Emerging Practices for Addressing Motorcycle Crashes at Intersections

FHWA Safety Program

U.S. Department of Transportation
Federal Highway Administration

Safe Roads for a Safer Future
Investment in roadway safety saves lives

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FOREWORD

This project identifies emerging practices for infrastructure treatments that show promise in reducing motorcycle crashes at intersections. Intersections are a dangerous space for motorcycling and our hope in pursuing this work was to find quantitative proof that infrastructure treatments like increased surface friction, improved signage, and changes to signals (and other possible treatments) can reduce the frequency and severity of motorcycle crashes. There are, however, few examples of intersection infrastructure treatments designed and implemented specifically to improve *only* motorcycle safety. This report examines case studies of several treatments that State and local agencies implemented to improve general safety in intersections and which may have had a benefit for motorcycle safety as well. FHWA encourages the use of these examples to help transportation safety practitioners design and implement treatments at sites where motorcycle safety is of particular concern.

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This project focused on identifying intersection infrastructure treatments that produced a quantifiable improvement in motorcycle safety. The project team conducted a motorcycle crash analysis focusing on identifying characteristics that directly influence or are overrepresented in motorcycle crashes at intersections. Next, the team conducted a literature review identifying infrastructure-related countermeasures either specifically designed to improve motorcycle safety or that might improve motorcycle safety as part of an overall safety improvement. The project team contacted six States that reported implementing one or more of the candidate intersection treatments (Illinois, Kentucky, North Carolina, Ohio, Pennsylvania, and Texas). This final report describes six case studies arising from those contacts.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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ACRONYMS

AADT	annual average daily traffic
AMA	American Motorcycle Association
BOT	Board of Transportation
CMF	crash modification factor
DFT	Dynamic Friction Test
EB	empirical Bayes
EDC	Every Day Counts
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FYA	flashing yellow arrow
HFST	high friction surface treatment
HSIP	Highway Safety Improvement Program
ICWS	intersection conflict warning system
KYTC	Kentucky Transportation Cabinet
MUTCD	Manual on Uniform Traffic Control Devices
NCDOT	North Carolina Department of Transportation
ODOT	Ohio Department of Transportation
O.N.E.	Once is Never Enough
SHSP	Strategic Highway Safety Plan
SOC	Safety Oversight Committee
SPF	safety performance functions
TMC	Traffic Management Center

UIIG	Unsignalized Intersection Improvement Guide
VMT	vehicle miles traveled

EXECUTIVE SUMMARY

In the U.S. in 2016, motorcyclist fatalities reached their highest level since 2008. In 2015 (the most recent year for which detailed data are complete) one-third of motorcyclist fatalities occurred at intersections.[1,2] The vulnerability of motorcyclists and their unique handling characteristics present a special challenge to road safety efforts. The Federal Highway Administration (FHWA) initiated this project to identify infrastructure treatments that may impact motorcycle safety at intersections and, where possible, quantify or characterize the effectiveness of those treatments. Based on a literature review, the project team identified a list of candidate infrastructure treatments with a potential for motorcycle safety benefits. Next, the team reached out to agencies around the U.S. looking for those with experience implementing any of the candidate treatments. Finally, the team documented the experiences based on information and feedback received from Kentucky, North Carolina, and Ohio. The treatments described here include signal phasing, warning signs, and high friction surfacing. Although data limitations presented a barrier to quantifying motorcycle safety improvements at the selected sites, some of the case studies have shown positive results in previous research for all crash types. Therefore, the case studies are presented as emerging practices that agencies may consider implementing at intersections to reduce motorcycle crashes.

I. BACKGROUND

In the U.S. in 2016, motorcyclist fatalities reached their highest level since 2008.[1] Motorcycles represented 3 percent of registered vehicles and an estimated 0.6 percent of Vehicle Miles Traveled (VMT) yet accounted for 17 percent of all occupant fatalities in 2015.[2] In the same year, the fatality rate for motorcyclists, per registered vehicle, was six times the rate for passenger car occupants. Based on 2015 Fatality Analysis Reporting System (FARS) data, the highest frequency most harmful events for motorcycles in fatal crashes (5,076) were collisions with other moving motor vehicles (54 percent), collisions with fixed objects such as signs, barriers, and vegetation" (24 percent), and non-collisions including run-off-road and "rollover" events (17 percent).[3]

One-third of the motorcyclist fatalities that occurred in 2015 were at intersections. The highest percentage of intersection-related motorcyclist fatalities were at four-way intersections (55 percent), followed by T-intersections (41 percent).[4] Motorcycle crash data points to a need for transportation agencies to address the vulnerability of motorcyclists and their unique handling characteristics at intersections. In the U.S., agencies have reviewed motorcycle safety efforts domestically and abroad that focus on infrastructure-related improvements; however, it is rare to find implementation of motorcycle-specific infrastructure treatments at intersections. Over 40 States include motorcycle safety as an emphasis area in their Strategic Highway Safety Plans (SHSP), but few of the strategies listed target infrastructure improvements. Intersection safety emphasis areas in SHSPs also do not include motorcycle-specific strategies. This project was a first attempt to explore, quantify, or characterize the potential effectiveness of emerging infrastructure-based treatments implemented at intersections that could have a positive impact by reducing motorcycle crashes.

The project team conducted a motorcycle crash analysis focusing on identifying characteristics that directly influence or are overrepresented in motorcycle crashes at intersections. Next, the team conducted a literature review identifying infrastructure-related countermeasures either specifically designed to improve motorcycle safety or that might improve motorcycle safety as part of an overall safety improvement. The project team developed a list of infrastructure treatments with likely motorcycle safety benefits. Many of the treatments reduce the types of crashes that occur at intersections that often involve motorcycles. As part of this review, the project team used the Crash Modification Factor (CMF) Clearinghouse to link countermeasures with a potential benefit to motorcyclists with existing practices in States.[5] The project team contacted six States that reported implementing one or more of the candidate intersection treatments (Illinois, Kentucky, North Carolina, Ohio, Pennsylvania, and Texas). The final step involved selecting six projects as case studies and to document those experiences in this final report.

AUDIENCE

The audience for this document includes:

- State safety engineers, designers, and planners.
- Local and Metropolitan Planning Organization/Regional Planning Commission safety engineers, designers, and planners.
- State Highway Safety Office motorcycle safety program managers and other personnel.
- Researchers.
- Motorcycle safety interest groups.
- Professional organization members.

II. PERMISSIVE GREEN TO FLASHING YELLOW ARROW PROTECTED-PERMISSIVE LEFT-TURN PHASING – ROANOKE RAPIDS, NC

TREATMENT DESCRIPTION

Replacing a fully permissive green left-turn phase with a flashing yellow arrow (FYA) that provides a protected, followed by permissive left-turn movement at signalized intersections aims to avoid confusion for drivers turning left on a permissive circular green light. The concern is that drivers turning left on a permissive circular green signal indication might mistake that indication as implying the left turn has the right of way over opposing traffic, especially under some geometric conditions.

The following signal displays for FYA are prescribed on the FHWA MUTCD website:[6]

1. During a protected left-turn movement, the left-turn signal face shall display only a steady left-turn GREEN ARROW signal indication.
2. During a permissive left-turn movement, the left-turn signal face shall display only a flashing left-turn YELLOW ARROW signal indication.
3. During a prohibited left-turn movement, the left-turn signal face shall display only a steady left-turn RED ARROW or a steady CIRCULAR RED.
4. A steady left-turn YELLOW ARROW signal indication shall be displayed following every steady left-turn GREEN ARROW signal indication.
5. A steady left-turn YELLOW ARROW signal indication shall be displayed following the flashing left-turn YELLOW ARROW signal indication if the permissive left-turn movement is being terminated and the left-turn signal face will subsequently display a steady red signal indication. The signal section that displays the steady left-turn YELLOW ARROW signal indication during change intervals shall not be used to display the flashing left-turn YELLOW ARROW signal indication for permissive left turns.
6. When a permissive left-turn movement is changing to a protected left-turn movement, a steady left-turn GREEN ARROW signal indication shall be displayed immediately upon termination of the flashing left-turn YELLOW ARROW signal indication. A steady left-turn YELLOW ARROW signal indication shall not be displayed between the display of the flashing left-turn YELLOW ARROW signal indication and the display of the steady left-turn GREEN ARROW signal indication.
7. During flashing mode operation, the display of a flashing left-turn YELLOW ARROW signal indication shall be only from the signal section that displays a steady left-turn YELLOW ARROW signal indication during steady mode (stop-and-go) operation.

