Evaluation of the Safety Effectiveness of “Vehicle Entering When Flashing” Signs and Actuated Flashers at 74 Stop-Controlled Intersections in North Carolina

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ABSTRACT

The purpose of this project is to evaluate the safety effectiveness of “Vehicle Entering When Flashing” (VEWF) intersection conflict warning systems at stop-controlled intersections. North Carolina Department of Transportation (NCDOT) has utilized this treatment consisting of vehicle actuated sign and flasher assemblies placed at or near the intersection to warn motorists on the major and/or minor road of vehicles entering the intersection. Although this countermeasure has been used for years in North Carolina, and similar intersection conflict warning system have been used in other States, there has been minimal safety evaluation to prove or validate its effectiveness.

Four categories of VEWF systems are evaluated. Sites are categorized based on the direction of the alert and placement from the intersection. Crash modification factors (CMFs) are provided for all sites and each category, as well as exclusively for sites with two-lane at two-lane intersection configurations. Empirical Bayes before and after techniques were utilized to overcome the regression to the mean threat. Deployments with major road alerts in advance of the intersection and a combination of both major and minor road alerts were determined to be most effective for two-lane at two-lane stop controlled intersections with CMFs for total crashes of 0.68 and 0.75, respectively.
INTRODUCTION

Motorists entering two-way stop-controlled intersections from the stop condition are required to make complex decisions considering the speed and direction of approaching vehicles. Errors in judgment may lead to a severe crash, especially when approaching vehicles are traveling at high speeds. Intersection-related crashes comprise a substantial portion of all crashes on our roadway system. In 2008, there were over 17,000 reported crashes at stop-controlled intersections in North Carolina resulting in over 7,000 fatal and injury crashes (1).

Traffic engineers have a limited number of tools to address crash patterns at stop-controlled intersections. Signalization is not always the best solution to reduce crashes, especially under high speed, low volume conditions. When the mainline traffic is required to stop under these conditions, the number of rear-end crashes may increase (2). Also, traffic signals do not always improve mobility for the intersection as a whole. While they may reduce delays on the lower volume roads, they also increase delays on the higher volume roads which may carry much more traffic (2).

Traditional continuously operating flashers at stop controlled intersections are meant to improve driver awareness and call attention to unexpected intersection conditions; however they do not address the gap-acceptance problem and have therefore provided only a modest improvement in safety (3).

The construction of a directional crossover or crossover closure is one of the few proven countermeasures to address frontal impact crashes at full movement intersections of multilane divided roadways; however, these treatments may come with strong political opposition and may not be quick and easy, short-term solutions. Also, they are not applicable to two-lane at two-lane intersections.

In many cases the conversion of traffic control from two-way to all-way stop control is an effective solution for reducing crash patterns at lower volume two-lane at two-lane intersections. The all-way stop treatment generally produces extremely competitive projects at sites with a strong pattern of frontal impact crashes that do not meet traffic signal warrants (4). In certain locations, however, proposed use of this treatment has come with formidable public opposition and other treatments were necessary.

Transportation agencies have turned to innovative treatments in recent years as a method to help motorists with the decision making process at stop-controlled intersections. North Carolina Department of Transportation (NCDOT) has utilized a treatment consisting of vehicle actuated sign and flasher assemblies placed at or near the intersection to provide motorists on the major and/or minor road with a warning of vehicles entering the intersection. These systems, known as “Vehicle Entering When Flashing” (VEWF), focus on aiding the driver in successfully negotiating the intersection. They are typically used as a treatment for locations with frontal impact crash patterns that may be caused by poor gap acceptance and/or sight distance issues. The stopped motorists still need to determine safe gaps in traffic and when it is safe to proceed, but depending on the sign configuration, either the stopped motorists are provided with more information to judge the suitability of available gaps in traffic or the through motorists are made aware of the vehicle at the approaching intersection. The VEWF systems are designed to be inherently simple and easy for unfamiliar motorists to understand. The first known VEWF systems in North Carolina were deployed in 1996 in Martin County (Division 1) and Rutherford County (Division 13). There are currently over 80 VEWF systems in North Carolina.

The intent of the VEWF system warning is to help drivers avoid conflicts and ultimately reduce the number of crashes, specifically high severity frontal impact crashes. However, there
has been little study to quantify their safety benefits. If the treatment is found to be effective in certain applications or under certain conditions, it may provide NCDOT and other transportation agencies with alternatives to more traditional safety tools aimed at reducing crash rates at non-signalized at-grade high crash intersections. It is a tool that is of particular interest because it is both low cost and relatively quick to implement. Therefore, we would like to determine the safety effectiveness of VEWF systems, as well as their most effective use and placement.

PROJECT SCOPE

The purpose of this project is to determine if the installation of VEWF systems reduce the number and severity of crashes at various types of two-way stop controlled intersections. Because a variety of sign configurations are used, we also want to determine if a particular sign placement and usage provides more safety benefit. This study will compare the crash data of stop controlled intersections before and after the assembly installation. The goal is to develop crash modification factors (CMFs) that reflect North Carolina conditions and decision-making. Other places with similar conditions might benefit from the findings as well.

