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Effective Pedestrian/Non-Motorized Crossing Enhancements Along Higher Speed Corridors

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16. Abstract
The purpose of this research was to examine crashes along higher speed roads (speed limit of 45 mph or more) excluding freeways, at signalized and unsignalized locations, determine predominant causes of these crashes, and to identify countermeasures for these crashes. Assessment of high crash corridors included an examination of the number of crashes per mile with particular focus on fatal and incapacitating crashes. Most high crash corridors were in urban or suburban locations. Few high crash corridors occurred in rural areas. Once the research team had identified high crash corridors site visits were made to examine crash causation using the crash narrative and diagram form the police crash report. If crashes occurred at night site visits were also made during dark conditions and light meter readings were taken at each crash location. Countermeasures were selected based on cost effectiveness and appropriateness which considered best known information on Crash Reduction Factors, and the Cost of Crashes. The results indicated that many of the severe crashes at these locations occurred at night. Light meter readings indicated that most serious crashes occurred at locations with light level readings below 20 lux with many occurring at locations with light level reading between 1 and 6 lux.

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Executive Summary

This study examined the causes of crashes along higher speed roads. Many fatal or incapacitating pedestrian and bicycle crashes in Michigan have occurred on higher speed corridors with a speed limit of 45 mph or higher and a high proportion of these crashes occurred at night. AASHTO defines a higher speed road as having speeds greater than or equal to 50 mph. However, from the perspective of pedestrian and bicyclist safety, 45 mph would be considered a higher speed road. Therefore, we included corridors with a 45 mph speed limit or higher. The high percentage of fatal crashes is not surprising given the combination of higher speeds and poor nighttime visibility. Most of these crashes occurred on urban roads given the higher exposure of pedestrians and bicyclists. These data are in accord with other studies. For example, Eluru, Bhat, and Hensher (2008) found that pedestrian and bicycle severity was greater on higher speed roads and at night.

Chapter 2 of this report reviewed the literature on pedestrian and bicycle crash countermeasures and placed the highest weight on crash modification factors. The review relied heavily on the FHWA Crash Modification Factors Clearinghouse, and many of the countermeasures have data from the clearinghouse that provides information on alternative treatments or modifications to some countermeasures based on local application. The clearinghouse also provides direct access to studies that analyze the results of the countermeasure and many of these were examined in our review. The research team also placed a high weight on the revised star rating for each of the Crash Reduction Factors (CRF). However, because of the difficulty involved in controlling all the variables in crash studies and the smaller number of cases involved in pedestrian and bicycle crashes, there is a great deal of variability in the results of crash analysis studies. After identifying proven countermeasures, each countermeasure was examined regarding whether it was suited for application on higher speed roads. Potential countermeasures were examined for application at traffic signals, at uncontrolled intersections and midblock locations. Corridor wide improvements, countermeasures for reducing speeding and countermeasures for improving lighting were also carefully explored.

Chapter 3 reviewed the non-motorized treatments for use on high-speed roads adopted by Michigan and its neighboring states. This examination focused on states with a similar climate. There was a high degree of similarity observed in policies adopted by each of these states that were primarily in accord with federal guidelines and past research. Most state practices reviewed in this chapter had similar standards and guidelines for implementing pedestrian treatments on higher-speed roads. For instance, for higher speeds (45 mph or more) and high volumes crossing locations, most states consider implementing treatments that force drivers to stop for pedestrians. These treatments include the use of traffic signals, Pedestrian Hybrid Beacon (PHB), or grade separation. Most previous studies on pedestrian treatments on high-speed roads are based on the Rectangular Rapid Flashing Beacon (RRFB) and PHB showing that these treatments are effective on those roads.

Chapter 4 identified high crash locations, from statewide crash data recorded between the beginning of 2009 the end of 2020. These data were analyzed by severity, area type (rural vs urban), lighting conditions, and location of crash (intersection vs midblock). Pedestrian crashes and bicycle crashes were analyzed separately. Higher speed roads were classified at roads with a speed limit of 45 mph or more, but did not include freeways. Heat maps were generated using

ArcGIS software, followed by identification of high-crash sites. The following sections present the findings of crash analysis and selection of high-crash sites. Most crashes along higher speed roads occurred in clusters along corridors where these roads transitioned through urban and suburban locations. The risk of daytime and nighttime crashes also varied across these sites. Examining crashes that involved a fatality (K) or an incapacitating injury (A) or K&A crashes at each site revealed that 70% occurred at night.

Specific crash patterns were observed at many of these sites. Rural crash locations were more randomly distributed and only occurred in clusters at locations where the speed limit was reduced where a higher speed road traversed a small town, village, or city. It was also the case that the percentage of K&A crashes were much higher on the higher speed roads for both pedestrian and bicycle crashes and the percentage of crashes that occurred at night increased with increasing speed limit.

The site visits allowed the research team to determine factors related to each crash and the types of countermeasures that would likely be effective. The WMU team visited crash sites with the police crash report (UD-10 Traffic Crash Report) using the police narrative and crash diagram section of the the report to determine the exact location and cause of each day and night crash. The percentage of K&A crashes at these 9 sites that occurred at night averaged 69.5% with a range of 40% to 100%. More than half the K&A crashes occurred at night at all but one of the sites. If most crashes occurred at night the team visited the crash sites one hour or more after sundown and measured lighting levels using a Konica Minolta T-10A Illuminance Meter to measure the light intensity in Lux. Federal Highway studies indicate that 25 Lux is a good level of illumination to see a pedestrian crossing at night. Based on the crash diagram and narrative the light level reading was taken at the approximate vicinity of each crash. The team also examined all crash sites during the daytime to better determine the presence of engineering features at each site, such as lane width, type of crosswalk marking, curb turning radii, and presence or absence of any crash countermeasures that might influence the presence of a crash.