Figure 1 displays an installation of a FYA with protected-permissive phasing provided by NCDOT.

Figure 1. Photo. FYA with protected-permissive phasing. [7]

NCHRP report 493 stated that flashing yellow arrows are the recommended alternative to circular green for a permissive signal for left-turn movement.[8] The researchers completed a variety of analyses including engineering analyses, static and video-based driver comprehension studies, field implementation, video conflict studies, and crash analyses. Key findings of that research include:

- FYA is the recommended alternative to the circular green as the permissive signal display for a left-turn movement.
- FYA achieves a high level of understanding and correct response by left-turn drivers.
- FYA display in a separate signal face for the left-turn movement offers more versatility in field application. It operates in any of the various modes of left-turn operation by time of day and is easily programmed to avoid the "yellow trap" associated with some permissive turns at the end of the circular green display.

Noyce et al. evaluated the safety effectiveness of FYA permissive left-turn indication considering variables such as signal phasing, vehicle flow rates, posted speed limits, and intersection geometry.[9] The sites used represented diverse intersection characteristics. The study employed several evaluation methodologies, the most appropriate being an empirical Bayes (EB) before-after study for 19 treated locations with the appropriate data available. The study evaluated left turn crashes and found the following:

- Safety improved at intersections that already had protected-permissive phasing prior.
- Safety did not improve at intersections that operated with protected only left-turn phasing prior.

- Results were inconclusive for intersections that operated with permissive only left-turn phasing prior.

Srinivasan et al. evaluated FYA using a combination of EB and simple before-after results and found an 11-percent reduction in total crashes when converting to FYA from a non-FYA protected-permissive operation.[10]

A conflict can occur when another vehicle is turning left and enters the path of a motorcyclist passing through the intersection. By reducing the likelihood of conflict, the FYA protected-permissive phasing is a candidate treatment where crashes involving a motorcyclist of this nature are of a concern.

SITE DESCRIPTION

The case study site is in Roanoke Rapids, NC at the intersection of State Route 125 (East 10th Street) and Park Avenue. The location is a four-leg, signalized intersection in a suburban area.

East 10th Street is a four-lane roadway with a shared left-turn lane and a speed limit of 35 mph. Park Avenue is a two-lane roadway with left-turn lanes on both the western and eastern approaches serving mainly residential areas. The speed limit is 25 mph.

Figure 2 and Figure 3 show the intersection of North Carolina 125 (East 10th Street) and Park Avenue.

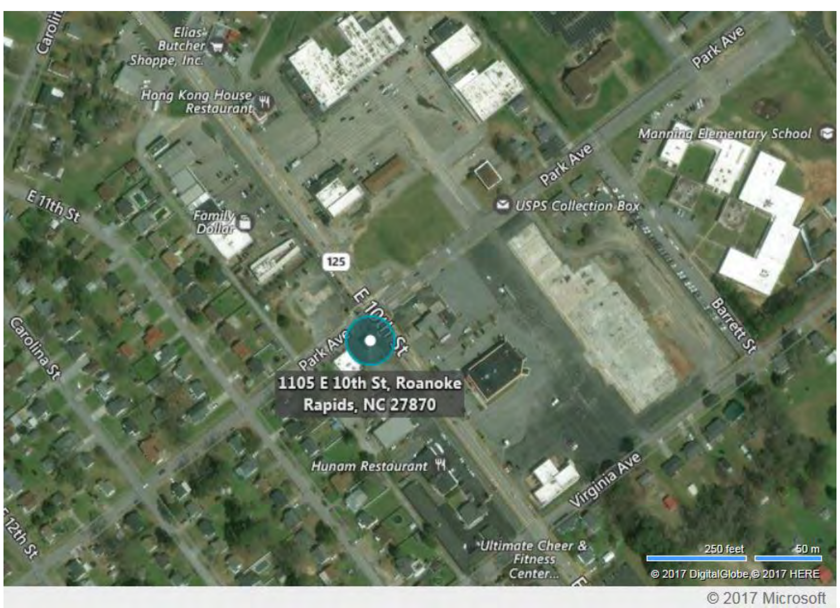

Figure 2. Photo. Aerial view of treatment site in Roanoke Rapids, NC.[11]

Figure 3. Photo. Zoom view of treatment site in Roanoke Rapids, NC.[11]

SITE IDENTIFICATION AND PROJECT APPROVAL

NCDOT first identified the site through the State's Highway Safety Improvement Program (HSIP). NCDOT staff conducted a detailed site review including the most recent 5-year crash history.

The review found that the recent crash history met NCDOT warrants for frontal impact crashes and the minimum severity index. These were based on the seven target crashes occurring in the 5-year period considered. Target crashes included left-turn same roadway on the treated approaches.

PROJECT FUNDING

NCDOT applied the treatment at a cost of $12,500. The NCDOT Spot Safety Program provided funding for the project. The Spot Safety Program uses State funding to address safety, potential safety, and operational issues.

SAFETY ANALYSIS

The purpose of the treatment site analysis is to observe trends in vehicle traffic and crash frequency for the before and after treatment periods. Because the analysis pertains to only a single site the intent is not to estimate a CMF.

The project team obtained data for crashes within 250 ft. of the intersection between 1999 and 2016. Traffic volume counts were obtained where available; however, volume estimates specific to motorcycles were not available. To facilitate the analysis, the project team used existing Safety Performance Functions (SPFs). SPFs are used in the approach to estimate the expected crash frequency, considering both the observed crash frequency and the expected frequency for a similar location and traffic volumes.[12]

Table 1 provides a summary of the data before and after construction. Crash data for 2015, the year of construction, are not included. Estimates of the Average Annual Daily Traffic (AADT) are not available for 2016, the year following construction. For analysis, the AADT is assumed to not change between before and after periods.

Table 1. Pre- and post-treatment data – Roanoke Rapids, NC.

Data	Before	After
Years of data	16	1
Major road AADT	14,000	n/a
Minor road AADT	1,500	n/a
Crashes	173	9
Motorcycle involved crashes	8	0

The SPF for total crashes is shown in Figure 4. Because the SPF does not predict vehicle-motorcycle crashes on their own, the proportion of motorcycle involved crashes in the before period at the site (five percent) is applied as a multiplier to the total crash SPF when predicting motorcycle involved crashes.

$$Total\ Crashes\ per\ year = exp^{(-9.3892+0.4706)}\ MajAADT^{0.7480}\ MinAADT^{0.4188}$$

Figure 4. Equation. Proposed SPF for total crashes for FYA.

Details on the EB methodology are available in the Highway Safety Manual.[12] Table 2 presents the results for total crashes and crashes involving a motorcycle.

Table 2. Expected and observed analysis results.

Data	Total Crashes	Crashes Involving Motorcycles
SPF	3.62/year	0.18/year
Expected after	10.32/year	0.31/year
Observed after	9	0

For total crashes, there is a small reduction for the observed (9 crashes) and expected crashes (10.32) following treatment. For motorcycle involved crashes, none were observed in the year following treatment while an average of 0.31 per year are expected.

TREATMENT BENEFITS FOR MOTORCYCLISTS

Countermeasures related to left-turn traffic signal phasing are widely used and appear in multiple configurations with varying levels of effectiveness. The consideration of crash frequency, severity, crash type, area type, traffic volume, cost, and other factors are used to select the appropriate application for a selected site.

Specific to crashes involving motorcycles, empirical proof of effectiveness is not feasible with the level of data available at this site. Although analysis limitations exist for this site, implementing the FYA treatment reviewed in this case study has shown positive results in other studies for crashes involving all motor vehicle types. Knowing that the FYA treatment can have a positive safety impact on crashes, agencies could assume that the treatment would also have a positive safety impact on motorcyclists. Figure 5 displays CMF's (from the FHWA CMF Clearinghouse) related to the specific treatment applied by NCDOT.[5]

Compare	CMF	CRF (%)	Quality	Crash Type	Crash Severity	Area Type	Reference	Comments
☐	0.935	6.5	★★★☆☆	All	All	Not specified	Simpson and Troy, 2015	
☐	0.654	34.6	★★★☆☆	All	K,A,B,C	Not specified	Simpson and Troy, 2015	
☐	0.598	40.2	★★☆☆☆	Left turn	All	Not specified	Simpson and Troy, 2015	Target crashes are defined as ... [*read more*]
☐	0.592	40.8	★★☆☆☆	Left turn	K,A,B,C	Not specified	Simpson and Troy, 2015	Target crashes are defined as ... [*read more*]

Compare   Reset Compare

**NOTE: You can compare CMFs across countermeasures, subcategories, and categories*

Figure 5. Capture. Permissive only to FYA protected/permissive left turn phasing.[5]

CONSIDERATIONS FOR TREATMENT APPLICATION

Proper site diagnosis is a critical component for countermeasure selection. NCDOT reported one issue related to concerns with the crash data. Due to inconsistencies in how crashes are coded, staff reviewed each crash report to identify the left-turn same roadway crashes. Oftentimes such crashes were coded as angle or sideswipe-opposite-direction.