Specific evaluation goals include:
- Development of CMFs for VEWF systems at stop controlled intersections
- Determine the safety effectiveness of the various categories of VEWF
- Determine the impact of major road cross section on treatment effectiveness
- Determine the impact of posted speed limits on treatment effectiveness

The measures of effectiveness for this project include:
1. Total Crashes
2. Target (Frontal Impact) Crashes
3. Injury Crashes, specifically Severe Injury Crashes

LITERATURE REVIEW

As part of a multistate Federal Highway Administration (FHWA) pooled fund study to evaluate low-cost highway safety strategies, a report entitled “Safety Evaluation of Flashing Beacons at Stop-Controlled Intersections” was published in 2007 to evaluate the safety effectiveness of flashing beacons (3). Three types of flashing beacons at stop-controlled intersections were considered collectively in the evaluation, including intersection control beacons, beacons mounted on STOP signs, and actuated beacons using 64 sites in North Carolina and 42 sites in South Carolina. The combined results using all flasher types show a statistically significant reduction in angle crashes of 13.3% (+/- 4.6%), with an injury and fatal crash reduction of 10.2% (+/-4.8%) percent. At a group of 17 actuated flasher sites in North Carolina, the study found a 14.0% (+/- 9.8%) reduction in angle crashes using Empirical Bayes methodology, although these results were not statistically significant at the 95% confidence level.

FHWA recently sponsored a technical report on the state of practice of route activated warning systems at stop-controlled intersections, which was published in February 2011 (5). The report includes the VEWF sites in North Carolina and also focuses on similar systems deployed in Missouri. It provides information and guidance on applying the technology, and includes practices used by these States on signing, design, and operation. The report notes
through-route activated warning systems have been successfully deployed by both States, and
show promise for improving safety at stop controlled intersections in other regions of the country
as well. The report further adds “through traffic advanced warning system is a tried technology.
While preliminary crash data analysis indicates the potential for a substantial reduction in
 crashes, there is insufficient data at this time to prove or validate its effectiveness.” (5) The
report recognizes the promise of certain configurations of these systems, but underscores the
need for a more robust evaluation of their safety effectiveness.

NCDOT has been a participant in the ENTERPRISE program transportation pooled
funded study “Developing Consistency in ITS Safety Solutions - Intersection Warning Systems”
TPF-5(231) (6). This study is working to provide agencies with more specific guidance for
intersection conflict warning systems in regard to placement, size, messaging, etc. due to the
broad range of systems in place and the lack of current standardization. The purpose is “to
develop a consistent approach for accelerated, uniform deployment and further evaluation of
intersection warning systems, and to recommend preliminary standards for MUTCD
consideration.” (6)

In December 2011, “Design and Evaluation Guidance for Intersection Conflict Warning
Systems (ICWS)” was prepared for the ENTERPRISE program and USDOT FHWA Office of
Safety (7). The document recommends design guidance for deploying intersection conflict
warning systems (ICWS) using current knowledge and practices. It also provides guidance to
enable agencies to evaluate their own ICWS deployments, and provides a basis for developing a
comprehensive multi-State evaluation of the systems. The report recognizes a comprehensive
observational before/after study should be conducted using the comparison group method so that
we may “better understand the collective effectiveness of ICWS and the best options for
standardization.” (7)

**VEWF CONFIGURATIONS**

VEWF systems provide an active, real-time warning that delivers motorists with more
information about intersection conditions. Depending on the assembly placement, they may be
used to warn drivers approaching an intersection if a vehicle is entering the intersection from the
minor road, or they may be used to provide guidance on gap selection for stopped drivers. The
assemblies include vehicle-actuated warning signs for stopped vehicles, vehicle-actuated
warning signs for through vehicles, or a combination of both.

Several different sign messages are used across North Carolina. A majority of signs read
“Vehicle Entering when Flashing”. Other messages include “Vehicle Entering”, “Watch for
Approaching Vehicles”, and “Vehicle Entering when Flashing from Left”. For the purposes of
this evaluation, we assume these signing variations are providing the driver with the same
general message.

Four categories of actuated signs and flashers are currently used in North Carolina. All
of the warnings depend upon detection of vehicle presence via inductive loops and activate
flashing beacon(s) in conjunction with a static sign. Figure 1 provides a typical photograph for
each category.

Category 1 – Overhead Signs and Flashers at the Intersection on Major, Loop on Minor
Category 2 – Overhead Signs and Flashers at the Intersection on Minor, Loop on Major
Category 3 – Post Mounted Signs and Flashers in Advance of Intersection on Major, Loop on
Minor
Category 4 – Locations with Combination of Category 1 through Category 3
FIGURE 1 Location photographs from a Category 1, 2 and 3 treatment intersection
Category 1 utilizes an overhead sign and flasher assembly placed at the intersection that
does not provide drivers on the through road with a warning of vehicle presence on the minor road. The
system operates through loop detector activation on the side-street to activate the signs. At least
one loop is placed on the minor road at the stop bar and in some cases an additional loop is
placed up to 960 feet before the intersection on the minor road based on location characteristics.
The system flashes for the duration of time a side-street vehicle is present.