At many high crash corridors there were no bicycle facilities, few opportunities to cross in a marked crosswalk. Another important variable was poor corridor lighting along many of the high crash corridors. One surprising finding was the low level of lighting (essentially dark) at many of the night crash sites classified as lighted. Visiting the sites also allowed the team to view pedestrians and bicyclists and observe their behavior. At many of the sites with poor lighting pedestrians and bicyclists appeared as shadowy figures. Light levels at these sites were extremely low with light readings of between 0.1 and 5.2 Lux. In many cases the legacy light sources were on low light posts, or poor light sources on higher posts. At some sites where higher intensity LED lighting was located near the crash site it was not aimed in such a manner as to illuminate the crosswalk. In many cases the police report would mention the driver stating they did not see the pedestrian. Regardless of potential right-of-way issues these crashes would have been less likely during the day because the driver in many cases would have seen the pedestrian in time to avoid a crash.

Another value of site visits was it enabled us to recommend countermeasures for each site. This enables the research team to narrow down the number of countermeasures that were most useful for pedestrian and bicycle crashes on higher speed roads. Countermeasures most useful for crashes at traffic signal locations included: LED light bars installed under mast arms, LED luminaires installed and aimed toward the crosswalk and entry locations at sites with span wires; tightening the turning radii; installation of high visibility crosswalk markings; and adding a leading pedestrian interval. Countermeasures most useful at unsignalized intersections and midblock crosswalks included: Installation of a PHB or RRFB along with advance stop or yield markings; and refuge or median islands. If an RRFB is installed adding dynamic crosswalk lighting is also recommended. Countermeasures most useful for corridor wide improvements included: Adding sidewalks, solar powered dynamic feedback signs; widening shoulders; and changing out legacy street lighting to LED street lighting. MDOT needs to review whether lighting at all marked and unmarked crosswalks locations can be considered part of the crosswalk treatment.

The last chapter of the report provides a method of using a cost benefit analysis to determine whether to install a particular countermeasure on a higher speed road. The results show the minimum number of non-motorized crashes that justify installation of a specific countermeasure. In addition, a standalone analysis tool that can be used to conduct cost-benefit analysis was developed and provided to MDOT as part of the deliverables.

Summary

The significant findings of this study were:

1. That K&A nighttime crashes were typically associated with low measured light level reading.
2. That whether the crash site was scored on the UD-10 Police Crash Report as lighted or unlighted may be an unreliable indicator of lighting at the crash site.
3. That a limited number of countermeasures were appropriate for application to higher speed roads and likely most effective in reducing crashes.
4. That many of the countermeasures identified as potentially effective were low or medium cost.

1 INTRODUCTION

Over the period from 2009 to 2018, pedestrian fatalities increased by 53%, from 4,109 to 6,283 (National Center for Statistics and Analysis, 2019; Schneider, 2020; Webb, 2019) with the proportion of traffic deaths involving pedestrians increasing by nearly 50%. NHTSA estimated that 7,342 pedestrians were killed in traffic fatalities in 2021, a 13% increase over the 2020s already historically high number. Pedestrian fatalities have risen since their lowest level in 2009 at 4,092. The analysis of FARS data show that most of these increases occurred at night on urban arterials and collector roads (Tefft, Arnold, & Horrey (2021); Hu, & Cicchino, (2018). This increase in the proportion pedestrian fatalities was the largest increase among 30 countries studied by the International Transport Forum (International Transport Forum, 2019). A recent analysis indicates that 90% of the increase in US pedestrian deaths from 2008 to 2017 occurred at night. According to NHTSA, on average about 72% of pedestrian fatalities recorded between 2011 and 2020 occurred after dark nationally; in Michigan the estimate is 73%. Also, 51% of pedalcyclist fatalities occurred at night nationally; in Michigan the estimate is 56%. However, these statistics are even more severe when considering the fact that only about 25% of all traffic volumes occurs after dark. This means that during the nighttime, when the least number of vehicles are on the road, the greatest number of pedestrians are killed in crashes. This shows a heightened need to add or improve safety measures to protect areas of roadway traffic with high pedestrian volume, especially after dark. Many fatal or incapacitating pedestrian and bicycle crashes in Michigan have occurred on higher speed corridors with a speed limit of 45 mph or higher. AASHTO defines a higher speed road as having speeds greater than or equal to 50 mph. However, from the perspective of pedestrian and bicyclist safety, 45 mph would be considered a higher speed road. Therefore, we included corridors with a 45 mph speed limit or higher. In the past 10 years there were 772 fatal pedestrian crashes on higher speed corridors in Michigan. The majority of these crashes occurred during night conditions (83%). Incapacitating crashes also occurred more often at night along these corridors (65%). Most of these crashes occurred on urban roads (71%). Sixty one percent of bicycle fatal crashes in Michigan occurred on higher speed roads and forty nine percent of these crashes occurred at night.

These data are in accord with other studies. For example, Eluru, Bhat, and Hensher (2008) found that pedestrian and bicycle severity was greater on higher speed roads and at night. They also found that crashes were more severe at traffic signals than at other locations. More specifically, Haleem and Abdel-Aty (2010) found that lower speed limits (less than 45 mph) reduced the probability of a fatal bicycle when compared to greater than 45 mph. In most studies, high vehicle speed also increases the frequency and severity of crashes involving pedestrians (Lee et al., 2005; Zegeer et al., 2006; Chimba et al.,2014; Garder, 2004; Sandt, Zegeer, & Martin, 2006; McMahon et al., 1999; Poch and Mannering, 1996). Most of these studies used the speed limit of the target zone as a predictor variable because it was easy to collect the data. However, Zegeer et al. (2006) collected the 85th percentile vehicle speed.

