

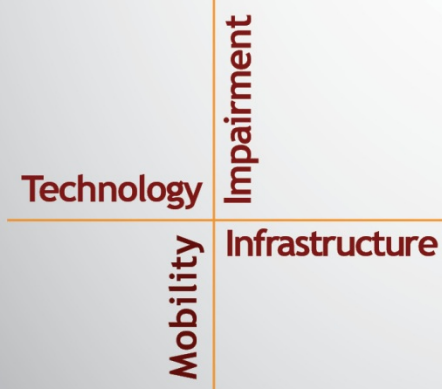
# NSTSCCE

## National Surface Transportation Safety Center for Excellence

### Safety Countermeasures at Unsignalized Intersections – A Toolbox Approach

Eric Li (Ph.D., P.E.) • Alejandra Medina • Ronald B. Gibbons  
(Ph.D, FIES)

Submitted: June 23, 2020



Housed at the Virginia Tech Transportation Institute  
3500 Transportation Research Plaza • Blacksburg, Virginia 24061

## **ACKNOWLEDGMENTS**

The authors of this report would like to acknowledge the support of the stakeholders of the National Surface Transportation Safety Center for Excellence (NSTSCE): Tom Dingus from the Virginia Tech Transportation Institute; John Capp from General Motors Corporation; Chris Hayes from Travelers Insurance; Terri Hallquist, Steven K. Smith, and Nicole Michel from the Federal Motor Carrier Safety Administration; Cathy McGhee from the Virginia Department of Transportation and the Virginia Transportation Research Council; and Jane Terry from the National Safety Council.

The NSTSCE stakeholders have jointly funded this research for the purpose of developing and disseminating advanced transportation safety techniques and innovations.

## EXECUTIVE SUMMARY

In 2015, approximately 8,000 intersection and intersection-related fatal crashes occurred on the nation's highway system, resulting in more than 8,400 fatalities. That death toll represented about 24% of the traffic-related deaths across the country. Combining fatalities and injuries, intersection and intersection-related crashes represent more than 50% of the traffic-related injuries across the nation. Unsignalized intersections are of particular concern. Between 2010 and 2014, unsignalized intersections were responsible for more than 70% of the intersection and intersection-related fatalities, making them an imperative issue for transportation agencies and researchers to tackle.

This report documents the Phase I findings of a project to improve safety at unsignalized intersections. The primary objectives of this research were to develop a comprehensive catalog and information guide containing tools that can be used at unsignalized intersections to reduce crashes.

The research team identified a total of 83 suitable safety countermeasures that can be used at unsignalized intersections to mitigate crash risks and documented them in an *Unsignalized Intersection Toolbox and Information Guide* (see [Appendix](#)). The catalog contains a one-page information guide for each countermeasure and is organized into four major categories: Engineering, Enforcement, Education, and Vehicle Technology. The categories were structured as follows:

- Sixty-six engineering countermeasures grouped into the following subcategories:
  - Traffic signs, including regular and enhanced signs
  - Markings and delineators, including pavement and curb markings, delineators, pavement treatment, and channelizing islands and devices
  - Other traffic control devices, including traffic signals and Intelligent Transportation System (ITS) devices
  - Geometric improvements, including intersection realignment and intersection reconfiguration measures
  - Other countermeasures that do not belong to the above subcategories
- Five enforcement countermeasures
- One education countermeasure
- Eleven vehicle technology countermeasures grouped into the following subcategories:
  - Onboard detection and warning systems
  - Automated vehicle control technologies
  - Connected vehicle technologies
  - Vehicle-environment interaction technologies

In addition to the *Unsignalized Intersection Toolbox and Information Guide*, the research team developed a software toolbox that allows users to browse, edit, and search for countermeasures in an intuitive manner. The software toolbox was developed with Qt 5, which can be modified in the future with minimal effort to directly access an enterprise database for storing and managing

the countermeasures. In addition to viewing and managing the existing tools, the toolbox allows users to edit existing tools and add new tools as needed, making it flexible and expandable to meet different user needs.

During this project, the research team identified a large number of safety countermeasures at unsignalized intersections that have great potential for cost-effective, systemic implementation. Among the various engineering solutions, for example, the following countermeasures are particularly promising for testing and potential implementation:

- Light-emitting diode (LED)-enhanced Stop signs (see page 33 in Appendix). Embedded LED lights around Stop signs can greatly improve their conspicuity, particularly during low-visibility conditions such as night, fog, or rain. The LED lights may be steady or flashing and can be powered with solar batteries. These signs typically cost less than \$10,000, including installation.
- Retroreflective panels on sign posts (see page 34 in Appendix). These are extremely low-cost solutions that have the potential to considerably improve sign conspicuity during low-visibility conditions if used properly. Retroreflective panels on sign posts can be particularly suitable for implementation on Stop and Yield signs at unsignalized intersections.
- Center line pavement markings in a median crossing (see page 40 in Appendix). Some wide median openings subject to through, left-turn, right-turn, and U-turn traffic can be extremely confusing to navigate and potentially risky for drivers to use. Center line pavement markings at such locations can be low-cost measures to reduce vehicle conflicts and therefore improve safety.
- Center line pavement markings on the minor road approach (see page 41 in Appendix). Traffic turning onto a minor street from a major roadway at a high speed can frequently encroach into the opposite direction of the minor approach, leading to increased risk for crashes. Center line pavement markings better indicate turning paths at the minor approaches and improve the conspicuity of unsignalized intersections.
- Installing intersection lighting (see page 100 in Appendix). Isolated rural intersections, particularly those with unconventional layouts (e.g., T- or Y-shaped intersections or intersections at roadways with wide medians), can be risky to navigate during the nighttime or other low-visibility conditions. Without properly identified travel paths, turning vehicles can be subject to high risks for roadway departures and head-on crashes. Low-cost lighting solutions, such as solar-powered LED lights, can be particularly beneficial at such locations in reducing nighttime crashes.

# TABLE OF CONTENTS

<b>LIST OF FIGURES.....</b>	<b>v</b>
<b>LIST OF ABBREVIATIONS AND SYMBOLS .....</b>	<b>vii</b>
<b>CHAPTER 1. BACKGROUND.....</b>	<b>1</b>
<b>INTRODUCTION .....</b>	<b>1</b>
<b>PROJECT OBJECTIVE AND SCOPE.....</b>	<b>3</b>
<b>CHAPTER 2. INTERSECTION TYPES AND ASSOCIATED SAFETY ISSUES.....</b>	<b>5</b>
<b>GEOMETRIC LAYOUTS OF INTERSECTIONS .....</b>	<b>5</b>
<b>TRAFFIC SIGNAL WARRANTING CONDITIONS .....</b>	<b>6</b>
<b>TRADITIONAL TRAFFIC CONTROL AT UNSIGNALIZED INTERSECTIONS.....</b>	<b>7</b>
<b>SAFETY ISSUES AT UNSIGNALIZED INTERSECTIONS.....</b>	<b>8</b>
<b>CHAPTER 3. UNSIGNALIZED INTERSECTION COUNTERMEASURES AND TOOLBOX .....</b>	<b>11</b>
<b>UNSIGNALIZED INTERSECTION COUNTERMEASURES AND INFORMATION GUIDE.....</b>	<b>11</b>
<b>UNSIGNALIZED INTERSECTION COUNTERMEASURE TOOLBOX .....</b>	<b>13</b>
<b>CHAPTER 4. CONCLUSION.....</b>	<b>19</b>
<b>SUMMARY OF RESULTS.....</b>	<b>19</b>
<b>RECOMMENDED COUNTERMEASURES FOR PHASE II TESTING.....</b>	<b>20</b>
<b>APPENDIX. UNSIGNALIZED INTERSECTION TOOLBOX AND INFORMATIONAL GUIDE.....</b>	<b>21</b>
<b>REFERENCES .....</b>	<b>125</b>



## LIST OF FIGURES

<b>Figure 1. Chart. Intersection and intersection-related crashes in U.S.....</b>	<b>1</b>
<b>Figure 2. Diagram. Conflict points at conventional intersection.....</b>	<b>2</b>
<b>Figure 3. Photo. Example of median U-Turn intersection in Chapel Hill, NC. ....</b>	<b>5</b>
<b>Figure 4. Screen capture. Sample countermeasure tool page.....</b>	<b>13</b>
<b>Figure 5. Screen capture. Toolbox home view. ....</b>	<b>14</b>
<b>Figure 6. Screen capture. Toolbox tools view.....</b>	<b>15</b>
<b>Figure 7. Screen capture. Toolbox tool detail view.....</b>	<b>16</b>
<b>Figure 8. Screen capture. Edit tool details.....</b>	<b>17</b>
<b>Figure 9. Screen capture. Toolbox help view. ....</b>	<b>18</b>





## LIST OF ABBREVIATIONS AND SYMBOLS

FARS	Fatality Analysis Reporting System
ITS	Intelligent Transportation Systems
LED	light emitting diode
MUTCD	<i>Manual on Uniform Traffic Control Devices for Streets and Roadways</i>
NCUTCD	National Committee on Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Administration
NSTSCE	National Surface Transportation Safety Center for Excellence
VTI	Virginia Tech Transportation Institute



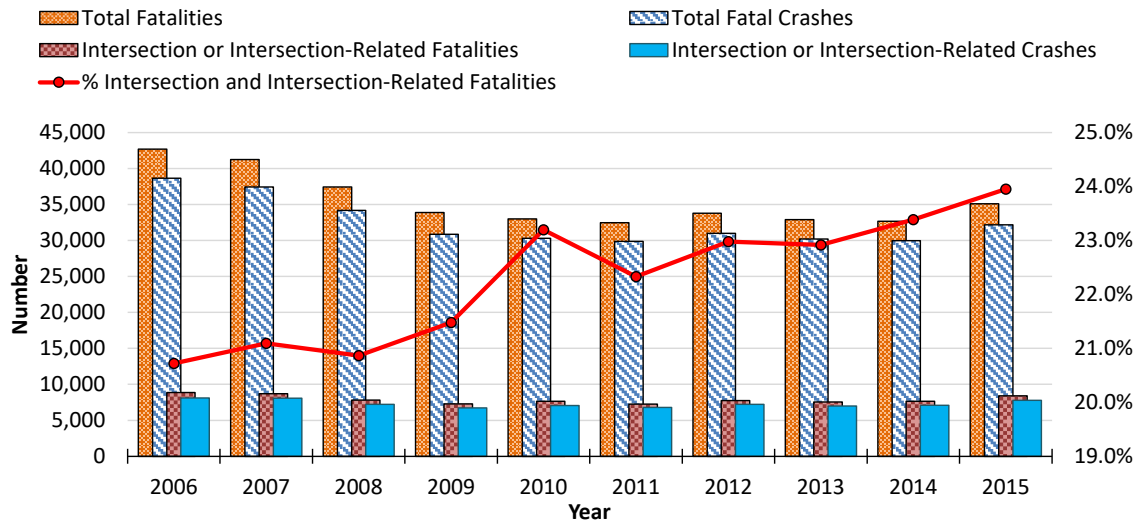
## CHAPTER 1. BACKGROUND

### INTRODUCTION

In 2015, approximately 8,000 intersection and intersection-related fatal crashes occurred on the nation’s highway system, resulting in more than 8,400 fatalities representing about 24% of the traffic-related deaths across the country (Table 1 and Figure 1).<sup>(1)</sup> Combining fatalities and injuries, intersection and intersection-related crashes represent more than 50% of traffic-related injuries in the United States.<sup>(2)</sup> As shown in Table 1 and Figure 1, statistics from the National Highway Traffic Safety Administration’s (NHTSA’s) Fatality Analysis Reporting System (FARS) indicate that, although the total number of fatal crashes in the nation has trended downward during the past decade, the number of intersection and intersection-related crashes has remained roughly the same, leading to an increasing proportion of such crashes and their associated fatalities.

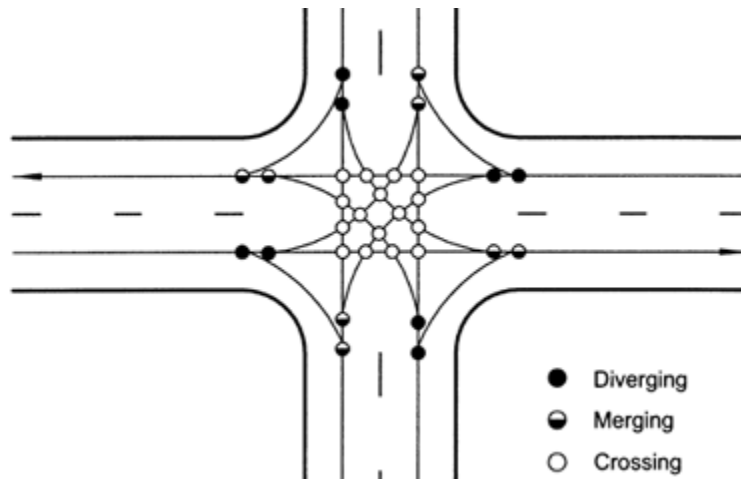
**Table 1. Intersection and intersection-related crashes in U.S. <sup>(1)</sup>**

Year	Intersection or Intersection-Related Fatal Crashes		Intersection or Intersection-Related Fatalities		Total Fatal Crashes	Total Fatalities
	Number	Percentage	Number	Percentage		
2006	8,108	21.0%	8,850	20.7%	38,648	42,708
2007	8,061	21.5%	8,703	21.1%	37,435	41,259
2008	7,231	21.2%	7,809	20.9%	34,172	37,423
2009	6,720	21.8%	7,278	21.5%	30,862	33,883
2010	7,073	23.3%	7,655	23.2%	30,296	32,999
2011	6,808	22.8%	7,253	22.3%	29,867	32,479
2012	7,216	23.3%	7,762	23.0%	31,006	33,782
2013	7,005	23.2%	7,538	22.9%	30,203	32,894
2014	7,098	23.7%	7,642	23.4%	29,989	32,675
2015	7,788	24.2%	8,405	24.0%	32,166	35,092



**Figure 1. Chart. Intersection and intersection-related crashes in U.S. <sup>(1)</sup>**

Intersections are risky to navigate due to conflicting traffic movements. For example, at a conventional 4-leg intersection of two 2-lane, 2-way roadways, there can be 32 conflict points, including 8 merging points, 8 diverging points, and 16 crossing conflict points. One approach to regulate traffic and mitigate potential crash risks at intersections is to use traffic signals. However, partly due to the associated costs, traffic signals are typically used only when a number of warranting conditions are met at a specific site, including, in particular, the traffic volumes using the intersection and the crash history. In many cases, intersections on roadways with relatively low traffic volumes are not controlled by traffic signals. These intersections, referred to as unsignalized intersections, represent a significant proportion of all the intersections in the U.S. highway system, particularly on rural and local roadways.



**Figure 2. Diagram. Conflict points at conventional intersection.** <sup>(3)</sup>

Many unsignalized intersections can be characterized as low-volume roadways and are often associated with high speeds. Consequently, crashes at unsignalized intersections frequently result in severe injuries. Between 2010 and 2014, for example, unsignalized intersections were responsible for more than 70% of intersection and intersection-related fatalities.<sup>(4)</sup> The magnitude of the statistics has made unsignalized intersection a safety concern among the traveling public, traffic engineers, and the research community. Currently, many state Departments of Transportation identify intersections as a safety emphasis area in their State Highway Safety Plans and Strategic Highway Safety Plans.

When addressing safety problems at unsignalized intersections, traffic safety engineers and researchers frequently feel shorthanded in selecting cost-effective countermeasures. Fortunately, a large number of conventional and innovative traffic control approaches are currently available for intersections, including those that fall in the category of Intelligent Transportation Systems (ITS). However, some of these devices or systems are cost prohibitive. For example, the installation, operation, and maintenance of traffic signals are typically associated with significant costs. Due to the sheer number of intersections in the nation, it is impractical for state and local transportation agencies to install these systems systemically. Some systems can even be counter-effective if used inappropriately. Therefore, having straightforward information and guidelines about existing traffic control measures for unsignalized intersections is essential, especially in identifying cost-effective methods that are suitable for systemic application.

## **PROJECT OBJECTIVE AND SCOPE**

The National Surface Transportation Safety Center for Excellence (NSTSC) at the Virginia Tech Transportation Institute (VTTI) funded this research with the following primary objectives:

- To identify a comprehensive catalog of traffic control devices and systems that are suitable for safety treatment at unsignalized intersections, with a focus on those that are low cost and can be used for systemic deployments (Phase I).
- To develop a toolbox of the identified countermeasures that allows straightforward and efficient selection of suitable countermeasures to satisfy a predefined set of site conditions (Phase I).
- To assess the effectiveness and suitability for systemic implementation of selected safety countermeasures at unsignalized intersections (Phase II).

This report documents the efforts and findings of the Phase I research defined by the first two objectives. To achieve these objectives, the research team conducted a comprehensive literature review to identify conventional and innovative safety countermeasures at unsignalized intersections. The literature review not only focused on engineering solutions, but also covered topics such as enforcement countermeasures, safety education methods, and vehicle technologies. The effort resulted in a collection of 83 countermeasures, each of which was compiled into a concise and user-friendly information guide describing its effectiveness, associated costs, and use conditions. Finally, the catalog of the countermeasures was incorporated into a software toolbox, where users can browse, compare, and query countermeasures in a straightforward manner.



## CHAPTER 2. INTERSECTION TYPES AND ASSOCIATED SAFETY ISSUES

### GEOMETRIC LAYOUTS OF INTERSECTIONS

In the context of geometric design, conventional intersections can be categorized by the number of legs:<sup>(6)</sup>

- 3-leg or T-intersections
- 4-leg intersections
- Multi-leg intersections
- Modern roundabouts

Depending on the use of auxiliary lanes and channelization, the configurations of conventional intersections can vary significantly. Auxiliary lanes used at intersections typically include dedicated right-turn lanes, left-turn lanes, U-turn lanes, and slip lanes. Channelization at intersections can be achieved through the use of channelization islands, medians, divisional islands, and refuge islands for pedestrians and bicyclists.

In addition to traditional intersection designs, practitioners and researchers have developed and implemented a number of non-traditional design alternatives specifically to mitigate the safety risks caused by left-turn traffic. Examples of non-traditional intersection designs include displaced left-turn, median U-turn, restricted crossing U-turn, and quadrant roadway intersections.<sup>(7-9)</sup> Restricted crossing U-turn intersections (Figure 3), for example, are particularly suitable for intersections between a major street and a minor street. This configuration is similar to median U-turn intersections, but requires all through traffic on the major street, and through and left-turn traffic on the minor street, to go through the downstream U-turn openings instead of going through the main intersection. Corridors with restricted crossing U-turn intersections are often referred to as super streets. This configuration may improve capacity and delay for the major street but can sometimes result in confusion for drivers unfamiliar with the site.



**Figure 3. Photo. Example of median U-Turn intersection in Chapel Hill, NC. <sup>(10)</sup>**

There are a number of other types of intersection designs to mitigate the operational impacts of left-turn traffic. Such designs can be modifications and/or combinations of the aforementioned configurations. Examples include jughandle intersections, where turning traffic is required to use a jughandle, and through-about intersections, where through traffic on the major road goes through the intersection directly while left-turn traffic on the major road and all traffic on the minor road have to use a traffic circle.

## **TRAFFIC SIGNAL WARRANTING CONDITIONS**

Traffic control signals are a common traffic control mechanism at intersections. Traffic signals allow for orderly traffic movements at intersections and therefore considerably improve operations and reduce certain types of crashes when used properly. The *Manual on Uniform Traffic Control Devices for Streets and Roadways* (MUTCD)<sup>(11)</sup> requires an engineering study of roadway, traffic, and other conditions to justify the selection and use of a traffic signal at an intersection.

According to MUTCD, a traffic control signal needs study should analyze the site data against nine warrants in order to determine if a traffic signal should be installed:<sup>(11)</sup>

- Eight-hour vehicular volume. This warrant requires that the vehicular traffic volumes of both streets for any 8 hours of an average day meet two sets of minimum requirements (Conditions A and B) specified in the manual. Condition A looks at the total volume of the intersecting traffic from both streets and is intended for application at locations where a large volume of intersecting traffic is the principal reason for considering a traffic control signal. Condition B measures the interruption of continuous traffic flow at the major streets and is intended for application at locations where the major street carries significant traffic, and traffic on the minor street suffers excessive delay or conflict in entering or crossing the major street.
- Four-hour vehicular volume. This warrant compares the volume of any 4 hours of an average day on both intersecting streets with the specified minimum volume conditions. This warrant is intended to be applied where the volume of intersecting traffic is the principal reason to consider a traffic control signal.
- Peak-hour vehicular volume. This warrant compares the peak-hour traffic volumes entering the intersection and the total stop delays on the minor street against the specified minimums. A traffic signal should be considered if the study shows that traffic on the minor street suffers excessive delays during the peak hour if a signal is not used.
- Pedestrian volume. This warrant analyzes the 4-hour or the peak-hour vehicular and pedestrian traffic against a set of minimums at specified site conditions to identify the need for a traffic signal in order to avoid excessive delay for pedestrians crossing the major street. The warrant is designed for locations where there exists a relatively large volume of pedestrian traffic crossing the major street.



- School crossing. This warrant allows for the consideration of a traffic control signal at locations where a relatively large group of school children needs to cross the street but the available gaps in the traffic stream do not adequately and safely permit it.
- Coordinated signal system. A traffic control signal may be considered for the purpose of allowing the progressive movement of traffic in a coordinated signal system.
- Crash experience. A signal can be considered if the engineering analysis shows that the use of a traffic control signal has the potential to effectively reduce crashes.
- Roadway network. A signal may be considered at some intersections if it will result in a desired concentration and organization of traffic flow on a roadway network.
- Intersection near a railroad crossing. This warrant looks at the potential need for a traffic control signal at an intersection located near a railroad crossing where large volumes of highway and railroad traffic may interfere.

Modern traffic signals have high installation and operational costs. It is estimated that purchasing and installing a new traffic signal costs anywhere between \$250,000 and \$500,000. Electric bills and routine maintenance amount to about \$8,000 a year. Each routine signal retiming further adds \$2,500 to \$3,100 on top of these costs.<sup>(12,13)</sup> In addition, when not properly used, traffic signals may result in increased delays and/or traffic crashes.

## **TRADITIONAL TRAFFIC CONTROL AT UNSIGNALIZED INTERSECTIONS**

There are generally three types of unsignalized intersections (excluding roundabouts) in the U.S.:

- Stop-sign-controlled intersections, where at least one approach is controlled by a Stop sign.
- Yield-sign-controlled intersections, where at least one approach is controlled by a Yield sign.
- Uncontrolled intersections, where none of the approaches are controlled by a regulatory traffic sign or signal. These are typically intersections on very low-volume roadways in residential areas or very rural roadways, such as low volume farm to market roads.

According to the *Uniform Vehicle Code*<sup>(14)</sup> developed by the National Committee on Uniform Traffic Control Devices (NCUTCD), vehicles approaching uncontrolled intersections must yield the right-of-way to any vehicle or pedestrian already in the intersection. When two vehicles approach such an intersection from different streets at approximately the same time, the driver of the vehicle on the left should yield the right-of-way to the vehicle on the right. Stop and Yield signs are used to assign the right-of-way to designed traffic flows at one or more approaches at unsignalized intersections. It is important to note that neither Stop nor Yield signs should be used for speed control at intersections.

According to the MUTCD,<sup>(11)</sup> a number of factors should be considered when deciding if Stop or Yield signs should be used at an unsignalized intersections, including vehicular and pedestrian traffic volumes, intersection geometric alignment, available sight distance, speed limits, and

historical crash data. In general, Stop or Yield signs are used on a minor street intersecting with a major street, a street entering a designated through highway or street, at intersections of streets with low traffic volume, or at an unsignalized intersection in a signalized area/corridor.

Yield signs are less restrictive than Stop signs, and therefore are used at conditions where a full stop is not necessary at all times.<sup>(11)</sup> MUTCD requires the use of Stop signs on minor streets of intersections when one or more of the following conditions exist:

- The traffic volume on the major street exceeds 6,000 vehicles per day.
- Vehicles from the side street have to stop in order to adequately observe conflicting traffic due to factors such as limited sight distances or high speeds.
- A relatively high number of crashes reported in the past may be reduced by the use of Stop signs.

When both intersecting streets have approximately equal traffic volumes and the intersection does not warrant a traffic signal, multi-way or all-way Stop signs can be used.<sup>(11)</sup> Multi-way Stop-sign-controlled intersections typically meet a number of conditions defined by crash history and vehicular, pedestrian, and bicycle volume.<sup>(11)</sup> In addition, multi-way Stop-sign controls are used at intersections where a traffic control signal is warranted but is awaiting installation, or to achieve certain operational and safety benefits, such as regulating conflicting turning traffic.

In many cases, a range of additional signs or other devices is used to improve the conspicuity of and/or compliance with the Stop or Yield signs at unsignalized intersections. Examples of such devices or mechanisms include supplemental signs, enlarged signs, signs enhanced with light-emitting diodes (LEDs) or flags, advance warning signs, and intersection beacons. A variety of pavement markings can also be used to improve traffic control at unsignalized intersections.

## **SAFETY ISSUES AT UNSIGNALIZED INTERSECTIONS**

Due to conflicting and/or stopping traffic, a majority of crashes at intersections are multi-vehicle crashes. The following types of crashes are frequently recorded at unsignalized intersections:<sup>(15,16)</sup>

- Angle crashes. Angle crashes are crashes where two motor vehicles impact at an angle. Angle crashes, which are very common, are frequently related to left-turn and, to a lesser degree, right-turn movements at intersections. Among angle crashes, right-angle crashes are typically caused when vehicles turn left onto or cross a major street from a minor street during an inadequate gap. Some angle crashes, particularly right-angle crashes, can result in severe injuries when traffic on the major roadway travels at a high speed. According to the Federal Highway Administration, every 100 reported angle crashes at unsignalized intersections result in approximately 1 to 3 fatalities and 5 to 15 serious injuries.<sup>(17)</sup>
- Rear-end crashes. Rear-end crashes are highly attributable to slowing or stopping traffic at intersections. Such crashes can also happen when slow vehicles turn onto roadways with a relatively high speed limit. Rear-end crashes are common for both signalized and

unsignalized intersections, but crashes at unsignalized intersections on rural high-speed roadways can be more severe.

- Sideswipe crashes. Sideswipe crashes refer to crashes where two vehicles make contact, but the initial engagement does not overlap the corner of either vehicle, so there is no significant involvement of the front or rear surface areas of either vehicle. The impact then swipes along the surface of the vehicle parallel to the direction of travel. Sideswipe crashes can occur between vehicles traveling in the same direction or in the opposite direction. Such crashes are more common on multilane highways, but can also occur at intersections, particularly after a vehicle turns onto the major road from a minor road.
- Fixed-object crashes (including parked vehicles). Although less common, fixed-object crashes can occur at intersections, particularly during the nighttime. Common objects involved in such crashes at intersections include curbs, sign/signal structures, utility poles, trees, guardrail, and parked vehicles. High speeds, inattention, and low visibility are factors that frequently contribute to this type of crashes at intersections.
- Other crashes. Studies suggested a nontrivial proportion of run-off-road crashes, particularly at rural intersections during the nighttime, and head-on crashes, particularly at rural T-intersections.

Studies also found that more than 60% of intersection-related crashes involved vehicles turning left at intersections, followed by vehicles crossing intersections (35%) and vehicles turning right (3%). In addition, older drivers (e.g., 65 and older, and 55–65) were proportionally more likely to be involved in intersection-related crashes.<sup>(15)</sup>

A number of factors can contribute to crashes at unsignalized intersections, including human errors, intersection configurations, and environmental conditions. Studies have identified the following factors that are most commonly reported for crashes at intersections:<sup>(15,18)</sup>

- Inappropriate or inadequate traffic control at intersections. Examples include Stop- or Yield-sign-controlled intersections that warrant a higher level of traffic control method; Stop or Yield signs that are not adequately conspicuous or visible due to obstructions (e.g., roadside vegetation), clutter, or aging; traffic control signs that are located contradictory to driver expectations; incorrectly placed/used traffic control signs and devices; and lack of supplemental signs and/or markings for driver guidance.
- Inappropriate intersection design or inadequate intersection sight distance. Examples include the lack of turning lanes/bays, incorrectly configured turning lanes, intersections located within vertical curves, highly skewed intersection configurations, hidden intersections without clear sign/markings guidance, limited intersection sight distance due to roadway alignments and/or sight obstructions, and inadequate lighting at intersections.
- Inadequate or nonexistent pavement markings and/or channelization devices at certain intersections. At intersections where a minor road crosses a multilane arterial, it is frequently hard to identify the appropriate turning path at the intersection for traffic from the minor road due to the crown, superelevation, and/or the median of the major roadway. Other examples include intersections where minor roadways are hidden due to roadside

vegetation or that cannot be clearly identified during the nighttime; large median openings allowing through, left-turn, and U-turn movements; and intersections where a relatively large volume of pedestrians/bicyclists compete for right-of-way. Without adequate pavement markings and/or channelization, it can be difficult and risky to navigate through such intersections.

- Intersections with excessive delays for traffic on the minor road. In some cases, although the traffic volume on the major road is low, the distribution pattern of the traffic on the major road during certain time periods may be such that few suitable gaps exist to allow for vehicles from the minor road to turn. This condition will cause excessive delays for traffic from the minor road and may result in crashes due to gap misjudgment.
- Excessive conflicts within or near intersections. Due to adjacent driveways or side streets, some intersections can have significantly more conflict points within or near them, creating high risks for crashes.
- There are also a number of driver errors that can frequently contribute to crashes at unsignalized intersections:
  - Inadequate observation
  - Misjudgment of other vehicle's maneuver
  - Turning with obstructed view
  - Illegal maneuver
  - Inattention or driver distraction
  - Misjudgment of gaps

## CHAPTER 3. UNSIGNALIZED INTERSECTION COUNTERMEASURES AND TOOLBOX

### UNSIGNALIZED INTERSECTION COUNTERMEASURES AND INFORMATION GUIDE


The research team identified a total of 83 safety countermeasures that can be used at unsignalized intersection to mitigate crash risks and documented them in an *Unsignalized Intersection Toolbox and Information Guide* (see [Appendix](#)). The document contains a one-page information guide for each countermeasure and is organized into four major categories: Engineering, Enforcement, Education, and Vehicle Technology.

- **Engineering countermeasures.** This group includes 69 engineering solution safety countermeasures with the following subcategories:
  - Traffic signs, including regular signs and enhanced signs
  - Markings and delineators, including pavement and curb markings, delineators, pavement treatment, and channelizing islands and devices
  - Other traffic control devices, including traffic signals and ITS devices
  - Geometric improvements, including intersection realignment and intersection reconfiguration measures
  - Other countermeasures that do not belong to the above subcategories
- **Enforcement countermeasures.** This group includes five countermeasures or actions for ensuring that traffic regulations and traffic control measures are followed properly for improved safety.
- **Education countermeasures.** This category includes one countermeasure, pedestrian/driver safety education, which can be carried out for specific communities or population groups via outreach, media campaigns, or safety education events.
- **Vehicle technology countermeasures.** This group includes 11 technologies relevant to onboard vehicle safety systems, vehicle automation, and vehicle-based communication. The countermeasures in this category are further grouped into the following subcategories:
  - Onboard detection and warning systems
  - Automated vehicle control technologies
  - Connected vehicle technologies
  - Vehicle-environment interaction technologies

Readers should note that vehicle technology countermeasures are very different than engineering, enforcement, and education countermeasures. The latter are public agency focused, meaning their implementations are typically led by public agencies such as state Departments of Transportation, Departments of Public Safety, and Departments of Motor Vehicles. The researchers, however, included such countermeasures upon stakeholder recommendation and to provide information about emerging vehicle safety features that may reduce the needs for certain engineering countermeasures or require different types of countermeasures when used widely.

Figure 4 shows a sample engineering countermeasure information page. As the sample shows, each countermeasure information guide includes the following information:

- **Basic countermeasure information.** Includes information such as name, category, subcategory, and the primary source containing more detailed information about the countermeasure.
- **Safety benefits.** Identifies the safety benefits based on published evaluations of the countermeasure. In many cases, this includes the crash modification factor developed for the countermeasure based on the *Highway Safety Manual*<sup>(19)</sup> methodology. A crash modification factor smaller than 1 indicates positive safety impacts (i.e., helps to reduce crashes if used).
- **Usage type.** Identifies whether the countermeasure is suitable for systemic application or spot treatment based on characteristics such as design and implementation costs.
- **Target problem.** Lists the major safety issues the countermeasure may help to mitigate.
- **Cost.** The implementation cost associated with the countermeasure. The research team estimated the implementation costs based on information obtained during the literature review. Cost was categorized into broad ranges: very low (\$5,000 or less), low (\$5,000–\$10,000), medium (\$10,000–\$25,000), medium high (\$25,000–\$50,000), and high (more than \$50,000).
- **Keywords.** Includes keywords associated with the countermeasure that can be used for searching and indexing.
- **Usage.** Contains general information on when and how the countermeasure should be used.
- **Pros and cons.** Lists the major advantages and disadvantages associated with the countermeasure.
- **Installation and configuration.** Includes more-detailed information about how the countermeasure should be installed and/or configured in order to be most effective.
- **Example applications.** Includes implementation examples the research team found in the published literature that demonstrate the benefits and usage of the countermeasure.

