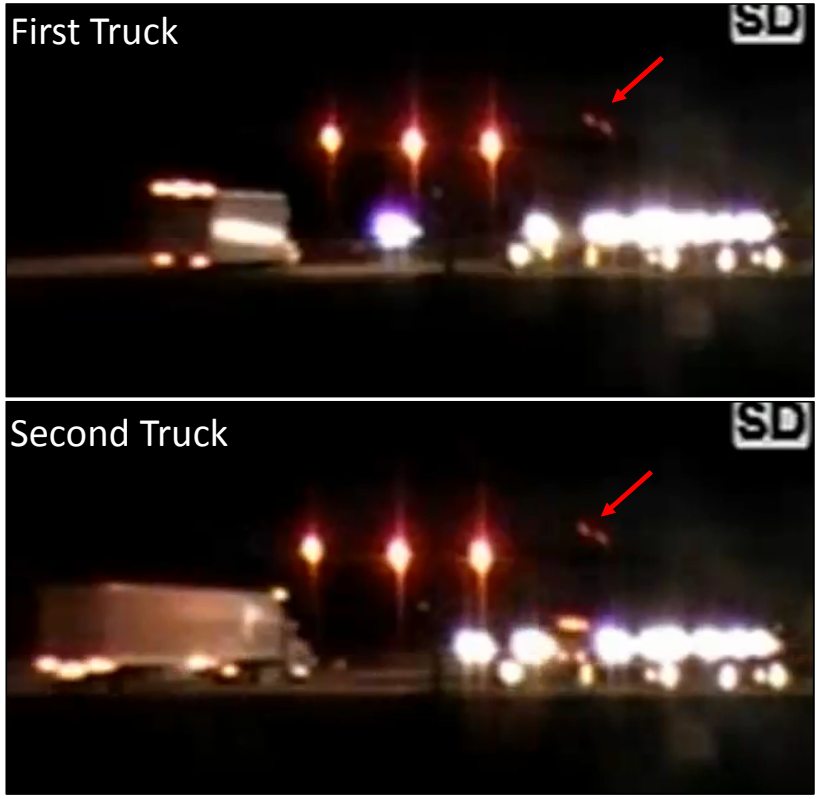

**Source: Bonneson & Zimmerman 2004**

- All-red clearance intervals are used to help combat red light running crashes by creating a safety cushion for vehicles entering the intersection on red prior to an opposing movement receiving a green indication.
- A one-second all-red clearance interval may only capture ~ 80% of red light violators. The remaining will enter the intersection when the next phase has a green indication.
- Extending clearance timing by a static amount for every cycle may have negative implications to delay, congestion, and driver adaptation.

# Introduction

## Dynamic All Red Extension (DARE)

- NCDOT developed and piloted a system that intervenes in the operation of a traffic signal when it senses a vehicle is likely to violate the red indication of a main line approach by holding the signal controller timing in the all-red clearance interval before switching right of way, thus allowing the offending vehicle time to clear the intersection before the next phase receives a green indication.




Video captured back-to-back violators after Wake Co. DARE installation. First truck ran red at 1 s and second truck ran red at 3 s. All-red was extended.