Studies have also revealed that drivers cannot see and react in time to a dark clad pedestrian if they were driving over 30 mph. Compounding this problem is the fact that pedestrians overestimate their own visibility because: 1. The pedestrian is adapted to a relatively low ambient illumination level; and facing the glare of the oncoming headlights the pedestrian may be unable to appreciate how difficult the driver's detection task is, and may be convinced that he or she is visible. Data show that 95% of pedestrians in testing situations indeed overestimate their visibility (Allen, Hazlett, Tacker, & Graham, 1968). Preliminary data show that pedestrians can learn to accurately estimate their visibility through education programs (Tyrrell, & Patton, 2000). Another approach is to increase pedestrian visibility in crosswalks. New LED lighting devices provide improved tools for improving lighting.

2 LITERATURE REVIEW OF CRASH COUNTERMEASURES

Crash countermeasures are continually under development. Effectiveness of many of these countermeasures often are expressed using surrogate data on safety, including observed yielding by motorists to pedestrians, or measured compliance with traffic safety laws such as safe passing of cyclists, reductions in speed, or other operational characteristics that have the potential to improve safety. One of the best validated surrogate measures is the occurrence of near crashes or conflicts. Examples of this type of measure are evasive actions and the time interval between the evasive maneuver and the evaded crash. The best approach is to examine the relationship between a countermeasure and crashes. Crash modification factors examine the relationship between crashes and the presence of the countermeasure. The major difficulty in obtaining crash countermeasure or crash modification factors for crashes involving pedestrians and cyclists is the sample size and adequate control of the presence or absence of the countermeasure.

In 2009, the FHWA launched the Crash Modification Factors Clearinghouse, an online repository and search tool designed to provide access to studies that have been published on various types of improvements intended to reduce crashes. Many of the countermeasures discussed below have data from the clearinghouse that provides information on alternative treatments or modifications to some countermeasures based on local application.

The clearinghouse also provides direct access to studies that analyze the results of the countermeasure. These are provided with a confidence level or star rating, as many of the papers are independently prepared and may not have been peer-reviewed. Because the star ratings system in the clearinghouse has been revised, each Crash Reduction Factor (CRF) shown below indicates the revised star rating.

Because of the difficulty involved in controlling all the variables in crash studies and the smaller number of cases involved in pedestrian and bicycle crashes, there is a great deal of variability in the results of crash analysis studies. Another factor contributing to the high level of variability for newer devices is the amount of outreach activity and the number of installations in the area being evaluated. These factors should be considered when using these indices.

The countermeasures that are discussed below have shown potential to reduce the occurrence of pedestrian and/or bicycle crashes. Appendix 9.1 shows photos of sample countermeasures. Countermeasures are presented in the following categories:

- Intersection Improvements, Signalized and Unsignalized
- Speed Reductions
- Roadway Improvements
- Lighting

2.1 Signalized Intersection Improvements

2.1.1 Advance Stop Line

Advanced placement of the stop line from 4 ft to 20 ft can increase the distance drivers stop before the crosswalk and reduce the percentage of drivers stopping in the crosswalk from 25% to 7% (Retting and Van Houten, 2000). This treatment was also associated with an increase of 0.7 s in the elapsed time between the start of the green signal phase and the lead vehicle entering the intersection. The use of advance or offset stop lines can reduce conflicts between vehicles turning right on red and pedestrians because it increases the sight distance of drivers turning right on red who make a full stop behind the line (Zegeer and Cynecki, 1986).

Effectiveness
This intervention does not have a crash modification factor. While anecdotal evidence suggests this is a promising countermeasure, no research has quantified its effectiveness for pedestrians or bicyclists.

Implementation and Operational Considerations
- **Planning Time**: Short
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** GOOD (Can reduce serious crashes on multilane roads)

2.1.2 Leading Pedestrian Interval

A leading pedestrian interval (LPI) provides pedestrians with the walk signal prior to parallel traffic getting the green signal. This allows pedestrians to enter the crosswalk before left turning vehicles, and before right turn vehicles if right turns on red is prohibited. In the U.S., 20% of pedestrian crashes involve vehicles turning right at signalized intersections. The largest proportion of these crashes (60%) involves faster, left-turning vehicles. Van Houten, Retting, Farmer, Van Houten, & Malenfant (1999) found that a leading pedestrian phase reduces conflicts between turning vehicles and pedestrians, the driver, the pedestrian or both to take evasive action to avoid a crash. It also has been shown to reduce crashes between turning vehicles in a number of studies listed in the Crash Modification Factors Clearinghouse.

Effectiveness
The LPI is associated with pedestrian CRFs of 13% to 19% (5 Star Ratings) 8.8, 9, 10 and 58.7% (4 Star Ratings) and 46% (3 Star Rating). Because of the low cost and the high energy involved in left turns this intervention should prove very cost effective.

Implementation and Operational Considerations
- **Planning Time**: Medium: Developing a timing plan typically tops out at ~30 hours but adding timing to pedestrian signals may be less complex than a full re-timing.
- **Build Time**: Short (Less than 1 week).
- **Applicability to Higher Speed Roads:** GOOD (suburban applications with pedestrian demand)

2.1.3 Countdown Signals

Pedestrian countdown signals display how much time is available to cross. One study conducted in Michigan showed that pedestrians can estimate how much time they need to cross based on the countdown timer indication (Van Houten et.al. (2015). Therefore, it is not surprising that they increase the percentage of pedestrians crossing before the end of the countdown interval.