	<b>Name</b>	LED-Enhanced Stop Sign
	<b>Category</b>	Engineering Countermeasures
	<b>Sub-Category</b>	Signs, Enhanced Signs
	<b>Source</b>	MUTCD (Section 2A.07; Sign R1-1), MDOT <sup>7</sup> , VTRC <sup>8</sup> , TTI <sup>9</sup>
	<b>Safety Benefits</b>	CMF: 0.59 <sup>1,10</sup>
	<b>Usage Type</b>	Spot treatment, Visibility Treatment
	<b>Target Problem</b>	Low STOP sign compliance, Low visibility
	<b>Cost</b>	Low (\$\$)
	<b>Key Words</b>	Stop Control, Light Emitting Diode, LED, Visibility, Unsignalized, Low Cost
<b>Usage</b> <ul style="list-style-type: none"> <li>Used at stop controlled intersection approaches to enhance conspicuity of traditional stop signs. The LED-enhanced stop sign may result in higher stop-sign compliance rate particularly during lower-visibility conditions such as nighttime and foggy conditions.</li> <li>Studies suggested that the use of LED-enhanced STOP signs could result in significantly higher compliance rate and lower speeds, particularly during low-visibility conditions such as nighttime.<sup>2,3</sup></li> <li>Targeted users of this device are motor vehicles and bicycles. Pedestrians and other users will benefit as well due to improved stop-sign compliance rate.</li> </ul>		
<b>Pros and Cons</b> <ul style="list-style-type: none"> <li>High visibility, relatively low cost, higher compliance rate; and</li> <li>Is associated with higher cost compared to traditional STOP signs, requires a power source.</li> </ul>		
<b>Installation and Configuration</b> <p>Follow installation guidelines for standard STOP signs (MUTCD 2B.05: Stop Sign [R1-1]). In addition<sup>11</sup>:</p> <ul style="list-style-type: none"> <li>Size of sign can be 30x30, 36x36, or 48x48.</li> <li>LEDs can be set to flash or steady mode.</li> <li>LEDs have low power requirements and are typically powered by standalone solar panel units.</li> <li>Can be activated by vehicles or on continuously throughout the day.</li> <li>Need to make sure not to overuse LEDs in signs, as drivers may become accustomed to their presence and fail to respond as desired.</li> <li>Can be applied in conjunction with other treatments to increase sign conspicuity.</li> <li>LEDs must be red or white if used with STOP (R1-1) or YIELD (R1-2) signs, white if used with other regulatory signs, and white or yellow if used with warning or school signs.</li> </ul>		
<b>Example Applications</b> <p>Many states have used LED enhanced stop signs.</p>		

**Figure 4. Screen capture. Sample countermeasure tool page.**

## UNSIGNALIZED INTERSECTION COUNTERMEASURE TOOLBOX

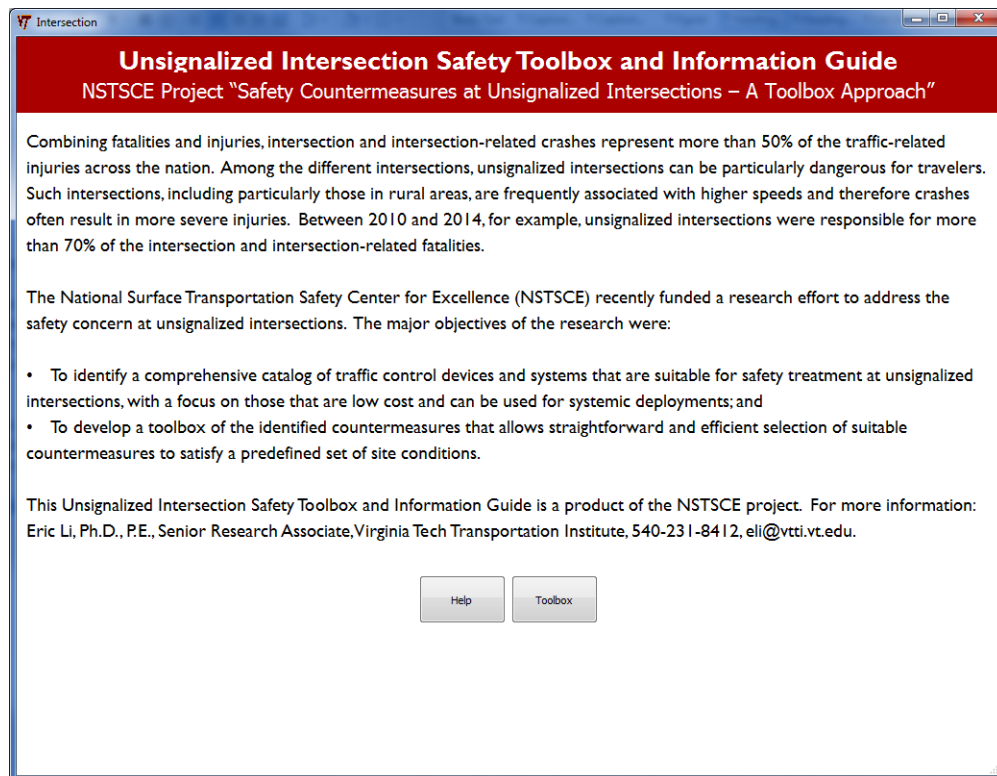
In addition to the *Unsignalized Intersection Toolbox and Information Guide* document, the research team developed a software toolbox that allows users to browse, edit, and search for countermeasures in an intuitive manner. When developing the software toolbox, the research team considered a number of platforms, including Microsoft<sup>®</sup> Access, other desktop applications, and Web-based applications. However, a quick comparison of the options suggested that Access had limited flexibility in allowing customized interfaces and the storage/retrieving of image files. Developing and implementing a Web-based application would have required access to server

space for the entire lifetime of the toolbox software, which implies reserving and maintaining the server space for an unknown period of time when the toolbox is developed and used. Due to these limitations, the research team decided to develop the toolbox as a stand-alone tool.

Based on previous project experience and software availability, the research team chose Qt software for the toolbox development. Qt is a C++ based framework of libraries and tools specialized for developing cross-platform applications.<sup>(20)</sup> It is known to be robust for developing multi-platform graphical user interfaces, with functions supporting data management, such as Structured Query Language (SQL) database access and Standard Meta Language (SML) parsing. The research team used Qt 5 for development of the toolbox, with particular consideration of database management and application extendibility. The developed software toolbox is an expandable, stand-alone application that does not require installation. Users can simply copy the application package and activate the executable to access the toolbox. The code set can be also modified in the future with minimal effort to allow the interface to directly access an enterprise database for storing and managing the countermeasures.

The toolbox contains the following major functions and interfaces:

- **Toolbox home view** (Figure 5). When users load the toolbox executable, the main home page launches to show background information on the NSTSCE project for which the application was developed. The home screen contains two buttons: Help and Toolbox. The former opens the toolbox help page and the latter opens the tools view.



**Figure 5. Screen capture. Toolbox home view.**



- **Toolbox tools view** (Figure 6). The tools view contains three areas:
  - **Database explorer.** This area contains a structure of the categories and subcategories to facilitate tool browsing. Users can click a category or subcategory to expand or collapse it, and to display the list of tools within each category or subcategory.
  - **Tool list.** This area lists the tools meeting the specified criteria, including the basic information for each tool. To show a list of tools, a user may navigate to a specific category or subcategory in the database explorer view, or search for specific tools via the search function provided in the tool search area.
  - **Tool search.** The toolbox includes a detailed search function that allows users to search tools based on name, category, subcategory, source, usage type, target problem, cost, and/or keywords. To perform a search, a user first enters the desired phrases into the search text boxes and then clicks the Search button to execute the search. The tools that meet the specified criteria will then be displayed in the tool list area.

In the tool search area, the application also displays an animated cost meter for each tool a user single-clicks from the tool list area. The cost meter indicates one of the five cost ranges where the implementation cost of a tool falls.

**Database Explorer**

- ENGINEERING COUNTERMEASURES
  - Signs
  - Markings and Delineators
    - Pavement and Curb Markings
    - Delineators
    - Pavement Treatment
    - Channelizing Islands and Devices
  - Other Traffic Control Devices
  - Geometric Improvements
  - Other
- ENFORCEMENT COUNTERMEASURES
- EDUCATION COUNTERMEASURES
- VEHICLE TECHNOLOGY COUNTERMEASURES

**Search**

Name:

Category:

Sub-Category:

Source:

Usage Type:

Target Problem:

Cost:

Keywords:

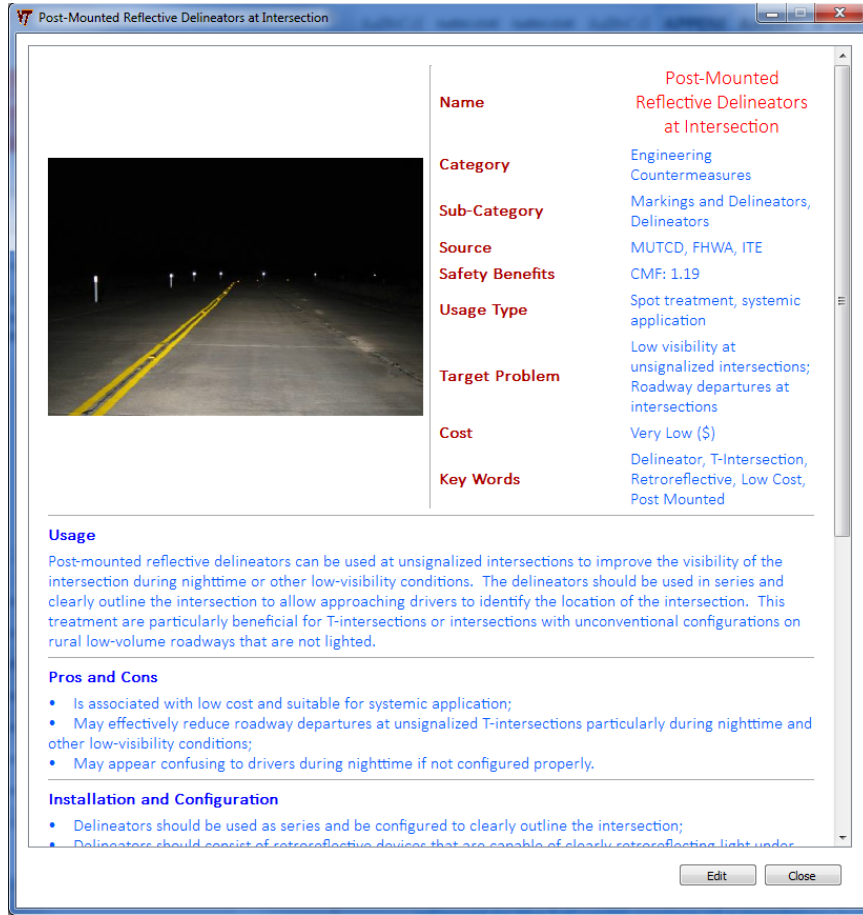
**Cost for Implementation**

Very Low, Low, Medium, Medium-High, High

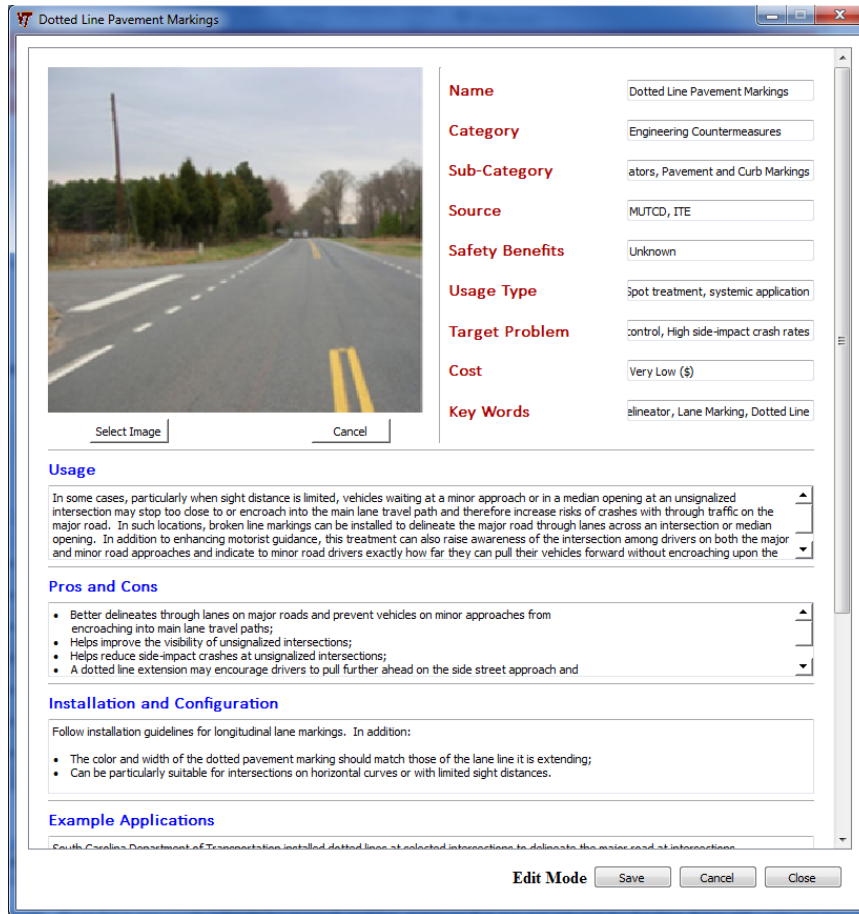
	Name	Category	Sub-Category	Source	Safety Benefits	Usage Type	Target Problem	Cost
1	Wider Longitudinal ...	Engineering Counter...	Markings and Deline...	Non-MUTCD, ITE	CMF: 0.53-0.62	Spot treatment, syst...	Inadequate visibility ...	Low (\$\$)
2	Center Line Paveme...	Engineering Counter...	Markings and Deline...	Non-MUTCD, ITE	Unknown.	Spot treatment, syst...	Inadequate motorist ...	Very Low (\$)
3	Center Line Paveme...	Engineering Counter...	Markings and Deline...	MUTCD, ITE, FHWA	CMF: 0.473	Spot treatment, syst...	Inadequate motorist ...	Very Low (\$)
4	Dotted Line Paveme...	Engineering Counter...	Markings and Deline...	MUTCD, ITE	Unknown	Spot treatment, syst...	Lack of traffic contro...	Very Low (\$)
5	Dotted Turn Path M...	Engineering Counter...	Markings and Deline...	MUTCD, ITE	Unknown	Spot treatment, syst...	Lack of motorist gui...	Very Low (\$)
6	Raised Pavement Ma...	Engineering Counter...	Markings and Deline...	MUTCD, ITE	CMF: 0.79-0.91	Spot treatment, syst...	Lack of intersection ...	Low (\$\$)
7	Crosswalk Markings ...	Engineering Counter...	Markings and Deline...	MUTCD, ITE	Unknown	Spot treatment, syst...	High pedestrian-mo...	Very Low (\$ - M...

**Figure 6. Screen capture. Toolbox tools view.**

Double-clicking a tool on the tool list brings up a new window listing detailed information about the tool (Figure 7). The window is modeled with the same format and contents as the tool pages within the information guide (see [Appendix](#)). The window also contains an Edit button that allows users to edit and save all information displayed on the window (Figure 8).



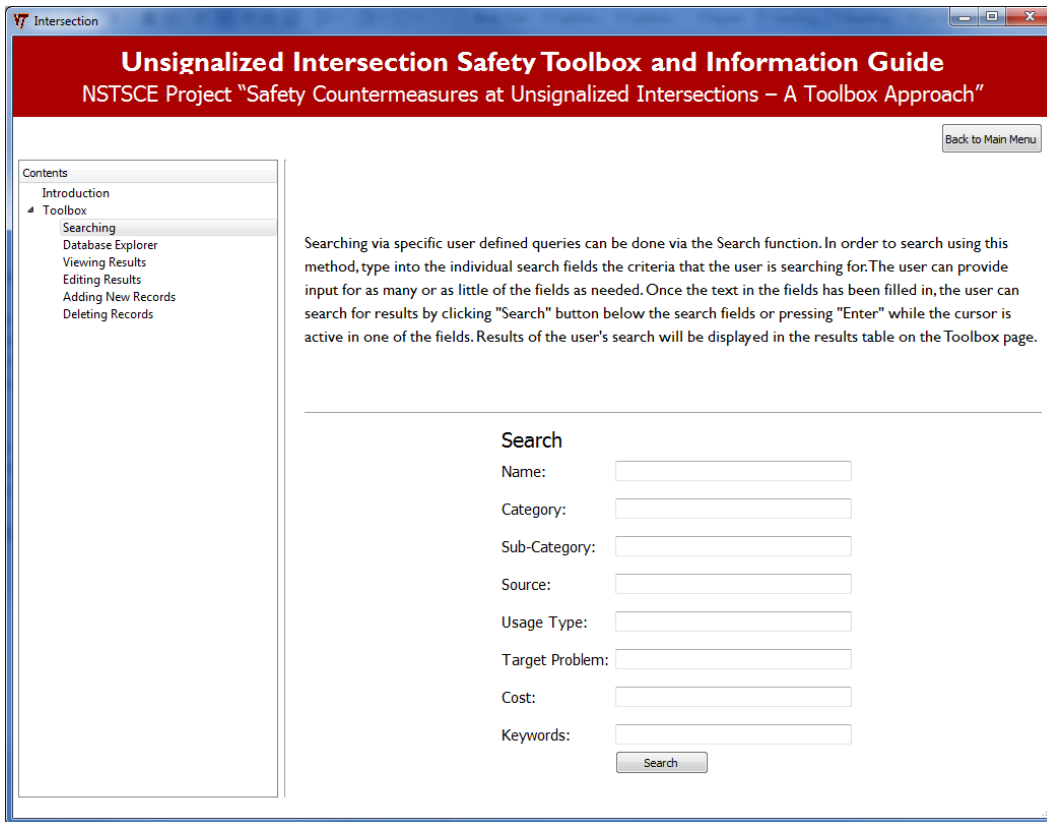
**Figure 7. Screen capture. Toolbox tool detail view.**



**Figure 8. Screen capture. Edit tool details.**

At the bottom of the tools view, the toolbox application also includes two buttons, Add and Remove, to allow users to add new tools or remove an existing tool.

- **Toolbox help view** (Figure 9). This window contains information to help new users get started with the application. The help pages contain descriptions of all major functions and pages, including how to access and operate them.



**Figure 9. Screen capture. Toolbox help view.**

## CHAPTER 4. CONCLUSION

### SUMMARY OF RESULTS

Traffic safety at intersections is a major concern for roadway users, state and local transportation agencies, and other public and private stakeholders. Crashes occurring at unsignalized intersections frequently involve high speeds and therefore result in severe injuries. This report documents the findings of the first phase of a project to improve safety at unsignalized intersections. The primary objectives of this research were to develop a comprehensive catalog and information guide of tools that can be used at unsignalized intersections to reduce crashes.

The research team identified a total of 83 safety countermeasures that can be used at unsignalized intersections to mitigate crash risks and documented them in an *Unsignalized Intersection Toolbox and Information Guide*. The document contains a one-page information guide for each countermeasure and is organized into four major categories: Engineering, Enforcement, Education, and Vehicle Technology. The categories were structured as follows:

- Sixty-six engineering countermeasures grouped into the following subcategories:
  - Traffic signs, including regular signs and enhanced signs
  - Markings and delineators, including pavement and curb markings, delineators, pavement treatment, and channelizing islands and devices
  - Other traffic control devices, including traffic signals and ITS devices
  - Geometric improvements, including intersection realignment and intersection reconfiguration measures
  - Other countermeasures that do not belong to the above subcategories
- Five enforcement countermeasures
- One education countermeasure
- Eleven vehicle technology countermeasures grouped into the following subcategories:
  - Onboard detection and warning systems
  - Automated vehicle control technologies
  - Connected vehicle technologies
  - Vehicle-environment interaction technologies

In addition to the *Unsignalized Intersection Toolbox and Information Guide* document, the research team developed a software toolbox that allows users to browse, edit, and search for countermeasures in an intuitive manner. The software toolbox was developed with Qt 5, which can be modified in the future with minimal effort to directly access an enterprise database for storing and managing the countermeasures. In addition to allowing users to view and manage the existing tools, the toolbox allows users to edit existing tools and add new tools as needed, making it flexible and extendable to meet different user needs.

## RECOMMENDED COUNTERMEASURES FOR PHASE II TESTING

During this project, the research team identified a large number of safety countermeasures at unsignalized intersections with great potential for cost-effective, wider, or systemic implementation. Among the various engineering solutions, for example, the following countermeasures are particularly promising for testing and potential implementation:

- **Retroreflective panels on sign posts** (see page 34 in Appendix). These are extremely low-cost solutions that have the potential to considerably improve sign conspicuity during low-visibility conditions if used properly. Retroreflective panels on sign posts can be particularly suitable for implementation on Stop and Yield signs at unsignalized intersections.
- **Center line pavement markings in a median crossing** (see page 40 in Appendix). Navigation can be extremely confusing and potentially risky at some wide median openings that are subject to through, left-turn, right-turn, and U-turn traffic. Center line pavement markings at such locations can be low-cost measures to reduce vehicle conflicts and therefore improve safety.
- **Center line pavement markings on the minor road approach** (see page 41 in Appendix). Traffic turning onto a minor street from a major roadway at a high speed can frequently encroach into the opposite direction of the minor approach, leading to increased risks for crashes. Center line pavement markings better indicate turning paths at the minor approaches and improve the conspicuity of unsignalized intersections.
- **LED-enhanced Stop signs** (see page 33 in Appendix). Embedded LED lights around Stop signs can greatly improve sign conspicuity, particularly during low-visibility conditions, such as at nighttime or during foggy and rainy weather. The LED lights may be steady or flashing and can be powered with solar batteries. These signs typically cost less than \$10,000, including installation. Such devices may be more widely deployed via systematic identification of suitable sites (e.g., critical locations with more of stop sign running activities). Note that part of the value of using these devices is the novelty that they are only placed at critical locations.
- **Install intersection lighting** (see page 100 in Appendix). Isolated rural intersections, particularly those with unconventional layouts (e.g., T- or Y-shaped intersections or intersections at roadways with wide medians), can be risky to navigate during the nighttime or other low-visibility conditions. Without properly identified travel paths, turning vehicles can be subject to high risks for roadway departures and head-on crashes. Low-cost lighting solutions, such as solar-powered LED lights, can be particularly beneficial in reducing nighttime crashes at such locations. Note that due to maintenance requirements, transportation agencies may be reluctant to widely implement low-cost rural intersection lighting. Agencies, however, may start implementing this countermeasure first at strategic locations where nighttime safety is a known issue.

## **APPENDIX. UNSIGNALIZED INTERSECTION TOOLBOX AND INFORMATIONAL GUIDE**

### **UNSIGNALIZED INTERSECTION SAFETY TOOLBOX AND INFORMATION GUIDE**

NSTSCE Project “Safety Countermeasures at Unsignalized Intersections – A Toolbox Approach”

**Yingfeng (Eric) Li, Ph.D., P.E.**

Senior Research Associate, Virginia Tech Transportation Institute  
540-231-8412, [eli@vtti.vt.edu](mailto:eli@vtti.vt.edu)

**Haiyan Hao**

Student Researcher, Virginia Tech Transportation Institute  
[haiyan94@vt.edu](mailto:haiyan94@vt.edu)

**Alejandra Medina**

Senior Research Associate, Virginia Tech Transportation Institute  
540-231-1508, [amedina@vtti.vt.edu](mailto:amedina@vtti.vt.edu)

**Ronald Gibbons**

Director, Center for Infrastructure-Based Safety Systems (CIBSS), Virginia Tech Transportation Institute  
540-231-1581, [rgibbons@vtti.vt.edu](mailto:rgibbons@vtti.vt.edu)

National Surface Transportation Safety Center for Excellence  
Virginia Tech Transportation Institute, 3500 Transportation Research Plaza, Blacksburg, Virginia 24061  
December 2017





## LIST OF COUNTERMEASURES

<b>ENGINEERING COUNTERMEASURES – SIGNS – REGULAR SIGNS .....</b>	<b>25</b>
Duplicate Stop Sign.....	26
Adding Movement and Lane Control Signs (R3-1-8; R3-18, 20L/R, 27, 33).....	27
Oversized Stop Sign (R1-1) .....	28
Stop Sign (R1-1) .....	29
Yield Sign (R1-2).....	30
Yield/Stop Here To/For Pedestrians Sign (R1-5, 5a, 5b, and 5c) .....	31
<b>ENGINEERING COUNTERMEASURES – SIGNS – ENHANCED SIGNS .....</b>	<b>32</b>
LED-Enhanced Stop Sign.....	33
Retroreflective Panels on Sign Posts .....	34
Signs with Red or Orange Flags .....	35
Warning Signs with Perimeter Retroreflective Sheeting.....	36
<b>ENGINEERING COUNTERMEASURES – MARKINGS AND DELINEATORS – PAVEMENT AND CURB MARKINGS .....</b>	<b>37</b>
Bicycle Lane Markings Across Intersection.....	38
Buffered Bike Lanes.....	39
Center Line Pavement Markings in a Median Crossing.....	40
Center Line Pavement Markings on the Minor Road Approach.....	41
Crosswalk Markings at Unsignalized Intersections.....	42
Dotted Line Pavement Markings .....	43
Dotted Lines Through Full Median Openings .....	44
Dotted Turn Path Markings .....	45
Raised Pavement Markers at Intersection Approach.....	46
Speed Reduction Pavement Markings.....	47
Transverse Rumble Strips on Intersection Approach .....	48
Wider Longitudinal Pavement Markings .....	49
<b>ENGINEERING COUNTERMEASURES – MARKINGS AND DELINEATORS – DELINEATORS .....</b>	<b>50</b>
Post-Mounted Reflective Delineators at Intersection.....	51
<b>ENGINEERING COUNTERMEASURES – MARKINGS AND DELINEATORS – PAVEMENT TREATMENT.....</b>	<b>52</b>
Colored Bike Lanes .....	53
Install High-Friction Surface Treatment on Intersection Approaches .....	54
Raised Intersection .....	55
<b>ENGINEERING COUNTERMEASURES – MARKINGS AND DELINEATORS – CHANNELIZING ISLANDS AND DEVICES .....</b>	<b>56</b>
Channelization to Limit Turning Movements .....	57
Crossing Island for Pedestrians.....	58
Install Splitter Island on Minor Road Approaches .....	59
Provide Offset to Left-Turn Lanes.....	60
Provide Offset to Right-Turn Lane on Major Approaches .....	61
<b>ENGINEERING COUNTERMEASURES – OTHER TRAFFIC CONTROL DEVICES – TRAFFIC SIGNALS.....</b>	<b>62</b>
Adjacent Traffic Signal Retiming.....	63
Intersection Control Beacon.....	64
Rectangular Rapid-Flashing Beacon .....	65
Stop Beacon.....	66
<b>ENGINEERING COUNTERMEASURES – OTHER TRAFFIC CONTROL DEVICES – INTELLIGENT TRANSPORTATION SYSTEMS DEVICES .....</b>	<b>67</b>
Intersection Conflict Warning System (ICWS) .....	68
Vehicle Actuated Variable Message Sign.....	69
<b>ENGINEERING COUNTERMEASURES – GEOMETRIC IMPROVEMENTS – INTERSECTION REALIGNMENT.....</b>	<b>70</b>
Convert Between a Four-Legged Intersection and Two T-Intersections .....	71
Install a Mini-Roundabout.....	72
Install a Neighborhood Traffic Calming Circle .....	73

Install a Roundabout .....	74
Modify Skewed Intersections .....	75
Modify Horizontal/Vertical Alignment of Intersection Approach .....	76
Modified T-Intersection .....	77
<b>ENGINEERING COUNTERMEASURES – GEOMETRIC IMPROVEMENTS – INTERSECTION RECONFIGURATION .....</b>	<b>78</b>
Bus Bulb Outs .....	79
Close One or More Legs of the Intersection .....	80
Close Median Opening .....	81
Diverter .....	82
Extend Left-Turn Lane .....	83
Extend Right-Turn Lane .....	84
Increase Intersection Curb Radius .....	85
Install a Left-Turn Lane on the Major Road .....	86
Install a Right-Turn Lane along the Major Road .....	87
Install Curb Extensions at Crosswalk .....	88
Install Left-Turn Acceleration Lane .....	89
Install Pedestrian Overpasses/Underpasses .....	90
Install Right-Turn Acceleration Lane .....	91
Lane Narrowing with Median Rumble Strips .....	92
Merge and Weave Area Redesign .....	93
Reduce Width of Travel Lanes on Major Road Approaches .....	94
Reduced Intersection Curb Radius .....	95
Restrict Driveway Access .....	96
<b>ENGINEERING COUNTERMEASURES – OTHER .....</b>	<b>97</b>
Clear Intersection Sight Triangles .....	98
Eliminate Parking at or Near Intersection .....	99
Install Intersection Lighting .....	100
Relocate a Bus Stop .....	101
<b>ENFORCEMENT COUNTERMEASURES .....</b>	<b>102</b>
Automated Speed or Stop Sign Enforcement .....	103
Enforcement for Drivers at Pedestrian Crossings .....	104
Enforcement for Legal Pedestrian Crossings .....	105
Targeted Speed Enforcement .....	106
Targeted Stop Sign Enforcement .....	107
<b>EDUCATION COUNTERMEASURES .....</b>	<b>108</b>
Pedestrian/Driver Education .....	109
<b>VEHICLE TECHNOLOGY COUNTERMEASURES – ONBOARD DETECTION AND WARNING SYSTEMS .....</b>	<b>110</b>
Forward Collision Warning System .....	111
Onboard Bicycle Detection System .....	112
Pedestrian Detection HUD .....	113
Rear Cross Traffic Alert .....	114
<b>VEHICLE TECHNOLOGY COUNTERMEASURES – AUTOMATED VEHICLE CONTROL TECHNOLOGIES .....</b>	<b>115</b>
Automatic Brake at Intersections .....	116
Automatic Emergency Braking .....	117
<b>VEHICLE TECHNOLOGY COUNTERMEASURES – CONNECTED VEHICLE TECHNOLOGIES .....</b>	<b>118</b>
Vehicle-to-Vehicle Communications .....	119
<b>VEHICLE TECHNOLOGY COUNTERMEASURES – VEHICLE-ENVIRONMENT INTERACTION TECHNOLOGIES .....</b>	<b>120</b>
Active High Beam .....	121
Pedestrian Airbag System .....	122
Pedestrian Detection and Signaling .....	123
Smart Intersections .....	124

## ENGINEERING COUNTERMEASURES – SIGNS – REGULAR SIGNS



<b>Name</b>	Duplicate Stop Sign
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Signs, Regular Signs
<b>Source</b>	MUTCD, ITE <sup>1</sup> , FHWA <sup>2</sup>
<b>Safety Benefits</b>	Improved sign conspicuity, Improved sign compliance (No crash modification factors [CMFs] identified)
<b>Usage Type</b>	Spot treatment
<b>Target Problem</b>	Low Stop sign compliance, High crash rates at stop-controlled intersection
<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Duplicate, Stop Sign, R1-1, Regulatory, Warning, Low Cost

### Usage

Installation of a second identical Stop sign on the left-hand side of the roadway or overhead to supplement an existing sign can effectively improve sign conspicuity and result in a higher compliance rate by motorists. In addition to Stop signs, duplicate signs for other regulatory or warning signs can be also installed to improve their conspicuity. For example, duplicate advance Stop warning signs can be used to warn motorists and further improve the visibility of the upcoming Stop signs.

### Pros and Cons

- Improves visibility of Stop signs and therefore motorist compliance.
- Associated with higher costs due to more signs being installed and more space being required.

### Installation and Configuration

Follow the MUTCD installation guidelines for standard Stop signs and relevant warning signs. In addition, consider the following:

- Potential visual clutter that may affect drivers' view of the existing sign should be removed.
- Duplicate signs should not be overused because drivers may become accustomed to their presence and fail to respond as desired.
- This treatment may be used in conjunction with other treatments to increase sign conspicuity.
- When left-side signing is used on a street without a median, a center line should be considered.

### Example Applications

Winston-Salem, North Carolina, was able to reduce crashes at stop-controlled intersections by adding additional Stop signs to the left side of the road.<sup>2</sup>

Note: See MUTCD for detailed information on usage and installation.

<sup>1</sup> Add a Duplicate Regulatory or Warning Sign. <http://www.ite.org/uiig/treatments/16%20Duplicate%20Sign.pdf?pass=83>. Accessed Sept. 12, 2017.  
<sup>2</sup> Stop Sign-Controlled Intersections: Enhanced Signs and Markings – A Winston-Salem Success Story. Publication FHWA\_SA-09-010, Federal Highway Administration. [http://safety.fhwa.dot.gov/intersection/conventional/unsignalized/case\\_studies/fhwasa09010/](http://safety.fhwa.dot.gov/intersection/conventional/unsignalized/case_studies/fhwasa09010/). Accessed October 24, 2016.  
<sup>3</sup> <http://www.readingeagle.com/news/article/dangerous-intersection-in-oley-township-gets-more-signs>



Source: MUTCD

<b>Name</b>	Adding Movement and Lane Control Signs (R3-1-8; R3-18, 20L/R, 27, 33)
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Signs, Regular Signs
<b>Source</b>	MUTCD
<b>Safety Benefits</b>	No CMFs identified
<b>Usage Type</b>	Spot treatment
<b>Target Problem</b>	Conflicting traffic movements
<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Movement Prohibition, Lane Control, MUTCD, Left Turn, Right Turn, Low Cost

### Usage

Movement prohibition signs, intersection lane control signs, mandatory movement lane control signs, optional movement lane control signs, and advance intersection lane control signs are required at intersections to clearly indicate if a specific movement is prohibited, and what movements are permitted for the traffic from a certain lane.

Targeted users of the intersection movement and lane control signs are motor vehicles.

### Pros and Cons

- Better indicates what movements are permitted from a specific lane at an intersection.
- Restricting access where previously permitted can be unpopular with the public.

### Installation and Configuration

According to MUTCD:

- Movement prohibition signs should be placed where they will be most easily seen by road users intending to make the movement, such as the right/left corner of the intersection and/or over the roadway.
- Do not use No Left Turn and No U-Turn signs at approaches to roundabouts.
- When intersection lane control signs are mounted overhead, each sign should be placed over the lane or a projection of the lane to which it applies.
- Signs with mandatory movement wording should be placed only at locations that are adjacent to the full-width portion of a mandatory turn lane. It should not be installed adjacent to a through lane in advance of a turn bay taper or adjacent to a turn bay taper.
- Mandatory movement lane control signs should be accompanied by lane-use arrow markings.
- Optional movement lane control signs should be located in advance of the intersection and indicate all permissible movements from specific lanes.
- The optional movement lane control sign should not be used alone to effect a turn prohibition.
- When used, advance intersection lane control signs should be installed in advance of the intersection (e.g., either in advance of the tapers or at the beginning of the turn lane).