Category 2 has an overhead sign and flasher assembly placed at the intersection to
provide drivers on the minor road with a warning of vehicle presence on the major road. The
system operates through loop detector activation on the major road to activate the signs.
Detection is placed 300-1,000 feet before the intersection. The location for mainline detection is
selected based on speeds and stopping sight distances. Depending on the location characteristics,
the system flashes up to 6-13 seconds after a mainline vehicle initially crosses the sensor in
either direction. Each subsequent vehicle then resets the timer. This flashing period is based on
the time it should take a vehicle traveling at the speed limit to clear the intersection after
triggering the sensor.

Category 3 operates similarly to Category 1, with the loop detector activation on the
minor road to activate the signs, although the signs and flashers are post mounted and located
350-975 feet in advance of the intersection. At least one loop is placed on the minor road at the
stop bar and in some cases an additional loop is placed up to 1,000 feet before the intersection on
the minor road based on location characteristics. The system flashes for the duration of time a
side-street vehicle is present.

Category 4 locations utilize a combination of Category 1 through Category 3 sign and
flasher assemblies. Seven of the eight locations use VEWF signs for both major and minor
approaches. The type and placement of signs and vehicle detection varies among the treatment
locations.

SITE SELECTION

Many of the VEWF systems were completed through the NCDOT Spot Safety Program, which is
used to develop smaller improvement projects to address safety and operational issues (8). A
majority of the treatment sites selected for study were obtained by searching this program
database; therefore many of the treatment sites had identified crash patterns/crash potential in the
before period.

The criteria for selecting treatment sites for study are as follows:

- At grade intersection under two-way stop sign control for the duration of the study
  period
- At least three years of ‘before’ crash data available
- At least one year of ‘after’ crash data available
- Presence of a VEWF system in the after period

A total of 74 intersections met these criteria and were analyzed for this project. Category
1 consists of 24 intersections, Category 2 consists of 19 intersections, Category 3 consists of 23
intersections, and Category 4 consists of 8 intersections.

Treatment sites were located in urban and rural areas with mainline approach speed
limits ranging from 35 mph to 55 mph, although the majority of sites were rural, isolated,
high speed facilities. The intersection annual average daily traffic (AADT) ranged from
approximately 3,000 to 30,000 vehicles entering per day. The type of mainline facilities varied with the intersection geometry including two-lane at two-lane, multilane (3 - 5 lanes) undivided at two-lane, and four-lane divided at two-lane sites.

**RESULTS**

A before and after crash analysis was performed at each intersection utilizing the Traffic Engineering Accident Analysis (TEAAS) software developed by NCDOT’s Traffic Engineering Branch. The software accesses the North Carolina Traffic Records Database which contains all reported crashes in the State since 1990. The current crash reporting threshold in North Carolina is $1,000. Because the installation dates varied from 1996 through 2010, the time periods analyzed for each location varied depending on when the treatment was installed. In most cases, the ending dates for the analyses were determined by the available crash data at the time the crash analysis was completed, which was through October 31, 2011. The before and after time periods consisted of an equal number of years when available; however, there was an unequal number of years at some locations with less than three years of after period data available. At these locations an adjustment was made to account for the different before and after time periods. To account for construction and installation periods, the three months surrounding the installation dates were omitted from this analysis. The crash analyses were terminated before other known countermeasures were implemented. At least 24 sites had other treatments implemented after VEWF was installed. The data consisted of all crashes within 150 feet of the treatment intersections.

Crash data are provided for total, frontal impact, injury, and severe injury crashes. Injury crashes include fatal and non-fatal injury crashes combined. Severe injury crashes include only fatal (K) and disabling (Class-A) injury crashes. Frontal impact crash types considered are as follows: left turn, same roadway; left turn, different roadways; right turn, same roadway; right turn, different roadways; head on; and angle. Frontal impact crashes occurring in the intersection or related to the intersection are considered target crashes for this countermeasure.

**Empirical Bayes Method**

There are notable limitations with using a naïve before and after analysis because it assumes nothing changed from the before period to the after period except for the treatment, and any changes in crashes can be attributed to the treatment. Therefore, Empirical Bayes before and after techniques were utilized to account for selection bias and to overcome the threat of regression to the mean, along with other potential deficiencies in a naïve before and after analysis. Regression to the mean is the presumption a site will return to its long-term mean crash frequency after an extraordinarily high or low period. Regression to the mean was a significant threat in our case because crash history was known to be a factor in the selection of treatment at many of the locations.

The Empirical Bayes approach requires the use of reference sites as well as before period data from the treatment site to estimate the expected safety of the treatment site had no improvements been made. We then compare the actual number of after period crashes at the treatment site to the expected number of after period crashes at the treatment site without improvements.