# Introduction

## DARE Video Clip

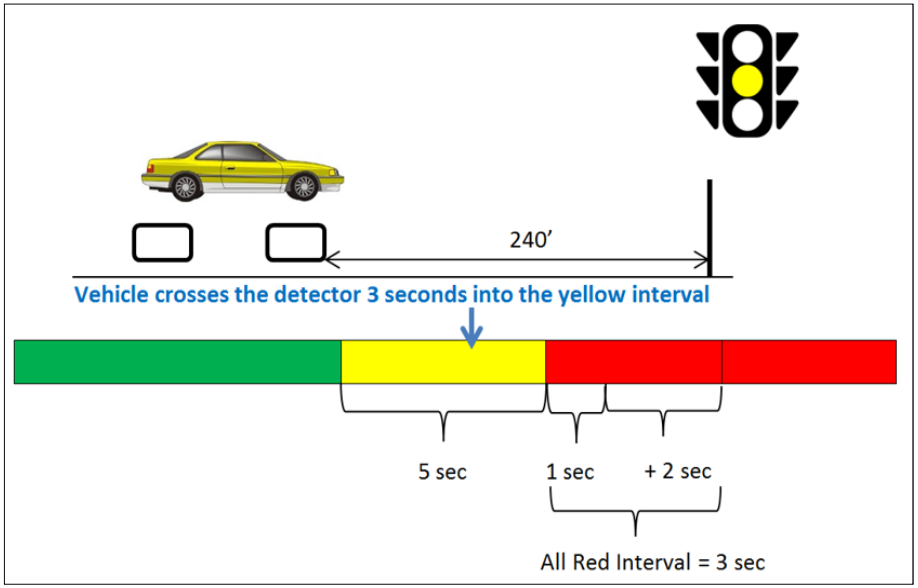
http://youtu.be/LKCQvtPFMsQ

# Introduction

## How It Works (Simplistic Version):

**Example Site:**

- **Yellow Interval: 5 seconds**
- **Default Red Interval: 1 second**
- **Alarm Time: 5 seconds**
- **Closest Loop is 240' from Stop Bar**
- **Vehicle below crosses the loops at 3 seconds into the yellow interval**
- **5 second stop time is placed on red interval**
  - **Vehicle has remaining 2 seconds of yellow, 1 second of default red, and 2 seconds of red extension = 5 seconds from the time they cross the loops.**
- **Total All-Red Time: 3 sec**




The system is termed "dynamic" as the amount of time the red clearance is increased can vary from one cycle to the next. If back to back vehicles violate during the same red clearance interval, the alarm time is reset with each subsequent violation.

# Introduction

## How It Works (Signal Equipment)

- Oasis/2070 Controller
- Detection method – Two 6’ X 6’ inductive loops spaced 10’ apart
- Northstar Controls Model NQ4 Speed Advisory System
  - Unit is typically placed in separate cabinet next to inductive loops
  - Loop outputs feed into inputs of NQ4 logic unit and determines if preset speed threshold has been violated (threshold varies by location – typically 5 mph below design speed)
  - We tweaked the outputs from our NQ4 detector systems to get the controller to handle the necessary “holds”
  - Duration of alarm output is 5 seconds

# Introduction

## Timeline:

**2011 (Feb)** – First Site installed in Division 1 (Ahoskie)

**2012 (Fall) –** Signal Designs Completed & Before Period Data Collected for Eight Pilot Sites in Divisions 1, 2, 3, 5 & 11 – *Pilot Study evaluated compliance & system operation*

**2013 (Jan – Oct) –** Eight Pilot Sites Installed

**2013 (Sept)** – Additional Site Installed in Division 9 in conjunction with Wavetronix SmartSensor Advance (SR 3010/NC 8 at US 52/NC 8 Exit 92 SB Ramp)

**2014 (Oct) –** Compliance Data Collection Concluded at Eight Pilot Sites

# Introduction

## Timeline:

**2015 (July)** – New site installed (12-14-209 - US 74 at SR 2245 (Bethlehem Rd))

**2016 (Sept)** – New site installed (01-15-37634 – US 17 at NC 45)

**2016 (Dec)** – New site installed (06-15-37961 - NC 87 at SR 2220 (Tom Starling Rd))

**TBD** – New sites slated in Divisions 3, 5, 11, 12, 14:

03-16-42323 - US 17 and SR 1563 (Sloop Point Loop Rd)

05-16-0786 - US 158 (Oxford Loop Rd) at (1) US 15, (2) NC 96 & (3) US 158 Bus (Roxboro Rd)

11-17-203 - US 601 at SR 2221 (Rockford Rd)

12-17-210 - US 74 at SR 1158 (Beaverdam Church Rd)/SR 1315 (Plato Lee Rd)

14-17-213 - US 19 (Dellwood Rd) at US 276 (Russ Ave) (East Intersection)

# Pilot Study

## Pilot Study – Site Selection

- In the site selection process, we were specifically looking for rural, isolated signals on higher speed facilities with enough reported red light running crashes to allow for post-installation crash analysis evaluation.
- Mainline posted speed limits range from 45 mph to 60 mph.
- 2011 AADT for the mainline approaches range from approx 4,700 to 29,500 vehicles per day.
- The mainline cross sections vary, but a majority are four-lane divided facilities.
- Both mainline approaches were treated at most sites.

| County | Treated Approaches | Distance to Loop (ft) | Yellow Interval (sec) | Default Red Interval (sec) | Mainline AADT (vehicles per day) | Mainline Speed Limit (mph) |
|---|---|---|---|---|---|---|
| Pasquotank | US 17 - Both | 290 | 5.5-5.6 | 1.0-1.1 | 15,500 | 60 |
| Surry | US 52 - Westbound | 240 | 5.1 | 2.0 | 14,500 | 55 |
| Pasquotank | US 17 - Both | 290 | 5.5 | 1.0 | 8,900 | 60 |
| Carteret | NC 24 - Both | 240 | 5.3 | 1.1 | 16,000 | 55 |
| Brunswick | US 17 - Both | 240 | 5.2-5.3 | 1.0-1.2 | 17,000 | 55 |
| Wake | US 70 Bus - Eastbound | 240 | 5.2 | 1.2 | 29,500 | 55 |
| Surry | US 601 - Both | 155 | 4.3 | 1.0 | 4,700 | 45 |
| Perquimans | US 17 - Both | 290 | 5.5 | 2.0 | 13,500 | 55 |

# Pilot Study

## Pilot Study – Compliance Data

- Do drivers adapt to the system over time and does driver behavior change after the systems are installed?
- Driver behavior may change if motorists routinely run the red light and encounter lengthened all-red intervals; however, we felt it was more likely for driver behavior to remain relatively unchanged if the red was only extended a handful of times daily in a rural environment and if most drivers did not realize the system was in place.