### Example Applications

Intersection movement and lane control signs are a traditional traffic control method used across the United States.

Note: See MUTCD for detailed information on usage and installation.



Source: MUTCD

<b>Name</b>	Oversized Stop Sign (R1-1)
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Signs, Regular Signs
<b>Source</b>	MUTCD
<b>Safety Benefits</b>	Improved sign conspicuity, Improved sign compliance (no CMFs identified)
<b>Usage Type</b>	Spot treatment, Systemic application
<b>Target Problem</b>	Low Stop sign compliance
<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Oversized, Stop Sign, R1-1, 36 x 36, Regulatory, Warning, Low Cost

**Usage**

Oversized Stop signs can be used instead of regular Stop signs to improve sign conspicuity and therefore improve motorist compliance at stop-controlled intersections. This treatment is particularly suitable for stop-controlled approaches with high-speed traffic, or approaches where drivers are less likely to expect Stop signs (e.g., roadway with distant adjacent intersections or stop-controlled intersections on high-speed roadways). Oversized Stop signs can be also used to replace existing regular Stop signs as a countermeasure for low motorist compliance and higher crashes at stop-controlled intersections.

**Pros and Cons**

- Increased Stop sign conspicuity and therefore motorist compliance.
- Slightly higher installation cost; may require more space for installation.


**Installation and Configuration**

Follow MUTCD installation requirements for the standard Stop sign. Oversized Stop signs are 36 x 36 inches.

**Example Applications**

Oversized Stop signs are used across the nation at locations where regular Stop signs are determined to be inadequate.

Note: See MUTCD for detailed information on usage and installation.

 <p>Source: MUTCD</p>	<b>Name</b>	Stop Sign (R1-1)
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Signs, Regular Signs
	<b>Source</b>	MUTCD
	<b>Safety Benefits</b>	CMF: 0.78–1.4 <sup>1,2</sup> (for installing Stop signs at minor road approaches)
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	General safety at unsignalized intersections
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Stop Control, Sign, R1-1, MUTCD, Low Cost

### Usage

MUTCD requires that the use of Stop signs on the minor streets of intersections when one or more of the following conditions exist:

- The traffic volume on the major street exceeds 6,000 vehicles per day.
- Vehicles from the side street have to stop in order to adequately observe conflicting traffic due to factors such as limited sight distances or high speeds.
- There is a history of a relatively high number of crashes that may be reduced by the use of Stop signs.

When both intersecting streets have approximately equal traffic volumes and the intersection does not warrant a traffic signal, multi-way or all-way Stop signs can be used. Multi-way, Stop-sign controlled intersections typically meet a number of conditions defined by crash history and vehicular, pedestrian, and bicycle volume. In addition, multi-way Stop-sign controls are also used at intersections where a traffic control signal is warranted but is awaiting installation, or to achieve certain operational and safety benefits such as regulating conflicting turning traffic. Stop signs should not be used for speed control.

Targeted users of this device are motor vehicles and bicycles. Pedestrians and other users will benefit as well when vehicles come to a complete stop to allow them to cross the intersection.

### Pros and Cons

- More restrictive than Yield signs; allows more time for driving-related decision-making.
- Can result in unnecessary delays if not used properly compared to Yield signs.

### Installation and Configuration

- The Stop sign shall be installed on the near side of the intersection on the right-hand side of the approach to which it applies. When the Stop sign is installed at the required location but the sign's visibility is restricted, a Stop Ahead sign shall be installed in advance of the Stop sign.
- At wide-throat intersections or where two or more approach lanes of traffic exist on the signed approach, an additional Stop sign may be installed on the left-hand side to improve compliance. At channelized intersections or at divided roadways separated by a median, the additional Stop sign may be placed on a channelizing island or in the median. An additional Stop sign may also be placed overhead facing the approach at the intersection to improve observance of the right-of-way control.


### Example Applications

Stop signs are a traditional traffic control method used across the United States.


Note: See MUTCD for detailed information on usage and installation.

<sup>1</sup> Haleem, K., M. Abdel-Aty, and K. Mackie. "Using a Reliability Process to Reduce Uncertainty in Predicting Crashes at Unsignalized Intersections." *Accident Analysis and Prevention*, Vol. 42, No. 2, Elsevier, 2010, pp. 654-666.


<sup>2</sup> Haleem, K., and M. Abdel-Aty. "The Group Least Absolute Shrinkage and Selection Operator 'GLASSO' Technique: Application in Variable Selection and Crash Prediction at Unsignalized Intersections." Presented at the 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.

 <p>Source: MUTCD</p>	<b>Name</b>	Yield Sign (R1-2)
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Signs, Regular Signs
	<b>Source</b>	MUTCD
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	General safety at unsignalized intersections
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Yield, Sign, MUTCD, R1-2, Low Cost
<p><b>Usage</b></p> <p>According to MUTCD, a number of factors should be considered when deciding if Stop or Yield signs should be used at an unsignalized intersections, including vehicular and pedestrian traffic volumes, intersection geometric alignment, available sight distance, speed limits, and historical crash data. In general, Stop or Yield signs are used on a minor street intersecting with a major street, a street entering a designated through highway or street, at intersections of streets with low traffic volume, or at an unsignalized intersection in a signalized area/corridor.</p> <p>Yield signs are less restrictive than Stop signs, and therefore are used at conditions where a full stop is not necessary at all times. Yield signs should not be used for speed control.</p> <p>Targeted users of this device are motor vehicles and bicycles.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Less restrictive than Stop signs; less delay to traffic.</li> <li>• Can result in safety risks if not used properly compared to Stop signs.</li> </ul>		
<p><b>Installation and Configuration</b></p> <p>According to MUTCD, Yield signs are installed similarly to Stop signs:</p> <ul style="list-style-type: none"> <li>• The Yield sign should be installed on the near side of the intersection on the right-hand side of the approach to which it applies. When the Yield sign is installed at this required location but the sign's visibility is restricted, a Yield Ahead sign shall be installed in advance of the Yield sign.</li> <li>• At wide-throat intersections or where two or more approach lanes of traffic exist on the signed approach, an additional Yield sign may be installed on the left-hand side to improve compliance. At channelized intersections or at divided roadways separated by a median, the additional Yield sign may be placed on a channelizing island or in the median. An additional Yield sign may also be placed overhead facing the approach at the intersection to improve observance of the right-of-way control.</li> </ul>		
<p><b>Example Applications</b></p> <p>Yield signs are a traditional traffic control method used across the United States.</p> <p>Note: See MUTCD for detailed information on usage and installation.</p>		



 <p style="text-align: center; font-size: small;">Source: MUTCD</p>	<b>Name</b>	Yield/Stop Here To/For Pedestrians Sign (R1-5, 5a, 5b, and 5c)
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Signs, Regular Signs
	<b>Source</b>	MUTCD
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Pedestrian-vehicle conflicts
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Yield Sign, Pedestrians, Crosswalk, Low Cost, MUTCD, R1-5, R1-5a, R1-5b, R1-5c
<p><b>Usage</b></p> <p>According to MUTCD, Yield Here To/Stop Here For Pedestrians signs:</p> <ul style="list-style-type: none"> <li>• Are used to clearly indicate to road users where to yield/stop when pedestrians are present.</li> <li>• Are used when yield/stop lines mark a crosswalk in advance at an uncontrolled multilane approach. Stop Here For Pedestrians signs are used where state law specifically requires that a driver must stop for a pedestrian in a crosswalk.</li> <li>• May be used in advance of a crosswalk at an uncontrolled multilane approach even if yield/stop lines are not used.</li> </ul> <p>Targeted users of Yield Here To (Stop Here For) Pedestrians signs are motor vehicles for the benefit of pedestrians.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Helps to clearly indicate where motor vehicles should stop for or yield to pedestrians.</li> </ul>		
<p><b>Installation and Configuration</b></p> <p>According to MUTCD, Yield Here To/Stop Here For Pedestrians signs:</p> <ul style="list-style-type: none"> <li>• Should be placed 20 to 50 feet in advance of the nearest crosswalk line.</li> <li>• Parking should be prohibited in the area between the yield (stop) line and the crosswalk.</li> <li>• Should not be used in advance of crosswalks that cross an approach to or departure from a roundabout.</li> <li>• May be used in advance of a crosswalk that crosses an uncontrolled multilane approach to indicate to road users where to yield/stop even if yield/stop lines are not used.</li> <li>• A “STATE LAW” legend may be displayed in conjunction with the signs if applicable.</li> <li>• A Pedestrian Crossing (W11-2) warning sign may be placed overhead or may be post-mounted at the crosswalk location where Yield Here To/Stop Here For Pedestrians signs are installed.</li> </ul>		
<p><b>Example Applications</b></p> <p>Yield Here To (Stop Here For) Pedestrians signs are a traditional traffic control method used across the United States.</p> <p>Note: See MUTCD for detailed information on usage and installation.</p>		

## ENGINEERING COUNTERMEASURES – SIGNS – ENHANCED SIGNS

	<b>Name</b>	LED-Enhanced Stop Sign
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Signs, Enhanced Signs
	<b>Source</b>	MUTCD (Section 2A.07; Sign R1-1), MDOT <sup>1</sup> , VTRC <sup>2</sup> , TTI <sup>3</sup>
	<b>Safety Benefits</b>	CMF: 0.59 <sup>4,4</sup> (CMFs for replacing standard Stop sign with LED Stop sign)
	<b>Usage Type</b>	Spot treatment, Visibility treatment
	<b>Target Problem</b>	Low Stop sign compliance, Low visibility
	<b>Cost</b>	Low (\$\$)
	<b>Keywords</b>	Stop Control, Light-Emitting Diode, LED, Visibility, Unsignalized, Low Cost

### Usage

- Used at stop-controlled intersection approaches to enhance conspicuity of traditional Stop signs. The LED-enhanced Stop sign may result in a higher Stop sign compliance rate, particularly during lower-visibility conditions such as at night and in fog.
- Studies suggest that the use of LED-enhanced Stop signs could result in a significantly higher compliance rate and lower speeds, particularly during low-visibility conditions such as nighttime.<sup>2,3</sup>
- Targeted users of this device are motor vehicles and bicycles. Pedestrians and other users will benefit as well due to an improved Stop sign compliance rate.

### Pros and Cons

- High visibility, relatively low cost, higher compliance rate.
- Associated with higher cost compared to traditional Stop signs; requires a power source.

### Installation and Configuration

Follow installation guidelines for standard Stop signs (MUTCD 2B.05: Stop Sign [R1-1]). In addition:<sup>5</sup>

- Size of sign can be 30 x 30, 36 x 36, or 48 x 48 in.
- LEDs can be set to flash or steady mode.
- LEDs have low power requirements and are typically powered by stand-alone solar panel units.
- Can be activated by vehicles or on continuously throughout the day.
- Need to make sure not to overuse LEDs in signs, as drivers may become accustomed to their presence and fail to respond as desired.
- Can be applied in conjunction with other treatments to increase sign conspicuity.
- LEDs must be red or white if used with Stop (R1-1) or Yield (R1-2) signs, white if used with other regulatory signs, and white or yellow if used with warning or school signs.

### Example Applications

Many states have used LED-enhanced Stop signs.

<sup>1</sup> Davis, G. A., J. Hourdos, and H. Xiong. *Estimating the Crash Reduction and Vehicle Dynamics Effects of Flashing LED Stop Signs*. Minnesota Department of Transportation, January 2014.

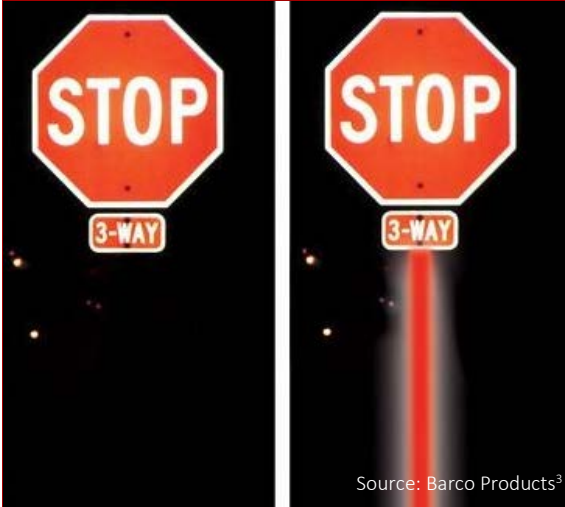
<sup>2</sup> Arnold, E. D., and K. E. Lantz. *Evaluation of Best Practices in Traffic Operations and Safety: Phase I: Flashing LED Stop Sign and Optical Speed Bars*. Report FHWA/VTRC 07-R34. Virginia Transportation Research Council, 2007.

<sup>3</sup> Gates, Timothy J., and H. Gene Hawkins. *Applications for Advanced Sign Sheeting Materials*. Report 0-4271-S. Texas Transportation Institute (TTI), 2004.

<sup>4</sup> Xiong, H., and G. A. Davis. "Crash Reduction Effects of Flashing LED Stop Signs." Presented at the 91st Annual Meeting of the Transportation Research Board, January 22-26, Washington, DC, 2012.

<sup>5</sup> Freeman, J. R., J. A. Bansen, B. Wemple, and R. Spinks. *Innovative Operational Safety Improvements at Unsignalized Intersections*. Kittelson & Associates, Inc., 2008.

<sup>6</sup> <https://www.tapconet.com/solar-led-division/flashing-led-stop-sign-blinkerstop>

	<b>Name</b>	Retroreflective Panels on Sign Posts
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Signs, Enhanced Signs
	<b>Source</b>	MUTCD, ITE <sup>1</sup>
	<b>Safety Benefits</b>	Increased sign conspicuity, Increased sign compliance (no CMFs identified)
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Low sign compliance, Limited sign visibility
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Retroreflectivity, Sign Post, Visibility, Panel, Night, Low Cost

### Usage

A strip of retroreflective material can be added to an existing sign post to enhance visibility during all lighting conditions. This is a cost-effective solution to enhance existing signs and improve their conspicuity, particularly during the nighttime. The treatment is suitable for systemic application, particularly at unsignalized intersections on rural low-volume roads.

### Pros and Cons

- Improved sign conspicuity, particularly during the nighttime.

### Installation and Configuration

Follow the MUTCD installation guidelines for the standard sign, to which retroreflective panels are added. In addition, the following should be considered:

- The color of the strip should match the color of the sign's background, except that strip color on Yield (R1-2) and Do Not Enter (R5-1) signs shall be red.
- The retroreflective strip should be at least 2 inches wide and should extend the entire length of the post to within 2 feet of the ground.
- Remove potential visual clutter that may affect drivers' view of the existing sign.
- This treatment may be used in conjunction with other treatments to increase sign conspicuity.

### Example Applications

The Virginia Department of Transportation installed retroreflective panels on sign posts to increase visibility and compliance at selected unsignalized intersections.<sup>2</sup>

Note: See MUTCD for detailed information on usage and installation.

<sup>1</sup> Install Reflective Panels on Sign Posts. [http://www.ite.org/uiig/treatments/19 reflective panel on sign post.pdf?pass=88](http://www.ite.org/uiig/treatments/19%20reflective%20panel%20on%20sign%20post.pdf?pass=88). Accessed Oct. 24, 2016.

<sup>2</sup> Cottrell, B. H., and L. E. Dougald. *Evaluation of Retroreflective Material on Stop Sign Posts in Virginia*. Virginia Department of Transportation, 2009.

<sup>3</sup> <http://www.barcoproducts.com/reflective-sign-post-panel>



Source: Unsignalized Intersection Improvement Guide<sup>1</sup>

<b>Name</b>	Signs with Red or Orange Flags
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Signs, Enhanced Signs
<b>Source</b>	MUTCD, ITE <sup>1</sup>
<b>Safety Benefits</b>	No CMFs identified
<b>Usage Type</b>	Spot treatment
<b>Target Problem</b>	Low sign compliance, Limited sign visibility
<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Warning Sign, Flag, Visibility, Night, Low Cost

### Usage

To improve the conspicuity of warning signs, one or more red or orange flags (cloth or retroreflective sheeting) may be added above a standard regulatory or warning sign, with the flags oriented at 45 degrees to the vertical. This treatment is used when improved conspicuity of a standard sign is desired based on engineering judgment and historical crash and traffic data.

### Pros and Cons

- Improves sign conspicuity and therefore motorist compliance.
- Costs are slightly higher than regular signs without the flags.

### Installation and Configuration

The installation and configuration of standard signs that are to be enhanced should follow MUTCD. In addition:

- Flag orientation should be 45 degrees to the vertical.
- Remove potential visual clutter, including nonessential or illegal signs in close vicinity that may affect drivers' view of the existing sign.
- Flags should not be overused, as drivers may become accustomed to their presence and fail to respond as desired.
- This treatment can be used in conjunction with other treatments to increase sign conspicuity.
- May require periodic flag maintenance or replacement.

### Example Applications

This treatment is used throughout the country to enhance the conspicuity of existing regulatory or warning signs when determined to be necessary based on engineering judgement.

Note: See MUTCD for detailed information on usage and installation.

<sup>1</sup> Install Red or Orange Flags to a Regulatory or Warning Sign. [http://www.ite.org/uiig/treatments/21\\_flags\\_on\\_sign.pdf?pass=23](http://www.ite.org/uiig/treatments/21_flags_on_sign.pdf?pass=23). Accessed Oct. 24, 2016.



Source: ITE<sup>1</sup>

<b>Name</b>	Warning Signs with Perimeter Retroreflective Sheeting
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Signs, Enhanced Signs
<b>Source</b>	MUTCD, ITE <sup>1</sup>
<b>Safety Benefits</b>	CMF: 0.85 <sup>2</sup> (CMF for 3-inch yellow retroreflective sheeting added to signal backplates)
<b>Usage Type</b>	Spot treatment, Systemic application
<b>Target Problem</b>	Low sign compliance, Limited sign visibility
<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Warning Sign, Retroreflective Sheeting, Visibility, Night, Low Cost

### Usage

To improve the conspicuity of warning signs, a solid yellow, solid fluorescent yellow, or diagonally striped black and yellow (or black and fluorescent yellow) strip of retroreflective sheeting may be added around the perimeter of the signs. This treatment is used when better conspicuity of a standard sign is desired based on engineering judgment and historical crash and traffic data.

### Pros and Cons

- Improves sign conspicuity and therefore motorist compliance.
- Costs are slightly higher than regular signs without the perimeter retroreflective sheeting.

### Installation and Configuration

- MUTCD requires that the strip of sheeting to be at least 3 inches wide around the perimeter of the warning sign.
- This treatment can be used in conjunction with other treatments to increase sign conspicuity.
- Improvements in sign conspicuity may also be achieved by removing nonessential and unauthorized signs in close vicinity to the warning signs.

### Example Applications


The practice of adding retroreflective sheeting around the perimeter of regular warning signs is used throughout the country.

Note: See MUTCD for detailed information on usage and installation.

<sup>1</sup> Add Retroreflective Sheeting to the Perimeter of a Warning Sign. [http://www.ite.org/uiig/treatments/20 reflective perimeter sheeting.pdf?pass=55](http://www.ite.org/uiig/treatments/20%20reflective%20perimeter%20sheeting.pdf?pass=55). Accessed Oct. 24, 2016.

<sup>2</sup> Sayed, T., P. Leur, and J. Pump. "Safety Impact of Increased Traffic Signal Backboards Conspicuity." 2005 TRB 84th Annual Meeting: Compendium of Papers CD-ROM, Vol. TRB#05-16, Washington, D.C., 2005.

ENGINEERING COUNTERMEASURES – MARKINGS AND DELINEATORS – PAVEMENT AND CURB MARKINGS

 <p>Source: ITE<sup>1</sup></p>	<b>Name</b>	Bicycle Lane Markings Across Intersection
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
	<b>Source</b>	MUTCD, ITE <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	High frequency of bicycle crashes, Bicyclist-motorist conflicts at intersections
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Dotted, Lane Marking, Bicycle Lane, Pavement Marking, Visibility, Yielding

### Usage

Typically, bicycle lanes along the major road at an unsignalized intersection are not clearly marked at the minor road approaches. This practice sometimes results in motorists on the minor approaches failing to detect cyclists or encroaching into the bike lane when waiting to enter the intersection. Dotted pavement markings extending a bicycle lane across an intersection or driveway can help motorists better identify the location of the bike lane and draw their attention to potential cyclists crossing the intersection. The markings can also help to identify the location of the intersection.

### Pros and Cons

- Helps to improve the visibility of bike lanes and the intersection.
- Helps motorists better identify potential crossing bicyclists and therefore reduce bicyclist-motorist conflicts.
- Requires extra costs and maintenance for additional markings.
- May confuse intersection users if too many pavement markings are added within an intersection.

### Installation and Configuration

Follow MUTCD guidelines and requirements for standard bicycle lane installation. In addition:

- Dotted pavement markings should extend the bicycle lane across the vehicle right-turn transition area where a right-turn lane is present, but not across a near-side lane drop that terminates in a right-turn lane.
- The color of the dotted pavement markings should match the color of the lane lines to be extended.
- The lane extension markings may be solid based on engineering judgement for extra restriction or emphasis.


### Example Applications

This treatment is used in multiple states across the country.

Note: See MUTCD for additional information on usage and installation of bike lane markings.

<sup>1</sup> Install Bicycle Lane Pavement Markings Across the Intersection. [http://www.ite.org/uiig/treatments/33\\_bicycle\\_lane\\_markings.pdf?pass=9](http://www.ite.org/uiig/treatments/33_bicycle_lane_markings.pdf?pass=9). Accessed Oct. 28, 2016.



	<b>Name</b>	Buffered Bike Lanes
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
	<b>Source</b>	PedBikeInfo <sup>1</sup> , NACTO <sup>2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Bicyclist-motorist conflicts, High rate of bicycle crashes
	<b>Cost</b>	Low (\$\$)
<b>Keywords</b>	Bike Lane, Bicyclist Safety, Motorist-Bicyclist Conflicts	

### Usage

Buffered bike lanes are conventional bike lanes paired with a designated buffer space separating the bike lane from the adjacent motor vehicle lane and/or parking lane. By providing greater separation distance between motor vehicles and bicyclists, the treatment helps to reduce possible bicyclist-motorist conflicts.

### Pros and Cons

- Increases bicyclist comfort and convenience.
- Provides space for bicyclist to pass another bicyclist.
- Encourages bicycling by contributing to the perception of safety among users of the bicycle network.
- More pavement space is required than an unbuffered bike lane.

### Installation and Configuration


- The buffer should be marked with two solid white lines except where cars are expected to cross at driveways.
- The buffer area should have diagonal cross hatching or chevron markings.
- The combined width of the buffer and bike lane is considered to be the “bike lane width,” and bike lanes can be narrower if buffers have been applied.
- For buffered bike lanes next to on-street parking, a 5-foot minimum width is recommended to encourage bicyclists to ride outside the reach of a parked vehicle’s door.
- A 7-foot bike lane is recommended for locations with a high volume of bicyclists, where bicyclist speed differentials are significant, or where side-by-side riding is desired.
- On wide one-way streets with buffered bike lanes, consider adding a buffer to the opposite side parking lane if the roadway appears too wide.
- May use color at the beginning of each block to discourage motorists from entering the buffered lane.
- May use different paving material in the buffer area to separate it from the bike lane.

### Example Applications

Washington, D.C., installed buffered bike lanes on a major road to alleviate crashes between bikers and vehicles.

<sup>1</sup> Mead, J., A. McGrane, C. Zegeer, and L. Thomas. *Evaluation of Bicycle-Related Roadway Measures: A Summary of Available Research*. [http://www.pedbikeinfo.org/cms/downloads/06\\_13\\_2014\\_bikesafe\\_lit\\_review\\_final.pdf#page=47](http://www.pedbikeinfo.org/cms/downloads/06_13_2014_bikesafe_lit_review_final.pdf#page=47). Accessed Oct. 28, 2016.

<sup>2</sup> Buffered Bike Lanes. <https://nacto.org/publication/urban-bikeway-design-guide/bike-lanes/buffered-bike-lanes/>. Accessed Sept. 6, 2017.

 <p>Source: ITE<sup>1</sup></p>	<b>Name</b>	Center Line Pavement Markings in a Median Crossing
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
	<b>Source</b>	Non-MUTCD, ITE <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Inadequate motorist guidance, Conflicts involving turning vehicles in the median
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Center Line, Pavement Marking, Median Crossing, Turning Movements

### Usage

Median openings at unsignalized intersections are used by left-turning vehicles, through vehicles, and vehicles turning around, in many cases, concurrently. The different maneuvers at such locations frequently result in conflicts and therefore increased crash risks both at the median crossings and along the approaches on the major road. The installation of yellow longitudinal pavement markings to delineate the centerline of a median crossing can more safely and orderly guide vehicles through the median crossing.

### Pros and Cons

- Provides clear guidance for vehicle to navigate through median crossing.
- Helps promote two-stage crossing of major road.
- Requires extra costs for installation of additional pavement markings.

### Installation and Configuration

Follow MUTCD requirements and guidance for how lane markings should be installed at median crossings. In addition:

- The opening of the median should be able to accommodate one or more vehicles.
- When the median is too narrow, queuing vehicles may encroach on the through lanes of the major road.
- May need to identify turn-around lanes at median crossings.


### Example Applications

Goldsboro, North Carolina, installed center line markings to provide a buffer area between opposing traffic in the crossing area.<sup>1</sup>

Note: See MUTCD for additional information on usage and installation of pavement markings.

<sup>1</sup> Install Center Line Pavement Markings in a Median Crossing.

<http://www.ite.org/uiig/treatments/23%20Center%20Line%20Markings%20in%20Median.pdf?pass=73>. Accessed Jan. 18, 2017.

 <p style="text-align: right; font-size: small;">Source: ITE<sup>1</sup></p>	<b>Name</b>	Center Line Pavement Markings on the Minor Road Approach
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
	<b>Source</b>	MUTCD, ITE <sup>1</sup> , FHWA <sup>2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Inadequate motorist guidance at intersection
	<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Center Line, Pavement Marking, Minor Approach, Lane Marking	

### Usage

The installation of a double yellow center line on a minor road approach that extends 50 to 100 feet from the stop line can help to guide vehicles turning from the major road, promote proper vehicle placement, and attract minor road users' attention to the intersection ahead.

### Pros and Cons

- Provides additional guidance for vehicles turning onto the minor approach to avoid head-on collisions.
- Improves the visibility of the intersection.
- Provides additional guidance for vehicles approaching from the minor approach.
- Requires extra costs for installation.

### Installation and Configuration

Follow MUTCD requirements and guidance for how lane markings should be installed at median crossings. In addition:

- Motorists need adequate sight distance of the treatment to allow an appropriate amount of time to respond.
- The center line markings may be further enhanced with retroreflective raised pavement markers.


### Example Applications

A Winston-Salem study examined a number of cases where a short interval of double yellow center lines (up to 50-feet) and stop bars (12-inches wide) were installed for the minor approaches at unsignalized intersections. The study found an average crash reduction of 52.7% and injury reduction of 70% per year.<sup>1</sup>

Note: See MUTCD for additional information on usage and installation of pavement markings.

<sup>1</sup> Install Center Line Pavement Markings on the Minor Road Approach. [http://www.ite.org/uiig/treatments/24 center line markings on minor approach.pdf?pass=5](http://www.ite.org/uiig/treatments/24%20center%20line%20markings%20on%20minor%20approach.pdf?pass=5). Accessed Oct. 26, 2016.

<sup>2</sup> Stop Sign-Controlled Intersections: Enhanced Signs and Markings – A Winston-Salem Success Story. Publication FHWA\_SA-09-010, Federal Highway Administration. [http://safety.fhwa.dot.gov/intersection/conventional/unsignalized/case\\_studies/fhwasa09010/](http://safety.fhwa.dot.gov/intersection/conventional/unsignalized/case_studies/fhwasa09010/). Accessed October 24, 2016.

	<b>Name</b>	Crosswalk Markings at Unsignalized Intersections
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
	<b>Source</b>	MUTCD, ITE <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	High pedestrian-motorist crash rates, Low intersection visibility
	<b>Cost</b>	Very Low (\$) – Medium (\$\$\$) (may require geometric modification of approach)
	<b>Keywords</b>	Crosswalk, Markings, Pedestrian, Bicyclist, Urban, Crashes, Sidewalk

### Usage

At unsignalized intersections where there is a high frequency of pedestrian crashes, or where motorists frequently fail to detect or yield to pedestrians, adding or modifying crosswalk markings, particularly at minor approaches, can help to clearly identify crosswalks, raise drivers' attention to crossing pedestrians, and improve intersection visibility. This treatment is particularly useful when a sidewalk or roadside pedestrian/bicycle trail is present.

### Pros and Cons

- Increases drivers' attention to crossing pedestrians and helps to reduce pedestrian-motorist conflicts.
- Helps improve intersection visibility.
- Requires extra costs for the installation of crosswalk markings and, potentially, modification of existing intersection layout.

### Installation and Configuration

Follow MUTCD guidelines and requirements for crosswalk marking installation and configuration. In addition:

- Supplement the crosswalk with warning signs or beacons along uncontrolled approaches.
- If used on uncontrolled multilane approaches, a yield (or stop) line should be applied properly and placed an adequate distance (20 to 50 feet) in advance of the crosswalk to give motorists and pedestrians a clear line of sight.
- The placement of the crosswalk should be near the pedestrian-traveled pathway (extension of the sidewalk network) to deter jaywalking.
- Crosswalks should be accompanied by wheelchair ramps on both sides to improve accessibility.
- For uncontrolled crosswalks on multilane streets of 10,000 ADT or more (15,000 ADT with a raised median), additional treatments should be considered to improve safety and facilitate crossings.

### Example Applications

Marked crosswalks at unsignalized intersections are used across the country to improve pedestrian safety.

Note: See MUTCD for additional information on usage and installation of pedestrian crosswalks.

<sup>1</sup> Install or Modify Crosswalk Markings. <http://www.ite.org/uiig/treatments/30%20Crosswalk%20Markings.pdf?pass=33>. Accessed June 12, 2017.



<b>Name</b>	Dotted Line Pavement Markings
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
<b>Source</b>	MUTCD, ITE <sup>1</sup>
<b>Safety Benefits</b>	No CMFs identified
<b>Usage Type</b>	Spot treatment, Systemic application
<b>Target Problem</b>	Lack of traffic control, High side-impact crash rates
<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Delineator, Lane Marking, Dotted Line

### Usage

In some cases, particularly when sight distance is limited, vehicles waiting at a minor approach or in a median opening at an unsignalized intersection may stop too close to or encroach into the main lane travel path and therefore increase the risk of a crash with through traffic on the major road. In such locations, broken line markings can be installed to delineate the major road through lanes across an intersection or median opening. In addition to enhancing motorist guidance, this treatment can also raise awareness of the intersection for drivers on both the major and minor road approaches and indicate to minor road drivers exactly how far they can pull their vehicles forward without encroaching upon the major road through lane.

### Pros and Cons

- Better delineates through lanes on major roads and prevents vehicles on minor approaches from encroaching into main lane travel paths.
- Helps improve the visibility of unsignalized intersections.
- Helps reduce side-impact crashes at unsignalized intersections.
- A dotted line extension may encourage drivers to pull further ahead on the side street approach and inadvertently lead them to disregard pedestrians and bicyclists who may be present.
- Requires extra costs.

### Installation and Configuration

Follow installation guidelines for longitudinal lane markings. In addition:


- The color and width of the dotted pavement marking should match those of the lane line it is extending.
- Can be particularly suitable for intersections on horizontal curves or with limited sight distances.

### Example Applications

The South Carolina Department of Transportation installed dotted lines at selected intersections to delineate the major road at intersections.

Note: See MUTCD for additional information on usage and installation of pavement markings.

<sup>1</sup> Install Dotted Line Pavement Markings. [http://www.ite.org/uiig/treatments/25 dotted line markings.pdf?pass=19](http://www.ite.org/uiig/treatments/25%20dotted%20line%20markings.pdf?pass=19). Accessed Oct. 26, 2016.



<b>Name</b>	Dotted Lines Through Full Median Openings
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
<b>Source</b>	FHWA <sup>1</sup> , NCHRP <sup>2</sup>
<b>Safety Benefits</b>	No CMFs identified
<b>Usage Type</b>	Spot treatment, Systemic application
<b>Target Problem</b>	Lack of intersection awareness
<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Dotted Line, Median Opening, Edgeline Extension

### Usage

Placing dashed lines through full median openings can help road users distinguish the median area from the through roadway, which makes approaching drivers more aware of the upcoming intersections. It also helps left-turning vehicles properly cross the median without encroaching into the through lanes. This treatment is particularly useful for large or irregularly shaped median openings to provide lane continuity through the intersection.

### Pros and Cons

- Enhances drivers' awareness of the intersection.
- Helps left-turning vehicles properly navigate through the intersection.

### Installation and Configuration


- The line extension marking should be a dotted line type that provides noticeably shorter line segments separated by shorter gaps than used for typical broken lines (FDOT recommended a dotted line with a 6-foot skip and a 10-foot gap).
- If left-turn lanes are provided along the major road, the line color should be white to serve as an extension of the left-turn lane line.
- If there are not exclusive turn lanes from the major road, the line color should be yellow to be consistent with median cross-over areas.
- For narrow median openings, this treatment provides additional information to drivers to allow them to judge whether the width of the median opening is sufficient to provide refuge for two-stage gap acceptance.
- This treatment targets unsignalized intersections on divided highways, which is particularly appropriate for intersections with rear-end, right-angle, or turning collisions related to lack of driver awareness of the presence of the intersection.
- This treatment better delineates the median opening area and is applicable to most median openings regardless of width or length.

### Example Applications

This countermeasure is used in multiple cases across the country.

<sup>1</sup> Strategy E7. Provide Dashed Markings (Extended Left Edgelines) for Major-Road Continuity Across the Median Opening at Divided Highway Intersections. [https://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa08008/ue7.cfm](https://safety.fhwa.dot.gov/intersection/other_topics/fhwasa08008/ue7.cfm). Accessed Sept. 20, 2017.