A linear assumption was used to account for changes in traffic volume experienced at the treatment sites. The increase in traffic volumes was a concern because of the long duration of
before and after periods at each of the sites. Some of the analysis periods were over ten years in
duration, and the average before period was approximately five years.

The criteria used for selecting reference sites are as follows:
- At grade intersection under two-way stop sign control for the duration of the
study period, and
- Exhibited similar intersection geometry to the treatment group.

Aerial maps and NCDOT traffic volume maps were used in the selection of reference
sites and to confirm they met these criteria. Reference site crash data were compiled separately
for the individual before periods at the treatment sites. Approximately five reference sites per
treatment site were chosen, which includes 317 two-lane at two-lane reference sites and 59 four-
lane divided at two-lane reference sites. We were unable to obtain a suitable reference group for
the 7 multi-lane undivided at two-lane treatment sites, therefore the Empirical Bayes analysis
was completed excluding these sites. Table 1 provides the results of the Empirical Bayes
analysis with the traffic volume adjustment for all locations, as well as Categories 1-4.

The value after the “+/-” notation indicates the standard deviation of an estimated value.
Conventional Hauer (1997) symbology and methodology was used in the countermeasure
evaluation (9).

In the following tables, parameter estimates are denoted as follows:

\( \lambda \) = Actual number of after period crashes,
\( \pi \) = Predicted number of after period crashes,
CMF = Ratio of what safety was with the treatment to what it would have been without
the treatment, used as a multiplicative factor used to compute the expected number of
crashes after implementing a given countermeasure,
CRF = Estimate of the percent reduction in crashes that might be expected after
implementing the countermeasure (10)

The results are provided in the following tables as both CMF and CRF estimates; however for
ease of discussion, the results will be discussed using CRF estimates. The CRF is calculated as
\((1 - \text{CMF}) \times 100\).
TABLE 1 Parameter Estimates Using Empirical Bayes Methods with Consideration for Traffic Increase (All Sites)

<table>
<thead>
<tr>
<th></th>
<th>λ</th>
<th>π</th>
<th>CMF</th>
<th>CRF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Crashes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Sites</td>
<td>952 +/- 31</td>
<td>1020 +/- 34</td>
<td>0.932 +/- 0.043</td>
<td>6.8% +/- 4.3%</td>
</tr>
<tr>
<td>Category 1</td>
<td>315 +/- 18</td>
<td>287 +/- 19</td>
<td>1.091 +/- 0.094</td>
<td>-9.1% +/- 9.4%</td>
</tr>
<tr>
<td>Category 2</td>
<td>295 +/- 17</td>
<td>305 +/- 18</td>
<td>0.965 +/- 0.081</td>
<td>3.5% +/- 8.1%</td>
</tr>
<tr>
<td>Category 3</td>
<td>275 +/- 17</td>
<td>340 +/- 20</td>
<td>0.807 +/- 0.067</td>
<td>19.3% +/- 6.7%</td>
</tr>
<tr>
<td>Category 4</td>
<td>67 +/- 8</td>
<td>89 +/- 10</td>
<td>0.749 +/- 0.120</td>
<td>25.1% +/- 12.0%</td>
</tr>
<tr>
<td><strong>Target Crashes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Sites</td>
<td>774 +/- 28</td>
<td>799 +/- 30</td>
<td>0.968 +/- 0.050</td>
<td>3.2% +/- 5.0%</td>
</tr>
<tr>
<td>Category 1</td>
<td>248 +/- 16</td>
<td>225 +/- 16</td>
<td>1.096 +/- 0.105</td>
<td>-9.6% +/- 10.5%</td>
</tr>
<tr>
<td>Category 2</td>
<td>246 +/- 16</td>
<td>235 +/- 16</td>
<td>1.043 +/- 0.097</td>
<td>-4.3% +/- 9.7%</td>
</tr>
<tr>
<td>Category 3</td>
<td>226 +/- 15</td>
<td>272 +/- 17</td>
<td>0.827 +/- 0.076</td>
<td>17.3% +/- 7.6%</td>
</tr>
<tr>
<td>Category 4</td>
<td>54 +/- 7</td>
<td>67 +/- 8</td>
<td>0.797 +/- 0.144</td>
<td>20.3% +/- 14.4%</td>
</tr>
<tr>
<td><strong>Injury Crashes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Sites</td>
<td>580 +/- 24</td>
<td>619 +/- 26</td>
<td>0.936 +/- 0.055</td>
<td>6.4% +/- 5.5%</td>
</tr>
<tr>
<td>Category 1</td>
<td>176 +/- 13</td>
<td>184 +/- 15</td>
<td>0.950 +/- 0.104</td>
<td>5.0% +/- 10.4%</td>
</tr>
<tr>
<td>Category 2</td>
<td>174 +/- 13</td>
<td>177 +/- 14</td>
<td>0.976 +/- 0.105</td>
<td>2.4% +/- 10.5%</td>
</tr>
<tr>
<td>Category 3</td>
<td>191 +/- 14</td>
<td>214 +/- 15</td>
<td>0.890 +/- 0.090</td>
<td>11.0% +/- 9.0%</td>
</tr>
<tr>
<td>Category 4</td>
<td>39 +/- 6</td>
<td>44 +/- 7</td>
<td>0.870 +/- 0.187</td>
<td>13.0% +/- 18.7%</td>
</tr>
<tr>
<td><strong>Severe Injury Crashes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Sites</td>
<td>51 +/- 7</td>
<td>60 +/- 8</td>
<td>0.836 +/- 0.159</td>
<td>16.4% +/- 15.9%</td>
</tr>
<tr>
<td>Category 1</td>
<td>13 +/- 4</td>
<td>18 +/- 4</td>
<td>0.689 +/- 0.242</td>
<td>31.1% +/- 24.2%</td>
</tr>
<tr>
<td>Category 2</td>
<td>16 +/- 4</td>
<td>18 +/- 4</td>
<td>0.859 +/- 0.282</td>
<td>14.1% +/- 28.2%</td>
</tr>
<tr>
<td>Category 3</td>
<td>21 +/- 5</td>
<td>21 +/- 5</td>
<td>0.932 +/- 0.279</td>
<td>6.8% +/- 27.9%</td>
</tr>
<tr>
<td>Category 4</td>
<td>1 +/- 1</td>
<td>3 +/- 2</td>
<td>0.242 +/- 0.212</td>
<td>75.8% +/- 21.2%</td>
</tr>
</tbody>
</table>