Compliance data collected using cameras mounted to signal poles or other nearby fixed objects.

# Pilot Study

## Pilot Study – Compliance Data

- Analyzed yellow light runners (YLR) and red light runners (RLR).
- For both measures, we were interested in the hourly frequency, the rate per entering through vehicle, and the rate per cycle.
- Data were collected prior to installation and at the 1-month, 3-month, 6-month and 12-month marks after installation.
- Up to 52 hours of before period data and up to 130 hours of after period data were collected at each intersection.


In all, we collected over 1,000 hours of data to determine how the countermeasure may affect vehicle compliance

# Pilot Study

## Pilot Study – Compliance Data

- Compliance rates before and after DARE installation were compared using two-sided unpaired *t*-tests.
- **YLR** – No statistically significant changes in YLR/hour associated with increases (***see report***)
- **RLR** – Comparing before period to 12-month after period, none of the sites experienced a statistically significant change in RLR/hour. Two of seven sites experienced statistically significant changes associated with an increase in RLR in earlier post-installation periods that diminished by the 12-month post-installation period.

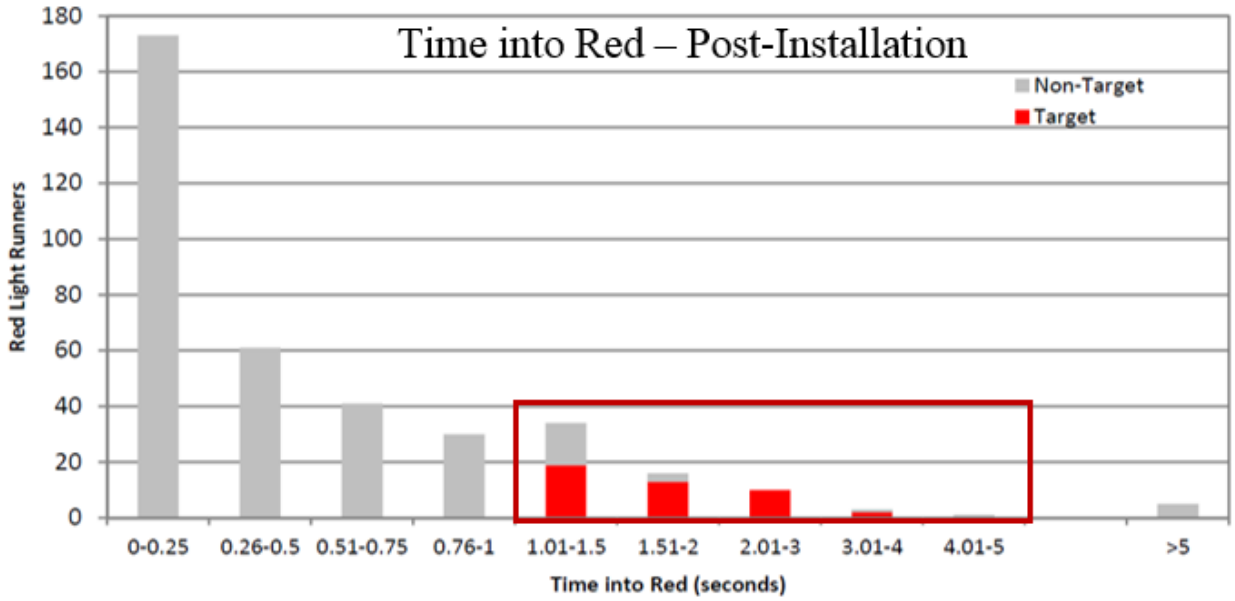
[a] Denotes a statistically significant change from pre-installation to post-installation conditions. Differences in compliance rates post-installation were declared significant for *p*-values less than 0.05.