<sup>2</sup> Neuman, T., R. Pfefer, K. Slack, D. Harwood, I. Potts, D. Torbic, and E. Kohlman Rabbani. *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: -- Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*. National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington, D.C., 2003.

	<b>Name</b>	Dotted Turn Path Markings
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
	<b>Source</b>	MUTCD, ITE <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Lack of motorist guidance, High sideswipe crash rate involving turning vehicles
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Delineator, Turning Path, Dotted Line, Sideswipe Crash

### Usage

At unsignalized intersections where turning vehicles from the major approaches frequently fail to identify the proper path when turning onto a minor approach or turning onto a median-divided major approach due to limited sight distance or vertical alignment features, dotted line markings can be used to delineate the path for turning maneuvers at the intersection. In addition to enhancing motorist guidance, this treatment can also raise awareness of the intersection among drivers on both the major and minor road approaches and guide drivers safely into the proper path.

### Pros and Cons

- Provides better guidance for turning vehicles, particularly when sight distance is limited due to horizontal or vertical alignment features.
- Helps improve the visibility of unsignalized intersections.
- Helps reduce sideswipe crashes at unsignalized intersections.
- Requires extra costs for additional pavement marking.
- May confuse motorists if too many pavement markings are added within an intersection.

### Installation and Configuration

Follow installation guidelines for longitudinal lane markings. In addition:


- The color and width of the dotted pavement marking should match those of the lane line it is extending.
- Dotted lane extension lines may be solid for extra restriction.

### Example Applications

The Arizona Department of Transportation installed dotted turn path markings to help drivers stay in their lanes when turning.<sup>1</sup>

Note: See MUTCD for additional information on usage and installation of pavement markings.

<sup>1</sup> Install Dotted Turn Path Markings. [http://www.ite.org/uiig/treatments/28 dotted turn path markings.pdf?pass=64](http://www.ite.org/uiig/treatments/28%20dotted%20turn%20path%20markings.pdf?pass=64). Accessed Oct. 26, 2016.

 <p>Source: ITE<sup>1</sup></p>	<b>Name</b>	Raised Pavement Markers at Intersection Approach
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
	<b>Source</b>	MUTCD, ITE <sup>1</sup>
	<b>Safety Benefits</b>	CMF: 0.79–0.91 <sup>2</sup> (CMFs for installing raised pavement markers on rural roads)
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Lack of intersection visibility, Head-on collisions at unsignalized intersections
	<b>Cost</b>	Low (\$\$)
	<b>Keywords</b>	Raised Pavement Marker, Delineator, Retroreflective, Visibility

### Usage

At intersections where motorists frequently fail to properly detect the location, configuration, and traffic control of the intersection, raised pavement markers may be installed to better delineate the travel lanes and raise attention to the location and configuration of the intersection. Raised pavement markers with retroreflective sheeting or LEDs are particularly helpful during the nighttime and other low-visibility weather conditions, and for intersections with unusual lane configuration or geometrical alignment features.

### Pros and Cons

- Provides better guidance for vehicles approaching an unsignalized intersection particularly during low-visibility conditions.
- Helps improve the visibility of unsignalized intersections.
- Requires extra costs for the raised markers.

### Installation and Configuration

Follow MUTCD for guidelines and requirements relevant to raised pavement marker installation. In addition:

- Typical colors are white, yellow, or red, although other colors may be used for certain specific applications.
- Use snow-plowable raised pavement markers in locations where snow can be present.
- Raised pavement markers are not desirable for use in bicycle paths or to designate bike lane lines or edgelines, and they should not be used to delineate crosswalks.
- Non-retroreflective raised pavement markers should not be used alone without supplemental retroreflective or internally illuminated markers as a substitute for other types of pavement markings.
- Raised pavement markers may be enhanced with LEDs.

### Example Applications

The Florida Department of Transportation has installed raised pavement markings along roadways to improve visibility and awareness of roadway markings.<sup>1</sup>

Note: See MUTCD for additional information on usage and installation of raised pavement markers.

<sup>1</sup> Install Raised Pavement Markers. [http://www.ite.org/uiig/treatments/29 raised pavement markers.pdf?pass=5](http://www.ite.org/uiig/treatments/29%20raised%20pavement%20markers.pdf?pass=5). Accessed Oct. 28, 2016.

<sup>2</sup> Sun, X., and S. Das. *Developing Louisiana Crash Reduction Factors*. Louisiana DOT Final Report FHWA/LA.12/506. Louisiana Department of Transportation and Development, October 2013.





<b>Name</b>	Speed Reduction Pavement Markings
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
<b>Source</b>	Non-MUTCD, ITE, <sup>1</sup> FHWA <sup>2</sup>
<b>Safety Benefits</b>	No CMFs identified
<b>Usage Type</b>	Spot treatment
<b>Target Problem</b>	Intersection speeding, High rates of speed-related crashes
<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Speed Reduction, Pavement Marking, Peripheral Transverse Marking, Speeding, Traffic Calming

### Usage

At intersections where speeding is a problem on major approaches, speed reduction pavement markings may be considered in order to reduce speeding behavior. Speed reduction pavement markings, sometimes referred to as peripheral transverse pavement markings, are white pavement markings along both edges of the travel lane to give drivers the impression that their speed is increasing. These markings are placed perpendicular to the edges of the travel lane but are not bars extending fully across the travel lane.

### Pros and Cons

- Helps improve the visibility of intersection.
- Helps reduce speeds and therefore decreases the likelihood of speed-related crashes.
- Low cost, easy installation, and only a small amount of material required.
- Effect may decrease under wet conditions or if located outside the normal vehicle wheel path.
- Effect may decrease over time as drivers get used to the markings.

### Installation and Configuration

- The spacing between adjacent markings can be constant or decreasing to create different perceptions.
- The markings may be used in conjunction with appropriate warning signs and other traffic control devices but do not replace such devices. They should be installed at the same locations as the warning signs.
- May be particularly suitable at locations where the intersection is not highly visible to upcoming traffic due to sight obstacles or vertical/horizontal curves.
- Only lanes having a longitudinal line (center line, edgeline, or lane line) on both sides should be considered for this treatment.
- Markings should be 4–12 inches wide and up to 18 inches long.


### Example Applications

The Florida Department of Transportation installed speed reduction pavement markings at selected unsignalized intersections. An evaluation study found that the markings reduced speed marginally by 0.6 mph on average at the four sites at which tests were conducted.<sup>3</sup>

<sup>1</sup> Install Speed Reduction Pavement Markings. [http://www.ite.org/uiig/treatments/36 speed reduction markings.pdf?pass=78](http://www.ite.org/uiig/treatments/36%20speed%20reduction%20markings.pdf?pass=78). Accessed Oct. 28, 2016.

<sup>2</sup> Low-Cost Safety Enhancements for Stop-Controlled and Signalized Intersections. [http://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa09020/chap\\_6.cfm#s62](http://safety.fhwa.dot.gov/intersection/other_topics/fhwasa09020/chap_6.cfm#s62). Accessed Jan. 20, 2017.

<sup>3</sup> Freeman, J. R., J. A. Bansen, B. Wemple, and R. Spinks. *Innovative Operational Safety Improvements at Unsignalized Intersections*. Kittelson & Associates, Inc., 2008.


 <p>Source: FHWA Safety<sup>4</sup></p>	<b>Name</b>	Transverse Rumble Strips on Intersection Approach
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
	<b>Source</b>	ITE <sup>1</sup> , MnDOT <sup>2</sup>
	<b>Safety Benefits</b>	CMF: 0.82–0.87 <sup>3</sup> (CMFs for Install transverse rumble strips on stop controlled approaches in rural areas)
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Speeding, Low Stop sign compliance, Frequent rear-end crashes
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Transverse Rumble Stripes, Intersection Approaches, Driver Awareness
<p><b>Usage</b></p> <p>Transverse rumble strips can be used at unsignalized intersections to alert approaching drivers of the upcoming intersection. Such measures can be particularly beneficial at intersections where users do not expect Stop signs, intersecting roads have a high speed limit, frequent speeding vehicles are observed, and/or there is a history of rear-end crashes.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Improves motorists’ awareness of upcoming intersection and traffic control devices.</li> <li>• Reduces speeding at intersection approaches.</li> <li>• Can generate noise, which may disturb nearby residents.</li> </ul>		
<p><b>Installation and Configuration</b></p> <ul style="list-style-type: none"> <li>• This treatment is often used in combination with Intersection Warning (W2-1 through W2-8), Advance Traffic Control (W3-1 or W3-2), or Pedestrian Crossing (W11-2) signs.</li> <li>• Transverse rumble strips need routine maintenance, especially for intersection approaches with high volumes of large vehicle traffic.</li> <li>• Transverse rumble strips can be raised or depressed. Raised rumble strips can be damaged by snowplowing activities.</li> </ul>		
<p><b>Example Applications</b></p> <p>The Florida Department of Transportation installed transverse rumble strips at several intersections to improve safety.</p>		

<sup>1</sup> Install Transverse Rumble Strips on the Intersection Approach. [http://www.ite.org/uiig/treatments/68 transverse rumble strips.pdf?pass=24](http://www.ite.org/uiig/treatments/68%20transverse%20rumble%20strips.pdf?pass=24). Accessed Nov. 4, 2016.

<sup>2</sup> Corkle, J., M. Marti, and D. Montebello. *Synthesis on the Effectiveness of Rumble Strips*. Report No. MN/RC-2002-07. Minnesota Department of Transportation, 2001.

<sup>3</sup> Crash Modification Factors Clearinghouse. <http://www.cmfclearinghouse.org>, accessed 09/11/2019.

<sup>4</sup> [https://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa08008/ue6.cfm](https://safety.fhwa.dot.gov/intersection/other_topics/fhwasa08008/ue6.cfm)


 <p>Source: FHWA Safety<sup>3</sup></p>	<b>Name</b>	Wider Longitudinal Pavement Markings
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Pavement and Curb Markings
	<b>Source</b>	ITE <sup>1</sup>
	<b>Safety Benefits</b>	CMF: 0.53–0.62 <sup>2</sup> (CMFs for wider markings and both centerline and edgeline rumble strips with resurfacing and fatal and injury crashes)
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Inadequate visibility of intersection or roadway alignment
	<b>Cost</b>	Low (\$\$)
	<b>Keywords</b>	Longitudinal Pavement Markings, Wide, Visibility, Lane Marking
<p><b>Usage</b></p> <p>Increasing the width of center line and/or edgeline pavement markings along an intersection approach can help better delineate the travel lanes and attract attention to the intersection ahead. Enhanced pavement markings also help drivers to better identify the road condition during the nighttime and other low-visibility conditions. The typical width of longitudinal markings on roadways of lower functional classification is 4 inches while MUTCD allows longitudinal markings to be 4 to 6 inches wide.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Helps improve visibility of travel path and the upcoming intersection.</li> <li>• Helps draw attention of motorists to the upcoming intersection.</li> <li>• Has higher installation and maintenance costs compared to regular pavement markings.</li> </ul>		
<p><b>Installation and Configuration</b></p> <p>Follow installation guidelines for standard Longitudinal Pavement Markings. In addition:</p> <ul style="list-style-type: none"> <li>• Determine the start of treatment based on the deceleration distance from the intersection (see AASHTO's <i>A Policy on Geometric Design of Highways and Streets</i> for deceleration distances).</li> <li>• Coordinate the start of the wider markings with the location of the advanced warning sign.</li> </ul>		
<p><b>Example Applications</b></p> <p>The Missouri Department of Transportation used wider lane markings on selected rural low-volume roadways and identified a CMF between 0.53 and 0.62 for the cases evaluated.<sup>2</sup></p>		
<p>Note: See MUTCD for additional information on usage and installation of pavement markings.</p>		

<sup>1</sup> Install Wider Longitudinal Pavement Markings. [http://www.ite.org/uiig/treatments/22\\_wider\\_markings.pdf?pass=100](http://www.ite.org/uiig/treatments/22_wider_markings.pdf?pass=100). Accessed Oct. 24, 2016.

<sup>2</sup> Potts, I. B., D. W. Harwood, C. D. Bokenkroger, and M. M. Knoshaug. *Benefit/Cost Evaluation of MoDOT's Total Striping and Delineation Program: Phase II*. MRIGlobal Project No. 110749. Missouri Department of Transportation, June 2011.

<sup>3</sup> [https://safety.fhwa.dot.gov/cm\\_v\\_rtc/ch3.cfm](https://safety.fhwa.dot.gov/cm_v_rtc/ch3.cfm)

## ENGINEERING COUNTERMEASURES – MARKINGS AND DELINEATORS – DELINEATORS

 <p style="text-align: right; font-size: small;">Source: FHWA<sup>1</sup></p>	<b>Name</b>	Post-Mounted Reflective Delineators at Intersection
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Delineators
	<b>Source</b>	MUTCD, FHWA <sup>1</sup> , ITE <sup>2</sup>
	<b>Safety Benefits</b>	CMFs not identified
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Low visibility at unsignalized intersections, Roadway departures at intersections
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Delineator, T-Intersection, Retroreflective, Low Cost, Post-Mounted

### Usage

Post-mounted reflective delineators can be used at unsignalized intersections to improve the visibility of the intersection during the nighttime or other low-visibility conditions. The delineators should be used in series and clearly outline the intersection to allow approaching drivers to identify the location of the intersection. This treatment is particularly beneficial for T-intersections or intersections with unconventional configurations on rural low-volume roadways that are not lighted.

### Pros and Cons

- Low cost and suitable for systemic application.
- May effectively reduce roadway departures at unsignalized T-intersections, particularly during the nighttime and other low-visibility conditions.
- May appear confusing to drivers during nighttime if not configured properly.

### Installation and Configuration

- Delineators should be used in series and be configured to clearly outline the intersection.
- Delineators should consist of retroreflective devices that are capable of clearly retroreflecting light under normal atmospheric conditions from a distance of 1,000 feet when illuminated by the high beams of standard automobile lights.
- Retroreflective elements for delineators shall have a minimum dimension of 3 inches.
- The color of the delineators should be consistent with the color of the edgelines.
- When delineators are applied continuously along the entire corridor, different-colored delineators should be placed at the intersection as a means of supplemental delineation of the roadway. For example, some corridors in Idaho have regularly spaced white delineators to provide supplemental delineation of the roadway but the delineators at unsignalized intersections are yellow.<sup>2</sup>

### Example Applications

Cheyenne, Wyoming, installed post-mounted reflective delineators to improve nighttime rural unsignalized intersection safety.<sup>2</sup>

Note: See MUTCD for detailed information on usage and installation.

<sup>1</sup> *Factors Influencing Operating Speeds and Safety on Rural and Suburban Roads*. <https://www.fhwa.dot.gov/publications/research/safety/15030/009.cfm>. Accessed Dec. 2, 2016.

<sup>2</sup> Install Post-Mounted Reflective Delineators at the Intersection. [http://www.ite.org/uiig/treatments/14\\_delineators.pdf?pass=8](http://www.ite.org/uiig/treatments/14_delineators.pdf?pass=8). Accessed Oct. 24, 2016.

ENGINEERING COUNTERMEASURES – MARKINGS AND DELINEATORS – PAVEMENT  
TREATMENT



Source: NACTO

<b>Name</b>	Colored Bike Lanes
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Markings and Delineators, Pavement Treatment
<b>Source</b>	PedBikeInfo <sup>1</sup> , NACTO <sup>2,3</sup>
<b>Safety Benefits</b>	One study found a reduction of bicyclist-motorist conflicts from 0.95 to 0.59 per 100 bicyclists <sup>4</sup> (No CMFs identified)
<b>Usage Type</b>	Spot treatment, Systemic application
<b>Target Problem</b>	Bicyclist-motorist conflicts
<b>Cost</b>	Medium High (\$\$\$\$)
<b>Keywords</b>	Bike Lane, Bicyclist Safety, Colored Pavement, Conflicts

### Usage

By installing colored bike lanes, the visibility of the bike lane and bike lane markings to motorists is enhanced, and therefore motorists are more likely to yield to bicyclists. This treatment is particularly beneficial for roadways with high volumes of bike traffic near schools/universities, in downtown areas, recreational areas, and in other areas where bike activities are encouraged.

### Pros and Cons

- Increases the visibility of bike lanes and bicyclists and therefore reduces possible bicyclist-motorist conflicts.
- Discourages illegal parking in the bike lane.
- Increases bicyclist comfort through clearly delineated space.

### Installation and Configuration

- The color green is recommended to minimize confusion with other standard control markings.
- Normal white bike lane lines shall be provided along the edges of the colored lane to provide consistency with other facilities and to enhance nighttime visibility.
- Most effective with skid-resistant and/or retroreflective surfaces.
- Installation of a “Yield to Bikes” sign is recommended at intersections or driveway crossings to reinforce that bicyclists have the right-of-way at colored bike lane areas.
- The configuration of color should be consistently applied through the corridor.
- Color can also be applied in a dashed pattern within a dashed bicycle lane to indicate merging areas.

### Example Applications


The Oregon Department of Transportation installed green bike lanes and bike boxes to increase pedestrian/ bicyclist safety on major roads.

<sup>1</sup> Bicycle Lanes. [http://www.pedbikeinfo.org/planning/facilities\\_bike\\_bikelanes.cfm](http://www.pedbikeinfo.org/planning/facilities_bike_bikelanes.cfm). Accessed Dec. 5, 2016.

<sup>2</sup> Colored Bike Facilities. <https://nacto.org/publication/urban-bikeway-design-guide/bikeway-signing-marking/colored-bike-facilities/>. Accessed Sept. 6, 2017.

<sup>3</sup> Colored Pavement Material Guidance. <https://nacto.org/publication/urban-bikeway-design-guide/bikeway-signing-marking/colored-pavement-material-guidance/>. Accessed Sept. 6, 2017.

<sup>4</sup> Hunter, W. W., D. L. Harkey, J. R. Stewart, and M. L. Birk. “Evaluation of Blue Bike-Lane Treatment in Portland, Oregon.” *Transportation Research Record: Journal of the Transportation Research Board*, No. 1705, 2000, pp. 107-115.3. City of Portland Office of Transportation. Portland’s Blue Bike Lanes: Improved Safety Through Enhanced Visibility.


	<b>Name</b>	Install High-Friction Surface Treatment on Intersection Approaches
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Pavement Treatments
	<b>Source</b>	ITE <sup>1</sup> , FHWA <sup>2</sup>
	<b>Safety Benefits</b>	CMF: 0.50 <sup>2</sup> (CMF for treatment on high-speed intersection approaches for wet pavement crashes)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problems</b>	Vehicle Skidding, Speeding, Wet Pavement, Friction, Slope
	<b>Cost</b>	Medium High (\$\$\$\$)
	<b>Keywords</b>	High-Friction Surface Treatment, Intersection Approach, Pavement Material, Skidding
<p><b>Usage</b></p> <p>At intersections with a high rate of crashes related to skidding vehicles and/or wet-weather crashes, or where vehicles have braking difficulties during wet conditions and approach at high speeds, treating the pavement with a coarser surface can increase the surface friction of the roadway and mitigate the problems.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Reduces crashes and conflicts resulting from high approaching speed, especially in wet weather.</li> <li>• Relatively low in cost compared to geometric improvements.</li> <li>• Durable and long-lasting if treated properly.</li> </ul>		
<p><b>Installation and Configuration</b></p> <ul style="list-style-type: none"> <li>• For through high-speed approaches to stop-controlled intersections, a minimum of 300 feet of surface treatment is recommended.</li> <li>• The length of surface treatment is dependent on motorists' sight distance, queue length, and vehicle approaching speeds.</li> <li>• Significant wheel rutting (2 inches in depth or greater) should be eliminated before applying this treatment.</li> <li>• After the skid resistant surface is installed, pavement markings need to be reapplied.</li> </ul>		
<p><b>Example Applications</b></p> <p>This countermeasure has been used in multiple cases across the country.</p>		

<sup>1</sup> Install a High-Friction Surface Treatment on the Intersection Approach. [http://www.ite.org/uiig/treatments/69 friction surface treatment.pdf?pass=13](http://www.ite.org/uiig/treatments/69%20friction%20surface%20treatment.pdf?pass=13). Accessed Nov. 7, 2016.

<sup>2</sup> "High-Friction Surfaces." [http://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa09020/chap\\_5.cfm#s53](http://safety.fhwa.dot.gov/intersection/other_topics/fhwasa09020/chap_5.cfm#s53). Accessed Nov. 7, 2016.

<sup>3</sup> [https://safety.fhwa.dot.gov/roadway\\_dept/pavement\\_friction/high\\_friction/](https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/high_friction/)



	<b>Name</b>	<b>Raised Intersection</b>
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Marking and Delineators, Pavement Treatment
	<b>Source</b>	FHWA <sup>1</sup> , NACTO <sup>2</sup>
	<b>Safety Benefits</b>	Lowered speeds, Increased rates of motorists yielding to pedestrians (No CMFs identified)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	High speeds at intersections, High crash rates involving pedestrians
	<b>Cost</b>	Medium High (\$\$\$\$) – High (\$\$\$\$\$)
	<b>Keywords</b>	Raised Intersection, Raised Crosswalk, Speed Calming, Pedestrian, Low Speed

### Usage

A raised intersection can be considered as a speed table for an entire intersection, and therefore is used for speed calming at intersections and to improve pedestrian safety. Raised intersections or crosswalks typically are used at places where a large volume of pedestrians is present, or where low speeds are needed for other reasons. Examples of places where raised intersections can be suitable include streets with pedestrian-friendly commercial developments, campuses, and neighborhoods.

### Pros and Cons

- Relatively high cost.
- Not a systemic treatment for unsignalized intersections.
- Improves safety (particularly for pedestrians) by reinforcing slower vehicle speeds at intersections.

### Installation and Configuration

- Raised intersections are achieved by elevating the entire intersection area with ramps on all approaches.
- The crosswalks on all approaches at the intersection are also elevated to enable pedestrians to cross the road at the same level as the sidewalk.
- Should not be used when sight distance at the intersection is limited or on steep grades.
- Fewer raised intersections are desired if the street is a bus or emergency vehicle route.
- Tactile warning strips should be added at the edges of the raised intersection to warn users.
- Special consideration may be required to ensure sufficient drainage and to accommodate snowplows.
- Raised intersections can be also used as an urban design element through the use of colored and/or texturized paving materials.

### Example Applications

Raised intersections are commonly used in many states. Evaluations at three sites in North Carolina and Maryland showed a reduction from 2.5–12.4 mph in 50<sup>th</sup> percentile vehicle speeds. A site in Massachusetts resulted in an increase from 10% to 55% of motorists yielding to pedestrians crossing the intersection.<sup>3,4</sup>


<sup>1</sup> Federal Highway Administration. “29. Traffic Calming - Raised Intersection; 30. Raised Pedestrian Crossing.” <https://safety.fhwa.dot.gov/saferjourney1/Library/countermeasures/29-30.htm>. Accessed Oct. 17, 2016.

<sup>2</sup> “Raised Intersections.” <https://nacto.org/publication/urban-street-design-guide/intersections/minor-intersections/raised-intersections/>. Accessed Sept. 11, 2017.

<sup>3</sup> Mead, J., C. Zegeer, and M. Bushell. *Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research*. [http://www.pedbikeinfo.org/cms/downloads/pedestrianlitreview\\_april2014.pdf#page=34](http://www.pedbikeinfo.org/cms/downloads/pedestrianlitreview_april2014.pdf#page=34). Accessed Oct. 17, 2016.

<sup>4</sup> Huang, H. F., and M. J. Cynecki. *The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior*. Publication FHWA-RD-00-104. FHWA, U.S. Department of Transportation, 2001.

ENGINEERING COUNTERMEASURES – MARKINGS AND DELINEATORS – CHANNELIZING ISLANDS AND DEVICES

 <p>Source: ITE<sup>1</sup></p>	<b>Name</b>	Channelization to Limit Turning Movements
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Channelizing Islands and Devices
	<b>Source</b>	Non-MUTCD, ITE <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	High crash rates involving left-turning vehicles
	<b>Cost</b>	Medium (\$\$\$) – Medium High (\$\$\$\$)
	<b>Keywords</b>	Median, Channelization, Barrier, Turning Movements, Island

### Usage

At intersections where left-turning or through traffic from the minor roadway results in significant impact on the operations and safety of the major roadway, channelization methods, including raised islands or delineators can be considered to regulate or eliminate certain movements. For example, by providing a U-turn lane at a downstream location to allow left-turning traffic to complete their intended movements, the left-turning maneuver at the intersection will be eliminated.

### Pros and Cons

- Reduces traffic conflicts and improves operations and safety.
- Results in additional travel time for traffic on the minor road.
- Channelization devices may result in challenges to maintenance and snow removal.
- Some applications may be high cost and require wider right-of-way.
- Limiting access can be controversial with adjacent landowners.

### Installation and Configuration

- Carefully verify that alternate routes are available for through and left-turning traffic on the minor road.
- Conduct sufficient outreach and involve all stakeholders such as local businesses, residents, and emergency responders.
- Ensure that channelization devices/islands are clearly marked and visible during adverse lighting and weather conditions.
- Use sufficient signage to ensure that users can safely and effectively navigate the intersection's layout.
- When U-turn lanes are provided, sufficient spacing should be provided between the U-turn location and the intersection to enable safe lane changes and to minimize operational impacts.
- Ensure that all design vehicles are accommodated.

### Example Applications

A number of variations of this treatment are available across the country.

<sup>1</sup> Eliminate Turn Movements Using Design Alterations and Channelization. [http://www.ite.org/uiig/treatments/38 prohibit movements with channelization.pdf?pass=61](http://www.ite.org/uiig/treatments/38%20prohibit%20movements%20with%20channelization.pdf?pass=61). Accessed Oct. 28, 2016.



<b>Name</b>	Crossing Island for Pedestrians
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Markings and Delineators, Channelizing Islands and Devices
<b>Source</b>	FHWA, PedBikeSafe <sup>1</sup> , NACTO <sup>2</sup>
<b>Safety Benefits</b>	Improved pedestrian safety at intersections (No CMFs identified)
<b>Usage Type</b>	Spot treatment
<b>Target Problem</b>	High crash rates involving pedestrians
<b>Cost</b>	Medium (\$\$\$)
<b>Keywords</b>	Pedestrian Safety, Crossing Island, Center Island, Refuge Island, Crosswalk, Median

### Usage

Raised pedestrian crossing islands help protect crossing pedestrians from motor vehicles, allowing them to deal with only one direction of traffic at a time by crossing the first half of the road, waiting safely in the middle of the street for an adequate gap in traffic, and then crossing the second half of the street. This treatment may be used on either the minor approaches or the major approaches where vehicles cross at a relatively high speed or where there are large pedestrian volumes.

### Pros and Cons

- Allows pedestrians to only deal with traffic in one direction while crossing the street.
- Provides safety harbors for pedestrians while crossing the street or waiting to cross the second half of the street.
- Has a higher risk of fixed-object crashes due to the islands and associated traffic sign structure.

### Installation and Configuration

- Crossing islands should be designed to safely accommodate the design pedestrian volumes and are recommended to be at least 4 feet wide.
- Islands should be illuminated or highlighted with retroreflective materials to ensure that they are clearly visible to motorists during adverse visibility conditions.
- When crossing islands are installed, appropriate and adequate signage should be used to inform motorists.
- Crossing islands should be designed to accommodate wheelchairs and scooters and should sufficiently consider turning vehicles and bicycles.
- Approximate costs for crossing islands range from \$535 to \$1,065 per foot. Typical total construction costs may range from \$3,500 to \$40,000.


### Example Applications

Crossing islands are used across the country, particularly at urban intersections where large volumes of pedestrians are present.<sup>3</sup>

<sup>1</sup> Crossing Islands. [http://pedbikesafe.org/pedsafe/countermeasures\\_detail.cfm?cm\\_num=6](http://pedbikesafe.org/pedsafe/countermeasures_detail.cfm?cm_num=6). Accessed Oct. 17, 2016.

<sup>2</sup> Pedestrian Safety Islands. <https://nacto.org/publication/urban-street-design-guide/intersection-design-elements/crosswalks-and-crossings/pedestrian-safety-islands/>. Accessed Sept. 11, 2017.

<sup>3</sup> Mead, J., C. Zegeer, and M. Bushell. *Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research*. [http://www.pedbikeinfo.org/cms/downloads/pedestrianlitreview\\_april2014.pdf#page=34&zoom=100,69,350](http://www.pedbikeinfo.org/cms/downloads/pedestrianlitreview_april2014.pdf#page=34&zoom=100,69,350). Accessed Oct. 17, 2016.

 <p style="text-align: right; font-size: small;">Source: FHWA Safety<sup>4</sup></p>	<b>Name</b>	Install Splitter Island on Minor Road Approaches
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Channelizing Islands and Devices
	<b>Source</b>	Non-MUTCD, ITE <sup>1</sup> , FHWA <sup>2</sup>
	<b>Safety Benefits</b>	CMF: 0.7 <sup>3</sup> (for total crashes and angle and crossing crashes)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Low visibility of intersection, High crash rates involving major road turning vehicles
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Splitter Island, Minor Road Approach, Raised Median

### Usage

Separating opposing lanes by installing a splitter island increases intersection visibility and helps to guide entering and exiting traffic. This method can be particularly beneficial at intersections where drivers approach at high speeds on the minor road, or where drivers misperceive the intersection and intersection traffic control devices. The method can also be considered at intersections where high crash rates are observed between vehicles turning from the major road and vehicles approaching on the minor road.

### Pros and Cons

- Provides separation between vehicles entering and exiting minor roads.
- Enhances intersection visibility for minor road motorists.
- Helps to better guide traffic into the intersection.

### Installation and Configuration

Follow recommendations and requirements in AASHTO's *A Policy on Geometric Design of Highways and Streets* for detailed information on the installation of splitter islands. In addition:

- A minimum median surface area of 100 square feet is required to make raised medians conspicuous to drivers.
- A minimum island width of 4 feet and length of 20–25 feet or 100 feet in rural area and urban areas, respectively, are recommended. If a pedestrian refuge island is provided within the splitter island, a minimum width of 6 feet is required to accommodate a bicycle or a person pushing a stroller.
- Where a pedestrian refuge is provided within the splitter island, ADA requirements must be met.
- Appropriate offsetting and blunting of the approach noses to the splitter islands is recommended.
- Provide adequate retroreflective marking to ensure that the island is highly visible during all visibility conditions.

### Example Applications

The Virginia Department of Transportation installed splitter islands on selected intersections in Lorton in order to reduce speeds and reduce crashes involving turning vehicles.

<sup>1</sup> Install a Splitter Island on the Minor Road Approach. <http://www.ite.org/uiig/treatments/50%20Splitter%20Island.pdf?pass=97>. Accessed Jan. 23, 2017.

<sup>2</sup> Bared, J., Hughes, W., Jagannathan, R., and Gross, F. *Two Low Cost Safety Concepts for Two Way Stop Controlled, Rural Intersections on High Speed Two Lane, Two Way Roadways*. Report No. FHWA-HRT-08-063. Federal Highway Administration, Washington, D.C., 2008.


<sup>3</sup> *Innovative Operational Safety Improvements at Unsignalized Intersections*. [http://www.fdot.gov/traffic/doc\\_library/PDF/Final%20Report%20-%20Contract%20C8K21.pdf#page=107](http://www.fdot.gov/traffic/doc_library/PDF/Final%20Report%20-%20Contract%20C8K21.pdf#page=107). Accessed Aug. 30, 2017.

<sup>4</sup> [https://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa08008/ue3.cfm](https://safety.fhwa.dot.gov/intersection/other_topics/fhwasa08008/ue3.cfm)

<p style="text-align: center;">Source: FHWA<sup>2</sup></p>	<b>Name</b>	Provide Offset to Left-Turn Lanes
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Channelizing Islands and Devices
	<b>Source</b>	ITE <sup>1</sup> , FHWA <sup>2</sup>
	<b>Safety Benefits</b>	CMF: 0.66 <sup>2</sup> (CMF for improve left-turn lane offset to create positive offset)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Lack of intersection sight distance, Conflicts involving opposing left-turning vehicles
	<b>Cost</b>	Medium (\$\$\$) to High (\$\$\$\$\$)
	<b>Keywords</b>	Left-Turn Lane, Offset, Sight Distance, Separation, Median
<p><b>Usage</b></p> <p>At intersections where the sight distance is obstructed by the presence of opposing left-turning vehicles, or where crashes may happen between left-turning and opposing through vehicles, separating left-turn lanes from their adjacent same-direction through lanes via a parallel or tapered offset may improve the left-turning drivers' sight distance.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Enhances sight distance for opposing left-turn vehicles.</li> <li>• Requires adequate median width or lane width to provide offset.</li> <li>• May be confusing for some drivers.</li> </ul>		
<p><b>Installation and Configuration</b></p> <ul style="list-style-type: none"> <li>• To achieve a positive effect, the left-turn lanes should be shifted to the left.</li> <li>• This treatment requires adequate median width or lane width to provide an offset, which may increase the intersection width and result in a longer crossing distance for pedestrians.</li> <li>• When paint carets are used to create the left-turn offset, in-street or median Stop (R1-1) signs for wide street approaches may be considered. If Stop signs are placed in the street, breakaway posts should be used.</li> </ul>		
<p><b>Example Applications</b></p> <p>The Wisconsin Department of Transportation installed offset left turns at some intersections to reduce crashes involving left-turning vehicles.</p>		

<sup>1</sup> Provide Offset to Left-Turn Lanes. [http://www.ite.org/uiig/treatments/54 offset left-turn lane.pdf?pass=18](http://www.ite.org/uiig/treatments/54%20offset%20left-turn%20lane.pdf?pass=18). Accessed Oct. 31, 2016.

<sup>2</sup> Persaud, B., C. Lyon, K. Eccles, N. Lefler, and F. Gross. *Safety Evaluation of Offset Improvements for Left-Turn Lanes*. Report No. FHWA-HRT-09-035. Federal Highway Administration. Washington, D.C., June 2009.