Note: Bold denotes results that are statistically significant at the 95% confidence interval using the Chi-Square test.

When considering 67 treatment locations, the results of the Empirical Bayes analysis with the traffic volume adjustment yielded a 7% (+/- 4%) reduction in total crashes, a 3% (+/- 5%) reduction in target crashes, a 6% (+/- 6%) reduction in injury crashes, and a 16% (+/- 16%) reduction in severe injury crashes. Note that the Category 4 results, as well as the results for severe injury crashes for all categories, should be viewed with some reserve due to the small sample sizes.

Figure 2 provides a graphical view of the CRFs calculated using the Empirical Bayes method for total crashes in Categories 1-4. Note that a positive CRF estimate indicates a reduction in crashes. As shown in the figure, there was a noticeably greater reduction in total crashes for Categories 3 and 4 than Categories 1 and 2. Category 1 actually showed an increase in total crashes.
Comparison of Results by Intersection Lane Geometry

The data set is comprised of 56 two-lane at two-lane intersections, 11 four-lane divided at two-lane intersections, and 7 multi-lane undivided at two-lane intersections. The number of available sites within each intersection configuration limited further study solely to the group of two-lane at two-lane intersections, which provides a good sample of crash data and enables more detailed Empirical Bayes analysis, although we provide the following commentary on the four-lane divided at two-lane intersections.

Seven of 11 (64%) of the four-lane divided locations are known to have had additional safety countermeasures installed within several years after the VEWF was completed, which is an indicator that the VEWF system was not effective at these sites. The naïve crash analysis results for four-lane divided at two-lane intersections also show no apparent reduction in crashes at these sites. Overall, the locations with this intersection geometry did not experience a reduction in total, target, injury or severe injury crashes. The use of VEWF systems at four-lane divided at two-lane intersections may be more a “band-aid” treatment that does not address the root cause of crashes in this situation and a geometric change (i.e. directional crossover, offsetting minor road legs, or crossover closure) may be a more appropriate solution to address crash patterns likely related to gap-acceptance. Although the number of treatment sites is relatively low, based on the naïve crash analysis results and our experience with the treatment locations, we believe the installation of VEWF systems is not an appropriate treatment for most intersections with a four-lane divided roadway experiencing a strong frontal impact crash pattern. If more locations are available in other States, further study should re-examine the effectiveness of VEWF systems at four-lane divided locations using a larger group of sites. Also, multi-lane undivided locations should be analyzed using Empirical Bayes methodology if
more locations are available for study in the future. The remainder of this paper will focus on
VEWF systems for two-lane at two-lane intersections.

**Two-Lane at Two-Lane Intersections**

Table 2 provides the results of the Empirical Bayes analysis with the traffic volume adjustment
for two-lane at two-lane intersections. The results are provided separately by individual category
and for all categories combined. When analyzing all two-lane at two-lane sites combined, the
results demonstrate a reduction in crashes for all of the crash types analyzed. The results
indicate the Category 3 and 4 locations generally experienced the greatest reductions in crashes.
The Category 3 group shows the largest reduction in total, target and injury crash types. As
stated previously, the Category 4 results, as well as the results for severe injury crashes for all
categories, should be viewed with some reserve due to the small sample sizes.