FUTURE APPLICATIONS

The FYA treatment is widespread throughout North Carolina, and they continue systematically to implement the countermeasure. NCDOT implements the FYA treatment for new signals and when replacing older signals, when warranted. As of 2013, over 1,600 FYA treatments were in design or installed in North Carolina.

SUMMARY

Research has shown FYA phasing as a replacement for fully permissive left-turn phasing is a treatment that is an effective strategy to reduce crashes between left-turning and opposing through movement vehicles. It stands to reason that the effectiveness would extend to motorcycle-vehicle crashes specifically. The treatment does not completely eliminate the potential for conflicts to occur. The application of protected-only phasing would provide increased protection for motorcyclists specifically by further reducing the opportunity for left-turning conflicts.

An analysis of the site under consideration indicates that total and motorcycle crashes are slightly lower in the year following implementation than would be expected in an average year. However, this comparison does not account for changes in traffic volumes, which were not available on a yearly basis, or other trends over time affecting expected crash rates.

AGENCY CONTACT INFORMATION

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III. ADJUSTING THE SENSITIVITY OF LOOP DETECTORS AT ACTUATED SIGNALS – YOUNGSTOWN, OH

TREATMENT DESCRIPTION

Actuated traffic signals use controllers with inductive loop detectors to 'call' for service on the intersection approach where the controller monitors traffic. Often, agencies use this type of control for side streets with low traffic volumes but where signalization is needed periodically to interrupt the flow of traffic on the main street. Some intersections use actuated control for all approaches, typically at busy but isolated intersections where demand fluctuates.

Due to the smaller size of motorcycles, controllers may not detect their presence and, after experiencing excessive delay, riders may proceed through the intersection against a red light, creating a conflict with other vehicles.

In 2009, the Ohio Department of Transportation (ODOT) worked closely with the American Motorcyclist Association (AMA) to implement a program to rectify traffic signals where the loop detectors were not recognizing motorcycles or bicycles waiting for the signals to change. Figure 6 displays a promotion of the service provided by ODOT's Office of Traffic Operations homepage.[13]

Featured Items

Report a Bicycle/Motorcycle Signal Malfunction - [New!]
ODOT invites Bicycle and Motorcycle riders to contact an ODOT advocate to report detection problems with a traffic signal. Email bike.report@dot.state.oh.us or call (614) 387-0722

Figure 6. Capture. Contact information for loop detector adjustment reporting.[13]

The program allows individuals to report a problem intersection to the ODOT Traffic Management Center (TMC). Staff review each location to verify jurisdiction. ODOT then follows up with district office or local jurisdiction to increase the sensitivity of the loop detector. An ODOT Loop Detection Troubleshooting Checklist addresses reported issues at each site.[14] ODOT has received over 130 signal adjustment requests through February of 2017.

SITE DESCRIPTION

The location for the case study is in Youngstown, Ohio at the intersection of Interstate Boulevard and State Route 46. The location is a three-leg, signalized intersection in a suburban area.

State Route 46 is a four-lane roadway with a dedicated left-turn lane on the northern leg and a two-way left-turn lane on the southern leg. The speed limit is 40 mph. Interstate Boulevard is a two-lane roadway giving access to commercial developments. The following list details the workflow communication for the site which began on September 3, 2014 and was resolved by September 30, 2014:

- ODOT received email complaint referencing signal.
- Called to verify signal was ODOT which was confirmed.
- Emailed District 4 personnel regarding identified issue.
- Emailed reporter to advise the District had been contacted.
- District confirmed completion.
- Emailed reporter that sensitivity was adjusted.

The local jurisdiction adjusted the sensitivity of the loop detector on Interstate Boulevard on September 30, 2014. Figure 7 and Figure 8 show the intersection of Interstate Boulevard and State Route 46, including the location of a loop detector.

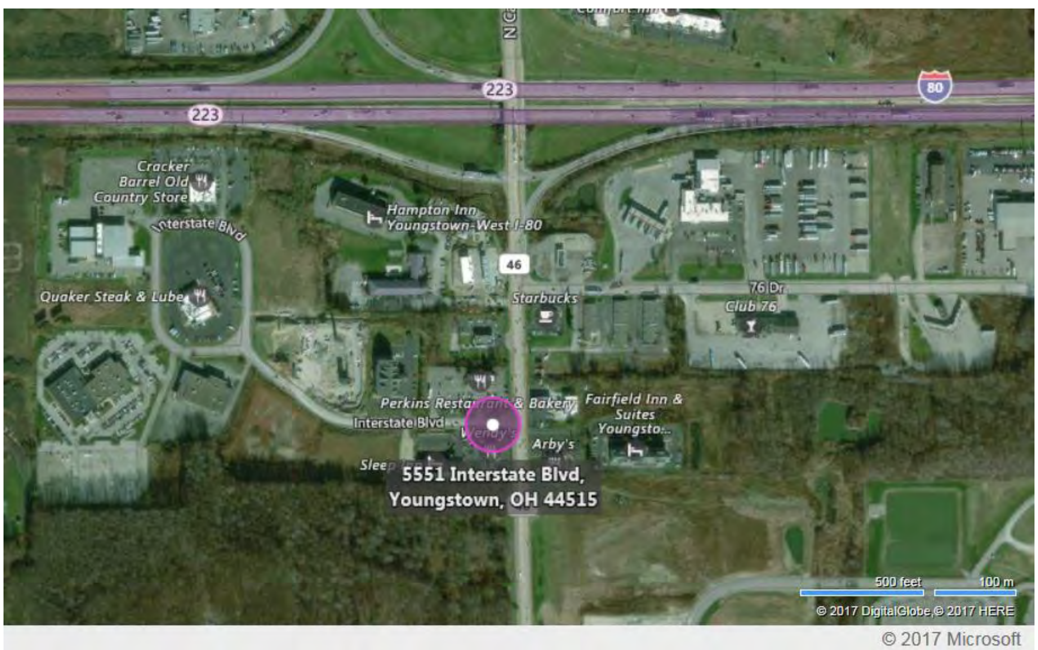

Figure 7. Photo. Aerial view of treatment site in Youngstown, OH.[15]

Figure 8. Photo. Zoom view of treatment site in Youngstown, OH. [15]

SITE IDENTIFICATION AND PROJECT APPROVAL

The ODOT TMC identifies sites based on citizen reports and routes reports to the local ODOT District or local jurisdiction for inspection and to resolve any detection issues.

PROJECT FUNDING

If the signal in question is on the State system network under ODOT jurisdiction, the ODOT district signal and maintenance teams will adjust the loops. If the signal is under the jurisdiction of a local agency, then the request is forwarded to the appropriate contact at that jurisdiction for adjustment. These fixes are low cost and are incorporated into normal staff duties. ODOT does not track costs separately.

SAFETY ANALYSIS

The treatment site analysis examines trends in vehicle traffic and crash frequency for the before and after treatment periods. The project team obtained data for crashes within 250 ft. of the intersection between 2011 and 2017. The team obtained traffic volume counts where available; however, the team did not obtain either motorcycle-specific volume estimates for the intersection or counts for the minor road.

Table 3 shows a summary of before and after data, excluding 2014 (the year of implementation).

Table 3. Pre- and post-treatment data – Youngstown, OH.

Data	Before	After
Years of data	3	3
Major road AADT	19,030	19,500
Minor road AADT	n/a	n/a
Crashes	2	4
Motorcycle involved crashes	1	1

Total crashes experienced a slight increase from 0.7 per year to 1.3 per year. There was a single crash involving a motorcycle in both the before and after periods. The crash frequencies should not be used to make any conclusions on the safety impact of the loop detector sensitivity adjustments since the number of crashes is small and no account has been made for regression-to-the-mean or time trends in crashes. Additionally, it should be noted that the process for identifying sites is based on failure to detect and serve a motorcycle, and not necessarily based on crashes involving motorcycles. This distinction is important when considering the results shown in Table 3.

TREATMENT BENEFITS FOR MOTORCYCLISTS

Increasing the sensitivity of loop detectors for proper motorcycle detection may reduce the likelihood of motorcycles entering an intersection against a red light and the corresponding safety risks.