 <p>Source: FHWA Safety<sup>3</sup></p>	<b>Name</b>	Provide Offset to Right-Turn Lane on Major Approaches
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Markings and Delineators, Channelizing Islands and Devices
	<b>Source</b>	ITE <sup>1</sup> , NCHRP <sup>2</sup>
	<b>Safety Benefits</b>	Unknown
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Inadequate intersection sight distance due to right-turning vehicles
	<b>Cost</b>	Medium (\$\$\$) – High (\$\$\$\$\$)
	<b>Keywords</b>	Offset, Right Turn, Sight Distance, Separation

### Usage

Traffic turning right from the major approaches of unsignalized intersections can frequently block the sight line of vehicles on the minor approaches waiting to turn onto the major road, resulting in increased crash risks. At such intersections, the right turn lanes may be separated further from the through lanes via the use of a painted or raised offset. Such design can improve the sight distances at the intersections and therefore allow traffic from the minor approaches to turn onto the major roadway more safely.

### Pros and Cons

- Improves motorists' sight distance at intersections and mitigates crash risks.
- May require existing pavement to be expanded and/or additional right-of-way.
- If not properly designed, offset right turn lanes may result in shorter sight distances.

### Installation and Configuration

- Ensure the offset is properly added to clear sight triangles.
- Adequately address pedestrian and bicyclist safety, if applicable, when adding the offset and widening the pavement.
- Provide advance signage and sufficient markings to improve safety.
- May require longer deceleration lanes at downhills and for certain alignments.
- Consider adding offset by narrowing through lanes or shoulders if possible to avoid additional right-of-way acquisition.
- Device costs may be highly variable and depend largely on the existing right-of-way. Construction involves paving and marking a portion of the existing shoulder.

### Example Applications

The Iowa Department of Transportation installed offset right-turn lanes at some intersections in Cedar Falls to minimize accidents resulting from passing cars.<sup>2</sup>


<sup>1</sup> Provide Offset to a Right-Turn Lane. [http://www.ite.org/uiig/treatments/58\\_offset\\_right-turn\\_lane.pdf?pass=91](http://www.ite.org/uiig/treatments/58_offset_right-turn_lane.pdf?pass=91). Accessed Nov. 2, 2016.

<sup>2</sup> Maze, T., J. Hochstein, R. Souleyrette, H. Preston, and R. Storm. *NCHRP Report 650: Median Intersection Design for Rural High-Speed Divided Highways*. Transportation Research Board, Washington D.C., 2010.

<sup>3</sup> [https://safety.fhwa.dot.gov/intersection/other\\_topics/fhwas08008/ub8\\_offset\\_rturn\\_lanes.pdf](https://safety.fhwa.dot.gov/intersection/other_topics/fhwas08008/ub8_offset_rturn_lanes.pdf)

ENGINEERING COUNTERMEASURES – OTHER TRAFFIC CONTROL DEVICES – TRAFFIC SIGNALS



 <p>Source: Unsignalized Intersection Improvement Guide<sup>1</sup></p>	<b>Name</b>	Adjacent Traffic Signal Retiming
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Other Traffic Control Devices, Traffic Signals
	<b>Source</b>	ITE <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Lack of sufficient gaps for turning traffic, Poor operational performance
	<b>Cost</b>	Very Low (\$) – Low (\$\$)
	<b>Keywords</b>	Traffic Signal, Retiming, Adjacent Intersection, Gap, Traffic Pattern

### Usage

In some cases, it might be feasible to change the timing of adjacent traffic signals on the major roadway in order to create longer gaps in the major road traffic that will allow traffic on the minor approaches to enter the intersection. Depending on needs, the adjacent traffic signal in one or both directions may be retimed. This treatment may be used for intersections on urban corridors where gap misjudgment is a frequent contributing factor for crashes or there are excessive delays on the minor road approaches. When using this method, however, it is necessary to carefully assess the operational and safety impacts on the adjacent intersections where signal timing is modified.

### Pros and Cons

- Creates longer gaps for traffic to enter the intersection from the minor approaches.
- Avoids adding additional treatment at the unsignalized intersection in question.
- May result in negative impacts on the safety and operations at the adjacent intersections.
- May require coordination among more intersection signals within the vicinity.


### Installation and Configuration

- May require signal retiming at the adjacent intersection in one or both directions.
- May require signal retiming at one or more intersections in each direction.
- Impacts should be considered not only for adjacent signals but for the signalized corridor as a whole.
- May need to consult with other agencies (state, county, or local) to coordinate signal timing.

### Example Applications

Unknown

<sup>1</sup> Re-Time Adjacent Traffic Signals. <http://www.ite.org/uiig/treatments/10-re-time-adjacent-traffic-signals.pdf?pass=10>. Accessed Oct. 21, 2016.

 <p style="text-align: right; font-size: small;">Source: FHWA<sup>1</sup></p>	<b>Name</b>	Intersection Control Beacon
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Other Traffic Control Devices, Traffic Signals
	<b>Source</b>	MUTCD, FHWA <sup>1</sup>
	<b>Safety Benefits</b>	CMF: 0.949 <sup>1</sup> (CMF for adding beacons at stop-controlled intersections)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	High crash rates at unsignalized intersections
	<b>Cost</b>	Medium (\$\$\$)
	<b>Keywords</b>	Signal, Stop Control, Beacon, Warning, Visibility, Flashing

### Usage

An intersection control beacon may be used at intersections with high-speed traffic or a higher rate of failure to obey Stop signs to increase visibility of the intersection and compliance with the stop control. The intersection control beacon should consist of only flashing circular red or yellow signals. When the intersection is not all-way stop controlled, the flashing yellow signals should face the uncontrolled approaches.

The users of this treatment are motor vehicles.

### Pros and Cons

- Increases visibility of intersections and Stop signs.
- Increases compliance rates for stop controls.
- Is associated with higher installation and maintenance costs compared to only Stop signs and requires a power source.

### Installation and Configuration


- An intersection control beacon is usually mounted over the center of an intersection visible from every approach.
- When necessary, a beacon may be installed for each lane of a street to increase conspicuity.
- Intersection control beacons should consist of one or more signal faces directed toward each approach to an intersection, with flashing red signals indicating a stop control and flashing yellow signals indicating that caution is needed.
- A Stop sign should be used on approaches displaying a flashing red signal indication.
- If multiple horizontally aligned red signal indications are used on an approach, they should be flashed simultaneously; if two vertically aligned red signal indications are used on an approach, they should be flashed alternately.
- An intersection control beacon is generally located over the center of an intersection but may be installed at other suitable locations.

### Example Applications

Intersection control beacons are used across the country, particularly at intersections on rural high-speed roadways.

Note: See MUTCD for detailed information on usage and installation.

<sup>1</sup> Srinivasan, R., D. Carter, K. Eccles, B. Persaud, N. Lefler, C. Lyon, and R. Amjadi. *Safety Evaluation of Flashing Beacons at STOP-Controlled Intersections*. <http://www.fhwa.dot.gov/publications/research/safety/08044/>. Accessed Oct. 21, 2016.

 <p>Source: MUTCD<sup>2</sup></p>	<b>Name</b>	Rectangular Rapid-Flashing Beacon
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Other Traffic Control Devices, Traffic Signals
	<b>Source</b>	Non-MUTCD, ITE <sup>1</sup>
	<b>Safety Benefits</b>	Reduced pedestrian crashes, Improved vehicles yielding to pedestrians (no CMFs identified)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	High frequency of pedestrian crashes, Low motorists yielding to pedestrians
	<b>Cost</b>	Medium (\$\$\$) – Medium High (\$\$\$\$)
<b>Keywords</b>	Rectangular, Rapid Flashing Beacon, Traffic Signal, Pedestrian, Crosswalk	

### Usage

Rectangular rapid-flashing beacons (RRFBs) are used in conjunction with regulatory or warning signs to increase the conspicuity of signs and draw attention to approaching drivers, particularly during low-visibility conditions. When used with pedestrian crossing signs, the beacons can draw the attention of motorists to crossing pedestrians and therefore increase the compliance of vehicles yielding to pedestrians, thus reducing pedestrian crashes. The flashing beacon may come in different forms and is typically activated through a push button when a pedestrian needs to cross.

### Pros and Cons

- Improves signal visibility and can effectively draw attention to the sign with which it is used.
- Requires a power source (typically a solar panel) to function.
- Relatively high costs for installation and maintenance.

### Installation and Configuration


- Use in combination with a crosswalk, wheelchair ramps, advance warning signs or pavement markings, and overhead lighting.
- Not to be used on intersection approaches controlled by Stop (R1-1) or Yield (R1-2) signs or traffic signals.
- There is no MUTCD warrant for the RRFB, but approval is needed from FHWA if not already granted to the home agency or state.
- May not be as effective on wider multilane streets or higher speed streets.
- May need public involvement meetings and outreach to educate the public on RRFB operations.

### Example Applications

A study showed that the use of push-button-activated flashing beacons at intersections in San Francisco led to a significant reduction in vehicle/pedestrian conflicts, from 6.7% pre-treatment to 1.9% post-treatment, as well as a significant increase in vehicles yielding, from 70% pre-treatment to 80% post-treatment.<sup>1</sup>

<sup>1</sup> Install a Rectangular Rapid-Flashing Beacon (RRFB). [http://www.ite.org/uiig/treatments/32\\_rectangular\\_rapid\\_flashing\\_beacon.pdf?pass=2](http://www.ite.org/uiig/treatments/32_rectangular_rapid_flashing_beacon.pdf?pass=2). Accessed Oct. 28, 2016.

<sup>2</sup> [https://mutcd.fhwa.dot.gov/resources/interim\\_approval/ia11/fhwamemo.htm](https://mutcd.fhwa.dot.gov/resources/interim_approval/ia11/fhwamemo.htm)

 <p>Source: FHWA<sup>1</sup></p>	<b>Name</b>	Stop Beacon
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Other Traffic Control Devices, Traffic Signals
	<b>Source</b>	MUTCD, FHWA <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Low stop control compliance
	<b>Cost</b>	Medium (\$\$\$)
	<b>Keywords</b>	Stop Control, Visibility, Flashing Beacon, Warning

### Usage

A stop beacon can be used in conjunction with a Stop sign at unsignalized intersections to increase the conspicuity of the Stop sign. Such devices are typically used at intersections where drivers frequently fail to obey stop controls or there is a higher frequency of crashes involving running a Stop sign. In addition, a stop beacon can also be used at locations or conditions where visibility is limited, such as those where adverse weather conditions occur frequently.

The users of this countermeasure are primarily motorists.

### Pros and Cons

- Improves visibility and potentially compliance rate compared to traditional Stop signs.
- Associated with higher installation and maintenance costs and requires a power source.

### Installation and Configuration

- A stop beacon should consist of one or more signal sections of a standard traffic signal face with a flashing circular red signal indication.
- One or two red beacons may be installed; when two vertically aligned beacons are used, they should be flashed alternately.
- The bottom of the signal housing of a stop beacon shall be not less than 12 inches or more than 24 inches above the top of a Stop sign.
- A stop beacon shall be used only to supplement a Stop sign, a Do Not Enter sign, or a Wrong Way sign.
- The beacon may be actuated to flash red when approaching vehicles are detected through loop detectors.

### Example Applications

Stop beacons are used across the country at stop-controlled intersections where compliance with the Stop sign is low and/or there is a high rate of crashes attributable to running the Stop sign.

Note: See MUTCD for detailed information on usage and installation.

<sup>1</sup> *Stop Sign-Controlled Intersections: Enhanced Signs and Markings – A Winston-Salem Success Story*. Publication FHWA\_SA-09-010. Federal Highway Administration. [http://safety.fhwa.dot.gov/intersection/conventional/unsignalized/case\\_studies/fhwasa09010/](http://safety.fhwa.dot.gov/intersection/conventional/unsignalized/case_studies/fhwasa09010/). Accessed October 24, 2016.

ENGINEERING COUNTERMEASURES – OTHER TRAFFIC CONTROL DEVICES – INTELLIGENT  
TRANSPORTATION SYSTEMS DEVICES



<b>Name</b>	Intersection Conflict Warning System (ICWS)
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Other Traffic Control Devices, ITS Devices
<b>Source</b>	FHWA, <sup>1</sup> ITE <sup>2</sup>
<b>Safety Benefits</b>	CMF: 0.733 <sup>1</sup> (CMF for adding ICWS at two-lane intersections)
<b>Usage Type</b>	Spot treatment
<b>Target Problem</b>	Limited sight distance, High crash rates involving vehicles from the minor road
<b>Cost</b>	High (\$\$\$\$)
<b>Keywords</b>	Intelligent Transportation Systems, ITS, Conflict, Flashing, Signal, Warning

### Usage

ICWS is an ITS system used to warn motorists approaching an intersection of potential conflicts with other approaching vehicles. Such systems detect oncoming vehicles on the major road, minor road, or both, and then issue a warning for those vehicles to use caution. Such systems are typically used at intersections where sight distances are limited and vehicles on one or more approaches frequently fail to identify conflicting vehicles from other approaches.

### Pros and Cons

- Enhances visibility and conspicuity.
- Reduces likelihood of collisions at unsignalized intersections.
- Associated with relatively high installation and maintenance costs and requires a power source.

### Installation and Configuration

- ICWS can come in different variations, such as one or multiple flashing beacons and a static or flashing warning sign with varying wording.
- The system can be designed for the major road approaches only, the minor road approaches only, or the approaches of both roads.
- Requires similar equipment to a traffic signal: controller, cabinet, detection devices (loops or video), and possibly LED message signs.
- Message should be simple and easy to understand.
- The system should be placed at a distance from the intersection that would allow approaching vehicles adequate time to react.
- When ICWS design incorporates dynamic messages, some agencies program their devices to display random dots on the message screen when they are not working properly.


### Example Applications

Example applications can be found in Richmond, Virginia, where an ICWS was installed to warn drivers of an upcoming intersection.

<sup>1</sup> Himes, S., F. Gross, K. Eccles, and B. Persaud. *Safety Evaluation of Intersection Conflict Warning Systems (ICWS)*. <https://www.fhwa.dot.gov/publications/research/safety/15076/index.cfm>. Accessed Oct. 21, 2016.

<sup>2</sup> Install an Intersection Conflict Warning System (ICWS). [http://www.ite.org/uiig/treatments/13 intersection conflict warning system.pdf?pass=93](http://www.ite.org/uiig/treatments/13%20intersection%20conflict%20warning%20system.pdf?pass=93). Accessed Oct. 21, 2016.

<sup>3</sup> <http://www.dot.state.mn.us/its/projects/2011-2015/ricws.html>

	<b>Name</b>	Vehicle Actuated Variable Message Sign
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Other Traffic Control Devices, ITS Devices
	<b>Source</b>	FDOT <sup>1</sup>
	<b>Safety Benefits</b>	35%–40% reduction in intersection conflicts <sup>2</sup>
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Low visibility, Low compliance with intersection regulatory signs
	<b>Cost</b>	Medium (\$\$\$) – Medium high (\$\$\$\$)
	<b>Keywords</b>	Vehicle Actuated, Message Sign, ITS System, LED Traffic Signs

### Usage

Vehicle-actuated variable message signs at unsignalized intersections can give warning or instruction messages to motorists to improve safety at intersections. The changeable messages can provide motorists information on approaching conflicting vehicles to help avoid potential collisions, regulate vehicle behavior on major roadways, or improve compliance with stopping on the minor street intersection approaches.

### Pros and Cons

- Capable of displaying multiple types of messages to warn approaching traffic of conflicting traffic and potential hazards.
- Uses LED technology and is highly visible during adverse visibility conditions.
- More expensive than a common sign.

### Installation and Configuration

- Messages should be as simple as possible and easily understood.
- Signs should be placed far enough in advance of the intersections to allow adequate time for an approaching driver to read the message and respond to a potential conflicting vehicle.
- Activation methods include weight sensor, height sensor, speed, radar, and induction loops.
- Can be combined with data collection technology to survey intersection traffic patterns or monitor vehicle behaviors.<sup>1</sup>

### Example Applications

The Virginia Department of Transportation installed vehicle actuated variable message signs in Prince William County to reduce side-impact crashes at a dangerous intersection.

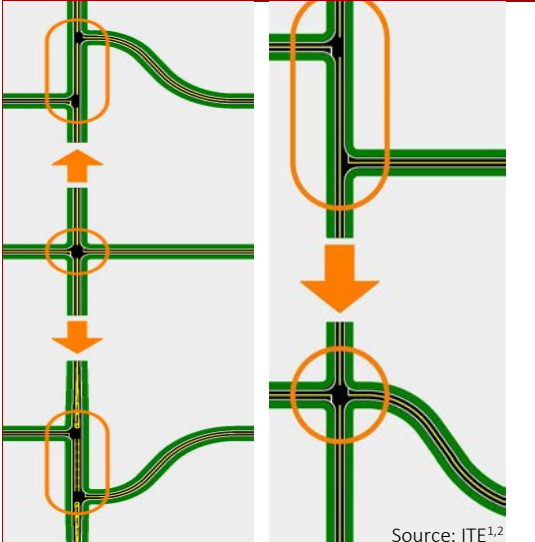
<sup>1</sup> *Innovative Operational Safety Improvements at Unsignalized Intersections*. [http://www.fdot.gov/traffic/doc\\_library/PDF/Final%20Report%20-%20Contract%20C8K21.pdf#page=69](http://www.fdot.gov/traffic/doc_library/PDF/Final%20Report%20-%20Contract%20C8K21.pdf#page=69). Accessed Aug. 30, 2017.

<sup>2</sup> Peabody, D., P. Garder, G. Audibet, W. Thompson, M. Redmond, and M. Smith. "Evaluation of a Vehicle-Actuated Warning System for Stop-Controlled Intersections Having Limited Sight Distances." 2001 International Conference on Rural Advanced Technology and Transportation Systems, 2001.

<sup>3</sup> <http://mallatite.co.uk/traffic-management/interactive-traffic-signs-vehicle-activated-road-signs/>

ENGINEERING COUNTERMEASURES – GEOMETRIC IMPROVEMENTS – INTERSECTION  
REALIGNMENT



	<b>Name</b>	Convert Between a Four-Legged Intersection and Two T-Intersections
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvement, Intersection Realignment
	<b>Source</b>	Non-MUTCD, ITE <sup>1,2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Minor road through traffic safety
	<b>Cost</b>	High (\$\$\$\$\$)
	<b>Keywords</b>	Convert, T-Intersection, Through Traffic, Intersection Realignment

### Usage

Based on engineering study results, it may be necessary in some cases to convert an existing four-legged intersection to two T-intersections to eliminate through movement on the minor road and therefore reduce crashes (typically due to lack of sufficient gaps on the major road to safely allow through traffic on the minor road to pass). In other cases, it may be desired to convert two adjacent T-intersections to a four-legged intersection to improve operations and safety. In practice, the latter is more often used due to its obvious safety and operational benefits.

### Pros and Cons

- May effectively eliminate or facilitate through traffic on minor roads.
- Requires intersection realignment and therefore frequently additional right-of-way.
- May result in unintended operational or safety consequences if not used correctly.
- Typically high cost.

### Installation and Configuration

- Consider the use of auxiliary lanes on major street during conversion to avoid rear-end collisions or to facilitate turning movements.
- Careful operational or design solutions need to be used when converting to two T-intersections to ensure safety and operations between the two closely located intersections.
- Conduct adequate outreach to ensure support from users and stakeholders.
- Ensure sufficient traffic control and signage.

### Example Applications

The Oregon Department of Transportation converted a 4-way intersection in Albany into two 2-legged intersections to decrease accidents resulting from through traffic at the intersection. The Pennsylvania Department of Transportation converted two T-intersections into a 4-way intersection in Boalsburg in order to improve traffic flow at the intersection.<sup>1,2</sup>

<sup>1</sup> Convert a Four-Legged Intersection to Two T-Intersections. <http://www.ite.org/uiig/treatments/41-four-leg-to-2-t-intersections.pdf?pass=90>. Accessed Oct. 31, 2016.

<sup>2</sup> Convert Two Offset T-Intersections to a Single Four-Legged Intersection. <http://www.ite.org/uiig/treatments/42-2-t-intersections-to-four-leg.pdf?pass=19>. Accessed Oct. 31, 2016.

	<b>Name</b>	Install a Mini-Roundabout
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Realignment
	<b>Source</b>	ITE <sup>1</sup> , FHWA <sup>2</sup>
	<b>Safety Benefits</b>	CMF: 0.7 <sup>2</sup> (CMF compares to signalized intersection)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Speeding, Conflicts involving left-turning vehicles
	<b>Cost</b>	High (\$\$\$\$\$)
	<b>Keywords</b>	Mini-Roundabout, Circular Flow, Speeding, Limited Right-of-Way

### Usage

At intersections with limited right-of-way, a low-speed, low-volume traffic pattern, and few heavy vehicles, a mini-roundabout is an effective alternative to all-way stop control to reduce crashes caused by intersection speeding. Mini-roundabouts are also used frequently for speed calming on roadways in neighborhoods or residential/commercial areas.

### Pros and Cons

- Effective alternative to all-way-stop-controlled intersections to improve safety and reduce delays.
- Encourages slower speeds through the intersection with proper design.
- May need additional right-of-way for installation.

### Installation and Configuration

See detailed design guidelines for roundabouts in AASHTO's *A Policy on Geometric Design of Highways and Streets* and the FHWA roundabout information guide.<sup>3</sup> In addition:

- Should be designed to minimize vehicles driving over the center island as much as possible.
- Some mini-roundabouts may allow left turns in front of the mini-roundabout to better accommodate emergency vehicles or long vehicles.
- Splitter islands on approaches to mini-roundabouts may use pavement markings only.
- Use striped-pattern pavement markings on the raised center to enhance its visibility.


### Example Applications

The Delaware Department of Transportation installed a mini-roundabout to improve traffic flow at a small T-intersection.

<sup>1</sup> Install a Mini-Roundabout. [http://www.ite.org/uiig/treatments/62 mini-roundabout.pdf?pass=64](http://www.ite.org/uiig/treatments/62%20mini-roundabout.pdf?pass=64). Accessed Nov. 4, 2016.

<sup>2</sup> Intersection Safety Roundabouts. <http://safety.fhwa.dot.gov/intersection/innovative/roundabouts/fhwasa10007/>. Accessed Nov. 4, 2016.

<sup>3</sup> *Roundabouts: An Informational Guide*. FHWA-RD-00-67. Exhibit 5.2, p. 106. Federal Highway Administration, Washington, D.C., June 2000. <https://www.fhwa.dot.gov/publications/research/safety/00067/index.cfm>.

 <p>Source: PedBikeSafe<sup>2</sup></p>	<b>Name</b>	Install a Neighborhood Traffic Calming Circle
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Realignment
	<b>Source</b>	ITE <sup>1</sup> , PedBikeSafe <sup>2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Speeding
	<b>Cost</b>	Low (\$\$) – Medium (\$\$\$)
	<b>Keywords</b>	Center Island, Traffic Calming, Aesthetic

### Usage

A neighborhood traffic calming circle is constructed in the center of residential street intersections, which can reduce vehicle speeds by forcing motorists to maneuver around them. It helps reduce crashes related to intersection speeding and can serve as an alternative to all-way stop control. Unlike mini-roundabouts, the neighborhood traffic calming circles use yield control or no control and have no splitter islands on the approaches.

### Pros and Cons

- Reduces speeds by forcing vehicles to maneuver around them when entering the intersection.
- Does not require approaching vehicles to fully stop and therefore reduces unnecessary delays.
- May result in increased crashes involving vehicles colliding with the circle.

### Installation and Configuration


- May use small intersection curb radii to discourage high-speed right turns.
- Design sufficient accommodation for large vehicles such as school buses and emergency vehicles.
- Design and maintain the landscaping of the circle to ensure that it does not affect sight distance at the intersection.
- Provide adequate signing and ensure conspicuity during low-visibility conditions (see MUTCD for more details).
- The cost is estimated at approximately \$5,000 to \$15,000 per circle, which varies depending on whether the residential traffic circle is landscaped and/or if it is on an asphalt or concrete street. A residential traffic circle typically has a service life of 25 years.<sup>2</sup>

### Example Applications

The Washington Department of Transportation used this countermeasure widely in Seattle due to the success of previous installations.

<sup>1</sup> Install a Residential Traffic Circle. [http://www.ite.org/uiig/treatments/63 residential traffic circle.pdf?pass=89](http://www.ite.org/uiig/treatments/63%20residential%20traffic%20circle.pdf?pass=89). Accessed Nov. 4, 2016.

<sup>2</sup> Mini-Circles. [http://www.pedbikesafe.org/bikesafe/countermeasures\\_detail.cfm?CM\\_NUM=25](http://www.pedbikesafe.org/bikesafe/countermeasures_detail.cfm?CM_NUM=25). Accessed Jan. 25, 2017.

 <p>Source: Walten, Telken, Foster<sup>5</sup></p>	<b>Name</b>	Install a Roundabout
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Realignment
	<b>Source</b>	ITE <sup>1</sup> , FHWA <sup>2</sup> , NCHRP <sup>3</sup>
	<b>Safety Benefits</b>	CMF: 0.22-0.88 for conversion from two-way stop control, 0.33-0.99 for conversion from signalized, and 1.03 for conversion from all-way stop-controlled intersections <sup>3</sup>
	<b>Usage Type</b>	Spot treatment
	<b>Target Problems</b>	Speeding at intersections, Conflicts involving left-turning vehicles
	<b>Cost</b>	High (\$\$\$\$)
	<b>Keywords</b>	Roundabout, Circular Flow, Speeding, Delay, Traffic Calming

### Usage

At intersections where traffic and crash data do not warrant a traffic control signal, but traditional stop controls result in excessive delays, or where there are high rates of crashes involving left-turning vehicles, a severe problem of through traffic speeding, and/or both intersecting roadways have comparable importance and traffic volumes, a roundabout may be used to alleviate such problems. In some cases, a roundabout can perform better even when a signal is warranted. In Virginia, for example, roundabouts have to be looked at as an alternative whenever an intersection control study is performed.

### Pros and Cons

- Reduces crashes by reducing vehicle speeds and conflicts with left-turning vehicles.
- Reduces traffic delays by allowing vehicles to enter without stopping.
- Requires reconstruction of the intersection and potentially additional right-of-way.

### Installation and Configuration

See detailed design guidelines for roundabouts in AASHTO's *A Policy on Geometric Design of Highways and Streets* and the FHWA roundabout information guide.<sup>4</sup> In addition:

- Should be designed to sufficiently accommodate design vehicles, including emergency vehicles.
- Consider installing splitter islands and horizontal deflection in approach legs to help decrease the speed of entering traffic.
- Ensure that the center island does not inhibit sight distance from all approaches.
- For dual approach or departure lanes, adequate safety measures should be considered to ensure pedestrian safety, such as pedestrian signals, pedestrian hybrid beacons (PHBs), Rectangular Rapid Flash Beacons (RRFBs), or raised crosswalks.

### Example Applications

The Virginia Department of Transportation installed roundabouts in Blacksburg to increase traffic flow at the intersection and reduce accidents.

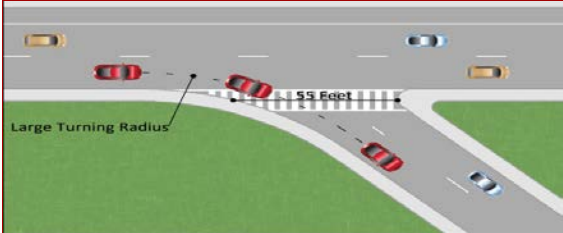

<sup>1</sup> Install a Roundabout. <http://www.ite.org/uiig/treatments/61%20Roundabout.pdf?pass=46>. Accessed Nov. 2, 2016.

<sup>2</sup> Federal Highway Administration Office of Safety. *Roundabouts—The Maryland Experience*. FHWA-SA-09-018. [http://safety.fhwa.dot.gov/intersection/innovative/roundabouts/case\\_studies/fhwasa09018/](http://safety.fhwa.dot.gov/intersection/innovative/roundabouts/case_studies/fhwasa09018/). Accessed Nov. 2, 2016.

<sup>3</sup> Crash Modification Factors Clearinghouse. Federal Highway Administration. <http://www.cmfclearinghouse.org>. Accessed 09/11/2019.

<sup>4</sup> *Roundabouts: An Information Guide*. FHWA-RD-00-67. Exhibit 5.2, pp. 106. Federal Highway Administration Washington, D.C., June 2000. <https://www.fhwa.dot.gov/publications/research/safety/00067/index.cfm>.

<sup>5</sup> <http://wالتelken.com/are-roundabouts-safer-than-normal-intersections%E2%80%A8/>

	<b>Name</b>	Modify Skewed Intersections
	<b>Category</b>	Engineering Countermeasures
 <p>Source: PedBikeSafe<sup>2</sup></p>	<b>Subcategory</b>	Geometric Improvements, Intersection Realignment
	<b>Source</b>	Non-MUTCD, ITE <sup>1</sup> , PedBikeSafe <sup>2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Speeding at intersections, Long pedestrian crossing distance, Short sight distance
	<b>Cost</b>	High (\$\$\$\$\$)
	<b>Keywords</b>	Skewed Intersection, Realignment, Crosswalk, Pedestrian Safety

### Usage

At intersections where the streets intersect at skew angles, the sight distance or visibility for drivers from both major and minor roads is limited, which increases the crash risks due to vehicles turning onto the major approach without sufficient gaps. Straightening the skewed alignment close to 90 degrees reduces the turning radii, which improves sight distances, reduces the speed of turning vehicles, and shortens pedestrian crossing distances.

### Pros and Cons

- Improves the sight distance of drivers for both major and minor roads.
- Reduces the turning radii and thereby reduces the speed of turning vehicles.
- Shortens pedestrian crossing distance at the intersection.
- High cost.

### Installation and Configuration

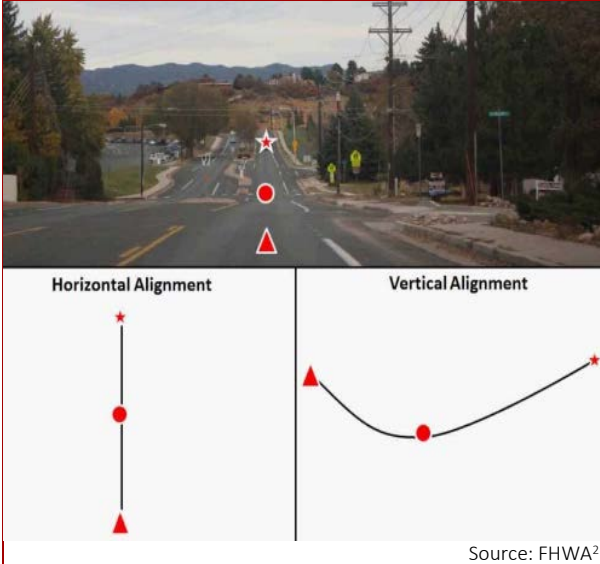
- Ensure that the perpendicular portion of the realigned minor approach is sufficiently long and does not result in safety problems for traffic approaching the intersection.
- Conduct sufficient outreach and involve all stakeholders such as local businesses, residents, and emergency responders.
- This treatment should only be considered after other less-restrictive measures have been tried and the problem is still not solved.
- Drivers should be notified to the changes in conditions before, during, and after construction.
- May require additional right-of-way.

### Example Applications

The New York Department of Transportation modified intersections in Grand Army Plaza (Brooklyn). In addition to potentially increased safety, the modification resulted in 1.5 new acres of pedestrian space, the addition of seven new crosswalks, and many new pedestrian signals.

<sup>1</sup> Realign the Intersection Approach to Reduce or Eliminate the Skew Angle. [http://www.ite.org/uiig/treatments/44\\_realign\\_for\\_skew.pdf?pass=24](http://www.ite.org/uiig/treatments/44_realign_for_skew.pdf?pass=24). Accessed Oct. 31, 2016.

<sup>2</sup> Modify Skewed Intersections. [http://www.pedbikesafe.org/pedsafe/countermeasures\\_detail.cfm?cm\\_num=29](http://www.pedbikesafe.org/pedsafe/countermeasures_detail.cfm?cm_num=29). Accessed Nov. 14, 2016.

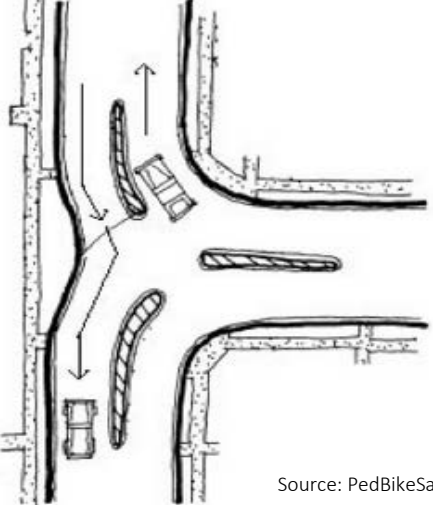
	<b>Name</b>	Modify Horizontal/Vertical Alignment of Intersection Approach
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Realignment
	<b>Source</b>	Non-MUTCD, ITE <sup>1</sup> , FHWA <sup>2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Inadequate intersection sight distance, Poor intersection visibility
	<b>Cost</b>	High (\$\$\$\$\$)
	<b>Keywords</b>	Horizontal, Vertical Alignment, Design, Intersection Approach
<p><b>Usage</b></p> <p>In some cases, the horizontal and/or vertical geometry design of nearby intersection legs results in insufficient sight distance for drivers at intersections and leads to high rates of crashes. If the sight distances cannot be improved through minor modifications of the intersection, realigning the curved legs of the intersection may be considered.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>Improves intersection sight distances for motorists.</li> <li>Improves the visibility of intersection and intersection traffic control devices.</li> <li>Relatively high cost.</li> </ul>		
<p><b>Installation and Configuration</b></p> <ul style="list-style-type: none"> <li>Conduct sufficient outreach and involve all stakeholders, such as business owners, residents, and emergency responders, whose properties and access points may be affected by the realignment in the early planning process.</li> <li>Because this treatment is costly, it should only be considered after other lower-cost treatment alternatives have been sufficiently considered.</li> <li>Additional right-of-way may be required.</li> </ul>		
<p><b>Example Applications</b></p> <p>This countermeasure is used as a spot treatment in many places across the country.</p>		

<sup>1</sup> Modify the Horizontal and/ or Vertical Alignment of an Intersection Approach.