**TABLE 2 Parameter Estimates Using Empirical Bayes Methods with Consideration for Traffic Increase**
*(Two-Lane at Two-Lane Intersections)*

<table>
<thead>
<tr>
<th>Category</th>
<th>λ</th>
<th>π</th>
<th>CMF</th>
<th>CRF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Crashes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Sites</td>
<td>729</td>
<td>27</td>
<td>812 +/− 30</td>
<td>0.897 +/− 0.047</td>
</tr>
<tr>
<td>Category 1</td>
<td>260</td>
<td>16</td>
<td>244 +/− 17</td>
<td>1.059 +/− 0.098</td>
</tr>
<tr>
<td>Category 2</td>
<td>264</td>
<td>16</td>
<td>276 +/− 17</td>
<td>0.953 +/− 0.084</td>
</tr>
<tr>
<td>Category 3</td>
<td>138</td>
<td>12</td>
<td>203 +/− 15</td>
<td>0.675 +/− 0.076</td>
</tr>
<tr>
<td>Category 4</td>
<td>67</td>
<td>8</td>
<td>89 +/− 8</td>
<td>0.749 +/− 0.115</td>
</tr>
<tr>
<td><strong>Target Crashes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Sites</td>
<td>583</td>
<td>24</td>
<td>626 +/− 26</td>
<td>0.929 +/− 0.055</td>
</tr>
<tr>
<td>Category 1</td>
<td>204</td>
<td>14</td>
<td>189 +/− 15</td>
<td>1.074 +/− 0.112</td>
</tr>
<tr>
<td>Category 2</td>
<td>224</td>
<td>15</td>
<td>223 +/− 16</td>
<td>1.001 +/− 0.096</td>
</tr>
<tr>
<td>Category 3</td>
<td>101</td>
<td>10</td>
<td>148 +/− 13</td>
<td>0.679 +/− 0.088</td>
</tr>
<tr>
<td>Category 4</td>
<td>54</td>
<td>7</td>
<td>67 +/− 8</td>
<td>0.797 +/− 0.144</td>
</tr>
<tr>
<td><strong>Injury Crashes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Sites</td>
<td>431</td>
<td>21</td>
<td>490 +/− 23</td>
<td>0.878 +/− 0.059</td>
</tr>
<tr>
<td>Category 1</td>
<td>146</td>
<td>12</td>
<td>158 +/− 14</td>
<td>0.917 +/− 0.108</td>
</tr>
<tr>
<td>Category 2</td>
<td>155</td>
<td>12</td>
<td>165 +/− 13</td>
<td>0.934 +/− 0.106</td>
</tr>
<tr>
<td>Category 3</td>
<td>91</td>
<td>10</td>
<td>123 +/− 12</td>
<td>0.732 +/− 0.102</td>
</tr>
<tr>
<td>Category 4</td>
<td>39</td>
<td>6</td>
<td>44 +/− 7</td>
<td>0.870 +/− 0.187</td>
</tr>
<tr>
<td><strong>Severe Injury Crashes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Sites</td>
<td>32</td>
<td>6</td>
<td>45 +/− 7</td>
<td>0.697 +/− 0.159</td>
</tr>
<tr>
<td>Category 1</td>
<td>10</td>
<td>3</td>
<td>15 +/− 4</td>
<td>0.613 +/− 0.236</td>
</tr>
<tr>
<td>Category 2</td>
<td>13</td>
<td>4</td>
<td>16 +/− 4</td>
<td>0.761 +/− 0.268</td>
</tr>
<tr>
<td>Category 3</td>
<td>8</td>
<td>3</td>
<td>10 +/− 3</td>
<td>0.699 +/− 0.301</td>
</tr>
<tr>
<td>Category 4</td>
<td>1</td>
<td>1</td>
<td>3 +/− 2</td>
<td>0.242 +/− 0.212</td>
</tr>
</tbody>
</table>

Note: Bold denotes results that are statistically significant at the 95% confidence interval using
the Chi-Square test.
Analysis of Mainline Speed Limits for Two-Lane at Two-Lane Intersections

Figure 3 provides a comparison of the CRF estimates calculated for two-lane at two-lane treatment intersections with mainline speed limits of 45 mph and 55 mph. The results are provided for total, target, injury and severe (K and A) injury crashes, regardless of category. Approximately 77% (43 of 56) of the two-lane at two-lane treatment sites have 55 mph mainline speed limits. The percentage of sites within each category was relatively similar for both speed limit groups.

The results demonstrate the two-lane at two-lane treatment sites show a reduction in crashes regardless of the mainline speed limit. However, the treatment sites with a 45 mph mainline speed limit may have been more effective at reducing crashes than sites with a 55 mph mainline speed limit. The results suggest that VEWF systems may provide more benefit for intersections with a lower mainline speed limit, although a larger sample of sites with 45 mph mainline speed limits should be analyzed to validate these results. Providing a warning directed at mainline motorists (in 3 of 4 categories) in conjunction with lower mainline speed limits, may create a situation that gives through vehicles more time to avoid vehicles entering the intersection from the minor road.