| Time Period | Observation Period (hours) | Number of Observations | Average RLR/Hour | Average RLR/ 1,000 veh | Average RLR/ Cycle |
|---|---|---|---|---|---|
| **Site 1** | | | | | |
| Pre-installation | 52 | 18 | 0.35 | 0.94 | 0.008 |
| 1 Month Post-installation | 52 | 25 | 0.48 | 1.48 | 0.011 |
| 3 Month Post-installation | 26 | 8 | 0.31 | 1.01 | 0.007 |
| 6 Months Post-installation | 26 | 12 | 0.46 | 1.32 | 0.010 |
| 12 Months Post-installation | 52 | 25 | 0.48 | 1.28 | 0.011 |
| **Site 2** | | | | | |
| Pre-installation | 26 | 15 | 0.58 | 2.58 | 0.010 |
| 1 Month Post-installation | 26 | 30 | 1.15[a] | 3.02 | 0.021[a] |
| 3 Month Post-installation | 13 | 5 | 0.38 | 1.05 | 0.007 |
| 6 Months Post-installation | 13 | 16 | 1.23[a] | 2.78 | 0.023[a] |
| 12 Months Post-installation | 13 | 12 | 0.92 | 2.01 | 0.017 |
| **Site 3** | | | | | |
| Pre-installation | 52 | 11 | 0.21 | 1.00 | 0.004 |
| 1 Month Post-installation | 49 | 15 | 0.31 | 1.45 | 0.006 |
| 3 Month Post-installation | 26 | 6 | 0.23 | 0.94 | 0.004 |
| 6 Months Post-installation | 26 | 10 | 0.38 | 1.95 | 0.007 |
| 12 Months Post-installation | 50 | 15 | 0.30 | 1.64 | 0.006 |
| **Site 4** | | | | | |
| Pre-installation | 52 | 18 | 0.35 | 0.85 | 0.008 |
| 1 Month Post-installation | 52 | 19 | 0.37 | 0.73 | 0.008 |
| 3 Month Post-installation | 26 | 11 | 0.42 | 1.04 | 0.010 |
| 6 Months Post-installation | 26 | 10 | 0.38 | 1.02 | 0.009 |
| 12 Months Post-installation | 26 | 9 | 0.35 | 0.82 | 0.007 |
| **Site 5** | | | | | |
| Pre-installation | 52 | 30 | 0.58 | 1.32 | 0.017 |
| 1 Month Post-installation | n/a | n/a | n/a | n/a | n/a |
| 3 Month Post-installation | 26 | 41 | 1.58[a] | 3.64[a] | 0.030[a] |
| 6 Months Post-installation | 26 | 34 | 1.31[a] | 3.16[a] | 0.027 |
| 12 Months Post-installation | 26 | 18 | 0.69 | 1.79 | 0.012 |
| **Site 6** | | | | | |
| Pre-installation | 18 | 10 | 0.56 | 0.59 | 0.020 |
| 1 Month Post-installation | 24 | 19 | 0.79 | 1.31 | 0.028 |
| 3 Month Post-installation | 12 | 6 | 0.50 | 0.42 | 0.026 |
| 6 Months Post-installation | 12 | 8 | 0.67 | 0.98 | 0.017 |
| 12 Months Post-installation | n/a | n/a | n/a | n/a | n/a |
| **Site 7** | | | | | |
| Pre-installation | 52 | 9 | 0.17 | 1.45 | 0.003 |
| 1 Month Post-installation | 52 | 5 | 0.10 | 0.70 | 0.001 |
| 3 Month Post-installation | 26 | 9 | 0.35 | 3.32 | 0.005 |
| 6 Months Post-installation | 26 | 3 | 0.12 | 1.07 | 0.002 |
| 12 Months Post-installation | 26 | 3 | 0.12 | 1.10 | 0.002 |

# Pilot Study

## Pilot Study – Compliance Data

- Approx. 12% of the 374 post-installation RLR captured were targeted by DARE, entering 1-5 s into red, as shown highlighted in red



# Pilot Study

## Pilot Study – Signal Operation Data

- Can DARE be installed and function properly in the long term?
- Signal logs were obtained by field personnel after DARE was installed to monitor the system operation over a longer duration of time, and to ensure the system could function with minimal surveillance for a 3-year period. We analyzed this information at several post-installation periods for each site.
- Signal logs differ from that summarized in the compliance study because it includes all activations of DARE, even those that may cross the stop bar with a yellow signal indication or those that may have stopped (false positives).
- Signal logs gave us additional measures of system performance, including: hourly frequency and average duration of red extensions, and a possible range of unnecessary red extensions as a measure of false positives.

# Pilot Study

## Pilot Study – Signal Operation Data

System Operation Data is summarized by

- (a) average number of red extensions/hour
- (b) average RLR/hour (range of post-installation values from compliance study)
- (c) possible number of unnecessary red extensions/hour
- (d) average length of red extension (sec)
- (e) possible length of time spent on unnecessary red extensions/hour (sec)

A possible range of hourly false positives (c) was calculated as (a) - (b). The possible length of time that may be spent on unnecessary red extensions per hour (e) was then calculated as (c) x (d).