Pedestrian countdown signals are required anywhere a pedestrian signal is used whenever new signals are installed or existing signals are replaced per the Michigan Manual on Uniform Traffic Control Devices (MUTCD).

Effectiveness
Ten studies have examined the effects of adding pedestrian countdown timers to pedestrian signals. All 10 studies have a Star Rating of 2. The mean CRF for these studies is 2.4%. However, one higher quality study (Star Rating of 4) shows a CRF of 8.8%. Two other studies with a 3 Star Rating show CRFs of 55% and 70%. From this we can conclude they have a safety benefit likely greater than 8 perhaps much higher. One of the studies conducted in Detroit, MI had a CRF of 70% (3 Star Rating) while another site in Kalamazoo, MI had a CRF of 55% (3 Star Rating).

Implementation and Operational Considerations
- **Planning Time**: Change out will save on maintenance and electrical costs.
- **Build Time**: Change out time (Less than 1 week).
- **Applicability to Higher Speed Roads:** GOOD (suburban applications with pedestrian demand)

2.1.4 Exclusive Left Turn (Leading/Lagging)

A solid green arrow indicates left turning vehicles have an exclusive phase. One can use either a leading or a lagging exclusive pedestrian phase. It is more convenient to use a lagging exclusive left turn phase when using a LPI and a lagging left turn phase should be considered when there is a high number of conflicts between left turning vehicles and pedestrians because a lagging left turn allows pedestrians to clear the crossing before left-turning vehicles begin to turn.

However, it is possible to use an LPI with a leading pedestrian phase. An exclusive left turn phase should be considered when left-turning traffic volumes are high, and a Michigan Left is not feasible. If used with prohibited permissive left turns, it reduces conflicts between left turns and pedestrians. The Exclusive Left Turn phase alone did not produce a reduction in vehicle/pedestrian crashes (Goughnour, 2018). CMF of 1 and CRF of 0.

Effectiveness
Three studies with a 4 Star Rating had showed changing a permissive left to protected left or protected plus permissive left had CRF of -13.6% (4 Star Rating) in Chicago, 28.2% (3 Star Rating) percent in NYC and -9.1% (4 Star Rating) combining Chicago, NYC and Toronto. Another example of variability likely related to uncontrolled variables. At present it appears this intervention will not improve pedestrian or bicycle safety.

Implementation and Operational Considerations
- **Planning Time**: Medium, requires a traffic study
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** POOR, (suburban applications with pedestrian demand)

2.1.5 Prohibited Left Turns (Michigan Left)

Prohibiting left turns at signalized intersections and providing room for U-turns at median crossovers is known as a Michigan Left. Michigan Lefts can be implemented on roads with a wide center median or where the cross-street has a wide center median. This countermeasure should be considered when there are crashes involving left-turning vehicles. This intervention can reduce crashes involving left turning vehicles by 10%. MDOT has found that Michigan Left turns reduces the number and severity of crashes and congestion. MDOT provides guidance on left-turn prohibitions in the MDOT Road Design Manual.

Effectiveness

Although there is no data on the effect of MI Lefts on pedestrian crashes, logic dictates that it should nearly eliminate left turn crashes. Since right turn crashes at signalized intersections are less frequent and involve lower speeds then left turn crashes it is almost certain this treatment would reduce serious pedestrian crashes.

Implementation and Operational Considerations

- **Planning Time**: Long planning time because it involves construction
- **Build Time**: Involves major construction
- **Applicability to Higher Speed Roads:** GOOD (suburban applications with pedestrian demand).

2.1.6 Flashing Yellow Arrow

A flashing yellow arrow is used rather than a green ball to indicate a permissive left turn.
This signal should be considered when crash rates involving permissive left turns are high. Crash rates at intersections where a flashing yellow arrow were found to be lower than intersection with the conventional green ball indication, but no effects were observed for pedestrian crashes.

Effectiveness

The Flashing Yellow Arrow was not found to have an effect on vehicle pedestrian crashes. The CMF is 1 and the CRF is 0. This study has a star rating of 2.

Implementation and Operational Considerations

- **Planning Time**: Short
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** POOR (since it appears to have no effect on pedestrian crashes).

2.1.7 Turning Vehicles Yield to Pedestrians (R10-15) Sign

Many serious crashes involving pedestrians at intersections are associated with a motorist turning left or right across the path of the pedestrian. The R10-15 sign is a low cost treatment that communicates to drivers that turning vehicles must yield to pedestrians who are crossing. The sign typically is installed next to the traffic signal head so that drivers see it when approaching the intersection.

Effectiveness
There has not been a safety evaluation of this particular sign demonstrating reductions in pedestrian crashes, though it is often used in combination with other treatments that have proven to be effective. However, behavior data examining evasive pedestrian and vehicle conflicts at marked crosswalks in 12 cities (Abdulsattar, et.al., 1996) The sign was installed at 12 marked crosswalks in two cities found a 20 to 65 percent reduction in conflicts with left turning vehicles and a 15% to 30% in conflicts with right turning vehicles. Both of these reductions in conflicts were statistically significant. Because left turning vehicles are faster and tend to produce more serious crashes these results hold some promise.

Implementation and Operational Considerations

- **Planning Time**: Short: Identify target intersections for installation of signs.
- **Build Time**: Short (1-3 Days)
- **Applicability to Higher Speed Roads:** FAIR (since behavioral data suggest it may be effective).