FIGURE 3  Comparison of CRFs for Treatment Sites with 45 mph and 55 mph Mainline Speed Limits (Two-Lane at Two-Lane Intersections)
DISCUSSION

The recommended CMF and CRF estimates for installation of a VEWF system at a two-lane at two-lane stop-controlled intersection are provided below. The safety estimates are provided separately by category because the categories demonstrated a range of effectiveness at reducing crashes. The factors were calculated using the Empirical Bayes method with consideration for traffic increase at 56 treatment sites. If the reader is interested in viewing the results based on a more expansive group of locations, please refer to the results section of this paper for factors using data from sites with a variety of intersection geometries. The results are provided here exclusively for two-lane at two-lane intersections because this geometry type is most representative of VEWF implementations in North Carolina.

Two-Lane at Two-Lane Stop Controlled Intersections:

Category 1 (overhead signs at intersection on major and loops on minor)

<table>
<thead>
<tr>
<th></th>
<th>CMF</th>
<th>CRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Crashes</td>
<td>1.06 +/- 0.10</td>
<td>-6% +/- 10%</td>
</tr>
<tr>
<td>Target Crashes</td>
<td>1.07 +/- 0.11</td>
<td>-7% +/- 11%</td>
</tr>
<tr>
<td>Injury Crashes</td>
<td>0.92 +/- 0.11</td>
<td>8% +/- 11%</td>
</tr>
<tr>
<td>Severe Injury Crashes</td>
<td>0.61 +/- 0.24</td>
<td>39% +/- 24%</td>
</tr>
</tbody>
</table>

Category 2 (overhead signs at intersection on minor and loops on major)

<table>
<thead>
<tr>
<th></th>
<th>CMF</th>
<th>CRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Crashes</td>
<td>0.95 +/- 0.08</td>
<td>5% +/- 8%</td>
</tr>
<tr>
<td>Target Crashes</td>
<td>1.00 +/- 0.10</td>
<td>0% +/- 10%</td>
</tr>
<tr>
<td>Injury Crashes</td>
<td>0.93 +/- 0.11</td>
<td>7% +/- 11%</td>
</tr>
<tr>
<td>Severe Injury Crashes</td>
<td>0.76 +/- 0.27</td>
<td>24% +/- 27%</td>
</tr>
</tbody>
</table>

Category 3 (advance post mounted signs on major and loops on minor)

<table>
<thead>
<tr>
<th></th>
<th>CMF</th>
<th>CRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Crashes</td>
<td>0.68 +/- 0.08</td>
<td>32% +/- 8%</td>
</tr>
<tr>
<td>Target Crashes</td>
<td>0.68 +/- 0.09</td>
<td>32% +/- 9%</td>
</tr>
<tr>
<td>Injury Crashes</td>
<td>0.73 +/- 0.10</td>
<td>27% +/- 10%</td>
</tr>
<tr>
<td>Severe Injury Crashes</td>
<td>0.70 +/- 0.30</td>
<td>30% +/- 30%</td>
</tr>
</tbody>
</table>

Category 4 (combination of Category 1-3 signing)

<table>
<thead>
<tr>
<th></th>
<th>CMF</th>
<th>CRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Crashes</td>
<td>0.75 +/- 0.12</td>
<td>25% +/- 12%</td>
</tr>
<tr>
<td>Target Crashes</td>
<td>0.80 +/- 0.14</td>
<td>20% +/- 14%</td>
</tr>
<tr>
<td>Injury Crashes</td>
<td>0.87 +/- 0.19</td>
<td>13% +/- 19%</td>
</tr>
<tr>
<td>Severe Injury Crashes</td>
<td>0.24 +/- 0.21</td>
<td>76% +/- 21%</td>
</tr>
</tbody>
</table>

There is a noticeable spread in the crash analysis results for total and target crashes for Categories 1 and 2 as compared with Categories 3 and 4. All categories show a reduction in severe injury crashes, although there was an especially small sample of severe injury crashes at the treatment locations.

Certain categories of VEWF systems show more promise for two-lane at two-lane intersections than others based on the crash analysis results. Category 2, with overhead signs at
the intersection on the minor, is intended to assist stopped drivers choose safer gaps and reduce
gap-related crashes, although the results for two-lane at two-lane sites reveal none of the studied

The results show an increase in total and target crashes for two-lane at two-lane

severe injury crashes. Overhead signs, which are located on span-wire in the intersection, may

Category 3, with post-mounted signs placed in advance of the intersection on the major
road, appears to be the most beneficial category for two-lane at two-lane intersections. Overall,

variations within the eight sites in this category. Future research should refine Category 4
signing and determine the optimal design when using alerts for both approaches.