<http://www.ite.org/uiig/treatments/45%20Horizontal%20or%20Vertical%20Realignment.pdf?pass=70>. Accessed Oct. 31, 2016.

<sup>2</sup> Change Horizontal and/or Vertical Alignment of Approaches to Provide More Sight Distance

[https://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa08008/uc3\\_horizontal\\_vertical\\_align.pdf](https://safety.fhwa.dot.gov/intersection/other_topics/fhwasa08008/uc3_horizontal_vertical_align.pdf). Accessed Sept. 18, 2017.

 <p>Source: PedBikeSafe<sup>1</sup></p>	<b>Name</b>	Modified T-Intersection
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Realignment
	<b>Source</b>	PedBikeSafe <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Speeding at T-intersection
	<b>Cost</b>	Medium (\$\$\$) – High (\$\$\$\$\$)
	<b>Keywords</b>	T-Intersection, Traffic Calming, Curb Extension, Median

### Usage

At T-intersections, or three-leg intersections on low-volume residential or downtown areas, the alignment of the straight roadway may be modified to reduce the traffic speed of through traffic and provide the perception of equal importance of all legs.

### Pros and Cons

- Reduces through vehicles' speeds.
- Discourages cut-through traffic movements.

### Installation and Configuration

- This treatment should be considered when vehicle volumes are low to moderate, and slower traffic speeds are desired.
- Consider the use of curb extensions, medians, or mini traffic circles to achieve desired effects.
- Intersection geometry, regulatory and warning signage, and/or pavement markings should clearly direct motorists at the intersection to reduce confusion regarding priority of movement.
- When designing the curb radii of curb extensions, consideration should be given to emergency vehicle access.
- Installation costs anywhere between \$20,000 and \$60,000, depending on the design and whether drainage and utilities need to be relocated.
- Should design adequate bicycle and pedestrian access.


### Example Applications

This countermeasure is used in multiple cases across the country.

<sup>1</sup> Modified T-Intersections. [http://www.pedbikesafe.org/pedsafe/countermeasures\\_detail.cfm?cm\\_num=26](http://www.pedbikesafe.org/pedsafe/countermeasures_detail.cfm?cm_num=26). Accessed Nov. 14, 2016.

ENGINEERING COUNTERMEASURES – GEOMETRIC IMPROVEMENTS – INTERSECTION  
RECONFIGURATION



 <p>Source: PedBikeSafe<sup>2</sup></p>	<b>Name</b>	Bus Bulb Outs
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	SF Better Streets <sup>1</sup> , PedBikeSafe <sup>2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Inadequate passenger waiting space, Conflicts between restarting buses and in-lane traffic
	<b>Cost</b>	Medium (\$\$\$) – High (\$\$\$\$\$)
	<b>Keywords</b>	Extension, Bus Stop, Sidewalk, Pedestrians, Crossing

### Usage

At bus stops where the space left for waiting passengers and passing pedestrians is not enough, installation of bus bulb outs provides extra passenger and pedestrian space and allows buses to stop in-lane without interfering with sidewalk flow. This treatment also helps to increase bus reliability and safety since the bus driver no longer needs to wait for a gap to re-enter the traffic.

### Pros and Cons

- Provides additional space for passengers to board and pedestrians to pass.
- Reduces the conflicts involving re-entering buses and in-lane traffic flow.
- Has positive traffic-calming effects by narrowing the roadway.
- The stopped bus may impact motor vehicle traffic flow negatively.

### Installation and Configuration


- The length of the bulb out should be long enough to allow passengers to board and the width should generally be 6 to 7 feet, but should not be wider than the adjacent parking lane.
- Bulb outs placed at intersections may be used in conjunction with a smaller curb radii design to help slow-turning vehicles.
- Use a rectilinear design to keep a direct path of travel and to regularize crossings and curb ramps.
- When placed at intersections, incorporate curb ramps into bulb out design.
- Costs for constructing bus bulbs range from \$15,000 to \$70,000 per bulb, depending upon drainage needs, utility relocation, construction materials, and patron amenities.<sup>2</sup>

### Example Applications

The city of San Francisco installed bus bulb outs in numerous locations during a massive overhaul of traffic improvements to reduce pedestrian crashes at intersections with bus stops.

<sup>1</sup> Curb Extensions (Bulb-outs). <http://www.sfbetterstreets.org/find-project-types/pedestrian-safety-and-traffic-calming/traffic-calming-overview/curb-extensions/>. Accessed Nov. 14, 2016.

<sup>2</sup> Bus Bulb Outs. [http://www.pedbikesafe.org/pedsafe/countermeasures\\_detail.cfm?cm\\_num=16](http://www.pedbikesafe.org/pedsafe/countermeasures_detail.cfm?cm_num=16). Accessed Nov. 14, 2016.

	<b>Name</b>	Close One or More Legs of the Intersection
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvement, Intersection Reconfiguration
	<b>Source</b>	Non-MUTCD, ITE <sup>1</sup> , PedBikeSafe <sup>2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	High pedestrian crashes, Safety and operational impacts of minor approach
	<b>Cost</b>	Low (\$\$) – High (\$\$\$\$\$) depending on the amount of reconfiguration required
<b>Keywords</b>	Roadway Closure, Pedestrian, Reconfiguration, Layout, Traffic Calming	

### Usage

In certain cases, it may be necessary to close one or multiple approaches of an unsignalized intersection based on engineering studies to promote a pedestrian friendly environment or reduce operational and safety impact from the approaches to a major road. The closure may be achieved through the installation of barriers or delineators, or an intersection reconfiguration. This treatment is more common in residential neighborhoods, commercial areas, or at intersections of major arterials and minor side streets/driveways with minimal traffic. This treatment can be intended to either reduce pedestrian crashes or motor vehicle crashes.

### Pros and Cons

- Reduces traffic conflicts and improves operations and safety.
- Results in additional travel time for traffic on minor road.
- Channelization devices may result in challenges to maintenance and snow removal.
- Some applications may be high cost and require additional right-of-way.
- The treatment can be unpopular with local residents.

### Installation and Configuration

- Carefully verify that alternate routes are available for through and left-turning traffic on the minor road.
- Conduct sufficient outreach and involve all stakeholders, such as local business, residents, and emergency responders.
- Ensure that channelization devices/islands are clearly marked and visible during adverse lighting and weather conditions.
- Ensure that pedestrians and bicycles can travel through the closed approach and that emergency access is available.
- May need to provide additional space for users that enter unintentionally to turn around.


### Example Applications

A New York City case study showed that, in addition to pedestrian safety improvements (e.g., 35% decrease in pedestrian injuries), improvements in traffic flow and mobility were demonstrated.<sup>2</sup>

<sup>1</sup> Close One or More Legs of the Intersection. [http://www.ite.org/uiig/treatments/40 close intersection leg.pdf?pass=37](http://www.ite.org/uiig/treatments/40%20close%20intersection%20leg.pdf?pass=37). Accessed Oct. 31, 2016.

<sup>2</sup> Miano, M. Reclaiming Broadway's Public Space. [http://www.pedbikesafe.org/pedsafe/casestudies\\_detail.cfm?cm\\_num=42&cs\\_num=105](http://www.pedbikesafe.org/pedsafe/casestudies_detail.cfm?cm_num=42&cs_num=105). Accessed Oct. 31, 2016.

<sup>3</sup> [https://safety.fhwa.dot.gov/speedmgt/ePrimer\\_modules/module3pt3.cfm](https://safety.fhwa.dot.gov/speedmgt/ePrimer_modules/module3pt3.cfm)

	<b>Name</b>	Close Median Opening
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvement, Intersection Reconfiguration
	<b>Source</b>	ITE <sup>1</sup> , FHWA <sup>2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Turning conflicts, Major road safety and operations issues
	<b>Cost</b>	Medium (\$\$\$) – Medium High (\$\$\$\$)
	<b>Keywords</b>	Median Opening, Closure, Channelization

### Usage

At intersections where traditional methods cannot effectively reduce crashes or crash risks due to turning and/or through traffic, a closed median may be installed to limit left turns from/to minor approaches, and through movement on the minor street. One example use of such a treatment is when the sight distance from the intersection is limited yet there are no cost-effective ways to clear the sight triangle.

### Pros and Cons

- Reduces traffic conflicts and improves operations and safety.
- May result in additional travel time for traffic on minor road.
- Channelization devices may result in challenges to maintenance and snow removal.
- Some applications may be high-cost and require additional right-of-way.

### Installation and Configuration

- Carefully verify that alternate routes are available for through and left-turning traffic on minor road.
- Conduct sufficient outreach and involve all stakeholders such as local business, residents, and emergency responders.
- Ensure that channelization devices/islands are clearly marked and visible during adverse lighting and weather conditions.
- Provide accessible design of the median that allows pedestrians and bicyclists to cross but not motorists.
- Use sufficient signage to ensure that users can safely and effectively navigate through the intersection.


### Example Applications

The North Carolina Department of Transportation closed a median at the intersection of a busy neighborhood and a major road in Wilmington to improve traffic flow and reduce crashes.<sup>1</sup>

<sup>1</sup> Close a Median Opening. [http://www.ite.org/uiig/treatments/43 close median.pdf?pass=5](http://www.ite.org/uiig/treatments/43%20close%20median.pdf?pass=5). Accessed Oct. 31, 2016.

<sup>2</sup> Strategy B12. Restrict or Eliminate Turning Maneuvers by Providing Channelization or Closing Median Openings. [https://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa08008/ub12.cfm](https://safety.fhwa.dot.gov/intersection/other_topics/fhwasa08008/ub12.cfm). Accessed Sept. 13, 2017.

<sup>3</sup> <http://timesofindia.indiatimes.com/city/thiruvananthapuram/pwd-to-close-median-opening-at-thulavila-after-rise-in-accidents/articleshow/57336577.cms>

	<b>Name</b>	Diverter
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	PedBikeSafe <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	High traffic volume at residential zone
	<b>Cost</b>	Low (\$\$) – Medium (\$\$\$)
	<b>Keywords</b>	Diverter, Reroute, Traffic Management, Restricted Movement

### Usage

A diverter is an island built at an intersection to discourage or prevent traffic from cutting through a residential neighborhood. Diverters can be used at intersections to restrict access to one direction of the roadway, desired movements, or the entire approach to improve safety, reduce access of through traffic, or reduce speed.

### Pros and Cons

- Restricts traffic volume in residential areas; especially when installed in a school zone, it can confer a safer environment for school students.
- May adversely affect other streets' traffic.
- Can adversely impact local residents.


### Installation and Configuration

- Based on their configuration, there are four types of diverters, each of which has a different use:
  - Diagonal diverters break up cut-through movements and force right or left turns in certain directions.
  - Star diverters consist of star-shaped islands, which force right turns from each approach.
  - Truncated diverters have one end open to allow additional turning movements.
  - Other types of island diverters can be placed on one or more approach legs to prevent through and left-turn movements and force vehicles to turn right.
- Consider less-restrictive and/or costly measures first (e.g., delineators).
- Evaluate traffic patterns to determine whether other streets would be adversely affected.
- Design diverters to allow bicycle, pedestrian, and emergency vehicle access. Diverters should not be used if this cannot be done and the street is a major bicycle corridor.
- Diagonal diverters may be used in conjunction with other traffic management tools and are most effective when applied to the entire neighborhood street network.
- Diverters should have strong neighborhood support.
- Ensure sufficient drainage design.

### Example Applications

The Oregon Department of Transportation installed diverters near an elementary school in Portland to calm traffic and reduce dangers to children in the area.<sup>1</sup>

<sup>1</sup> Diverter. [http://www.pedbikesafe.org/pedsafe/countermeasures\\_detail.cfm?cm\\_num=41](http://www.pedbikesafe.org/pedsafe/countermeasures_detail.cfm?cm_num=41). Accessed Nov. 14, 2016.

 <p>Source: FHWA Safety<sup>3</sup></p>	<b>Name</b>	Extend Left-Turn Lane
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	ITE <sup>1</sup> , NCHRP <sup>2</sup> , FHWA <sup>3</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Rear-end crashes involving left-turning vehicles
	<b>Cost</b>	Low (\$\$) – High (\$\$\$\$\$)
	<b>Keywords</b>	Left-Turn Lane, Extend Lane Length, Rear-end crashes, Reconfiguration
<p><b>Usage</b></p> <p>This method can be used at intersections where the approaches contain a high volume of left-turning vehicles, or where the length of the left-turn lanes cannot satisfy the deceleration and storage need. Insufficient storage for left-turning vehicles, particularly on high-speed roadways, can lead to higher risks of rear-end crashes involving stopped vehicles waiting to turn left.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Provides additional deceleration and storage space for left-turning vehicles and reduces crashes involving left-turn vehicles.</li> <li>• May mislead through-traffic drivers into entering the left-turn lane if the left-turn lane is too long and/or not adequately marked.</li> <li>• May require additional right-of-way or widening the existing pavement.</li> </ul>		
<p><b>Installation and Configuration</b></p> <ul style="list-style-type: none"> <li>• Additional right-of-way may be required.</li> <li>• Carefully consider operational needs and crash history.</li> <li>• During design, the length of the left-turn lane is determined by the entering taper, deceleration length, and storage length.</li> <li>• Installation costs are highly variable. Where restriping within an existing roadway is possible, the costs are nominal. Where widening and/or reconstruction are necessary, costs over \$100,000 per intersection approach may be incurred.<sup>2</sup></li> </ul>		
<p><b>Example Applications</b></p> <p>The North Carolina Department of Transportation used this measure in Raleigh in order to alleviate crashes involving left-turning vehicles.</p>		

<sup>1</sup> Extend the Left-Turn Lane. [www.ite.org/uiig/treatments/52\\_extend\\_left-turn\\_lane.pdf?pass=55](http://www.ite.org/uiig/treatments/52_extend_left-turn_lane.pdf?pass=55). Accessed Oct. 31, 2016.

<sup>2</sup> Neuman, T., R. Pfefer, K. Slack, D. Harwood, I. Potts, D. Torbic, and E. Kohlman Rabbani. *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: -- Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*. National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington, D.C., 2003.

<sup>3</sup> [https://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa08008/ub1\\_leftturnlanes.pdf](https://safety.fhwa.dot.gov/intersection/other_topics/fhwasa08008/ub1_leftturnlanes.pdf)

<p>The diagram illustrates the stages of an extended right-turn lane. It shows a vehicle approaching from the left, decelerating, and then moving laterally into the extended lane. Key stages are labeled: 'Deceleration completed', 'Lateral movement completed, full deceleration begins', 'Begin deceleration and lateral movement', and 'Begin perception reaction'. A note indicates 'Vehicle "clears" traffic lane speed differential ≤10 mph (15 km/h)'. Distances are marked as d3, d2, and d1, with a 'Minimum functional length' indicated. Source: FHWA Safety<sup>3</sup></p>	<b>Name</b>	Extend Right-Turn Lane
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	ITE <sup>1</sup> , FDOT <sup>2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Rear-end crashes involving right-turning vehicles
	<b>Cost</b>	High (\$\$\$\$)
<b>Keywords</b>	Left-Turn Lane, Extend Lane Length, Rear-end crashes, Reconfiguration	

### Usage

At intersections where the major roads contain a high volume of right-turning traffic, or where right-turning vehicles frequently crash with following vehicles due to the short deceleration and storage length of existing right-turn lanes, increasing the length of right-turn lanes can provide additional deceleration and storage area for turning vehicles and may mitigate these problems.

### Pros and Cons

- Provides additional deceleration and storage length for right-turning vehicles and reduces crashes involving right-turning vehicles.
- May mislead through traffic if the right-turn lane is excessively long and/or not adequately marked.
- May require additional right-of-way.

### Installation and Configuration

- Make sure the longer right-turn lane is justified based on the right-turn volume and crash data.
- Additional right-of-way and utility relocation may be required.
- In design, the length of the right-turn lane is determined by the entering taper, deceleration length, and storage length.
- Consider additional signage or a raised median to restrict right turns in and out of driveways on the intersection approach.

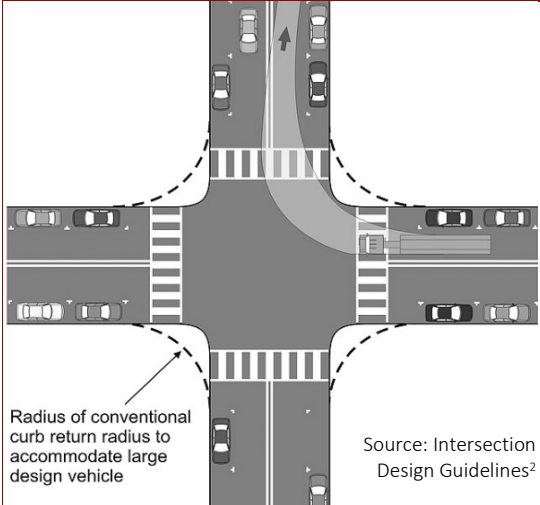
### Example Applications

This countermeasure is used as a spot treatment in many cases across the country.

<sup>1</sup> Extend the Right-Turn Lane. [http://www.ite.org/uiig/treatments/56 extend right-turn lane.pdf?pass=25](http://www.ite.org/uiig/treatments/56%20extend%20right-turn%20lane.pdf?pass=25). Accessed Nov. 2, 2016.

<sup>2</sup> Roadway Cost Per Centerline Mile. <http://www.fdot.gov/planning/policy/costs/costs-d7.pdf>. Accessed Nov. 2, 2016.

<sup>3</sup> <https://safety.fhwa.dot.gov/>

 <p>Radius of conventional curb return radius to accommodate large design vehicle</p> <p>Source: Intersection Design Guidelines<sup>2</sup></p>	<b>Name</b>	Increase Intersection Curb Radius
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	Non-MUTCD, ITE <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Turning conflicts, Poor operations
	<b>Cost</b>	High (\$\$\$\$)
	<b>Keywords</b>	Intersection Curb, Curb Radius, Turning Conflicts, Reconstruction, Large Vehicles

### Usage

Corner radii impact vehicle turning speeds and pedestrian crossing distances. Generally, a minimized corner radius creates a compact intersection with safer turning speeds but can cause difficulty for large vehicles to make turning maneuvers. At intersections where large turning vehicles routinely drive over the curb, crash with pedestrian facilities, or encroach upon other lanes when completing their turning maneuver, reconstruction of the intersection curbs to provide larger corner radii may be beneficial.

### Pros and Cons

- Provides additional space on the roadway to accommodate large turning vehicles.
- Lengthens pedestrian crossing distance.
- May encourage higher speeds at intersections.
- High cost.

### Installation and Configuration


- The design of the curb corner can be as simple as a single circular arc or use some other alternative to facilitate large turning vehicles, such as a three-centered curve or a simple offset curve with connecting tapers.
- If a larger corner radius is required to accommodate trucks or buses, a channelizing island with the tail pointing upstream may be considered to promote slower right turns. The island should be raised, large enough to accommodate pedestrians, and fully pedestrian accessible.

### Example Applications

This countermeasure is used as a spot treatment in many places across the country.

<sup>1</sup> Increase an Intersection Curb Radius. [http://www.ite.org/uiig/treatments/47 increase curb radius.pdf?pass=74](http://www.ite.org/uiig/treatments/47%20increase%20curb%20radius.pdf?pass=74). Accessed Oct. 31, 2016.

<sup>2</sup> <https://www.ite.org/css/online/DWUT10.html>

 <p>Source: FHWA Safety<sup>5</sup></p>	<b>Name</b>	Install a Left-Turn Lane on the Major Road
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	ITE <sup>1</sup> , FHWA <sup>2</sup>
	<b>Safety Benefits</b>	CMF: 0.67-0.98 <sup>3</sup> (CMFs for adding left-turn lane on both major road approaches)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Rear-end conflicts involving left-turning vehicles
	<b>Cost</b>	High (\$\$\$\$\$)
	<b>Keywords</b>	Left-Turn Lane, Rear-End Crashes, Opposing Left Turn Crashes, Realignment

### Usage

At intersections where the approaching major road contains heavy left-turn volumes, or where high rear-end collision rates are observed between vehicles turning left and following vehicles, installing a dedicated left-turn lane on the major road for deceleration and storage of left turning vehicles may mitigate these problems.

### Pros and Cons

- Reduces risks of rear-end crashes involving left-turning vehicles.
- Reduces the queue length due to vehicles stopped in through lanes waiting to turn left.
- Increases the crossing distance for pedestrians.

### Installation and Configuration

- Check left-turn warrants; see NCHRP Web-Only Document 193<sup>4</sup> for detailed information.
- Consider offsetting the left-turn lanes to improve visibility between turning vehicles and oncoming traffic for locations with opposing left-turn lanes.
- Additional right-of-way may be required.
- The length of the left-turn lane should be sufficient for left-turning vehicles to decelerate and provide adequate storage of vehicles waiting to turn.
- The additional lane may increase the crossing distance for pedestrians. As needed, a refuge island should be added to improve pedestrian safety.

### Example Applications

The Wisconsin Department of Transportation installed left-turn lanes on some intersections in Waunakee to increase traffic flow and reduce accidents from turning vehicles.

<sup>1</sup> Install a Left-Turn Lane on the Major Road. [http://www.ite.org/uiig/treatments/51 major road left-turn lane.pdf?pass=50](http://www.ite.org/uiig/treatments/51%20major%20road%20left-turn%20lane.pdf?pass=50). Accessed Oct. 31, 2016.


<sup>2</sup> Srinivasan, R., B. Lan, and D. Carter. *Safety Evaluation of Signal Installation With and Without Left Turn Lanes on Two Lane Roads in Rural and Suburban Areas*. Report No. FHWA/NC/2013-11. North Carolina Department of Transportation, Raleigh, North Carolina, October 2014.

<sup>3</sup> Crash Modification Factors Clearinghouse. Federal Highway Administration. <http://www.cmfclearinghouse.org>. Accessed 09/11/2019.

<sup>4</sup> Fitzpatrick, K., M. Brewer, W. Eisele, Y. Zhang, J. Gluck, H. Levinson, and V. Iragavarapu. "Development of Left-Turn Lane Warrants for Unsignalized Intersections." *Transportation Research Record: Journal of the Transportation Research Board*, No. 2301, pp. 55-65, 2012.

<sup>5</sup> [https://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa08008/ub1\\_leftturnlanes.pdf](https://safety.fhwa.dot.gov/intersection/other_topics/fhwasa08008/ub1_leftturnlanes.pdf)



 <p style="text-align: right; font-size: small;">Source: ITE<sup>1</sup></p>	<b>Name</b>	Install a Right-Turn Lane along the Major Road
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	ITE <sup>1</sup>
	<b>Safety Benefits</b>	CMF Range: 0.7–0.997 <sup>2</sup> (CMFs for installing right-turn lanes at intersection)
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Rear-end crashes involving right-turning vehicles
	<b>Cost</b>	Medium (\$\$\$) – High (\$\$\$\$\$)
	<b>Keywords</b>	Right-Turn Lane, Rear-End Crashes, Realignment

### Usage

At intersections where the major road contains significant right-turn volume and/or experiences high rear-end crashes involving right-turning vehicles, installing an auxiliary lane exclusively for the deceleration and storage of right-turning vehicles can be particularly beneficial.

### Pros and Cons

- Reduces rear-end crashes involving right-turning vehicles.
- Reduces the queue length due to vehicles being stopped in through lanes waiting to turn right.
- Increases the crossing distance for pedestrians.

### Installation and Configuration

- Additional right-of-way and utility relocation may be required.
- For intersections with a high volume of pedestrians crossing the major approach, consider sufficient signage and refuge islands to ensure pedestrian safety.
- May consider channelizing the right-turn lane or increasing the turning radius to improve operations, but this is not recommended for areas with frequent pedestrian crossings.
- The cost of construction to add a 300-foot exclusive right-turn lane to the existing pavement is \$220,000 for rural arterials and \$280,000 for urban arterials.<sup>3</sup>


### Example Applications

The North Carolina Department of Transportation installed right-turn lanes at selected intersections in Summerfield to reduce crashes caused by turning cars.

<sup>1</sup> Install a Right-Turn Lane along the Major Road. [http://www.ite.org/uiig/treatments/55 major road right-turn lane.pdf?pass=37](http://www.ite.org/uiig/treatments/55%20major%20road%20right-turn%20lane.pdf?pass=37). Accessed Oct. 31, 2016.

<sup>2</sup> Crash Modification Factors Clearinghouse. Federal Highway Administration. <http://www.cmfclearinghouse.org>. Accessed 09/11/2019.

<sup>3</sup> Roadway Cost Per Centerline Mile. <http://www.fdot.gov/planning/policy/costs/costs-d7.pdf>. Accessed Nov. 2, 2016

 <p>Source: PedBikeSafe<sup>3</sup></p>	<b>Name</b>	Install Curb Extensions at Crosswalk
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	Non-MUTCD, ITE <sup>1</sup> , PedBikeInfo <sup>2</sup> , PedBikeSafe <sup>3</sup>
	<b>Safety Benefits</b>	Decreased crossing distance for pedestrians, Improved yielding of motorists to pedestrians (no CMF identified)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Speeding at intersections and vehicle-pedestrian conflicts
	<b>Cost</b>	Medium (\$\$\$)
	<b>Keywords</b>	Curb Extension, Crosswalk, Pedestrian Safety

### Usage

At intersections where frequent vehicle-pedestrian conflicts are observed, or where large numbers of pedestrians cross the road, extending the curb at crosswalks reduces the crossing distance and helps to mitigate conflicts involving pedestrians and vehicles.

### Pros and Cons

- Reduces pedestrian crossing distance and exposure to traffic.
- Provides more space on narrow sidewalks for curb ramps and landings.
- Allows more visible placement of Stop signs.
- Improves motorists yielding to pedestrians.
- Reduces lane widths or number of lanes and may confuse motorists if not appropriately designed.

### Installation and Configuration

- Curb extensions should only be used where there is a parking lane, and where transit and bicyclists would be traveling outside the curb edge along the street.
- Consider the accommodation of large vehicles such as buses and emergency vehicles.
- Mid-block extensions may be used to enhance mid-block crossings.
- Ensure that curb extensions are properly designed to not block sight distances and not cause confusion to motorists.
- Emergency access can be improved by keeping parking clear near the curb extension and allowing emergency vehicles to turn onto the curb extension.
- Design adequate drainage.


### Example Applications

The Florida Department of Transportation installed curb extensions at selected intersections in Venice to reduce motorist turning speeds and pedestrian crossing distance.

<sup>1</sup> Install Curb Extensions at the Crosswalk. [http://www.ite.org/uiig/treatments/64\\_curb\\_extensions.pdf?pass=90](http://www.ite.org/uiig/treatments/64_curb_extensions.pdf?pass=90). Accessed Nov. 4, 2016.

<sup>2</sup> Mead, J., C. Zegeer, and M. Bushell. Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research. [http://www.pedbikeinfo.org/cms/downloads/pedestrianlitreview\\_april2014.pdf#page=27](http://www.pedbikeinfo.org/cms/downloads/pedestrianlitreview_april2014.pdf#page=27). Accessed Nov. 4, 2016.


<sup>3</sup> Curb Extensions. [http://www.pedbikesafe.org/pedsafe/countermeasures\\_detail.cfm?cm\\_num=5](http://www.pedbikesafe.org/pedsafe/countermeasures_detail.cfm?cm_num=5). Accessed Nov. 4, 2016.

	<b>Name</b>	Install Left-Turn Acceleration Lane
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	ITE <sup>1</sup> , NCHRP <sup>2</sup>
	<b>Safety Benefits</b>	CMF Range: 0.21–0.8 <sup>2</sup> (CMFs for installing median acceleration lane)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Long waiting delay, Speed differential, Rear-end crashes
	<b>Cost</b>	High (\$\$\$\$\$)
	<b>Keywords</b>	Left-Turn, Acceleration Lane, Realignment, Speed Differential, Traffic Merging
<p><b>Usage</b></p> <p>At intersections where rear-end crashes occur involving entering vehicles and through vehicles, or a high volume of left-turning vehicles enters major roads with high speed limits and/or high volume, or excessive delays are observed for left-turning minor road traffic waiting for safe gaps to merge onto the major road, installing an auxiliary lane that allows left-turning vehicles from the minor road to accelerate along the major road before merging can be considered.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Allows storage and acceleration for left-turning vehicles moving onto the major road.</li> <li>• Reduces time spent by minor road traffic waiting for a safe gap to merge.</li> <li>• May be high cost.</li> </ul>		
<p><b>Installation and Configuration</b></p> <ul style="list-style-type: none"> <li>• Use adequate markings and/or warning signs to notify motorists of the use of this lane before they enter.</li> <li>• Excessively long acceleration lanes may confuse drivers along the major road and appear to be an additional through lane.</li> <li>• If this treatment is a new to a community, sufficient outreach and education should be conducted.</li> <li>• Consider increasing the width of the acceleration lane to 14 feet for better accommodation.</li> <li>• The additional lane may increase the crossing distance for pedestrians. Consider a refuge island where appropriate.</li> <li>• This treatment may not be practical at locations where driveways and intersections are spaced within the distance of the acceleration lane.</li> </ul>		
<p><b>Example Applications</b></p> <p>The Arizona Department of Transportation installed left-turn acceleration lanes on selected intersections to allow turning vehicles to merge onto the major road more safely.</p>		

<sup>1</sup> Install a Left-Turn Acceleration Lane. [http://www.ite.org/uiig/treatments/53 left-turn acceleration lane.pdf?pass=63](http://www.ite.org/uiig/treatments/53%20left-turn%20acceleration%20lane.pdf?pass=63). Accessed Oct. 31, 2016.

<sup>2</sup> Maze, T., J. Hochstein, R. Souleyrette, H. Preston, and R. Storm. *NCHRP Report 650: Median Intersection Design for Rural High-Speed Divided Highways*. Transportation Research Board, Washington D.C., 2010.

<sup>3</sup> [https://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa08008/ub5.cfm](https://safety.fhwa.dot.gov/intersection/other_topics/fhwasa08008/ub5.cfm)

 <p>Source: PedBikeSafe<sup>2</sup></p>	<b>Name</b>	Install Pedestrian Overpasses/Underpasses
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	PedBikeInfo <sup>1</sup> , PedBikeSafe <sup>2</sup>
	<b>Safety Benefits</b>	Reduces pedestrian crossing crashes (no CMFs identified)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problems</b>	Pedestrian crossing crashes
	<b>Cost</b>	High (\$\$\$\$\$)
	<b>Keywords</b>	Pedestrian Crossing, Overpass, Underpass, Separation

### Usage

Pedestrian overpasses and underpasses allow for the uninterrupted flow of pedestrian movement separated from vehicular traffic. At intersections with high volume and high-speed traffic flow, and a high frequency of crashes during pedestrian crossings, the installation of pedestrian overpasses/underpasses can provide pedestrians with a safer crossing environment.

### Pros and Cons

- Provides pedestrian and vehicles with uninterrupted travel through the intersection.
- Separates pedestrians from traffic flows to provide a safer crossing environment.
- High cost.
- May obstruct drivers' sight distance.
- May discourage wheelchairs and bicyclists if slopes are steep or crossing distances are long.

### Installation and Configuration


- This is an expensive treatment and a careful cost-benefit analysis should be conducted to justify for the countermeasure.
- Provide sufficient accommodation for pedestrians, bicyclists, and users with disabilities.
- Overpasses work best when the topography allows for a structure without ramps, such as an overpass over a sunken highway.
- Entrances and exits to overpasses and underpasses should be clearly visible to encourage pedestrian use.
- Lighting, drainage, graffiti removal, and security are concerns associated with underpasses.
- Overpasses/underpasses must be wheelchair accessible, which can result in long ramps on either end.

### Example Applications

This countermeasure is used particularly in urban areas with significant commercial developments and/or tourism attractions.

<sup>1</sup> Mead, J., C. Zegeer, and M. Bushell. *Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research*. [http://www.pedbikeinfo.org/cms/downloads/pedestrianlitreview\\_april2014.pdf#page=37](http://www.pedbikeinfo.org/cms/downloads/pedestrianlitreview_april2014.pdf#page=37). Accessed Nov. 11, 2016.

<sup>2</sup> Pedestrian Overpasses/Underpasses. [http://www.pedbikesafe.org/pedsafe/countermeasures\\_detail.cfm?cm\\_num=10](http://www.pedbikesafe.org/pedsafe/countermeasures_detail.cfm?cm_num=10). Accessed Nov. 11, 2016.

 <p style="text-align: right; font-size: small;">Source: FHWA Safety<sup>2</sup></p>	<b>Name</b>	Install Right-Turn Acceleration Lane
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	ITE <sup>1</sup> , FHWA <sup>2</sup> , NCHRP <sup>3</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Excessive delay on minor approaches, High speeds on major approach
	<b>Cost</b>	High (\$\$\$\$)
<b>Keywords</b>	Right-Turn, Acceleration Lane, Realignment, Speed Differential, Traffic Merging	

### Usage

At intersections where frequent rear-end crashes occur involving right-turning vehicles entering the major roadway, or where there is a high volume of right-turn traffic from the minor approaches, or where right-turn traffic on the minor road experiences significant delays due to a lack of safe gaps, installing an auxiliary lane which allows sufficient space for right-turning traffic from the minor road to accelerate along the major road before merging may improve safety and operations.

### Pros and Cons

- Allows space for right-turning traffic to accelerate and merge and therefore reduces risks of rear-end collisions.
- Reduces the waiting time for minor road traffics to turn right onto the major roadway.
- May require additional right-of-way.
- May mislead through drivers if lane is excessively long or poorly marked.

### Installation and Configuration

- Carefully analyze traffic patterns and crash history to ensure that a right-turn acceleration lane is warranted.
- For roadways with significant pedestrian traffic, the addition of a right-turn lane may require the use of a refuge island to facilitate safe crossings for pedestrians.
- Provide sufficient guidance with traffic signs and markings to avoid confusion for through traffic.
- The countermeasure may require additional right-of-way and construction of the new lane, which can result in significant costs.

### Example Applications

The Virginia Department of Transportation installed a right-turn acceleration lane on intersections in Ashburn to reduce accidents from vehicles turning right onto a major highway.