| Post-Installation Time Period | Data Collected (Hours) | (a) Average Number of Red Extensions/Hour | (b) Average RLR/Hour (Range of Post-Installation Values From Table 3) | (c) Possible Number of Unnecessary Red Extensions/Hour | (d) Average Length of Red Extension (Sec) | (e) Possible Length of Time Spent on Unnecessary Red Extensions/Hour (Sec) |
|---|---|---|---|---|---|---|
| **Site 1** | | | | | | |
| 1 Month | 192 | 2.21 | 0.31 - 0.48 | 1.73 - 1.90 | 3.0 | 5.2 - 5.7 |
| 2 Years | 168 | 2.91 | | 2.43 - 2.60 | 2.9 | 7.0 - 7.5 |
| 3 Years | 120 | 3.07 | | 2.59 - 2.76 | 2.9 | 7.5 - 8.0 |
| **Site 2** | | | | | | |
| 2 Months | 192 | 2.54 | 0.38 - 1.23 | 1.31 - 2.16 | 2.7 | 3.5 - 5.8 |
| 3 Years | 192 | 2.42 | | 1.19 - 2.04 | 2.7 | 3.2 - 5.5 |
| **Site 3** | | | | | | |
| 1 Month | 336 | 0.63 | 0.23 - 0.38 | 0.25 - 0.40 | 3.2 | 0.8 - 1.3 |
| 2 Years | 432 | 0.55 | | 0.17 - 0.32 | 2.9 | 0.5 - 0.9 |
| 3 Years | 336 | 0.66 | | 0.28 - 0.43 | 2.9 | 0.8 - 1.2 |
| **Site 4** | | | | | | |
| 1 Month | 240 | 1.02 | 0.35 - 0.42 | 0.60 - 0.67 | n/a | N/A |
| 3 Years | 24 | 1.75 | | 1.33 - 1.40 | 2.8 | 3.7 - 3.9 |
| **Site 5** | | | | | | |
| 1 Year | 72 | 2.74 | 0.69 - 1.58 | 1.16 - 2.05 | 2.5 | 2.9 - 5.1 |
| 3 Years | 72 | 2.74 | | 1.16 - 2.05 | 2.4 | 2.8 - 4.9 |
| **Site 6** | | | | | | |
| 6 Months | 168 | 2.93 | 0.50 - 0.79 | 2.14 - 2.43 | 2.9 | 6.2 - 7.0 |
| 2 Years | 144 | 3.13 | | 2.34 - 2.63 | 2.8 | 6.6 - 7.4 |
| 3 Years | 168 | 2.68 | | 1.89 - 2.18 | 2.7 | 5.1 - 5.9 |
| **Site 7** | | | | | | |
| 3 Months | 1368 | 0.19 | 0.10 - 0.35 | 0 - 0.09 | 3.2 | 0 - 0.3 |
| 3 Years | 1368 | 0.16 | | 0 - 0.06 | 3.2 | 0 - 0.2 |
| **Site 8** | | | | | | |
| 2 Years | 144 | 1.22 | N/A | N/A | 1.4 | N/A |
| 3 Years | 72 | 1.68 | | N/A | 1.5 | N/A |

Results are provided as the average per site per treated approach

# Pilot Study

## Pilot Study – Signal Operation Data

- Comparing (a) to (b), there appeared to be a high proportion of false positives at the DARE sites. This was expected due to the conservative design used at the pilot sites: fixed point detection, detection placed hundreds of feet from intersection, and speed thresholds below the posted speed limit.

- But when a length of time, (d), is attributed to the possible number of unnecessary red extensions/hour, (c), the results showed the additional delay created by unnecessary red extensions, (e), is likely trivial, possibly ranging from 0 – 8 seconds per hour per treated approach at the pilot sites