Based on the results of this evaluation, NCDOT plans future installations of VEWF
systems to be limited to either Category 3 or Category 4 with post-mounted major road signing at
2-lane at 2-lane intersections. This realization/suggestion mirrors sentiments from the FHWA
report “Stop-Controlled Intersection Safety: Through Route Activated Warning Systems”, which
suggests present systems warning drivers on the through approach of a stopped vehicle are the
“only one of them [that] has the potential to be successfully implemented at a considerable
number of intersections and substantially reduce crashes at those intersections” at the current

The magnitude of effectiveness for VEWF systems should be viewed within context of
other low-cost countermeasures that are available for 2-lane at 2-lane intersections. Category 3
and 4 signing may have a niche at 2-lane at 2-lane intersections, but they are one of several low
cost countermeasures used by NCDOT to treat lower volume stop controlled two-lane at two-lane intersections experiencing severe angle crash patterns. Table 3 provides a summary of several low cost safety treatments used by traffic engineers to treat locations with this type of crash pattern. The total CRF, Injury CRF, average cost of installation, and intersection AADT range for locations used in past NCDOT evaluations are provided for conversion to all way stop control, installation of standard overhead flashing beacons, as well as installation of each VEWF Category (4, 11). While installation of either category 3 or 4 VEWF provides a sound reduction in total and injury crashes, conversion to all-way stop control provides a bigger benefit at a slightly lesser cost for low volume two-lane at two-lane intersections.

**TABLE 3** Comparison of several low cost safety treatments for 2-lane at 2-lane stop controlled intersections

<table>
<thead>
<tr>
<th></th>
<th>Total CRF</th>
<th>Injury CRF</th>
<th>Average Cost</th>
<th>Intersection AADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Way Stop (Installed with Overhead Flashing Beacons)</td>
<td>82 (+/-4)%</td>
<td>87 (+/-4)%</td>
<td>$20,000</td>
<td>1,400-9,900</td>
</tr>
<tr>
<td>All Way Stop (Signs Only)</td>
<td>61 (+/-3)%</td>
<td>72 (+/-4)%</td>
<td>$5,000</td>
<td>680-15,100</td>
</tr>
<tr>
<td>VEWF Category 3</td>
<td>32 (+/-8)%</td>
<td>27 (+/-10)%</td>
<td>$21,200</td>
<td>2,800-9,700</td>
</tr>
<tr>
<td>VEWF Category 4</td>
<td>25 (+/-12)%</td>
<td>13 (+/-19)%</td>
<td>$28,000</td>
<td>2,400-9,300</td>
</tr>
<tr>
<td>Overhead Flashing Beacon</td>
<td>12 (+/-6)%</td>
<td>9 (+/-8)%</td>
<td>$20,000</td>
<td>1,100-14,000</td>
</tr>
<tr>
<td>VEWF Category 2</td>
<td>5 (+/-8)%</td>
<td>7 (+/-11)%</td>
<td>$21,900</td>
<td>3,200-12,100</td>
</tr>
<tr>
<td>VEWF Category 1</td>
<td>-6 (+/-10)%</td>
<td>8 (+/-11)%</td>
<td>$22,800</td>
<td>1,500-12,200</td>
</tr>
</tbody>
</table>

1 VEWF costs obtained from sites with available project information in Spot Safety project files. All way stop and flashing beacon costs obtained from prior NCDOT evaluations.

2 Range of intersection AADTs for locations used in evaluations.

**Items for Future Research**

We are not able to account for all of the different location conditions and sign configurations (such as sign placement, message set, dynamic elements, etc.) in this study because of the number of variations within the data. These items should be investigated when more locations are available for analysis. We hope other states with similar conditions might benefit from the findings as well, however it should also be noted that other places using different variations of intersection conflict warning signs may have different experiences and results.

The following is a list of items that should be addressed in future research. It will be beneficial to determine the role each of these items play in improving VEWF effectiveness.

- Sign message
- Sign size
- Combined messaging on both major and minor approaches
- Distance on major approach from intersection to signs (for sites with advance post mounted signs)
- Distance on major and/or minor approaches from intersection to loops
- Number of loops on the minor approach (some have lead in loops)
• Variability of detector timing setting
• Other safety treatments used in conjunction with VEWF, such as flashing beacons
• Sight distance
• Roadway grade on major and minor approaches
• Traffic volume thresholds
• Additional analysis of intersection lane geometry (i.e. 4-lane divided at 2-lane and multilane undivided at 2-lane)

In the near future, multiple initiatives will be aimed at taking a more comprehensive look at standardization issues as well as at the crash effects of intersection conflict warning signs (ICWS) on a multi-state level. Hopefully this research will be able to address many of the items listed above. The following three pooled fund projects related to ICWS are underway:

• ENTERPRISE pooled fund study TPF-5(231), which retains the primary coordination role, will set systems requirements and a concept of operations for four types of ICWS (12).
• Traffic Control Devices pooled fund study TPF-5(065) will conduct human factors research on ICWS signing (12). The purpose of the project is to “further explore in a simulated environment which sign combination, placement and legend variables produce optimal driver understanding and behavior” (13).
• Evaluation of Low Cost Safety Improvements pooled fund study TPF-5(099) will conduct a nationally-oriented ICWS safety effectiveness evaluation as part of their Phase VII work plan. This evaluation will focus on a statistical analysis of crash data from sites installed around the country (13).

ACKNOWLEDGEMENTS
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