<sup>1</sup> Install a Right-Turn Acceleration Lane. [http://www.ite.org/uiig/treatments/57 right-turn acceleration lane.pdf?pass=1](http://www.ite.org/uiig/treatments/57%20right-turn%20acceleration%20lane.pdf?pass=1). Accessed Nov. 2, 2016.

<sup>2</sup> Strategy B9. Provide Right-Turn Acceleration Lanes at Intersections. [http://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa08008/ub9.cfm](http://safety.fhwa.dot.gov/intersection/other_topics/fhwasa08008/ub9.cfm). Accessed Jan. 23, 2017.

<sup>3</sup> Neuman, T., R. Pfefer, K. Slack, D. Harwood, I. Potts, D. Torbic, and E. Kohlman Rabbani. *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: -- Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*. National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington D.C., 2003.

	<b>Name</b>	Lane Narrowing with Median Rumble Strips
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	FDOT <sup>1</sup> , FHWA <sup>2</sup> , WDOT <sup>3</sup>
	<b>Safety Benefits</b>	A study conducted by WDOT found that this treatment reduced cross-collisions by 37%. <sup>3</sup>
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Low visibility of pavement markings, Crossover collisions
	<b>Cost</b>	Low (\$\$)
<b>Keywords</b>	Rumble Strips, Median, Lane Narrowing, Crossover Collisions, Separation	

### Usage

The installation of median rumble strips creates a channelized median island, which separates vehicles traveling in opposite directions and alerts drivers when they are leaving their driving lanes. The median island also narrows lane width from 12 feet to 9–10 feet, which is intended to reduce vehicle speeds at intersections.

### Pros and Cons

- Provides drivers with an audible warning and physical vibration when they stray from their driving lanes, hence reducing crossover collisions.
- Narrows the lanes to encourage drivers to slow down when approaching the intersection.
- Enhances the visibility of pavement markings.

### Installation and Configuration

- This treatment is generally not applicable for multilane roadways or divided roadways.
- The narrowed lane width should satisfy the minimum lane width requirement for different roadway types.
- The rumble strips can be raised or depressed. Raised rumble strips should not be used in areas where snowplowing is conducted.
- Installation is around \$0.30 per centerline-foot. On paving projects where they are used, they may constitute a 1%–5% increase in the project cost.<sup>2</sup>

### Example Applications

The New York Department of Transportation installed median rumble strips to narrow the lanes and slow vehicle speeds near multiple intersections in New York City.

<sup>1</sup> *Innovative Operational Safety Improvements at Unsignalized Intersections*. [http://www.fdot.gov/traffic/doc\\_library/PDF/Final%20Report%20-%20Contract%20C8K21.pdf#page=81](http://www.fdot.gov/traffic/doc_library/PDF/Final%20Report%20-%20Contract%20C8K21.pdf#page=81). Accessed Aug. 30, 2017.

<sup>2</sup> Center Line Rumble Strips. [https://safety.fhwa.dot.gov/roadway\\_dept/pavement/rumble\\_strips/t504040/t504040.pdf](https://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/t504040/t504040.pdf). Accessed Aug. 30, 2017.

<sup>3</sup> *The Gray Notebook*. <http://www.wsdot.wa.gov/NR/rdonlyres/1DCF9725-14D1-4341-A091-43E7A73A4298/0/GrayNotebookJun09.pdf#page=20>. Accessed Aug. 30, 2017.

	<b>Name</b>	Merge and Weave Area Redesign
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	PedBikeSafe <sup>1</sup> , PedBikeInfo <sup>2</sup>
	<b>Safety Benefits</b>	Significantly increased motorists yielding to bicyclists (no CMFs identified)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Motorist-bicyclist conflicts at merge area
	<b>Cost</b>	Low (\$\$) – Medium (\$\$\$)
	<b>Keywords</b>	Merge Area, Weave Area, Motorist-bicyclist conflict

### Usage

Merging and weaving areas can be particularly dangerous for bicyclists due to the high speeds and conflicts typically associated with the free-flow and yield-controlled conditions at these locations. Redesigning these areas to enhance the visibility of bicyclists can help reduce motorist-bicyclist conflicts at these locations. This can be achieved by reconfiguring the entry and exit intersection angles closer to 90°, combining the bike lane and right-turning lane, or coloring the bike lane at the weaving area.

### Pros and Cons

- Improves the visibility of bicyclists.
- Increases motorists yielding to bicyclists.

### Installation and Configuration

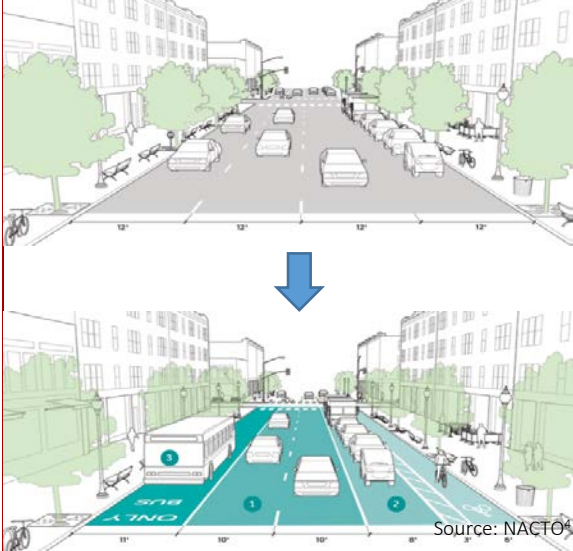
- Evaluate the appropriateness of this treatment at locations where entry and exit ramp revisions are considered.
- Consider replacing interchange ramps with intersections to reduce motor vehicle speeds, improve intersection sight distance, and reduce the exposure of bicyclists to motorists in conflict areas.
- Combine this treatment with other sight distance improvement methods.
- Avoid double left- and double-right turns for bicyclists.
- Costs for tighter turning radius reconstruction range from \$2,000 to \$20,000 per corner, depending on site conditions (e.g., drainage and utilities may need to be relocated).<sup>1</sup>

### Example Applications

The Oregon Department of Transportation redesigned the merge and weave areas at an intersection to reduce motorist/bicyclist conflicts.

<sup>1</sup> Merge and Weave Area Redesign. [http://pedbikesafe.org/bikesafe/countermeasures\\_detail.cfm?CM\\_NUM=21](http://pedbikesafe.org/bikesafe/countermeasures_detail.cfm?CM_NUM=21). Accessed Dec. 5, 2016.

<sup>2</sup> Mead, J., A. McGrane, C. Zegeer, and L. Thomas. *Evaluation of Bicycle-Related Roadway Measures: A Summary of Available Research*. [http://www.pedbikeinfo.org/cms/downloads/06%2013%202014%20BIKESAFE%20Lit%20Review\\_FINAL.pdf#page=50](http://www.pedbikeinfo.org/cms/downloads/06%2013%202014%20BIKESAFE%20Lit%20Review_FINAL.pdf#page=50). Accessed Sept. 11, 2017.

	<b>Name</b>	Reduce Width of Travel Lanes on Major Road Approaches
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	ITE <sup>1</sup> , FHWA <sup>2</sup> , FDOT <sup>3</sup> , NACTO <sup>4</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	High speed at intersection, High vehicle conflict rates with non-motorists
	<b>Cost</b>	Medium (\$\$\$) – Medium high (\$\$\$\$)
	<b>Keywords</b>	Lane Width, Reduction, Major Road Approach, Speeding, Delineator

### Usage

Narrower lane widths discourage vehicles from speeding on intersection approaches. At intersections where speeding is a problem, narrower lane widths may be considered. The reduction of lane widths can be achieved by using pavement markings, raised pavement markers, shoulder rumble strips, or some combination thereof.

### Pros and Cons

- Reduces vehicle speeds along intersection approaches.
- The additional space saved may be used to provide wider shoulders for bicyclists or greater separation between vehicles and pedestrians on the sidewalk.
- Can have adverse effect on capacity and level of service.

### Installation and Configuration

- Travel lane widths of 10 feet are generally recommended in urban areas. The reduced lane widths should not impact traffic operations.
- When determining the lane width, the lane volume and the overall assemblage of the street should be considered.
- When using rumble strips, the suitability of the existing pavement structure to support them should be assessed and their impacts on bicyclists and nearby residents should be taken into consideration.
- Pavement markings, raised pavement markers, and shoulder rumble strips need periodic maintenance.
- Installation costs range from \$10,000 to \$30,000 per intersection, excluding indirect construction costs.<sup>3</sup>

### Example Applications

The Pennsylvania Department of Transportation narrowed road widths from 12 feet to 10 feet at some intersections and added rumble strips in the median in an effort to reduce speeds on targeted roads.

<sup>1</sup> Reduce the Width of the Travel Lanes on the Major Road Approach. [http://www.ite.org/uiig/treatments/49 reduce lane width.pdf?pass=27](http://www.ite.org/uiig/treatments/49%20reduce%20lane%20width.pdf?pass=27). Accessed Oct. 31, 2016.

<sup>2</sup> Two Low-Cost Safety Concepts for Two-Way Stop-Controlled, Rural Intersections on High-Speed Two-Lane, Two-Way Roadways. <https://www.fhwa.dot.gov/publications/research/safety/08063/08063.pdf>. Accessed Jan. 23, 2017.

<sup>3</sup> Abdel-Aty, M. A., C. Lee, J. Park, J. Wang, M. Abuzwidah, and S. Al-Arifi. *Validation and Application of Highway Safety Manual (Part D) in Florida*. Florida Department of Transportation. Tallahassee, Florida. [http://www.fdot.gov/research/Completed\\_Proj/Summary\\_SF/FDOT-BDK78-977-14-rpt.pdf](http://www.fdot.gov/research/Completed_Proj/Summary_SF/FDOT-BDK78-977-14-rpt.pdf). May 2014.

<sup>4</sup> Lane Width. <https://nacto.org/publication/urban-street-design-guide/street-design-elements/lane-width/>. Accessed Sept. 18, 2017.





<b>Name</b>	Reduced Intersection Curb Radius
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Geometric Improvement, Intersection Reconfiguration
<b>Source</b>	ITE <sup>1</sup> , PedBikeSafe <sup>2</sup>
<b>Safety Benefits</b>	Reduced motor vehicle speeds, Improved pedestrian safety (no CMFs identified)
<b>Usage Type</b>	Spot treatment
<b>Target Problem</b>	High speeds at intersections, High crash rates involving pedestrians
<b>Cost</b>	High (\$\$\$\$\$)
<b>Keywords</b>	Curb Radius, Reduced Speed, Pedestrian Crossing, Visibility, Sight Distance

### Usage

Intersection curb radii are typically determined during roadway designs to accommodate design vehicles. However, large curb radii at intersections may result in higher speeds for turning vehicles (particularly right-turning vehicles), longer pedestrian crosswalks, and limited visibility of pedestrians to drivers. Curb radii may be reduced at locations with higher crash frequencies involving right-turning vehicles and pedestrians if doing so still accommodates the design vehicles. The use of reduced intersection curb radii should also take into consideration drainage needs and emergency vehicles.

### Pros and Cons

- Reduces speeds for right-turning vehicles.
- Associated with potentially higher likelihood of turning vehicles driving over the curb corners.
- Shortens crosswalks and improves visibility between motorists and pedestrians.
- Less accommodating to larger vehicles.
- Potentially reduces intersection capacity, particularly for right-turning traffic.

### Installation and Configuration


- Ensure that the reduced curb radius can accommodate emergency vehicles and other large design vehicles.
- A larger effective radius may be achieved by installing bicycle lanes, street parking, or edgelines directing vehicles away from the curb line or edge of pavement.
- Ensure that pedestrian crosswalks and sidewalks are designed/modified accordingly to benefit from the radius reduction.
- Designs must accommodate drainage at the corner.
- Reduced curb radii may be considered when the functional classifications of the existing roadways are lowered.
- It might be necessary to lower the speed limits of the roadways affected by the reconfiguration.
- Construction costs for reconstructing tighter turning radii are approximately \$15,000 to \$40,000 per corner, depending on site conditions (e.g., drainage and utilities may need to be relocated).

### Example Applications

San Francisco reduced curb radii in certain areas with heavy pedestrian volumes to reduce turning speeds and improve pedestrian safety at the intersections.<sup>1</sup>

<sup>1</sup> Reduce an Intersection Curb Radius. [http://www.ite.org/uiig/treatments/46 reduce curb radius.pdf?pass=32](http://www.ite.org/uiig/treatments/46%20reduce%20curb%20radius.pdf?pass=32). Accessed Oct. 17, 2016.

<sup>2</sup> Curb Radius Reduction. [http://www.pedbikesafe.org/PEDSAFE/countermeasures\\_detail.cfm?CM\\_NUM=28](http://www.pedbikesafe.org/PEDSAFE/countermeasures_detail.cfm?CM_NUM=28). Accessed Dec. 16, 2016.

 <p>Source: ITE<sup>1</sup></p>	<b>Name</b>	Restrict Driveway Access
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Geometric Improvements, Intersection Reconfiguration
	<b>Source</b>	ITE <sup>1</sup> , FHWA <sup>2</sup>
	<b>Safety Benefits</b>	Sample application reduced crash rate from 0.66 crashes per million to 0.06 <sup>2</sup>
	<b>Usage Type</b>	Spot treatment
	<b>Target Problems</b>	Conflicts and crashes involving vehicles entering and exiting driveways
	<b>Keywords</b>	Driveway Access, Channelization, Left Turn, Movement Restriction

### Usage

At locations where heavy traffic is present in both directions, through traffic frequently travels at a high speed, and/or closely located access points lead to complex or conflicting movements, prohibiting left turn movements at driveways may reduce vehicular conflicts and crash risks.

### Pros and Cons

- Reduces conflicts and crash risks caused by vehicles entering and exiting driveways.
- May require extra space.
- Nearby property owners may be resistant to this treatment.

### Installation and Configuration

- Make sure that alternative access driveways can safely accommodate entering and exiting vehicles.
- Consider using raised medians and channelizing islands to improve motorists' compliance with the access restriction.
- If applicable, design sufficient accommodation for pedestrians.
- Use adequate signs and pavement markings to improve the conspicuity of channelization devices.
- Seek sufficient inputs and support from affected property owners and stakeholders.
- May be implemented as part of a comprehensive corridor access management plan.

### Example Applications

The Oregon Department of Transportation restricted access near a major signalized intersection in La Grande and saw a significant reduction in crashes.

<sup>1</sup> Restrict Driveway Access. [http://www.ite.org/uiig/treatments/65\\_restrict\\_driveway\\_access.pdf?pass=98](http://www.ite.org/uiig/treatments/65_restrict_driveway_access.pdf?pass=98). Accessed Nov. 4, 2016.

<sup>2</sup> Access Management in the Vicinity of Intersections. [http://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa10002/#s15](http://safety.fhwa.dot.gov/intersection/other_topics/fhwasa10002/#s15). Accessed Nov. 4, 2016.

## ENGINEERING COUNTERMEASURES – OTHER

<p>Source: Finkelstein, J.<sup>4</sup></p>	<b>Name</b>	Clear Intersection Sight Triangles
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Other
	<b>Source</b>	ITE <sup>1</sup> , FHWA <sup>2</sup>
	<b>Safety Benefits</b>	CMF: 0.44–1.3 <sup>3</sup> (CMFs for increasing triangle sight distance and different crash severities)
	<b>Usage Type</b>	Spot treatment, Systemic application
	<b>Target Problem</b>	Inadequate sight distance, Inadequate visibility of intersection or traffic control
	<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Clearance, Intersection Sight Triangle, Sight Distance	

### Usage

At some intersections, vegetation and/or other fixed objects may obstruct the sight triangles and result in lack of sight distances or block the view of certain traffic control devices. In such cases, routine maintenance is important to clear the sight triangles and allow sufficient sight distances for drivers approaching the intersections.

### Pros and Cons

- Improves motorists' visibility of intersection and traffic control devices.
- Improves motorists' sight distances.

### Installation and Configuration

- If the obstruction is privately owned or on private property, coordination with property owners is needed.
- Review, revise, and enforce agency policy or local ordinances regarding planting and landscaping features for properties next to public roadways.
- The position of the minor road stop line may be adjusted to improve visibility from the minor road approach.
- If adequate sight distance cannot be maintained, consider modifying existing traffic control methods to improve safety (e.g., use all-way stop control).

### Example Applications


This countermeasure is used in multiple cases across the country.

<sup>1</sup> Clear the Intersection Sight Triangles. [http://www.ite.org/uiig/treatments/66\\_clear\\_sight\\_triangles.pdf?pass=71](http://www.ite.org/uiig/treatments/66_clear_sight_triangles.pdf?pass=71). Accessed Nov. 7, 2016.

<sup>2</sup> Rodegerdts, L. A., B. Nevers, and B. Robinson. *Signalized Intersections: Informational Guide*. FHWA-HRT-04-091. Federal Highway Administration, Washington, D.C., 2004.

<sup>3</sup> Crash Modification Factors Clearinghouse. Federal Highway Administration. <http://www.cmfclearinghouse.org>. Accessed 09/11/2019.

<sup>4</sup> Finkelstein, J. "Sight Distance Explained." <http://www.landscapes2.org/transportation/circulation/20-Intersections.cfm>. Accessed Nov. 7, 2016.

	<b>Name</b>	Eliminate Parking at or Near Intersection
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Other
	<b>Source</b>	ITE <sup>1</sup> , PedBikeSafe <sup>2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problems</b>	Inadequate sight distance, Inadequate visibility of intersection and traffic control
	<b>Cost</b>	Very Low (\$) – Medium (\$\$\$)
<b>Keywords</b>	Parking, Sight Distance, Intersection Sight Triangles, Visibility	

### Usage

Parked vehicles near an intersection may obstruct drivers' sight distance, impact their visibility of traffic control devices at intersections, and result in crashes and conflicts. Eliminating the parking near intersections can help this problem.

### Pros and Con

- Improves pedestrian and motorist sightline through intersections.
- Frees up roadway space for other uses.
- May impact access to adjacent properties.

### Installation and Configuration

- This treatment can be implemented with pavement markings, signage, and physical restrictions, such as a curb extension.
- Sufficiently involve stakeholders whose properties may be affected by the removal of parking space.
- The position of the minor road stop line may be adjusted to improve side street visibility.
- If stop or yield lines are used at a crosswalk of an uncontrolled multilane approach, parking should be prohibited in the area between the stop or yield line and the crosswalk.

### Example Applications

The Alabama Department of Transportation removed parking at a small T-intersection to improve the sight triangle for drivers turning onto the main road.

<sup>1</sup> Eliminate Parking at or near the Intersection. [http://www.ite.org/uiig/treatments/67\\_eliminate\\_parking.pdf?pass=36](http://www.ite.org/uiig/treatments/67_eliminate_parking.pdf?pass=36). Accessed Nov. 7, 2016.

<sup>2</sup> Parking Restrictions (at Crossing Locations). [http://www.pedbikesafe.org/pedsafe/countermeasures\\_detail.cfm?cm\\_num=9](http://www.pedbikesafe.org/pedsafe/countermeasures_detail.cfm?cm_num=9). Accessed Nov. 7, 2016.



<b>Name</b>	Install Intersection Lighting
<b>Category</b>	Engineering Countermeasures
<b>Subcategory</b>	Other
<b>Source</b>	Non-MUTCD, ITE <sup>1</sup> , FHWA <sup>2</sup> , PedBikeSafe <sup>3</sup>
<b>Safety Benefits</b>	CMF: 0.881 <sup>4</sup> (CMF for installing intersection lighting and for nighttime crashes)
<b>Usage Type</b>	Spot treatment
<b>Target Problems</b>	Inadequate nighttime visibility, Nighttime crashes
<b>Cost</b>	Very Low (\$) – Medium (\$\$\$)
<b>Keywords</b>	Nighttime Visibility, Intersection Lighting, Nighttime Crashes

### Usage

At unsignalized intersections near facilities with nighttime activities, with uncommon roadway configurations, with wide ditches separating both directions of major roads, and/or with little environmental lighting, the installation of streetlamps to provide nighttime illumination can improve comfort and safety for crossing pedestrians and motorists. The use of lighting at intersections also improves the visibility of the intersections to approaching motorists.

### Pros and Cons

- Enhances drivers' visibility of intersection and crossing pedestrians at night.
- Improves safety and comfort for crossing pedestrians.
- Requires extra costs for the installation and maintenance of streetlights.

### Installation and Configuration

- For wider streets or streets in commercial districts, the lighting should be installed on both sides.
- Use uniform lighting levels.
- For rural areas, streetlights may need isolated power sources such as solar power.
- Review the local policies and ordinances on lighting before applying this treatment.
- Illumination should be provided at pedestrian walkways and crosswalks.
- Consider LED lamps and solar power to lower costs.

### Example Applications

The Minnesota Department of Transportation installed intersection lighting at 34 different intersections to improve night vision and reduce nighttime crashes.


<sup>1</sup> Install Intersection Lighting. [http://www.ite.org/uiig/treatments/70 lighting.pdf?pass=5](http://www.ite.org/uiig/treatments/70%20lighting.pdf?pass=5). Accessed Nov. 7, 2016.

<sup>2</sup> Reducing Late-Night/Early Morning Intersection Crashes By Providing Lighting.

[http://safety.fhwa.dot.gov/intersection/conventional/unsignalized/case\\_studies/fhwasa09017/](http://safety.fhwa.dot.gov/intersection/conventional/unsignalized/case_studies/fhwasa09017/). Accessed Nov. 7, 2016.

<sup>3</sup> Lighting and Illumination. [http://www.pedbikesafe.org/pedsafe/countermeasures\\_detail.cfm?cm\\_num=8](http://www.pedbikesafe.org/pedsafe/countermeasures_detail.cfm?cm_num=8). Accessed Nov. 7, 2016.

<sup>4</sup> Crash Modification Factors Clearinghouse. Federal Highway Administration. <http://www.cmfclearinghouse.org>. Accessed 09/11/2019.

	<b>Name</b>	Relocate a Bus Stop
	<b>Category</b>	Engineering Countermeasures
	<b>Subcategory</b>	Other
	<b>Source</b>	ITE <sup>1</sup> , PedBikeSafe <sup>2</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problems</b>	Inadequate intersection sight distance, Vehicle-pedestrian conflicts
	<b>Cost</b>	Medium (\$\$\$)
	<b>Keywords</b>	Relocation, Bus Stop, Sight Distance, Pedestrian Crossing

### Usage

At intersections where the sight distance of pedestrians is obstructed by bus stops or stopped buses, or where the existing bus stop is not wheelchair accessible, relocation of the bus stop can accommodate pedestrian crossing more safely.

### Pros and Cons

- Reduces vehicle-pedestrian conflicts.
- Improves crossing pedestrians' intersection sight distance.

### Installation and Configuration

- Provide suitable access to and from the new transit stop location in accordance with the Americans with Disabilities Act.
- Provide adequate space to accommodate wheelchairs.
- Consider providing lighting at the bus stop for pedestrian security and bus driver visibility.
- Crosswalks should be placed behind the bus stop at mid-block crossings and far-side bus stop so that oncoming motorists can see the pedestrian.
- If both intersecting approaches have bus stops near the intersection, place them in the same quadrant if possible, so that pedestrians do not need to cross the road to switch buses.
- See the FHWA Transit Guide for more details on accommodating pedestrians with respect to transit.<sup>3</sup>

### Example Applications

This countermeasure is used in multiple cases across the country.



<sup>1</sup> Relocate a Bus Stop. [http://www.ite.org/uiig/treatments/71\\_relocate\\_bus\\_stop.pdf?pass=59](http://www.ite.org/uiig/treatments/71_relocate_bus_stop.pdf?pass=59). Accessed Nov. 11, 2016.

<sup>2</sup> Access to Transit. [http://www.pedbikesafe.org/pedsafe/countermeasures\\_detail.cfm?cm\\_num=15](http://www.pedbikesafe.org/pedsafe/countermeasures_detail.cfm?cm_num=15). Accessed Nov. 11, 2016.

<sup>3</sup> *Pedestrian Safety Guide for Transit Agencies*. Federal Highway Administration, Washington, D.C., 2008.

## ENFORCEMENT COUNTERMEASURES



  <small>Source: Unknown</small>	<b>Name</b>	Automated Speed or Stop Sign Enforcement
	<b>Category</b>	Enforcement Countermeasures
	<b>Subcategory</b>	N/A
	<b>Source</b>	ITE <sup>1</sup>
	<b>Safety Benefits</b>	CMF: 0.39–1.46 <sup>2</sup> (CMFs for installation of fixed speed cameras)
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Speeding and other illegal driver behaviors at intersections
	<b>Cost</b>	Unknown
<b>Keywords</b>	Speeding, Enforcement, Camera, Automated	

### Usage

Automated speed cameras are frequently used at major intersections to enforce speed limits and traffic signal obedience. Such cameras can also be used at unsignalized intersections to automatically enforce speed limits and reduce speeding, particularly when the intersections have a history of speed-related crashes. Cameras can also be used at unsignalized intersections with frequent pedestrian crossings to reduce speeding and protect pedestrians.

### Pros and Cons

- Reduces speeding behavior and therefore crash risks due to speeding.
- Relatively high cost and may not be suitable for systemic application.
- May be subject to privacy and legal concerns in some areas (speed enforcement is not legally permitted in some states).

### Installation and Configuration

Automated speed cameras are typically considered for use at unsignalized intersections when the intersections have a history of speeding-related crashes or there is a need to protect pedestrians from frequent speeding vehicles.


- Typically deployed with signs informing the public that photo enforcement is being used.
- Typically involves both law enforcement and transportation agencies during the planning, operation, and management of the devices.
- May require public meetings and hearings before implementation.
- Consider other engineering treatments such as speed-calming approaches that cost less and are less intrusive.

### Example Applications

Speed cameras are used in several states, including Maryland and California. Several locations in California have installed automatic cameras to enforce Stop signs at unsignalized intersections.

<sup>1</sup> Conduct Automated Speed Enforcement. <http://www.ite.org/uiig/treatments/75%20Automated%20Speed%20Enforcement.pdf?pass=19>. Accessed Sept 13, 2017.

<sup>2</sup> Crash Modification Factors Clearinghouse. Federal Highway Administration. <http://www.cmfclearinghouse.org>. Accessed 09/11/2019.

 <p>Source: Community Severance<sup>3</sup></p>	<b>Name</b>	Enforcement for Drivers at Pedestrian Crossings
	<b>Category</b>	Enforcement Countermeasures
	<b>Subcategory</b>	N/A
	<b>Source</b>	ITE <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Drivers not yielding to pedestrians in crosswalk
	<b>Cost</b>	Very Low (\$) to Low (\$\$) – Manual enforcement (depending on man hours) High (\$\$\$\$) – Automatic enforcement
	<b>Keywords</b>	Automatic Enforcement, Pedestrian Crossing, Right of Way, Yield, Crosswalk

### Usage

Pedestrians crossing an intersection are always subject to a level of risk due to their vulnerability in crashes. Drivers who fail to yield to pedestrians when they are crossing further increase the risks for pedestrian-involved crashes. Enforcement for drivers at pedestrian crossings can be considered at locations where there is a history of motor vehicles not yielding to pedestrians and/or a high frequency of pedestrian crashes. The enforcement may be conducted with automatic photo enforcement equipment or manual, targeted enforcement by police officers.

### Pros and Cons

- Helps improve vehicles yielding to pedestrians crossing intersections in crosswalks.
- Automatic photo enforcement may be subject to privacy or legal concerns.
- Automatic photo enforcement equipment is relatively costly.

### Installation and Configuration

- Enforcement can be considered at intersections where large numbers of pedestrians are present and there is a history of frequent pedestrian crashes.
- Automatic photo enforcement should be used with sufficient traffic signs for information and warning.
- Prior to the installation of automatic photo enforcement, the public should be involved and informed to ensure support.
- Enforcement should be conducted in conjunction with media coverage or community outreach to improve effectiveness and awareness.
- Enforcement can be part of a broader safety campaign.


### Example Applications

A large number of cities across the country have conducted pedestrian crossing enforcement.<sup>2</sup>

<sup>1</sup> Types of Treatments. <http://www.ite.org/uiig/treatments.asp>. Accessed Oct. 19, 2016.

<sup>2</sup> *Pedestrian Safety Enforcement Operations: A How-To Guide*. National Highway Traffic Safety Administration. <https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/812059-pedestriansafetyenforceoperahowtoguide.pdf>. Accessed Sept. 13, 2017.

<sup>3</sup> Community Severance. <https://communityseverance.wordpress.com/tag/pedestrian-crossing/>. Accessed Sept. 13, 2017

 <p>Source: Community Severance<sup>3</sup></p>	<b>Name</b>	Enforcement for Legal Pedestrian Crossings
	<b>Category</b>	Enforcement Countermeasures
	<b>Subcategory</b>	N/A
	<b>Source</b>	ITE <sup>1</sup>
	<b>Safety Benefits</b>	No CMFs identified
	<b>Usage Type</b>	Spot treatment
	<b>Target Problem</b>	Pedestrians crossing roadways illegally
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Pedestrian, Crossing, Crosswalk, Illegal, Enforcement, Jaywalking, Improperly
<p><b>Usage</b></p> <p>Pedestrians sometimes cross streets without using crosswalks or obeying pedestrian signals, resulting in increased risks for crashes involving pedestrians. In some cases, it is necessary to implement measures to prevent illegal street-crossing activities at unsignalized intersections to improve safety.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Reduces improper pedestrian street crossings and therefore improves safety.</li> </ul>		
<p><b>Installation and Configuration</b></p> <ul style="list-style-type: none"> <li>• Pedestrian crossing enforcement can be considered at intersections where large numbers of pedestrians are present and illegal pedestrian crossing activities create safety concerns.</li> <li>• Pedestrian crossings can also be regulated by engineering measures such as signs and physical barriers.</li> <li>• Enforcement should be conducted in conjunction with media coverage or community outreach to improve effectiveness and awareness.</li> <li>• Enforcement can be part of a broader safety campaign.</li> <li>• Citations may be issued for severe cases or repeating violations.</li> </ul>		
<p><b>Example Applications</b></p> <p>Washington, D.C., conducted pedestrian crossing enforcement as part of the city's Toward Zero Deaths campaign in 2013.<sup>2</sup></p>		

<sup>1</sup> Types of Treatments. <http://www.ite.org/uiig/treatments.asp>. Accessed Oct. 19, 2016.

<sup>2</sup> "Police Plan to Issue More Jaywalking Tickets They Can't Enforce." *Washington City Paper*. November 14, 2013.

<http://www.washingtoncitypaper.com/news/housing-complex/blog/13123770/police-plan-to-issue-more-jaywalking-tickets-they-cant-enforce>. Accessed Sept. 13, 2017.

<sup>3</sup> <https://communityseverance.wordpress.com/tag/pedestrian-crossing/>



Source: Hamlet Hub<sup>2</sup>

<b>Name</b>	Targeted Speed Enforcement
<b>Category</b>	Enforcement Countermeasures
<b>Subcategory</b>	N/A
<b>Source</b>	ITE <sup>1</sup>
<b>Safety Benefits</b>	No CMFs identified
<b>Usage Type</b>	Spot treatment
<b>Target Problem</b>	Speeding and speed-related crashes
<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Targeted, Speed Enforcement, Speeding, Radar, Police

### Usage

At intersections with an observed high rate of speeding vehicles and/or speed-related crashes, targeted speed enforcement can be used to enforce the speed limits and mitigate speeding-related crash risks. These enforcement activities may involve collaboration between transportation and law enforcement agencies. The activities can be conducted for specific sites based on complaints or crash history or as a part of a broader safety campaign across a large area for a relatively long period.

### Pros and Cons

- Reduces speeding at unsignalized intersections and therefore decreases the risk of speed-related crashes.

### Installation and Configuration

- Select sites based on citizen complaints and/or crash history with the collaboration of both law enforcement and transportation agencies.
- Conduct the enforcement in conjunction with media coverage and/or community outreach to improve effectiveness.
- Can be conducted as part of a broader safety campaign to reduce speeding or improve traffic safety.
- Conduct sufficient training for officers involved and provide regular feedback on their effectiveness.
- Interact with the court systems operating in the jurisdiction so that the judiciary understands the objectives.

### Example Applications

Targeted speed enforcement is routinely conducted in many municipalities across the country.

<sup>1</sup> Conduct Targeted Speed Enforcement. [http://www.ite.org/uiig/treatments/74 targeted speed enforcement.pdf?pass=89](http://www.ite.org/uiig/treatments/74%20targeted%20speed%20enforcement.pdf?pass=89). Accessed Nov. 11, 2016.

<sup>2</sup> <http://news.hamlethub.com/brewster/publicsafety/4928-speed-week-has-nys-police-targeting-speeding-drivers>



Source: Unknown

<b>Name</b>	Targeted Stop Sign Enforcement
<b>Category</b>	Enforcement Countermeasures
<b>Subcategory</b>	N/A
<b>Source</b>	ITE <sup>1</sup>
<b>Safety Benefits</b>	23%–83% reduction in Stop sign violation <sup>2</sup>
<b>Usage Type</b>	Spot treatment
<b>Target Problem</b>	Frequent Stop sign violations
<b>Cost</b>	Very Low (\$) (per event and per location)
<b>Keywords</b>	Enforcement, Stop Sign, Violation, Safety, Police, Law, Targeted

### Usage

Targeted Stop sign enforcement can be conducted at locations where running Stop signs is a common problem or be part of a system-wide safety campaign. Such enforcement activities help to reduce Stop sign infractions and increase public awareness of safety at unsignalized intersections.

### Pros and Cons

- Helps to reduce Stop sign infractions and increases public awareness of safety at unsignalized intersections.
- Long-term effectiveness may not be significant.

### Installation and Configuration

- This tool can be considered when a history of Stop sign violations and patterns of crashes related to Stop sign violations has been observed.
- The targeted enforcement may be part of a bigger safety campaign and facilitated by media coverage to improve effectiveness and awareness.
- The public may be informed through media or public outreach to gain support from communities.
- Both the highway and the law enforcement agencies should be involved in the planning of the enforcement effort.