| Post-Installation Time Period | Data Collected (Hours) | (a) Average Number of Red Extensions/Hour | (b) Average RLR/Hour (Range of Post-Installation Values From Table 3) | (c) Possible Number of Unnecessary Red Extensions/Hour | (d) Average Length of Red Extension (Sec) | (e) Possible Length of Time Spent on Unnecessary Red Extensions/Hour (Sec) |
|---|---|---|---|---|---|---|
| **Site 1** | | | | | | |
| 1 Month | 192 | 2.21 | 0.31 - 0.48 | 1.73 - 1.90 | 3.0 | 5.2 - 5.7 |
| 2 Years | 168 | 2.91 | | 2.43 - 2.60 | 2.9 | 7.0 - 7.5 |
| 3 Years | 120 | 3.07 | | 2.59 - 2.76 | 2.9 | 7.5 - 8.0 |
| **Site 2** | | | | | | |
| 2 Months | 192 | 2.54 | 0.38 - 1.23 | 1.31 - 2.16 | 2.7 | 3.5 - 5.8 |
| 3 Years | 192 | 2.42 | | 1.19 - 2.04 | 2.7 | 3.2 - 5.5 |
| **Site 3** | | | | | | |
| 1 Month | 336 | 0.63 | 0.23 - 0.38 | 0.25 - 0.40 | 3.2 | 0.8 - 1.3 |
| 2 Years | 432 | 0.55 | | 0.17 - 0.32 | 2.9 | 0.5 - 0.9 |
| 3 Years | 336 | 0.66 | | 0.28 - 0.43 | 2.9 | 0.8 - 1.2 |
| **Site 4** | | | | | | |
| 1 Month | 240 | 1.02 | 0.35 - 0.42 | 0.60 - 0.67 | n/a | N/A |
| 3 Years | 24 | 1.75 | | 1.33 - 1.40 | 2.8 | 3.7 - 3.9 |
| **Site 5** | | | | | | |
| 1 Year | 72 | 2.74 | 0.69 - 1.58 | 1.16 - 2.05 | 2.5 | 2.9 - 5.1 |
| 3 Years | 72 | 2.74 | | 1.16 - 2.05 | 2.4 | 2.8 - 4.9 |
| **Site 6** | | | | | | |
| 6 Months | 168 | 2.93 | 0.50 - 0.79 | 2.14 - 2.43 | 2.9 | 6.2 - 7.0 |
| 2 Years | 144 | 3.13 | | 2.34 - 2.63 | 2.8 | 6.6 - 7.4 |
| 3 Years | 168 | 2.68 | | 1.89 - 2.18 | 2.7 | 5.1 - 5.9 |
| **Site 7** | | | | | | |
| 3 Months | 1368 | 0.19 | 0.10 - 0.35 | 0 - 0.09 | 3.2 | 0 - 0.3 |
| 3 Years | 1368 | 0.16 | | 0 - 0.06 | 3.2 | 0 - 0.2 |
| **Site 8** | | | | | | |
| 2 Years | 144 | 1.22 | N/A | N/A | 1.4 | N/A |
| 3 Years | 72 | 1.68 | | N/A | 1.5 | N/A |

# Crash Data

- Results of 3-year before & after crash analysis at pilot sites show a reduction in ***Total***, ***Fatal & Injury***, and ***Angle*** Crashes but there is a high standard deviation around estimate so we're not clear on the magnitude of reduction.
- Pilot sites had moderate RLR crash patterns (most sites averaged 1 Angle Crash per year)
- The results showed an increase in ***Rear End*** Crashes but the standard deviation was also high around the estimate.
- We need more sites and more years of data before we can develop reliable CMFs --- **TBD**

https://www.youtube.com/watch?v=fcYdaCnLQRc&index=1&list=PLFPlSVRUEsJqDGOS458c2HfhYNy1QM4It

Video captured @ Wake Co. site where a pick-up entered 3 s into red & caused angle crash (no DARE)