2.1.8 Right-Turn Slip Lanes

Pork chop islands are wedge-shaped islands between a right-turn lane and through lanes at an intersection. This treatment breaks up a pedestrian crossing, making the crossing both safer and easier and has been shown to reduce pedestrian crashes by 29%. However, it is almost certainly a function of the turning radius of the travel lane(s). Pork chop islands should be considered at wide intersections where channelized right turn lanes are desired, or where a large turning radius would otherwise be required to prevent large, right-turning vehicles from encroaching on opposing traffic lanes. Care should be taken to design the right-turn lane to encourage slow speeds and improve visibility of crossing pedestrians by turning vehicles.
Reference Pedestrian Facilities Users Guide - Providing Safety and Mobility, p. 59
for more information.

Effectiveness
Although many papers talk about designing right-turn slip lanes with pedestrian safety in mind, there is little data on the safety impact of such designs.

Implementation and Operational Considerations

- **Planning Time**: Long planning time because it involves construction.
- **Build Time**: Involves major construction.
- **Applicability to Higher Speed Roads:** POOR (May be difficult to place on existing roadways).

2.1.9 Bicycle Signal Detection

Loop or video detectors can be used to detect and place a call for a bicyclist stopped at an intersection or in a turn lane. Bicycle location markings and signage is often included to ensure bicyclists are properly positioned to be detected. Conveniently located push buttons may be substituted for automatic loop detection. Bicycle signal detection may be used wherever bicycle connectivity is desired across signalized intersections. Bicycle detection can reduce the motivation for cyclists to cross against the signal and can increase cycle duration when crossing wider roads. Guidance for installation of bike signal detection markings is provided in the AASHTO Guide for the Development of Bicycle Facilities.

Effectiveness
There is no crash modification factor associated with this intervention.

Implementation and Operational Considerations

- **Planning Time**: Short if cameras are used to detect vehicles
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** POOR because most urban roads do not have bicycle facilities

2.1.10 Bicycle Signals

Bicycle signals are signals that regulate bicycle traffic flow. They can be actuated or pre-timed and may provide an exclusive signal phase for bicyclists at an intersection. Bicycle signals may be used in areas where bicyclists are subject to different traffic control than vehicles, such as at trail crossings, cycle tracks, or bicycle boulevards. Bike signals are helpful to clarify the separation of bicycle and automobile traffic, to give bicyclists a head start in mixed traffic conditions, or where one bicycle facility transitions to another (e.g., when a shared use path transitions to an on-street bike lane).
Guidance for installation of bike signals is provided in the NACTO Urban Bikeway Design Guide.

Effectiveness
No crash modification factor is presently available for this treatment.

Implementation and Operational Considerations

- **Planning Time**: Medium
- **Build Time**: Medium
- **Applicability to Higher Speed Roads:** POOR because most higher speed roads do not have bicycle facilities

2.1.11 Combined Bike/Turn Lanes

A combined bike/turn lane can be used where a bike lane and a right-turn lane occupy the same space. This treatment aligns the cyclist with the left side of the lane and reduces the possibility that a through cyclist will be stuck by a right turning vehicle. Combined bike/turn lanes should be considered only when a right-turn lane is needed along a street with a bike lane, and there is not enough street width to provide a separate bike lane to the left of the turn lane. Combined bike/turn lanes help to identify the presence and riding location of a through bicyclist on the left side of the lane. Signs help communicate the shared lane condition and instruct drivers that they shall yield to bikes in these locations. Pavement markings denoting the shared lane condition and signs posted “RIGHT TURN ONLY EXCEPT BIKES” or shared lane signs are posted to clarify the shared lane condition. Current guidance in the MUTCD suggests a lane drop resulting in a shared through or turn lane. Combined bike/turn lanes are not yet in the MUTCD and will require FHWA approval prior to installation. For more information, consult NACTO Urban Bikeway Design Guide.

Effectiveness

This intervention does not have a crash modification factor.

Implementation and Operational Considerations

- **Planning Time**: Short
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** POOR because most urban higher speed roads do not have bicycle facilities.

2.1.12 Exclusive Pedestrian Phase

A pedestrian only phase provides time for pedestrians to cross while all vehicle movement is stopped. This treatment allows pedestrians to walk in any direction across the intersection, including diagonally, during an exclusive phase. Several studies document safety benefits between 7% and 66% (Jensen, 1999; Vaziri, 1989), however, an exclusive pedestrian phase has been documented to degrade traffic flow (Kim et al., 2004). However, the use of EPP mostly beneficial with high pedestrian exposure it may not be particularly suited to crossings on higher speed roadways (Tian et al., 2001)

Effectiveness

The Exclusive Pedestrian Phase is associated with a CRF of 51% percent involving pedestrians. This CRF has a star rating of 2.

Implementation and Operational Considerations

- **Planning Time**: Short
- **Build Time**: Short if controller has capability to add it.
- **Applicability to Higher Speed Roads:** POOR, (This is essentially an urban treatment and would not have applicability to higher speed roads)

2.1.13 Prohibited or Restricted Right-Turn on Red

Right turns on red are prohibited using either regulatory signs or blank out LED signs. Right turn on red restrictions should be implemented where right-turning vehicles are involved with free flowing right-turn-on red crashes. Crash data show an increase in pedestrian and bicycle crashes when right turn on red is permitted. Severity of right turn on red crashes are typically lower because of the lower speed but increases with increasing right turn radius because of higher motor vehicle speeds. One study that examined SHRP 2 naturalistic driving data (Wu & Xu, 20170 showed that drivers making a right-turn-on-red have a high acceleration and a low level of observing behavior placing pedestrians and cyclists at higher risk.