CONSIDERATIONS FOR TREATMENT APPLICATION

ODOT did not record whether the loop detector adjustment request came from a bicyclist or a motorcyclist, although most are believed to come from motorcyclists. Also, analysis requires manual mapping of treated locations for crash data linkage, so use of geo-coordinates would make it easier to analyze safety impacts on a larger scale.

FUTURE APPLICATIONS

The program for citizens to report detection problems with a traffic signal is still active and listed on the ODOT website. ODOT has received over 130 signal adjustment requests through February of 2017.

SUMMARY

In the context of this project, the signal loop adjustments are a rare treatment in that they are very specifically aimed at servicing motorcycles (and bicycles). The treatment of adjusting signal loops is relatively straight-forward to apply at very little cost.

An analysis of the site under consideration indicates that total crashes are slightly higher in the years following sign installation with no change in motorcycle crashes. However, this comparison does not account for regression-to-the-mean, or other trends over time affecting expected crash rates. The frequency of crashes at this location also does not support conclusions on the safety effectiveness of the treatment.

In a related development, as of 2017, six States have proposed nine separate legislative bills that would allow motorcycles to legally proceed through a red light traffic signal phase.[16] The following example pending legislation from one of these States that relates to the countermeasure featured in this case study.[17]

> "Notwithstanding any law to the contrary, the driver of a motorcycle approaching an intersection that is controlled by a traffic-control signal utilizing a vehicle detection device that is inoperative due to the size of the motorcycle shall come to a full and complete stop at the intersection and, after exercising due care as provided by law, may proceed with due caution when it is safe to do so."

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IV. MOTORCYCLE SPECIFIC ADVANCED WARNING SIGNS AT INTERSECTIONS – STRONGSVILLE, OH

TREATMENT DESCRIPTION

Allstate® Insurance deployed their "Once is Never Enough™" (O.N.E.) campaign beginning in 2009. The O.N.E. awareness campaign encourages people to look twice for motorcycles at intersections and seeks to reduce the number of motorcycle crashes at intersections by installing permanent motorcycle warning signs.

Figure 9 displays a timeline of the Allstate® Insurance O.N.E.™ campaign.[18] In 2012, Allstate received notification from FHWA that the O.N.E.™ yellow diamond warning signage is allowed in accordance with the Manual on Uniform Traffic Control Devices (MUTCD) and that they could proceed with installations at signalized intersections. The signs are placed at the intersection approaches in advance of the intersection.

Figure 9. Graphic. Timeline of Allstate® Insurance "Once is Never Enough™" campaign.[18]

The signs were designed over a 2-year period to establish a standardized warning device for state and local agency use. Through the program, Allstate® works with local jurisdictions to identify candidate intersections and then donates and installs warning signs at the determined locations. Through the O.N.E.™ program, 171 "Watch for Motorcycles" warning signs have been installed in 38 cities throughout 19 States. Figure 10 provides an example of an installed "Watch for Motorcycles" warning sign.[19]

Figure 10. Photo. "Watch for Motorcycles" warning sign.[19]

SITE DESCRIPTION

The Strongsville, Ohio case study is the intersection of Royalton Road and Prospect Road. The location is a four-leg, signalized intersection in a suburban area.

Royalton Road is a four-lane roadway with left-turn lanes on both approaches to the intersection. Prospect Road is a two-lane roadway with right-turn and left-turn lanes on the southern leg and a right-turn and dual-left-turn lanes on the northern leg. Both legs on Prospect Road have an extra merging lane leading away from the intersection. Both roads have a posted speed limit of 35 mph.

The yellow signs which read, “Watch for Motorcycles” were installed on all four approaches on May 9, 2013. Figure 11 and Figure 12 show the location of the intersection of Royalton Road and Prospect Road.

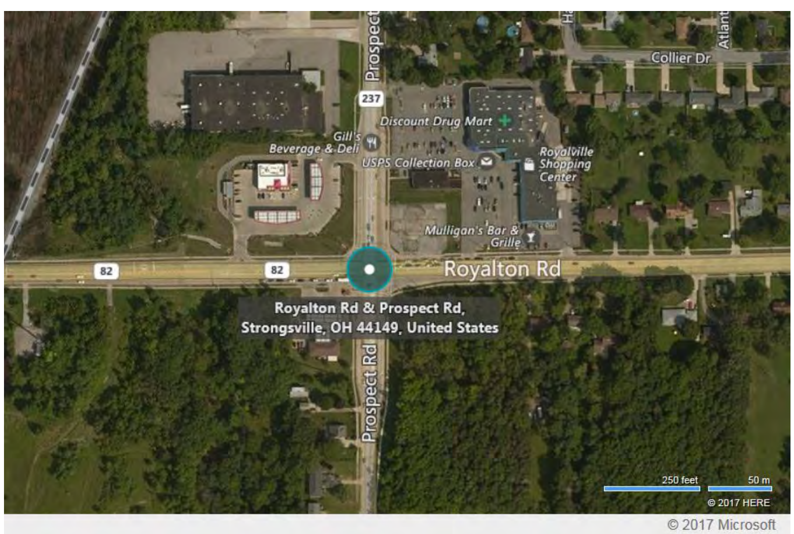

Figure 11. Photo. Aerial view of treatment site in Strongsville, OH.[20]

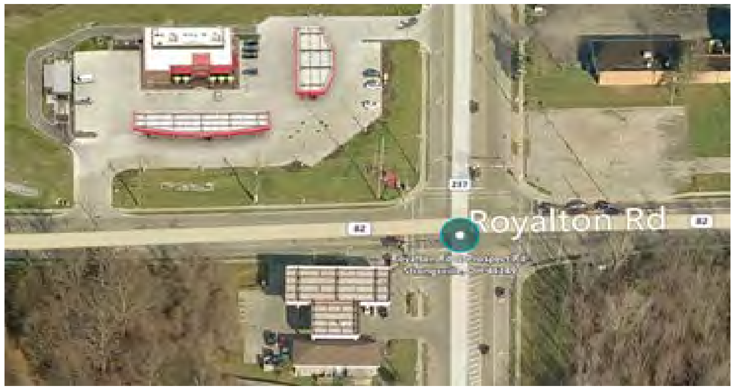

Figure 12. Photo. Zoom view of treatment site in Strongsville, OH.[20]

SITE IDENTIFICATION AND PROJECT APPROVAL

The City of Strongsville decided where to place the signs. In general, this process is followed by most cities, with signs placed in an area being developed or if there is a popular route for riders. The City of Strongsville was the first city to install the "Watch for Motorcycles" warning signs during the 2013 campaign.

PROJECT FUNDING

Allstate Insurance® provided the signs as a part of their O.N.E.™ campaign. City workers were responsible for the installation.

SAFETY ANALYSIS

The treatment site analysis examines trends in vehicle traffic and crash frequency for the before and after treatment periods. The project team obtained data for crashes within 250 ft. of the intersection between 2011 and 2016. The team obtained total traffic volume counts, however volume estimates for motorcycles specifically were not available.

Table 4 shows summary data for the before and after periods, excluding 2013 (the implementation year).

Table 4. Pre- and post-treatment site data – Strongsville, OH.

Data	Before	After
Years of data	2	4
Major road AADT	20,960	19,750
Minor road AADT	15,960	15,960
Crashes	24	43
Motorcycle involved crashes	0	1

The estimated traffic volumes decreased slightly following installation of the sign while total crashes also experienced a slight decrease to 10.8 per year from 12 per year. Before installation, there were no crashes involving motorcycles while there was one afterwards. However, the results from one site should not be used to make a conclusion on the safety effectiveness of the overall program since motorcycle crash involvements were not necessarily used in selecting the location and given the rarity and random nature of such crashes.

TREATMENT BENEFITS FOR MOTORCYCLISTS

Intersection advanced warning countermeasures are widely used and appear in many configurations with varying levels of effectiveness. The consideration of crash frequency, severity, and type along with area type, traffic volume, intersection sight distance, cost, and many other factors help staff select the appropriate configuration for a selected site. A perceived increase of driver awareness of motorcycles at intersections would likely improve safety; however, empirical proof for the effectiveness of "Watch for Motorcycles" signs is not feasible with the level of data available for this project.

CONSIDERATIONS FOR TREATMENT APPLICATION

The State indicates that choosing locations is difficult as motorcycle volumes are not typically available and the locations of motorcycle crashes is very random in nature. The responsible jurisdictions are free to choose sites based on criteria other than motorcycle crashes.