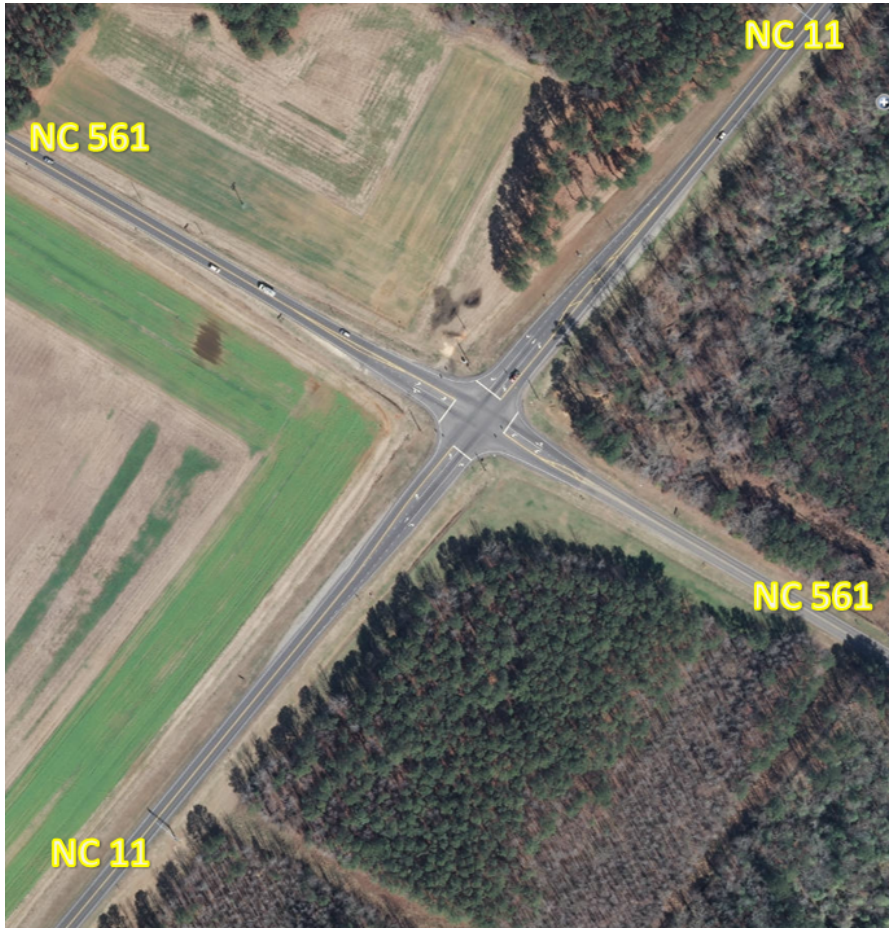
# Crash Data

## Before and After Case Study

NC 11 @ NC 561, Hertford County – Division 1

*Location Description & System Parameters*

- Installation Date: 2/2011
- Treated Approaches: NC 11 – Both
- Treated Road X-Section: 2 Ln
- Major/Minor AADT: 6,600/3,900 (2012)
- Signal: 2 Phase, Fully Actuated, Isolated
- Speed Limit (Major): 45 mph
- Yellow/Red Time: 5.2/3.0
- Alarm Time: 5
- Distance to Loops: 240'/256' (55 mph design)
- Other Existing CM: LVODS, Prepare to Stop LED
- Other New CM: Double Red, Red Rest
- GPS: 36.304214,-77.018872



# Crash Data

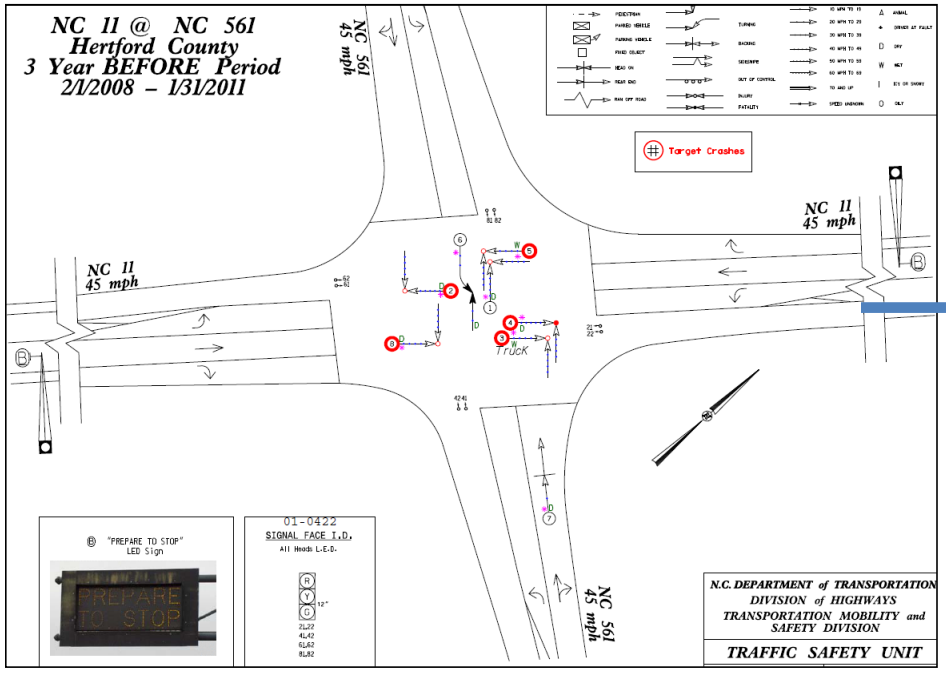
## Before and After Case Study

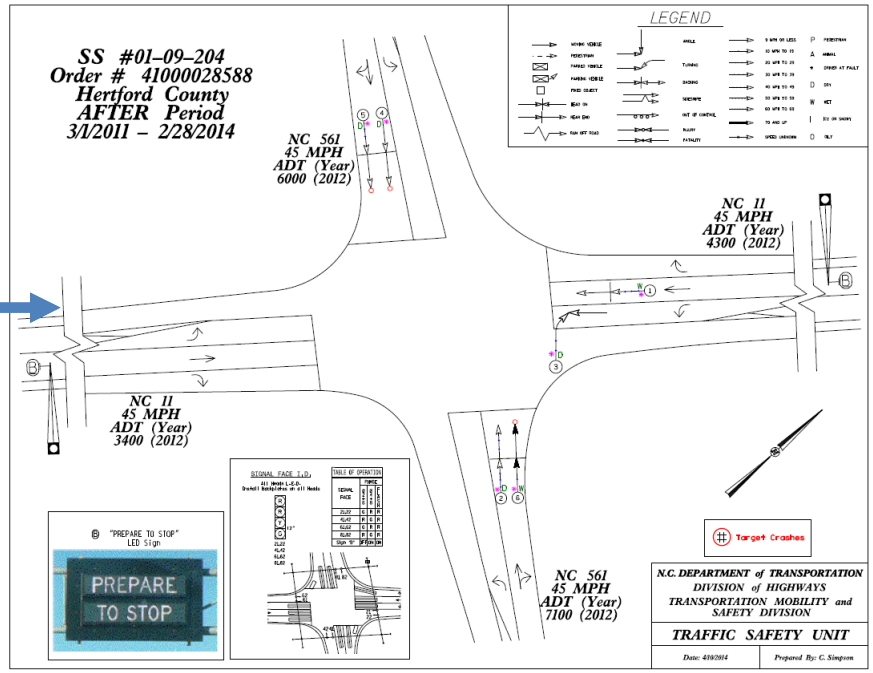
NC 11 @ NC 561, Hertford County – Division 1