Effectiveness

The CRF for seven studies examining the effect of installation of permitted right turn on red ranges from 43% to 108%. These studies all have relatively low 2 star ratings. These studies suggest that prohibiting right-turn on red would reduce crashes.

Implementation and Operational Considerations

- **Planning Time**: Medium: Identify sites and get approval to change traffic behaviors. Can be contentious.
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** FAIR (Only recommended when crashes are related to right-turns on red)

2.1.14 Midblock Signals

A midblock signal is a full traffic signal for vehicles in one direction and pedestrians in the cross direction. Midblock signals are almost always pedestrian activated, so it only interrupts traffic flow when a pedestrian places a call. Midblock signals are typically used on arterial roads at locations which have a large pedestrian generator on each side of the road. Typical locations are at a transit location or a major facility that is frequented by many individuals on foot. The guidelines for pedestrian warrants are specified in the MUTCD. Although a full signal generates a high compliance rate with motorists, pedestrians will typically attempt to cross even at high-volume, high-speed locations if the wait time is too long. One study showed that almost all pedestrians waited for the WALK indication when minimum green time was 30 seconds, but compliance dropped with increasing wait time. At two minutes one third of pedestrians will attempt to cross even when the intersection only has a yellow line separating traffic flow in each direction (Van Houten, Ellis, & Kim, 2007)

Effectiveness

This intervention has a CMF of .82 with a 4 star rating.

Implementation and Operational Considerations

- **Planning Time**: High
- **Build Time**: High
- **Applicability to Higher Speed Roads:** POOR (Unless a signal is warranted. PHB and RRFB are an alternative)

2.2 Unsignalized Improvements

2.2.1 High Visibility Crosswalk Markings

High visibility crosswalk markings better alert drivers to the presence of a crosswalk and better alert pedestrians of the preferred location to cross. Two popular high visibility marking formats are continental markings and zebra markings. Several studies indicate that high visibility markings were associated with fewer crashes (Chen et al., 2012; Feldman, Manzi, and Mitman, 2010). This treatment can be used at signalized as well as unsignalized crosswalks.

Effectiveness

There is one study showing a CRF of 40% with a Star Rating of 2. Another study examined yellow high visibility crosswalk markings at school crosswalks. This study found a CRF of 37% and had a Star Rating of 4. High visibility crosswalks are more visible to drivers and have been shown to increase motorist yielding rates. They can also require less maintenance than parallel line crosswalks, as vehicle wheels track between ladder bars of marking.

Implementation and Operational Considerations

- **Planning Time**: Short (if installing as upgrade to existing crosswalks), Medium (if installing crosswalks for the 1st time), need to develop engineering design for installment.
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** GOOD (Recommended for all marked crosswalks on higher speed roads)

2.2.2 High Visibility Crosswalk Signage

Crosswalk signage can also add to the conspicuity of a crosswalk. One way to increase the conspicuity of crosswalk signs is to use prismatic reflective sheeting not only on the W11-2 sign but also on the signpost as well. This type of treatment can be applied to double back signs on both sides of the road and on the pedestrian refuge island or median island if one exits. This type of installation can from a gateway like treatment that is very visible to drivers since they are passing between two signs that are very visible during the day and at night. This treatment would be implemented with pole mounted signs that conform to MUTCD 2A.19.

Effectiveness

This treatment does not have a CMF. One promising variation of this treatment would be the use of larger signs in a gateway configuration. This treatment has not yet been carefully evaluated. However, one study conducted as part of this project suggests it can be efficacious.

Implementation and Operational Considerations

- **Planning Time**: Short
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** GOOD.

2.2.3 Pedestrian/Bicycle Refuge Island or Raised Median

Pedestrian refuge islands placed between counter flowing traffic at uncontrolled crosswalks make it possible for pedestrians and cyclists to cross half of a two-way roadway at a time. This reduces impulsive attempts to accept short gaps which are difficult to discriminate at night. These gaps are also more difficult for children and older adults to discriminate. Refuge islands need to be large enough to accommodate a pedestrian with a stroller and a cyclist on a bicycle. Wider refuge islands can also be constructed in such a way to ensure the pedestrian is walking facing the direction of traffic before making the second half of the crossing. Pedestrian refuge islands have a crash modification ranging from 32% to 56% (Zegeer, et.al., 2017; FHWA, 2007).

Effectiveness

Refuge islands have been widely studied and are routinely identified as one of the most effective countermeasures to improve pedestrian safety at uncontrolled locations. Studies have shown a reduction in pedestrian crashes at marked and unmarked crosswalks with a 5 Star Rating, CRF of 46% for marked crosswalks (3 Star Rating) and a CRF of 31.5% for uncontrolled crosswalks with and without markings. (4 Star Rating). Several studies in Florida on urban and suburban arterials with a 2 Star Rating show medians have a CRF of 34%, 27%, 30%, 40% and 29%. Considering all studies with Star ratings of 2 or more, medians clearly have a benefit for pedestrians and the magnitude of the effect is reasonably consistent between studies.

Implementation and Operational Considerations

- **Planning Time**: Medium: identify areas of interest through public input/traffic data analysis and receive approval for installation.
- **Build Time**: Short (1-3 Days), though installation is complicated by traffic management which may add additional installation time.
- **Applicability to Higher Speed Roads:** GOOD (This treatment can be easily used on higher speed roads if adequate space is available)

2.2.4 Pedestrian Hybrid Beacon (PHB)

The pedestrian hybrid beacon consists of two red lights above a yellow light that are dark when the beacon is not active. When activated, the PHB beacon enters a series of signal phases to indicate that a pedestrian is crossing. When tested in Arizona and St. Petersburg, Florida, along with the recommended warning and regulatory signs, the hybrid beacon was associated with a 69% reduction in all crashes and a compliance rate of motorists yielding to pedestrians between 94-99% (Fitzpatrick, K., et al., 2006). The cost of pedestrian hybrid beacons varies based on the size of the roadway, but typically are less expensive than the cost of fully signalizing an intersection.