FUTURE APPLICATIONS

ODOT is focused on increasing safety on all public roads throughout Ohio. As a part of their HSIP, ODOT allocates funding to local safety programs and initiatives. One of the systemic safety programs is the Township Sign Upgrade Program. Although not associated with the "Watch for Motorcycles" signage program, the State is implementing advanced warning countermeasures. ODOT gives local agencies funding to upgrade safety warning signs at intersections and curves. The Ohio Local Technical Assistance Program center administers the program providing up to $2,000,000 annually to local jurisdictions. Since 2015, 128 townships have participated in the program, installing intersection and curve warning signs.

SUMMARY

States and local jurisdictions across the nation have begun instituting a "safe systems" approach in recent years by adopting a "Toward Zero Deaths" or "Vision Zero" philosophy. This approach is especially important to motorcyclists because it promotes safety considerations for all users of the transportation system with a goal of minimizing frequency and severity of crashes. The vulnerability of motorcyclists and their unique handling characteristics should be a regular consideration in safety planning. An example from New York State is draft legislation introduced in May 2017 to install "Watch for Motorcycles" signs on State highways.[21]

The O.N.E.™ signs constitute a rare treatment in that they are specifically aimed at reducing motorcycle-related crashes. An analysis of the site under consideration indicates that total crashes are slightly lower in the years following sign installation. However, this comparison does not account for changes in traffic volumes, regression-to-the-mean, or other trends over time affecting expected crash rates. The frequency of motorcycle crashes at this location (1 in 6 years) does not allow for any observations to be made.

The treatment of motorcycle warning signs is relatively straight-forward to apply at a low cost. Depending on the programs in a State, HSIP funds or other sources of safety improvement funds are possible sources of funding to implement similar signage.

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V. INTERSECTION CONFLICT WARNING SYSTEM: "VEHICLE ENTERING" OVERHEAD FLASHERS SUPPLEMENTED BY ADVANCED ROADSIDE SIGNS AND FLASHERS – ELIZABETH CITY, NC

TREATMENT DESCRIPTION

Advanced warning countermeasures serve the overall purpose of identifying an upcoming intersection and informing drivers of potential safety conflicts at the intersection. An Intersection Conflict Warning System (ICWS) uses upstream vehicle detectors to alert motorists of conflicting vehicles on an adjacent approach. The specific treatment in this case study is "Vehicle Entering" warning signs and flashing beacons actuated on the intersecting road. During operation, the side street will flash red continuously and the mainline is shown the "Vehicle Entering" supplemented by the advance shoulder-mounted flashers. This is somewhat atypical of ICWS implementations in the use of red flashers—most use yellow flashing signals exclusively. Figure 13 illustrates the treatment in the field.

Figure 13. Photo. "Vehicle Entering" overhead flashers.[22]

The strategy is intended to reduce the frequency of crashes by alerting drivers of conflicting vehicles on adjacent approaches at unsignalized intersections, particularly those with one-way or two-way stop control.

Himes et al. evaluated ICWS using an EB before-after study for estimating CMFs.[23] The estimated CMFs are shown in Table 5. Reductions in crashes following ICWS were found for total, fatal+injury, right-angle, rear-end and nighttime crashes, both at intersections of two-lane roads and intersections of a two-lane and a four-lane road. There is no motorcycle-specific CMF for this treatment.

Table 5. ICWS CMFs.[23]

Site Type	Total	Fatal+Injury	Right-Angle	Rear-End	Nighttime
Two-lane at two-lane	0.733	0.701	0.803	0.425	0.898
Four-lane at two-lane	0.827	0.802	0.850	0.973	0.612

For four-lane at two-lane intersections, ICWS were more effective when the predicted annual crash frequency was higher than three in the before period. This is logical because the strategy is often used at intersections with unusually high crashes or issues related to limited sight distance. For total crashes, there does not appear to be a benefit if the predicted crash frequency is less than or equal to three crashes per year before installation; however, there is a significant reduction for sites with more than three predicted crashes per year in the before period. The study also estimated a benefit/cost ratio for total crashes of 27:1 for two-lane at two-lane intersections and 10:1 for four- lane at two-lane intersections.

A conflict can occur when another vehicle enters the path of travel for a motorcyclist at an intersection. For this reason, the ICWS is a candidate treatment where crashes involving a motorcyclist of this nature are of a concern. The Unsignalized Intersection Improvement Guide (UIIG) lists the following conditions addressed by the ICWS:[24]

- Crash history involving vehicles entering or crossing major road.
- Difficulty among drivers in determining appropriate gaps in traffic.
- Awareness of the intersection is lacking.
- High running speeds are typical of major road traffic.

SITE DESCRIPTION

The case study in Elizabeth City, NC is the intersection of State Route 1169 (Four Forks Road/Pitts Chapel Road) and State Route 1101 (Peartree Road). The location is a four-leg, two-way stop-controlled intersection in a rural area. Both roadways are two-lane roads. NCDOT upgraded the existing overhead two-circuit flasher to "Vehicle Entering" actuated by side street traffic. The side street red flashes continuously and the mainline is supplemented by advance shoulder mounted flashers.

The two roadways intersect at a severely skewed angle and with limited sight distance on the northbound approach from Peartree Road. Posted speed limits are 55 mph on all approaches except for the eastern leg which is 45 mph.

NCDOT installed the warning system on January 25, 2010. Figure 14 and Figure 15 show the intersection of Peartree Road and Four Forks Road/Pitts Chapel Road, where "Vehicle Entering" overhead and roadside flashers were installed. The system remained in place until January 31, 2012 when NCDOT converted the intersection to all-way stop-control.

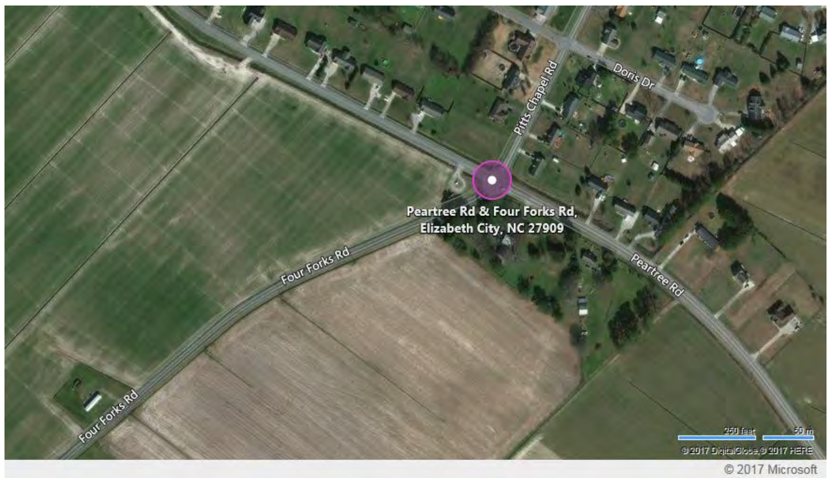

Figure 14. Photo. Aerial view with zoom of treatment site in Elizabeth City, NC.[25]

Figure 15. Photo. Zoom view of treatment site in Elizabeth, City, NC.[25]

SITE IDENTIFICATION AND PROJECT APPROVAL

NCDOT identified the site through the State's HSIP. NCDOT staff conducted a detailed site review which included a consideration of the preceding 5-year crash history.

PROJECT FUNDING

NCDOT applied the treatment at a cost of $40,000 using Spot Safety Program funds. The Spot Safety Program uses State funding to address safety, potential safety, and operational issues.

SAFETY ANALYSIS

The treatment site analysis examines trends in vehicle traffic and crash frequency for the before and after treatment periods. Because the analysis pertains to only a single site the intent is not to estimate a CMF.

The project team obtained data for crashes within 250 ft. of the intersection between 1999 and 2011 and obtained traffic volume counts where available; however, volume estimates for motorcycles specifically were not available. To facilitate analysis, the project team used existing SPFs. SPFs are used in the EB approach to estimate the expected crash frequency, considering both the observed crash frequency and the expected frequency for a similar location and traffic volumes.[11]

FHWA's Development of CMFs program developed the SPF's that the project team applied to similar sites in North Carolina for the evaluation of ICWS. A summary of the data before and after construction is provided in Table 6.

Table 6. Pre- and post-treatment site data – Elizabeth City, NC.