# Crash Data

## Before and After Case Study

NC 11 @ NC 561, Hertford County – Division 1




From 1990 - 2010, historically averaged 2.5 target crashes/year and a fatal or Class-A injury crash every other year. In 3 years post project, 0 target crashes (above). In 5 years post project, 1 target crash. No fatal or Class-A injury crashes in 5 years.

# Crash Data

## Before and After Case Study

NC 87 @ SR 2220, Cumberland County – Division 6

*Location Description & System Parameters*

- Installation Date: 12/2016
- Treated Approaches: NC 87 – Both
- Treated Road X-Section: 4 Ln Divided
- Major/Minor AADT: 13,000/3,200 (2014)
- Signal: 2 Phase, Fully Actuated, Isolated
- Speed Limit (Major): 55 mph
- Yellow/Red Time: 5.7/2.0
- Alarm Time: 5
- Distance to Loops: 240'/256'
- Other New CM: Prepare to Stop LED
- GPS: 34.949627, -78.844661

# Crash Data

## Before and After Case Study

NC 87 @ SR 2220, Cumberland County – Division 6


| Treatment Information | Before 3.0 Years | After 0.6 Years | Percent Reduction (-) Percent Increase (+) |
|---|---|---|---|
| Total Crashes | 25 | 4 | N/A |
| Total Severity Index | 10.62 | 2.85 | - 73.2 % |
| **Total Crashes Per Year** | **8.3 CPY** | **6.7 CPY** | **- 19.3 %** |
| | | | |
| Target Crashes – NC 87 RLR | 7 | 0 | N/A |
| Target Crash Severity Index | 17.11 | 0.00 | - 100.0 % |
| **Target Crashes Per Year** | **2.3 CPY** | **0.0 CPY** | **- 100.0 %** |

# Conclusions

## Driver Adaption

- Minimal driver habituation was observed when comparing pre-installation to 1-year post-installation compliance results.

## Operational Performance

- DARE can operate and work as designed for an extended period of time with minimal maintenance issues.
- DARE was not associated with noticeable increases in delay. Due to the conservative design, systems generally produced a high proportion of false positive red extensions but results showed the amount of time spent on unnecessary red extensions is likely trivial, possibly ranging from 0 – 8 seconds per hour per treated approach at the rural, isolated pilot sites.

# Conclusions

## Safety

- DARE will not prevent all red light running crashes but it will provide extra protection against crashes caused by a specific group of mainline red light runners.
- By annualizing the number of red light runners targeted by DARE in the after period compliance study, one could expect over 500 red light runners per treatment potentially targeted by DARE every year (for similar sites).
- We don't know the relationship between the frequency of red light runners and the frequency of Angle Crashes, but we expect a crash reduction in Angle Crashes since we are targeting a portion of red light runners. Results show some promise with the limited sample.
- DARE can be a low cost countermeasure at approx. $5,000/approach when using inductive loops for detection and by tweaking existing controllers.
- CMF's will be developed when after data from newly installed sites is available.

# Implementation of a Dynamic All-Red Extension at Signalized Intersections in North Carolina

## Evaluation of Driver Adaptation and Operational Performance

Carrie L. Simpson, Mark W. Harrison, and Shawn A. Troy


Link to Paper - http://trrjournalonline.trb.org/doi/pdf/10.3141/2624-03

clsimpson@ncdot.gov
stroy@ncdot.gov

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

**Target**

http://youtu.be/LKCQvtPFMsQ

https://youtu.be/qJ52wMowehM?list=PLFPlSVRUEsJqDGOS458c2HfhYNy1QM4It

https://youtu.be/-pHBTlOoKEU?list=PLFPlSVRUEsJqDGOS458c2HfhYNy1QM4It

https://youtu.be/FwjAiPbKKwA?list=PLFPlSVRUEsJqDGOS458c2HfhYNy1QM4It

https://youtu.be/4kSvUbj4c5E?list=PLFPlSVRUEsJqDGOS458c2HfhYNy1QM4It

**Non Target**

https://youtu.be/uRsEUNWd7vQ?list=PLFPlSVRUEsJqDGOS458c2HfhYNy1QM4It