### Example Applications

The city of Dixon, Illinois, conducted a Stop sign enforcement campaign in late 2017 after receiving large numbers of citizen complaints about drivers running Stop signs.<sup>3</sup>

<sup>1</sup> Conduct Targeted STOP Sign Enforcement. [http://www.ite.org/uiig/treatments/72\\_targeted\\_stop\\_sign\\_enforcement.pdf?pass=62](http://www.ite.org/uiig/treatments/72_targeted_stop_sign_enforcement.pdf?pass=62). Accessed Oct. 19, 2016.

<sup>2</sup> Provide Targeted Enforcement to Reduce Stop Sign Violations.

[http://safety.fhwa.dot.gov/intersection/other\\_topics/fhwasa08008/ug1\\_targeted\\_enforcement.pdf](http://safety.fhwa.dot.gov/intersection/other_topics/fhwasa08008/ug1_targeted_enforcement.pdf). Accessed Oct. 19, 2016.

<sup>3</sup> "Dixon Police: Stop Not Stopping." SaukValley.com. <http://www.saukvalley.com/2017/09/12/dixon-police-stop-not-stopping/amxoe92/>. Accessed Sept. 13, 2017.

## EDUCATION COUNTERMEASURES



Source: Unknown

<b>Name</b>	Pedestrian/Driver Education
<b>Category</b>	Education Countermeasures
<b>Subcategory</b>	N/A
<b>Source</b>	PedBikeSafe <sup>1</sup>
<b>Safety Benefits</b>	Unknown
<b>Usage Type</b>	Public education programs may benefit multiple locations
<b>Target Problem</b>	Public safety awareness and driver behavior/attitude
<b>Cost</b>	Very Low (\$) for a single event
<b>Keywords</b>	Driver Education, Safety, Driver Behavior, Attitude

### Usage

Public education programs on traffic safety at unsignalized intersections may be used to improve the safety awareness of drivers and pedestrians and reduce unsafe driver behaviors at such locations. Such education programs may be associated with driver licensing programs or certain traffic law enforcement activities, such as traffic schools for unsignalized intersection-related traffic safety violations. The program may also be conducted in communities where safety at unsignalized intersections has been identified as a common problem.

### Pros and Cons

- Public education is widely recognized as an effective tool to improve traffic safety in general.

### Installation and Configuration

- May be conducted as a part of the driver licensing process, or as a requirement or incentive similar to or part of traffic school.
- Can be a component of a long-term traffic safety program or educational campaign.
- Educational programs and materials should be sensitive to different groups of people.
- May be conducted in multiple languages and/or facilitated with multimedia tools.
- May be conducted as part of a public outreach event for new traffic control devices or safety improvements.
- May involve law enforcement agencies.


### Example Applications

Unknown

<sup>1</sup> Pedestrian/Driver Education. [http://www.pedbikesafe.org/pedsafe/countermeasures\\_detail.cfm?cm\\_num=61](http://www.pedbikesafe.org/pedsafe/countermeasures_detail.cfm?cm_num=61). Accessed Oct. 19, 2016.

VEHICLE TECHNOLOGY COUNTERMEASURES – ONBOARD DETECTION AND WARNING  
SYSTEMS



 <p>Source: MyCarDoesWhat.org<sup>1</sup></p>	<b>Name</b>	Forward Collision Warning System
	<b>Category</b>	Vehicle Technology Countermeasures
	<b>Subcategory</b>	Onboard Detection and Warning Systems
	<b>Source</b>	MyCarDoesWhat.org <sup>1</sup>
	<b>Safety Benefits</b>	Detection and warning of possible collisions
	<b>Usage Type</b>	Onboard safety system
	<b>Target Problem</b>	Distracted drivers, Failure to detect conflicting objects in vehicle path
	<b>Cost</b>	Unknown
	<b>Keywords</b>	Collision Avoidance, Warning, Vehicle Technology, Forward
<p><b>Usage</b></p> <p>Forward collision warning technology can detect conflicting objects or vehicles in the vehicle's path and warn the driver of a potential collision. The system is particularly beneficial in reducing distracted driving and collisions (such as rear-end collisions) caused by driver errors. Forward collision warning systems alone will not apply brakes automatically.</p> <p>This technology can be beneficial at intersections by helping to prevent vehicle-vehicle collisions.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Uses machine vision to detect other vehicles in the vehicle's path.</li> <li>• A forward collision warning system alone does not automatically apply brakes.</li> <li>• Machine vision can be affected by weather and visibility conditions.</li> <li>• Some systems may fail to detect motorcycles, bicycles, pedestrians, some farm machinery, and other vehicles smaller than a car.</li> </ul>		
<p><b>Installation and Configuration</b></p> <p>Forward collision warning systems rely on sensors located in the front of the vehicle to detect how close the vehicle ahead is. The sensors typically are camera- or radar-based and warnings can come in the form of sounds, visuals, vibrations or a quick brake pulse, or a mix of these.</p> <p>The sensors used by such systems may be blocked by ice or snow and affected by glare and adverse visibility conditions.</p>		
<p><b>Example Applications</b></p> <p>A large number of vehicle models are equipped with this system.</p>		

<sup>1</sup> MyCarDoesWhat.Org. <https://mycardoeswhat.org/safety-features/forward-collision-warning/>. Accessed Sept. 11, 2017.



<b>Name</b>	Onboard Bicycle Detection System
<b>Category</b>	Vehicle Technology Countermeasures
<b>Subcategory</b>	Onboard Detection and Warning Systems
<b>Source</b>	AutoBlog <sup>1</sup>
<b>Safety Benefits</b>	Preventing bicyclist crashes
<b>Usage Type</b>	Onboard safety system
<b>Target Problem</b>	Crashes involving bicyclists
<b>Cost</b>	Unknown
<b>Keywords</b>	Onboard, Vehicle Technology, Bicyclist, Detect, Automated Brake, Warning

### Usage

The system detects and warns drivers of bicyclists and pedestrians around the vehicle. When a bicyclist encroaches into the driving path and a collision becomes imminent, the system automatically applies brakes to avoid the collision.

This system is designed to prevent crashes involving cyclists and can be beneficial at intersections where cyclists are present.

### Pros and Cons

- Warns drivers of potential conflicting cyclists around the vehicle.
- Applies brakes when a collision with a cyclist becomes imminent.

### Installation and Configuration

The bicycle detection system relies on a radar unit integrated into the front grille, a camera fitted in front of the interior rear-view mirror, and a central control unit. The radar detects obstacles in front of the vehicle and calculates distance, while the camera determines what the object is. The central control unit continuously monitors and evaluates the traffic situation and determines the different scenarios. The system is capable of issuing warning and applying brakes automatically depending on different scenarios.

### Example Applications

Some Volvo models are equipped with this technology.

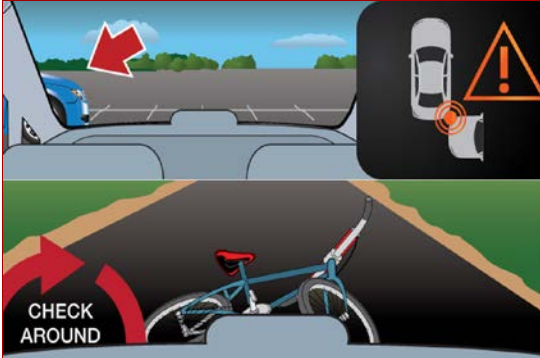
<sup>1</sup> Harley, M. (2013, March 7). Volvos Will Brake for Bicyclists with New Detection Technology. Retrieved from <http://www.autoblog.com/2013/03/07/volvos-will-brake-for-bicyclists-with-new-detection-technology/#slide-160272>

<sup>2</sup> <https://www.autosphere.ca/collisionmanagement/collision-news/2013/03/11/volvo-launches-pedestrian-detection-technology-in-geneva/>

	<b>Name</b>	Pedestrian Detection HUD
	<b>Category</b>	Vehicle Technology Countermeasures
	<b>Subcategory</b>	Onboard Detection and Warning Systems
	<b>Source</b>	AutoBlog <sup>1</sup>
	<b>Safety Benefits</b>	Preventing crashes involving pedestrians
	<b>Usage Type</b>	Onboard safety system
	<b>Cost</b>	Unknown
	<b>Keywords</b>	Onboard, Vehicle Technology, Alert, Heads-up Display, Pedestrian, Augmented Reality
<p>Source: Autoblog.com<sup>2</sup></p>		
<p><b>Usage</b></p> <p>The pedestrian detection heads-up display (HUD) system will detect multiple pedestrians around the vehicle and display their locations on an augmented reality HUD to allow the driver to actively avoid potential conflicts with pedestrians. When a pedestrian conflict becomes possible, the system will alert the driver and automatically brake if necessary to avoid the conflict.</p> <p>This onboard technology can be particularly beneficial at intersections where pedestrians are present.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Helps drivers detect pedestrians in advance of potential conflicts so they can take proactive actions to avoid possible conflicts.</li> <li>• Has the ability to detect pedestrians when views are obscured by blind spots or objects.</li> </ul>		
<p><b>Installation and Configuration</b></p> <p>The pedestrian detection HUD:</p> <ul style="list-style-type: none"> <li>• Detects and displays the positions of pedestrians around the vehicle on an augmented reality HUD to alert the driver of potential upcoming conflicts.</li> <li>• Issues warnings and initiates automated braking if necessary when a possible pedestrian collision is detected.</li> <li>• Uses connected vehicle technology to warn following vehicles of potential upcoming conflicts with pedestrians.</li> </ul>		
<p><b>Example Applications</b></p> <p>This system is patented by Honda. No implementations of this technology on commercially available vehicles have been identified.</p>		

<sup>1</sup> Stocksdales, J. "Honda Patents Show Technology that Could Give You X-Ray Vision." *Auto Blog*. Sept. 8, 2016.

<sup>2</sup> <https://www.autoblog.com/2016/09/08/honda-x-ray-augmented-reality-patent/>

 <p>Source: MyCarDoesWhat.org<sup>3</sup></p>	<b>Name</b>	Rear Cross Traffic Alert
	<b>Category</b>	Vehicle Technology Countermeasures
	<b>Subcategory</b>	Onboard Detection and Warning Systems
	<b>Source</b>	Edmunds <sup>1</sup> , MyCarDoesWhat.org <sup>2</sup>
	<b>Safety Benefits</b>	Prevent crashes while backing up
	<b>Usage Type</b>	Onboard safety system
	<b>Target Problem</b>	Insufficient driver view during backup
	<b>Cost</b>	Very Low (\$)
	<b>Keywords</b>	Back up, Vehicle Technology, Warning, Onboard

### Usage

In some circumstances, a driver may not be able to detect certain objects in the backing path or identify conflicting vehicles while backing up. The rear cross traffic alert is designed to warn drivers of objects in the backing path or cars entering the backing path. This system is most useful in parking lots or when backing out of a driveway. The system can also be beneficial at intersections when backing up is required in certain circumstances.

### Pros and Cons

- Provides visual and/or audio alerts when potential conflicting objects or vehicles are identified while backing up.
- May fail to detect certain objects such as pedestrians.
- May fail to detect objects if parking spaces are angled.
- Bushes or other sight obstacles may affect accuracy and reliability.

### Installation and Configuration

Rear cross traffic alert systems rely on sensors and cameras installed around the rear of the car. When conflicting vehicles or objects are identified, the system displays a visual warning sign on the dashboard or the mirror with a warning tone.

The safety system adds an average cost of \$2,373 to a 2015 vehicle.<sup>1</sup>

### Example Applications

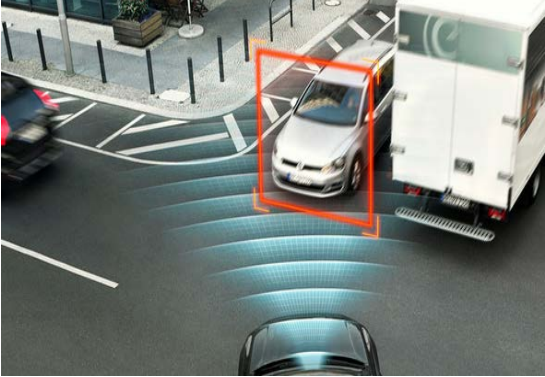
A wide range of vehicle models have this technology.

<sup>1</sup> Lienert, A. "Limitations of Rear Cross-Traffic Alert Systems Underscored in New Study." <https://www.edmunds.com/car-news/limitations-of-rear-cross-traffic-alert-systems-underscored-in-new-study.html>. Accessed Jan. 30, 2017.

<sup>2</sup> MyCarDoesWhat.org. ACC Adaptive Cruise Control. <https://mycardoeswhat.org/wp-content/uploads/2016/06/MCDW-Infographs2.pdf>. Accessed Feb. 12, 2018.


<sup>3</sup> <https://mycardoeswhat.org/safety-features/rear-cross-traffic-alert/>

VEHICLE TECHNOLOGY COUNTERMEASURES – AUTOMATED VEHICLE CONTROL  
TECHNOLOGIES

 <p style="text-align: right; font-size: small;">Source: Volvo Car USA<sup>2</sup></p>	<b>Name</b>	Automatic Brake at Intersections
	<b>Category</b>	Vehicle Technology Countermeasures
	<b>Subcategory</b>	Automated Vehicle Control Technologies
	<b>Source</b>	CarAdvice.com <sup>1</sup>
	<b>Safety Benefits</b>	Reduction of side-impact and head-on collisions at intersections
	<b>Usage Type</b>	Onboard safety system
	<b>Target Problem</b>	Vehicle conflicts at intersections resulting in crashes
	<b>Cost</b>	Unknown
	<b>Keywords</b>	Intersection, Braking, Automatic, Collision, Turning, Automated
<p><b>Usage</b></p> <p>The automatic intersection braking feature detects potential conflict vehicles at intersections and applies the brakes automatically to avoid or mitigate the severity of a collision.</p> <p>This system is specially designed to identify potential conflicts at intersections that might lead to a crash and take braking actions to avoid it. It is not clear if the system takes into account pedestrians, bicyclists, and motorcycles.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>Prevents or mitigates the severity of collisions at intersections.</li> </ul>		
<p><b>Installation and Configuration</b></p> <p>The automatic braking at intersections feature relies on machine vision and radar to detect encroaching vehicles. When the algorithm predicts a collision, the system applies the brake automatically to avoid or reduce the severity of the collision.</p>		
<p><b>Example Applications</b></p> <p>This feature is available on the new generation of the Volvo XC90 models.</p>		

<sup>1</sup> Fung, D. Volvo XC90 to Feature Auto Braking at Intersections, Run Off Road Protection. <http://www.caradvice.com.au/298204/volvo-xc90-to-feature-auto-braking-at-intersections-run-off-road-protection/>. Accessed Nov. 30, 2016.

<sup>2</sup> <https://www.media.volvocars.com/us/en-us/media/pressreleases/148123/all-new-volvo-xc90-two-world-firsts-in-one-of-the-safest-cars-in-the-world>

	<b>Name</b>	Automatic Emergency Braking
	<b>Category</b>	Vehicle Technology Countermeasures
	<b>Subcategory</b>	Automated Vehicle Control Technologies
	<b>Source</b>	SaferCar.gov <sup>1</sup>
	<b>Safety Benefits</b>	Preventing crashes and mitigating severity
	<b>Usage Type</b>	Onboard safety system
	<b>Target Problem</b>	Crashes caused by failures to identify objects on vehicle path
	<b>Cost</b>	Very Low (\$)
Source: ExtremeTech <sup>2</sup>	<b>Keywords</b>	Automated Vehicle, Braking, Rear-End Collision, Emergency, Dynamic Brake Support, Crash Imminent Braking
<p><b>Usage</b></p> <p>Automatic emergency braking (AEB) systems detect an impending forward crash with another vehicle or object in time to avoid or mitigate the crash. These systems are typically used with forward collision warning systems to first warn the driver of a potential collision and then automatically apply the brakes as needed to assist in preventing or reducing the severity of a crash. Dynamic brake support (DBS) and crash imminent braking (CIB) systems are also considered AEBs. AEBs may also be marketed under other names such as forward collision mitigation system, pre-crash warning and braking system, and intelligent braking.</p> <p>AEBs can be particularly beneficial at intersections where rear-end collisions frequently occur.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Helps to avoid or mitigate crashes when drivers fail to take sufficient actions.</li> <li>• May not prevent a crash if distance from the object is too short.</li> <li>• Sensor performance may be affected by snow, ice, dirt, glare, or other low-visibility conditions.</li> </ul>		
<p><b>Installation and Configuration</b></p> <p>The system is typically paired with a forward collision warning system and therefore relies on sensors installed in the front of the vehicle to scan the road ahead while driving. When the system determines that a crash becomes possible, it sends a warning to the driver to take corrective action. If no sufficient reaction is detected, the system applies the brakes automatically to slow or stop the vehicle.</p> <p>Sensors are typically camera- or radar-based. Warnings can be in the form of warning tones, visual alerts, and/or brake/steering wheel vibrations.</p> <p>Sensors used by AEBs may be affected by snow, ice, dirt, glare, or other low-visibility conditions.</p>		
<p><b>Example Applications</b></p> <p>Currently, a large number of commercially available vehicle makes/models are equipped with this technology.</p>		

<sup>1</sup> Automatic Emergency Braking. <http://www.safercar.gov/Vehicle-Shoppers/Safety-Technology/aeb-1>. Accessed Nov. 30, 2016.

<sup>2</sup> <https://www.extremetech.com/extreme/176093-v2v-what-are-vehicle-to-vehicle-communications-and-how-does-it-work>

VEHICLE TECHNOLOGY COUNTERMEASURES – CONNECTED VEHICLE TECHNOLOGIES





<b>Name</b>	Vehicle-to-Vehicle Communications
<b>Category</b>	Vehicle Technology Countermeasures
<b>Subcategory</b>	Connected Vehicle Technologies
<b>Source</b>	SaferCar.gov <sup>1</sup>
<b>Safety Benefits</b>	Reduction of crashes in general
<b>Usage Type</b>	Onboard safety system
<b>Target Problem</b>	Existing traffic safety concerns in general
<b>Cost</b>	Unknown
<b>Keywords</b>	Connected Vehicle, Vehicle to Vehicle, Communications, V2V, Vehicle Technology

### Usage

Vehicle-to-vehicle communication technology (V2V) enables communication between vehicles to allow drivers and automated vehicles (AVs) to make safety and operations decisions based on the information communicated. Information that is communicated among vehicles may include position, speed, and projected vehicle paths; upcoming safety hazards; and traffic conditions that require driver attention. V2V and other connected vehicle (CV) technologies have the potential to significantly reduce crashes and therefore improve safety on roadways and intersections.

### Pros and Cons

- Allows the driver of the vehicle to have a 360-degree “awareness” of other vehicles in the proximity.
- Improves safety and operations.
- Can be combined with AV technologies to yield significant safety and operations benefits.
- The technology may be vulnerable to cyber security and privacy concerns.

### Installation and Configuration

V2V technology uses Dedicated Short-Range Communications (DSRC). The onboard system collects data about the vehicle and its surroundings and then communicates the information directly or indirectly to other vehicles. The technology allows vehicles to rapidly broadcast and receive messages (up to 10 times per second) among vehicles within a range of approximately 300 meters. When combined with AV technologies, CV technologies can allow vehicles to make decisions further in advance and therefore result in significant safety and operations benefits.


### Example Applications

This technology is currently being developed and tested around the world.

<sup>1</sup> Vehicle-to-Vehicle Communications. <http://www.safercar.gov/Vehicle-Shoppers/Safety-Technology/v2v-comms>. Accessed Nov. 28, 2016.

<sup>2</sup> <https://www.extremetech.com/extreme/176093-v2v-what-are-vehicle-to-vehicle-communications-and-how-does-it-work>

VEHICLE TECHNOLOGY COUNTERMEASURES – VEHICLE-ENVIRONMENT INTERACTION  
TECHNOLOGIES

	<b>Name</b>	Active High Beam
	<b>Category</b>	Vehicle Technology Countermeasures
	<b>Subcategory</b>	Vehicle-Environment Interaction Technologies
	<b>Source</b>	DigitalTrends.com <sup>1</sup>
	<b>Safety Benefits</b>	Reduction of glare for other cars and therefore mitigation of crash risks
	<b>Usage Type</b>	Onboard safety system
	<b>Target Problem</b>	Crashes caused by the glare of high-beam lamps
	<b>Cost</b>	Unknown
	<b>Keywords</b>	Lamp, High Beam, Active, Glare, Visibility

### Usage

The Active High Beam function detects the headlamp beams of oncoming traffic or the rear lights of vehicles in front and switches the vehicle lighting from high beam to low beam. The lighting returns to high beam when the incoming light is no longer detected. The system also works with motorcycles when designed properly.

The active high beam function can be beneficial at unsignalized intersections by reducing glare for other vehicles.

### Pros and Cons

- Reduces glare for other vehicles and therefore mitigates nighttime crash risks.
- Reduces the driver workload required to constantly turn high beams on and off.
- Camera sensor reliability may be impacted by precipitation and other conditions such as fog and dirt.

### Installation and Configuration

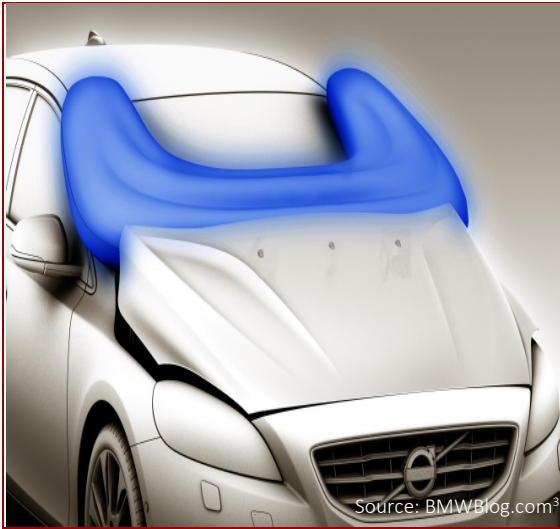
Active high beam uses a camera sensor in front of the interior rearview mirror to detect the headlamp beams of oncoming traffic or the rear lights of vehicles in front, and then switches from high beam to low beam. The adjustment of the head lamps is realized using several small pieces of metal within the headlight projector that are controlled by the system. The function can also take streetlights into account. The lighting returns to high beam about a second after the camera sensor no longer detects the headlamp beams from oncoming traffic or the rear lights from vehicles in front.

### Example Applications

Volvo has implemented this feature on some models sold in Europe. According to Volvo, their system operates at speeds above 9 mph and works with motorcycles.

<sup>1</sup> Jaynes, N. Volvo Unveils Active High Beam Control Technology Ahead of Geneva, Hints at Another Safety Tech Premiere. <http://www.digitaltrends.com/cars/volvo-unveils-active-high-beam-control-technology-ahead-of-geneva-hints-at-another-safety-tech-premiere/>. Accessed Nov. 30, 2016.

<sup>2</sup> [http://www.thecarconnection.com/news/1082703\\_volvos-latest-high-tech-trick-permanent-high-beam-headlights](http://www.thecarconnection.com/news/1082703_volvos-latest-high-tech-trick-permanent-high-beam-headlights)



<b>Name</b>	Pedestrian Airbag System
<b>Category</b>	Vehicle Technology Countermeasures
<b>Subcategory</b>	Vehicle-Environment Interaction Technologies
<b>Source</b>	AutoBlog.com <sup>1</sup>
<b>Safety Benefits</b>	Reduction of severe injuries during crashes involving pedestrians
<b>Usage Type</b>	Spot treatment, Systemic application
<b>Target Problem</b>	Severe injuries to pedestrians during collisions with motor vehicles
<b>Cost</b>	Very Low (\$)
<b>Keywords</b>	Vehicle Technology, Pedestrian, Airbag, Collision, Mitigate, Injury

**Usage**

The pedestrian airbag system activates when a vehicle collides with a pedestrian at a speed between 20 and 50 km/h. The airbag will serve as a cushion for the pedestrian to protect the pedestrian (particularly the head and neck area) from severe injuries. This system is designed to mitigate the severity of injuries to pedestrians involved in motor vehicle crashes.

The system is beneficial at an intersection when a pedestrian crash occurs by reducing the severity of injury to the involved pedestrians.

**Pros and Cons**

- Reduces pedestrian injury severity when a crash occurs.
- Requires additional costs to add the option or install the system.

**Installation and Configuration**


The pedestrian airbag technology utilizes seven sensors embedded in the front of the car to detect the human leg. If contact has been made, the control unit will deploy the airbag and pop the hood by 10 cm. The combined effect of the extra space between the hood and the hard components in the engine compartment, and the airbag will reduce the impact force to the pedestrian and therefore avoid severe injuries.

The airbag and its deployment system—two pyrotechnic bonnet struts—are estimated to cost about \$3,000 to replace.<sup>2</sup>

**Example Applications**

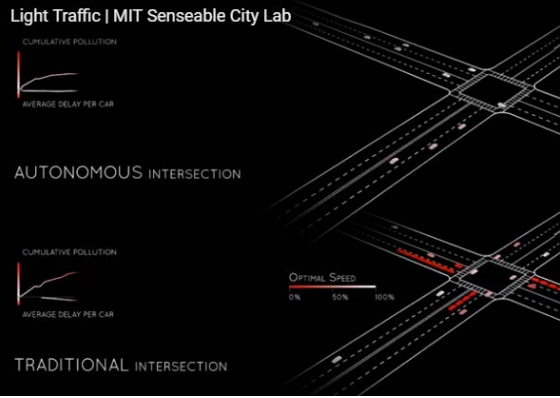
Currently, some commercially available Volvo models include this option.

<sup>1</sup> Korzeniewski, J. Volvo Protecting Pedestrians with Airbags on Outside of New V40. <http://www.autoblog.com/2012/03/08/volvo-protecting-pedestrians-with-airbags-on-outside-of-new-v40/>. March 8, 2012.  
<sup>2</sup> Dowling, J. Volvo Offers World's First Pedestrian Airbag. <http://www.news.com.au/technology/science/volvo-offers-worlds-first-pedestrian-airbag/news-story/01134d765993d652fe96b7d7e95e716a>. Accessed Jan. 30, 2017.  
<sup>3</sup> <http://www.bmwblog.com/2012/07/09/technical-analysis-pedestrian-airbags>

	<b>Name</b>	Pedestrian Detection and Signaling
	<b>Category</b>	Vehicle Technology Countermeasures
	<b>Subcategory</b>	Vehicle-Environment Interaction Technologies
	<b>Source</b>	AutoBlog.com <sup>1</sup>
	<b>Safety Benefits</b>	Reduction of pedestrian crashes through better communication
	<b>Usage Type</b>	Onboard safety system
	<b>Target Problem</b>	Potential pedestrian crashes resulting from lack of communication
	<b>Cost</b>	Unknown
Source: AutoBlog.com <sup>2</sup>	<b>Keywords</b>	Vehicle Technology, Pedestrian Detection, Communication, Smile
<p><b>Usage</b></p> <p>This technology allows communication between the vehicle and passing pedestrians. The system works by showing a smiling symbol when an equipped vehicle approaches a crosswalk to signal to pedestrians that it is safe to cross. This allows pedestrians to know that it is safe to cross and therefore eliminates miscommunication that might lead to pedestrian crashes and delays.</p> <p>This technology is designed to facilitate pedestrians when crossing a street. It can be beneficial at intersections where pedestrians are present.</p>		
<p><b>Pros and Cons</b></p> <ul style="list-style-type: none"> <li>• Improves vehicle-pedestrian communication and therefore reduces conflicts at intersections.</li> <li>• May require public education to ensure pedestrians understand the smile symbol.</li> </ul>		
<p><b>Installation and Configuration</b></p> <p>The system is designed to be used in conjunction with the advanced vehicle technology that detects pedestrians with onboard sensors. The system, however, goes one step further by showing a signal outside the vehicle to enable communication with pedestrians when they cross in front. This technology is particularly beneficial for autonomous vehicles as they may not have drivers who could make eye contact with pedestrians acknowledging the driver's awareness of them.</p>		
<p><b>Example Applications</b></p> <p>This is a concept being developed by researchers. The researchers did not find any commercially available vehicles with this technology.</p>		

<sup>1</sup> Snyder, J. B. This Self-Driving Car Smiles at Pedestrians. <http://www.autoblog.com/2016/09/16/this-self-driving-car-smiles-at-pedestrians/>. Accessed Nov. 18, 2016.

<sup>2</sup> <https://www.autoblog.com/2016/09/16/this-self-driving-car-smiles-at-pedestrians/>

 <p>Source: BGR.com²</p>	<b>Name</b>	Smart Intersections
	<b>Category</b>	Vehicle Technology Countermeasures
	<b>Subcategory</b>	Vehicle-Environment Interaction Technologies
	<b>Source</b>	AutoBlog.com <sup>1</sup>
	<b>Safety Benefits</b>	Reduction of vehicle conflicts at intersections and therefore improved safety and operations
	<b>Usage Type</b>	Potential systemic application. Used in conjunction with AV/CV technologies.
	<b>Target Problem</b>	Vehicle conflicts at intersections
	<b>Cost</b>	Unknown (not implemented)
	<b>Keywords</b>	Smart Intersection, Connected Vehicle, Traffic Lights, Conflicts

### Usage

Smart intersections would utilize a central control unit to communicate with approaching vehicles and allow them to safely pass through the intersection at optimal speeds to eliminate conflicts and reduce delays. This technology will eliminate the need for traffic signals and other traffic control devices at intersections.

### Pros and Cons

- Eliminates the need for traffic signals and other traffic controls at intersections.
- Improves operations and safety at intersections.
- Requires connected vehicles in order to function.

### Installation and Configuration

The smart intersection concept is based on communication between vehicles and a central control unit at intersections. The system would use collision detection sensors fitted to vehicles that communicate distance and speed information with the intersection. The information will be analyzed by the central control system, which will then provide specific spaces or “slots” for each vehicle approaching the intersection to pass through the intersection safely.

### Example Applications

Smart intersections are a concept proposed by researchers and are currently not implemented anywhere.

<sup>1</sup> Marker, J. MIT Plan May Eliminate the Need for Traffic Lights. <http://www.autoblog.com/2016/03/23/mit-plan-may-eliminate-the-need-for-traffic-lights/>. Accessed Nov. 18, 2016.

<sup>2</sup> BG.com. <http://bgr.com/2016/03/18/mit-smart-intersection-traffic-lights/>. Accessed 03/16/2018.

## REFERENCES

1. National Highway Traffic Safety Administration. (2017). Fatality Analysis Reporting System. Retrieved from <https://www-fars.nhtsa.dot.gov/Main/index.aspx>. Accessed 4/12/2017.
2. Federal Highway Administration. (2017). *Intersection safety – Background and objectives*. Retrieved from <https://www.fhwa.dot.gov/research/topics/safety/intersections/>. Accessed 4/12/2017.
3. Rodegerdts, L. A., Nevers, B., Robinson, B., Ringert, J., Koonce, P. Bansen, J., Nguyen, T., McGill, J., Stewart, D., Suggett, J. Neuman, T., Antonucci, N., Hardy, K., & Courage, K. (2004, August). *Signalized intersections: Informational guide* (Report No. FHWA-HRT-04-091). Washington, DC: Federal Highway Administration.
4. Federal Highway Administration. (2017). *Safety - Unsignalized intersections*. Retrieved from <https://safety.fhwa.dot.gov/intersection/conventional/unsignalized/>. Accessed 4/15/2017.
5. Trombly, J., Chandler, B., & White, T. (2011, August). *Highway Safety Improvement Program Self Assessment Tool* (Report No. FHWA-SA-11-043). Washington, DC: Department of Transportation.
6. American Association of State Highway and Transportation Officials. (2011). *A policy on geometric design of highways and streets* (6th Edition). Washington, DC: Author.
7. Hughes, W., Jagannathan, R., Sengupta, D., & Hummer, J. (2010, April). *Alternative intersections/interchanges: Information report (AIIR)* (Report No. FHWA-HRT-09-060). Washington, DC: Federal Highway Administration.
8. Federal Highway Administration. (2015). *Intersection safety – Innovative intersections*. Retrieved from <https://safety.fhwa.dot.gov/intersection/>. Accessed 4/15/2017.
9. AlternativeIntersections.org. (n.d.). Retrieved from <http://alternativeintersections.org/>. Accessed 4/13/2017.
10. Google Maps. Retrieved from <https://www.google.com/maps>. Accessed 4/14/2017.
11. Federal Highway Administration. (2012, May). *Manual on uniform traffic control devices for streets and highways* (2009 edition, last revised May 2012). Washington, DC: Author.
12. Washington State Department of Transportation. (n.d.). *Traffic signals*. Retrieved from <https://wsdot.wa.gov/Operations/Traffic/signals.htm>. Accessed 4/16/2017.
13. Intelligent Transportation Systems Joint Program Office. *From The National Traffic Signal Report Card: Costs to update signal timing is \$3,000 per intersection*. Retrieved from <http://www.itscosts.its.dot.gov/its/benecost.nsf/0/215F723DB93D293C8525725F00786FD8>. Accessed 4/16/2017.

14. National Committee on Uniform Traffic Control Devices. (2015, revised). *Uniform Vehicle Code*. Retrieved from <http://www.ncutcd.org/Documents/SharedDocs/2000UVC-ROROCh1and11.pdf>. Accessed 4/17/2017.
15. Choi, E. (2010, September). *Crash factors in intersection-related crashes: An on-scene perspective* (Report No. DOT HS 811 366). Washington, DC: National Highway Traffic Safety Administration.
16. Bauer, K. M., & Harwood, D. W. (2000, March). *Statistical models of at-grade intersection accidents – Addendum* (Publication No. FHWA-99-094). Washington, DC: Federal Highway Administration.
17. Golembiewski, G. A., & Chandler, B. (2011, January). *Intersection safety: A manual for local rural road owners* (Report No. FHWA-SA-11-08). Washington, DC: Federal Highway Administration.
18. Institute of Traffic Engineers. (2015). *Unsignalized intersection improvement guide* (UIIG). Retrieved from <http://www.ite.org/uiig/>. Accessed 4/18/2017.
19. American Association of Highway Transportation Officials. (2014). *Highway safety manual* (1st ed.). Washington, DC: Author.
20. The Qt Company. (2018). *Our company at a glance*. Retrieved from <https://www1.qt.io/company/>. Accessed 02/12/2018.