Data	Before	After
Years of data	11	2
Major road AADT	3,000 (average)	3,300 (average)
Minor road AADT	1,600 (average)	1,500 (average)
Crashes	37	8
Motorcycle involved crashes	3	0

Figure 16 shows the SPF for total crashes. Because the SPF does not predict vehicle-motorcycle crashes on their own the proportion of motorcycle involved crashes in the before period at the site, eight percent, is applied as a multiplier to the total crash SPF when predicting motorcycle involved crashes.

$$SSD = 1.47Vt + \frac{V^2}{30[(a/32.2) +/- G]}$$

Figure 16. Equation. SPF for total crashes for North Carolina.

The Highway Safety Manual provides more details on the EB methodology.[12] Table 7 presents the results for both total crashes and those involving a motorcycle.

Table 7. Expected and observed analysis results.

Data	Total Crashes	Crashes Involving Motorcycles
SPF	1.32/year	0.11/year
Expected after	5.50	0.27
Observed after	8	0

For total crashes, there was an increase in observed (8 crashes) over expected crashes (5.5) following treatment. For motorcycle involved crashes, none were observed in the 2 years following treatment while 0.27 were expected. Note that there are many examples of ICWS treatments showing overall crash reductions. The fact that this site saw an increase in total crashes should not be generalized. The site was chosen for this report specifically because there was a non-zero motorcycle crash count in the baseline period.

TREATMENT BENEFITS FOR MOTORCYCLISTS

Advanced warning countermeasures are widely used and appear in many configurations with varying levels of effectiveness. The consideration of crash frequency, severity and type along with area type, traffic volume, intersection sight distance, cost, and many other factors are used to select the appropriate configuration for a selected site.

The ICWS addresses a specific crash type that should also impact motorcycle safety. Since motorcycles are smaller and less conspicuous than other vehicles, they may be of particular concern when traveling a mainline roadway on approach to an unsignalized intersection. Specific to crashes involving motorcycles, empirical proof is not feasible with the level of data available. Although in this instance, analysis limitations exist, implementing an ICWS treatment reviewed in this case study has shown positive results in other studies for crashes involving all motor vehicle types.

CONSIDERATIONS FOR TREATMENT APPLICATION

NCDOT reported no issues related to implementation of the treatment. However, after 2 years, the agency changed the intersection to all-way stop-controlled to further improve safety. All-way stop-control is often used to mitigate right-angle and turning crashes in an environment where the AADT on both approaches are relatively balanced, although North Carolina has observed safety improvements where the volumes are not balanced.[26]

SUMMARY

Advanced warning countermeasures serve the overall purpose of identifying an upcoming intersection and the potential for traffic conflicts that may occur. Advanced warning systems are a relatively low-cost treatment which may be effective in reducing motorcycle crashes. Previous research has shown ICWS as an effective treatment for reducing crashes. It stands to reason that the effectiveness would extend to motorcycle-vehicle crashes specifically. One study of ICWS estimated a range of benefit/cost ratios between 16:1 to 39:1 for two-lane at two-lane intersections.[23]

An analysis of the site under consideration indicates that total crashes increased but motorcycle involved crashes decreased in the two years following implementation. However, this comparison does not account for trends over time affecting expected crash rates and a longer post-treatment period is desirable for further analysis.

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VI. INTERSECTION CONFLICT WARNING SYSTEM: ROADSIDE SIGNS AND FLASHERS ON MAJOR AND MINOR APPROACHES – EDDYVILLE, KY

TREATMENT DESCRIPTION

Advanced warning countermeasures serve the overall purpose of identifying an upcoming intersection, as well as informing drivers of potential safety conflicts at the intersection. An ICWS employs vehicle detectors to alert motorists of conflicting vehicles on an adjacent approach. An ICWS can be installed and operated in multiple configurations. The specific treatment for this site includes "Traffic Approaching When Flashing" post mounted signals that are actuated on the mainline and "Traffic Entering When Flashing" post mounted signals that are actuated on the minor road. The preceding case study included detailed information on the effectiveness of a different ICWS configuration. This study does not repeat the information.

SITE DESCRIPTION

The case study in Eddyville, KY is the intersection of KY93 and KY293/KY1055. Both roadways are two-lane roads in a rural area. The U.S. Census Bureau estimated the 2016 population of Eddyville at just above 2,500.[27] The intersection has four-legs and is stop-controlled on the minor approach. The east leg of KY293 is divided by a 15-ft. raised median and has exit ramps from I24 around 1,200 ft. from the intersection of KY93. The mainline (KY93) and the east leg (KY293) are functionally classified as rural major collectors. The west leg of the intersection (KY1055) is functionally classified as a rural minor collector. Figure 17 features one of the "Traffic Entering When Flashing" post mounted signals on KY93.

Figure 17. Photo. "Traffic Entering When Flashing" roadside sign and flashers on KY93.[28]

Post mounted flashers on the major and minor approaches activated by loop detectors were installed in August 2015. The installed flashers include a battery backup. Figure 18 (August 2013) and Figure 19 (June 2017) show before and after implementation conditions on KY93 on approach to KY293/KY1055.

Figure 18. Photo. Pre-treatment conditions for site (2013).[29]

Figure 19. Photo. Post-treatment conditions for site (2017).[30]

The two roadways intersect at a slightly skewed angle, but with no identified sight distance concerns. The speed limit for KY93 on the mainline approach is 55 mph. Figure 20 and Figure 21 show the intersection of KY93 and KY293/KY1055, where intersection conflict warning roadside signs and flashers were installed.

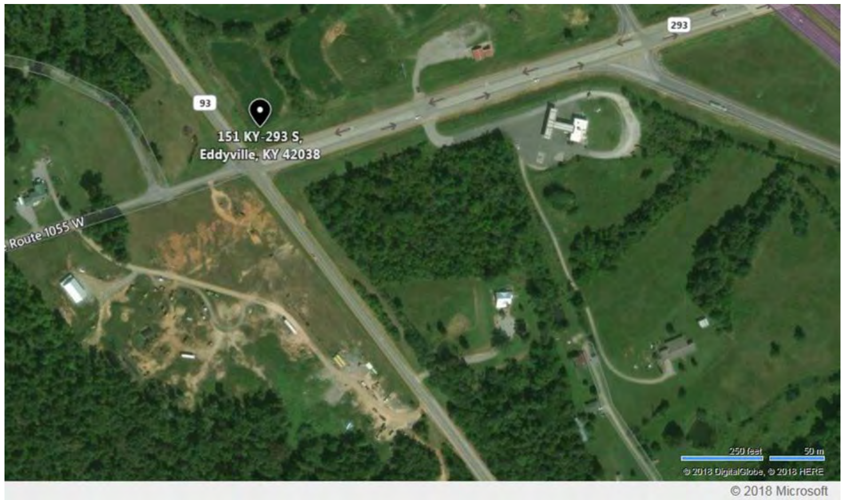

Figure 20. Photo. Aerial view of treatment site in Eddyville, KY.[31]

Figure 21. Photo. Zoom view of treatment site in Eddyville, KY. [31]

SITE IDENTIFICATION AND PROJECT APPROVAL

In Kentucky, site locations are primarily selected based on a crash history and patterns of crashes followed by a field review of each location. Prior to installing an ICWS, Kentucky Transportation Cabinet (KYTC) and the local District review the current traffic control in place to see if any additional countermeasures can be implemented prior to the installation of an ICWS. Other countermeasures that may be applied prior to installing an ICWS include dual stop signs, static advanced intersection warning, and vegetation maintenance.

For the specific site at KY93 and KY293/KY1055, the District identified a crash problem and implemented countermeasures to reduce crashes. Prior to ICWS instillation, the District added oversized stop signs and rumble strips on KY293/KY1055 and an overhead beacon at the intersection. When severe angle crashes continued, the District contacted KYTC about installing an ICWS. The installation was approved by KYTC and became the first ICWS in the State.

PROJECT FUNDING

The ICWS installation was approved and executed through an existing District master agreement. Funding for the project was approximately $65,000 and was allocated from District funds with approval by the KYTC Central Office.

SAFETY ANALYSIS

Exposure data for motorcyclists is lacking, which limits agencies ability to conduct predictive analysis concerning motorcycle crashes. The Kentucky 2015-2019 SHSP States that there was an average of 1,823 motorcycle crashes resulting in an average of 414 motorcyclist serious injuries and fatalities per year in Kentucky from 2010 through 2014.[32] Thirteen percent of traffic fatalities in Kentucky occurred at intersections in the same period. Pursuing the development and installation of ICWS is an engineering strategy listed in the intersection emphasis area.