Although the PHB has a red indication driver that are unfamiliar with the device may require education outreach or experience before compliance increases to very high levels. Studies conducted to evaluate driver comprehension of the PHB performed in Kansas indicated that driver's compliance as 90% and 95% (Godavarthy & Russell, 2016). These data suggest there may be more variation in results than would be inferred from the results obtained in Tucson. Familiarity with the device may be a major factor. For instance, the Fitzpatrick study was performed in Tucson where there were extensive outreach efforts and over 60 PHB devices deployed for several years before they were evaluated. A study conducted by Stapleton, Kirsch & Gates (2017) examined yielding at PHB, RRFB and R1-6 sign sites over time found driver yielding behavior for each of these three enhancements improved over time as drivers became more familiar with each device. Additionally, roadway factors and driving culture may also influence the effectiveness of these treatments.

One advantage offered by hybrid beacons is that they are less disruptive to motor vehicle throughput than a midblock signal. When coordinated signals are timed to obtain better speed limit compliance, Pedestrian hybrid beacons can be configured to maintain coordination. The MUTCD presents guidelines for when a pedestrian hybrid beacon could be used. The recommendations are a function of vehicular volumes and speeds, the crossing distance, and pedestrian volumes. The lowest threshold of pedestrian volumes is 25 per hour. Pedestrian hybrid beacons may be applicable at midblock crossings or at low volume intersections where a full signal is not warranted. One highly relevant study on the PHB examined the efficacy of this treatment on ten higher speed roadways (85 percentile speeds ranging between 44 and 54 mph). Driver yielding behavior at these sites averaged 97% which is close to the level observed on lower-speed streets. These data suggest this intervention would be effective on MDOT higher speed roads. The PHB is also associated with a 55% Crash Modification Factor with a 3 Star Rating (Zegeer, et.al. 2017)

Effectiveness
Hybrid Beacons have consistently produced relatively high CRFs. CRFs vary between a low of 24.5% for a 4 Star Rated study and 436% for three 5 Star studies. The highest rating was 69% for a 3 Star Study. The average CRF over nine studies is 46%.

Implementation and Operational Considerations

- **Planning Time**: Moderate
- **Build Time**: Moderate
- **Applicability to Higher Speed Roads:** GOOD (Intervention is known to reduce crashes when installed on higher speed roads)

2.2.5 Rectangular Rapid Flash Beacon

A rectangular rapid flashing beacon (RRFB) is a device that consists of a pair of high intensity light emitting diode (LED) lights mounted on poles under the pedestrian crosswalk sign and over the arrow on each of crosswalk at unsignalized pedestrian or bicycle trail crossing. Flashers are front and rear mounted at each installation position, so they form a gateway to approaching drivers. The signals rest in the dark phase until activated by a push button. When activated the lights flash in a rapid specific pattern which attracts the driver's attention (Shurbutt, et.al., 2009). This treatment produced a large, sustained increase in yielding at 18 locations in three urban areas that were maintained over a two year period following their instruction.

This study also compared alternating between two and four beacon configurations (the four beacon configuration included beacons on each side of a pedestrian refuge island. Results showed a large increase in motorist yielding behavior over baseline for two beacons and a significant increase with a four-beacons system over a two-beacon system. This study helped confirm that the RRFB effect is partly influenced by the gateway effect resulting from approaching and passing between multiple units. Another factor that may have been related to the efficacy of devices installed on a refuge island is ensuring that a beacon is visible to drivers in both lanes when a car stopped in an adjacent lane screens the motorist's view. The use of multiple beacons may also more effectively delineate the presence of a crosswalk. Data from another study also showed the RRFB system is more effective at night than during the day (Shurbutt et. al., 2009; Van Houten, Ellis, & Marmolejo, 2008). This treatment has a crash modification factor of 47% (Zegeer, et.al., 2017) However, this CMF was based on a limited size sample and is therefore less accurate than one based on a more robust sample size.

Two highly relevant studies on the RRFB examined the efficacy of this device on higher speed roadways (Fitzpatrick and Park, 2021; Hunter, Srinivasan, & Martell, 2012). These studies found

80% and 94% increase in yielding respectively on higher speed roads.

Effectiveness
This treatment has a crash modification factor of 47% with a 3 Star Rating and 36% with a 1 Star Rating. However, these CRFs were based on a limited size sample and are therefore less accurate than one based on a more robust sample size.

Implementation and Operational Considerations
- **Planning Time: Moderate**
- **Build Time: Short**
- **Applicability to Higher Speed Roads:** FAIR (This treatment has been shown to increase yielding on higher speed roads but is less researched on higher speed roads than the PHB. If used on a higher speed road, it should be used with advance stop and yield markings (see below)

2.2.6 Advance Stop and Yield Markings

Advance stop and yield markings at midblock crosswalks or crosswalks at uncontrolled locations can help reduce multiple threat crashes at multilane crosswalks where crossing pedestrians may not be seen by motorists approaching in an adjacent lane. Advance yield markings would be appropriate on MDOT roadways to encourage drivers to open the view of the crosswalks by stopping further in advance of the crosswalk (Van Houten et.al., 2003). This treatment can reduce the risk of following vehicles attempting to pass the vehicle stopped for the pedestrian. This sign is typically used with the R1-5a Yield Here to Pedestrian sign. The markings and the sign should be placed from 20 to 50ft in advance of the crosswalk. One study has shown that the markings have a larger effect than the sign, so using the sign alone may produce poorer results (Huybers, Van Houten, & Malenfant (2004). Advance yield markings have been shown to increase the percentage of drivers yielding in advance of the crosswalk and to reduce evasive conflicts between crossing pedestrians and vehicles by 79%. This treatment now has a crash modification factor of 25% (Zegeer, et.al.,2017)