The purpose of the treatment site analysis is to observe trends in vehicle traffic and crash frequency for the before and after treatment periods. Because the analysis pertains to only a single site the intent is not to estimate a CMF. Traffic volume counts were obtained where available; however, volume estimates for motorcycles specifically were not available. The most recent annual average daily traffic measures for intersection legs at KY93 and KY293/KY1055 are:

- Southern leg – 2,189 (2015).
- Northern leg – 3,156 (2016).
- Western leg – 482 (2014).
- Eastern Leg – 2,711 (2016).

Kentucky provided data for crashes within 250 ft. of the intersection from 2006 through 2016. A summary of the collision data before and after implementation is provided in Table 8.

Table 8. Pre- and post-treatment site data – Eddyville, KY.

Data	Before	After
Total crashes	37	4
Motorcycle involved crashes	3	0
All injuries	39	0
Fatal injuries	1	0

The crash data showed 37 total crashes with 3 involving a motorcyclist prior to installation in 2015. The location also had 39 injuries with 1 fatality during the before period. The after-installation period saw 4 total crashes with no injuries and none of the crashes involved a motorcyclist. In the before period, 78 percent (29 of 37) of total crashes were angle crashes. For the after-period angle crashes were 75 percent (3 of 4) of the total. All crashes involving motorcyclists in the before period were angle crashes. All crashes from 2006 to 2016 occurred in daylight conditions, except 3 in the before period.

A simple comparison of crash rates at this site show total crashes decreasing from 4.03 per year to 3.0 and motorcycle crashes decreasing from 0.31 per year to 0. The crash frequencies should not be used to make any conclusions on the general safety impact of an ICWS since the number of crashes is small with a short after period and no account has been made for changes in traffic volume, regression-to-the-mean, or time trends in crashes.

TREATMENT BENEFITS FOR MOTORCYCLISTS

Advanced warning countermeasures are widely used and appear in many configurations with varying levels of effectiveness. The consideration of crash frequency, severity and type along with area type, traffic volume, intersection sight distance, cost, and many other factors are used to select the appropriate configuration for a selected site.

The ICWS addresses a specific crash type that should also impact motorcycle safety. Since motorcycles are smaller and less conspicuous than other vehicles, they may be of concern when traveling a mainline roadway on approach to an unsignalized intersection or entering a roadway from a side road. Specific to crashes involving motorcycles, empirical proof is not feasible with the level of data available. Although in this instance, analysis limitations exist, implementing an ICWS treatment reviewed in this case study has shown positive results in other studies for crashes involving all motor vehicle types.

CONSIDERATIONS FOR TREATMENT APPLICATION

KYTC reported no issues related to implementation of the treatment and noted that the treatment seems promising and they are pleased with the outcomes. It is believed that the systems are more effective at getting the attention of motorists because of their interactive nature and by the fact they are very rarely seen on Kentucky highways. A potential concern is that over time or with over use of the treatment, motorists may come to rely on the ICWS too much and become less observant as they approach an intersection.

KYTC has set specific standards for ICWS installation and operations. All of the Kentucky ICWS installations that have been deployed as of 2017 follow the specifications featured in Figure 22 and Figure 23. KYTC continues to monitor these ICWS installations for any sign placement or flash time improvements that can be implemented.

$$SSD = 1.47Vt + \frac{V^2}{30[(a/32.2) +/- G]}$$

Figure 22. Equation. Stopping sight distance for mainline.

Where:

V = speed (mph), Posted Speed Limit or 85th Percentile Speed, whichever is *higher*

t = brake reaction time (2.5 sec)

a = deceleration rate (11.2 ft/s^2)

G = grade (rise/run, decimal format)

$$T = D \times \frac{1}{V} \times \frac{3600\ sec}{5280\ ft}$$

Figure 23. Equation. Flash time for beacons on the side road.

Where:

D = distance to be traveled (ft) (SSD + Intersection Width + 25 ft.)

V = speed (mph) (Use 45 mph)

FUTURE APPLICATIONS

As previously stated, the Kentucky SHSP lists developing and installing ICWS as an engineering strategy listed in the intersection emphasis.[32] Since the SHSP serves as an umbrella document for State safety planning, it is assumed that this treatment will become more widely implemented by KYTC in the coming years. The Kentucky SHSP does not include any engineering strategies in the motorcycle safety emphasis area and KYTC does not specifically consider motorcycles in project planning and programming.

Generally, Kentucky implements ICWS at site locations where angle crashes are the main crash type and the mainline has no control with a stop-controlled minor road. Since the installation of the ICWS in Eddyville, there have been six additional installations of the treatment. The additional ICWS sites are located in Boone, Graves, Knox, Laurel, McCracken, and McLean County. Some of the applications of recent installments have been used at four-lane intersections. In these instances, KYTC is using overhead warning signs as a part of the application.

SUMMARY

Advanced warning countermeasures serve the overall purpose of identifying an upcoming intersection or potential safety conflicts that may occur. Advanced warning systems are a relatively low-cost treatment which may be effective in reducing motorcycle crashes. The ICWS is a treatment that previous research has shown to be effective in reducing crashes. It stands to reason that the effectiveness would extend to motorcycle-vehicle crashes specifically. One study of the ICWS estimated a range of benefit/cost ratios could be 16:1 to 39:1 for two-lane at two-lane intersections.[23]

An analysis of the site under consideration indicates that total crashes and motorcycle involved crash rates decreased following implementation. The ratio of angle crashes to total crashes also declined in the after period. However, the comparison does not account for changes in traffic volume, regression-to-the-mean, or time trends in crashes.

AGENCY CONTACT INFORMATION

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VII. HIGH FRICTION SURFACE TREATMENT ON AN INTERSECTION APPROACH – CORBIN, KY

TREATMENT DESCRIPTION

KYTC defines a high friction surface treatment (HFST) as the application of a high-quality aggregate to the pavement using a polymer binder to increase pavement friction. The application of HFST on horizontal curves is a well-studied, cost-effective treatment listed as one of the FHWA *Proven Safety Countermeasures.*[33] FHWA also promoted HFST as an effective pavement overlay option as a part of their Every Day Counts (EDC) 2 initiative.[34] States have moved to applying HFST on approaches to intersections to mitigate skidding and rear-end crashes in wet or dry conditions.

The *Intersection Safety Strategies Brochure, 2nd Edition* (FHWA-SA-15-85) suggests HFST on signalized intersection approaches where agencies have diagnosed skidding as a safety problem, especially in wet conditions.[26] The brochure categorizes the treatment as a moderate cost measure. The UIIG features the application of HFST on intersection approaches as a recommended treatment for unsignalized intersections.[35] Treatment ID No. 069 from the UIIG gives additional details regarding targeted crash types, problems addressed, conditions addressed, and considerations. Table 9 shows CMFs that quantify the impact of increasing pavement friction at intersections. The listed CMFs are specific to intersections, and therefore illustrate the safety value of providing additional friction at intersections, but do not represent the HFST applications promoted by FHWA or used in Kentucky.

Table 9. CMFs for HFST at intersections.[5]

Treatment	Star Rating	CMF ID	CMF Value	CRF Value	Crash Type	Crash Severity
Increased pavement friction	5	194	0.76	24	All	All
Improve pavement friction (increase skid resistance)	4	2259	0.799	20.1	All	All
Improve pavement friction (increase skid resistance)	4	2273	0.582	41.8	Rear End	All

SITE DESCRIPTION

The site of the case study is in Corbin, KY at the intersection of US25E (Cumberland Gap Parkway) and KY1629 (Ohler Road). US25E serves as the mainline approach to the four-leg, signalized intersection. The southbound approach consists of one right-turn only, two through, and one separate left-turn only lanes.

The intersection is in a rural area with commercial properties along US25E. The U.S. Census Bureau estimated the population of Corbin at nearly 7,400.[27] The site is located about 2 mi. south from I75, which leads to a high volume of traffic on US25E. The posted speed limit is 45 mph on the approach, but the speed increases to 55 mph 2,000 ft. past the intersection.

District 11 of the KYTC initiated the application of a HSFT in Corbin, KY on southbound US25E (Cumberland Gap Parkway) approaching KY1629 (Ohler Road) in April 2011. The contractor applied the calcined bauxite aggregate treatment on the downgrade approach to reduce stopping distances and prevent rear-end crashes in both wet and dry conditions. Figure 24 and Figure 25 provide aerial imagery of the site and Figure 26 provides a street level view of where the HFST begins on US25E.

Figure 24. Photo. Aerial view of treatment site in Corbin, KY.[36]

Figure 25. Photo. Zoom view of treatment site in Corbin, KY.[36]

Figure 26. Photo. Street-level view of where the HFST begins on US25E.[37]

SITE IDENTIFICATION AND PROJECT APPROVAL

The Kentucky HSIP provides an opportunity for KYTC headquarters to partner with KYTC District personnel to deliver data-driven safety solutions. The KYTC District 11 and headquarters recommended the site for HFST application and inclusion in the HSIP. KYTC had previously identified the intersection of US25E and KY1629 as a high crash intersection in Kentucky's former "black spot" program. Figure 27 shows Kentucky's current methodology and implementation of site-specific intersection projects to improve safety.

Figure 27. Graphic. Methodology and implementation of site-specific intersection projects in Kentucky.[38]

PROJECT FUNDING

The project was funded through the Kentucky HSIP which aims to reduce the number of highway fatalities and serious injuries on all public roads toward zero. Kentucky recieves $41 million annually in HSIP funds. The HSIP FAST Act Investment Plan submitted by KYTC in 2017 indicates an investment of $7 million (17 percent of total HSIP funds) annually for intersection-related improvements.[38] HFST projects receive $500,000 (2-percent) annually through the HSIP.

Kentucky estimates HFST applications cost between $35 and $45 per yard^2. In this case, the contractor applied over 2,000 yards^2 of HFST to the southbound approach on US25E at a cost of approximately $54,000. The KYTC completed the project by applying the traffic control and pavement markings so the total cost of the project would include those materials and labor.

SAFETY ANALYSIS

Exposure data for motorcyclists is lacking, which limits agencies' ability to conduct predictive analysis concerning motorcycle crashes. The Kentucky 2015-2019 SHSP reports the annual average of 1,823 motorcycle crashes resulting in an average of 414 motorcyclist serious injuries and fatalities in Kentucky from 2010 through 2014.[32] Thirteen-percent of total traffic fatalities in Kentucky occurred at intersections in the same period. The intersection emphasis area lists HFST applications of HFST as an engineering strategy.

A previously published case study under the FHWA EDC initiative featured the Corbin, KY treatment site. The study concluded that observed total crashes per year were reduced by half.[39] Table 10 provides a summary of the previous case study data.

Table 10. Pre- and post-treatment site data – Corbin, KY.

Crashes	Before (3 Years)	After (1.3 Years)
Wet Weather Crashes	6	2
Dry Weather Crashes	27	5
Total Crashes	33	7
Total Crashes Per Year	11	5.38

For this case study, Kentucky provided data that included crashes within 250 ft. of the intersection from 2006 through 2016. The purpose of the treatment site analysis is to observe trends in vehicle traffic and crash frequency for the before and after treatment periods. Because the analysis pertains to only a single site the intent is not to estimate a CMF. Traffic volume counts are available for the after period; however, volume estimates for motorcycles specifically were not available. The AADT for US25E in 2016 was 26,039. The AADT on KY1629 was 3,143 in 2015.

The pre-treatment data (5.25 years) showed 54 total crashes with 0 involving a motorcyclist prior to installation in 2011. The location also had 43 injuries before installation of the HFST. The after period (5.67 years) showed 42 total crashes observed with 33 injuries and 1 fatality. For total crashes, there was a reduction in observed crashes from the before period (10.29/year) to the after period (7.14/year). The data showed a similar reduction in injuries in the before period (8.19/year) to the after period (6/year).

Examining targeted crash types for the treatment area reveals a greater reduction in the rate of crashes and injuries. Table 11 displays a site analysis provided by KYTC (2008-2017) specific to rear-end crashes in the southbound lane of US25E where the HFST application is located. The data includes injury severity and weather condition information. The data shows a reduction in rear-end crashes and rear-end injury crashes per year.

Table 11. Pre- and post-treatment site data for target (rear-end) crashes – Corbin, KY.

Crashes	Before (3.25 years)	After (6.5 years)
Wet weather crashes	7	6
Dry weather crashes	14	15
Total crashes	21	21
Total crashes per year	6.46	3.23
A-injury crash	1	1
B-injury crash	0	3
C-injury crash	7	6
Total injury crashes	8	10
Injury crashes per year	2.46	1.54

TREATMENT BENEFITS FOR MOTORCYCLISTS

The data shared in the previous section shows that the treatment helped reduce the targeted crash type (rear-end) at the site. Specific to crashes involving motorcycles, empirical proof is not feasible with the level of data available at this specific site. The available analysis did not allow for quantitative conclusions impacting motorcycle safety.

Although analysis limitations exist, implementing the HFST treatment has shown positive results at this site and in other studies for crashes involving all motor vehicle types. The risk to motorcyclists in rear-end crashes is exponentially greater compared to passenger vehicles due to their vulnerability while either waiting at or approaching an intersection. Knowing that a HFST applied to an intersection approach can reduce the number and severity of rear-end crashes, agencies could assume that the treatment would also have a safety impact on motorcyclists.

CONSIDERATIONS FOR TREATMENT APPLICATION

Kentucky has established an expected life of service for HFST from 5 to 7 years. Agencies should take into consideration that the HFST durability will rely on the pavement condition serving as its foundation. Kentucky aims to apply the HFST to pavement that is less than 3 years of age or in good condition. Agencies considering this treatment should expect shorter life of service at intersections with heavier traffic volumes braking.

KYTC monitors pavement condition and conducts a crash analysis before considering reapplying the HFST at any site. KYTC conducted a dynamic friction test (DFT) at the treatment site in August of 2015. The DFT found that the surface has performed well, but did find severe shedding in the last 50 ft. of pavement before the intersection. KYTC noted that even with the severe shedding, the application still provided better friction than a typical asphalt pavement. Figure 28 and Figure 29 display photos from the DFT conducted in 2015.

Figure 28. Photo. DFT at treatment site (left lane).[40]

Figure 29. Photo. DFT at treatment site (right lane). [41]

FUTURE APPLICATIONS

The focus of the Kentucky HFST program is wet-weather, rural crashes on curves. The treatment identified in this case study is a unique outlier to the State program that the KYTC District identified by diagnosing specific crash factors at a specific site. Kentucky has recently included some interchange ramps and inline interstate segments into the HFST program.

As previously discussed, Kentucky's 2015-2019 SHSP lists implementing HFSTs at intersection approaches as an engineering strategy in the intersection emphasis area.[28] At the time of this research, the treatment site in Corbin is currently the only intersection in Kentucky with a HFST. With the SHSP serving as an umbrella document for State safety planning, there is the potential for HFST to become more widely implemented by KYTC. The Kentucky SHSP does not include any engineering strategies in the motorcycle safety emphasis area and KYTC does not specifically consider motorcycles in project planning and programming.

SUMMARY

HFST can increase safety at intersections by reducing stopping distances and the propensity for skids (loss of control). HFST can be applied quickly and is a moderate-cost countermeasure. Previous research has shown HFST to be effective in reducing crashes. It stands to reason that the effectiveness would extend to motorcycle crashes specifically.

An analysis of the site under consideration indicates that total crashes and motorcycle involved crash rates decreased following implementation. The rates for wet and injury crashes also declined in the after period. However, the comparison does not account for changes in traffic volume, regression-to-the-mean, or time trends in crashes.

Jurisdictions may consider the installation of HFST at intersections in future planning efforts to serve as a potential safety benefit for motorcyclists. The treatment is relatively straight forward to apply at a reasonably low cost. Depending on the programs in a State, HSIP funds or other sources of safety improvement funds are possible sources of funding. The vulnerability of motorcyclists and their unique handling characteristics provide a unique challenge in transportation safety planning. When selecting an intersection treatment, agencies should assess the safety, operational, and accessibility impacts on all system users.

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VIII. CONCLUSION

The vulnerability of motorcyclists and their unique handling characteristics present a special challenge to road safety efforts. When selecting an intersection treatment, agencies should assess the safety, operational, and accessibility impacts on all system users. Many of the treatments documented in this compilation of case studies reduce the types of crashes that occur at intersections and often involve motorcycles.

Jurisdictions may consider implementing these treatments as part of future road safety planning efforts to provide potential safety benefit for motorcyclists. The treatments are relatively straight forward to apply and both relatively low in cost and cost effective. Depending on the programs in a State, HSIP funds or other sources of safety improvement funds are possible sources of funding.

States and local jurisdictions across the nation have begun instituting a “safe systems” approach in recent years by adopting a “Toward Zero Deaths” or “Vision Zero” philosophy. This approach is especially important to motorcyclists because it promotes safety considerations for all users of the transportation system with a goal of minimizing the frequency and severity of crashes. These case studies are presented as emerging practices that agencies may consider implementing at intersections where motorcycle safety is a concern.

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