Effectiveness
Studies have shown CRF of 25% with a 3 Star Rating. Because this treatment is used to prevent screening by vehicles that stop for pedestrians, it follows that the further in advance these markings can be placed the more effective they should be. It is interesting that this effect is much smaller than would be predicted by the reduction in conflicts found in the behavioral studies. However, in the behavioral studies the lines were always placed 50 ft or more in advance of the crosswalk, and the MUTCD allows them to be placed 20 to 50 ft in advance of the crosswalk.

Implementation and Operational Considerations
- **Planning Time**: Short: identify target sites using traffic data.
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** GOOD (Advance stop and yielding markings can reduce multiple threat crashes on multilane roads)

2.2.7 R1-6 In-Street Pedestrian Sign

The R1-6 Yield to Pedestrians in-street signs can be installed at crosswalks at unsignalized marked crosswalk locations. In-roadway yield signs are signs that can be placed in the center of the roadway or on a refuge or median island to remind drivers to yield right-of-way to or stop for pedestrians. These signs may have state law or local law at the top of the sign. These signs can also be used as temporary signs by school crossing guards. They work well at midblock crossings as well as unsignalized intersections. In-roadway yield signs have been shown to significantly improve motorist yielding compliance and reduce pedestrian crashes. In Michigan a yield symbol is used on the signs unless it is used in a city with a pedestrian stop ordinance.

Refer to Michigan MUTCD Section 2B.11 for guidance on the placement of in-roadway yield signs.

Effectiveness

While these signs have no associated CMF, they have been shown to "substantially" increase motorist yielding rates according to NCHRP Synthesis 498.

Implementation and Operational Considerations

- **Cost**: Installation costs are low, but maintenance costs are relatively high.
- **Planning Time**: Short
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** POOR (In-roadway signs do not survive well when placed on a lane line or a centerline on a higher speed road. However, placement at crosswalks on a refuge island or median island should be considered where one exists.)

2.2.8 Enforcement of Pedestrian Right-of-Way Laws

Because Michigan does not have a state law that requires motorists to yield (or stop) for pedestrians in an unsignalized crosswalk. Many local municipalities have written their own ordinance based on the Uniform Traffic Code (UTC). The wording in the UTC is as follows: Pedestrians; right-of-way in crosswalk; violation as civil infraction. (1) When traffic-control signals are not in place or are not in operation, the driver of a vehicle shall yield the right-of-way, slowing down or stopping if need be to so yield, to a pedestrian crossing the roadway within a crosswalk when the pedestrian is on the half of the roadway on which the on which the vehicle is traveling or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger, but a pedestrian shall not suddenly leave a curb or other place of safety and walk or run into a path of a vehicle that is so close that it is impossible for the driver to yield.

Van Houten, Malenfant, Huitema, and Blomberg (2013) evaluated a program that coupled police enforcement with inexpensive engineering upgrades (e.g., in-street STATE LAW YIELD TO PEDESTRIAN signs), education through earned media, the deployment of large road signs that provided feedback on the percentage of drivers yielding right-of-way to pedestrians during the preceding week along with the record at treated sites in Gainesville, Florida. The introduction of the high visibility enforcement over the course of a year during the original study led to a marked increase in yielding to pedestrians at the six enforcement crosswalk sites from a baseline level of 32% to a high of 62% for research assistant (staged) crossings and from 54% to 83% for naturally occurring (unstaged) crossings by the general public. At the six generalization crosswalk sites which did not receive any enforcement, yielding to pedestrians increased from 37% to 59% for staged crossings and from 50% to 73% for the unstaged naturalistic crossings. The original study ended in February of 2011.

While this study produced an immediate behavioral change with steady improvement in Gainesville drivers, the study ended before researchers could measure the persistence of any of the program's effects. In particular, the extent to which the GPD continued to enforce the yield-to-pedestrian laws, the post-study yielding rate to pedestrians, changes in pedestrian crash rates, and long-term changes in the safety culture of drivers in Gainesville were unknown.

A four-year follow-up study evaluated the extent to which increases in the percentage of drivers yielding to pedestrians in Gainesville, Florida observed in the original study persisted over time (Van Houten, Malenfant, Blomberg, Huitema, & Hochmuth, 2017). The results indicated the increase in yielding seen in the original study not only persisted but increased further during the follow-up period. Moreover, both the enforcement and generalization sites showed this continued improvement. This, together with the significant citywide drop in pedestrian crashes after the end of the intervention, supports a conclusion of program effectiveness and suggests the possibility of a substantial spread of effect from the original study's enforcement and education program. Later the efficacy of this program was replicated in Saint Paul Minnesota and Ann Arbor Michigan.

The follow-up study in Saint Paul evaluated a program to reduce the frequency of drivers passing vehicles stopped for pedestrians on multilane roads. The program consisted of a broadly advertised program where police would check the reckless endangerment box on the citation if someone passed a vehicle stopped for pedestrians in a crosswalk (Morris, Craig, & Van Houten, 2020). This intervention led to a sustained reduction in multiple threat crashes from 12% to 3%.

Effectiveness
This treatment does not have a CRF. However, crash reductions were associated with the increase in yielding in the Gainesville study.

Implementation and Operational Considerations

- **Planning Time:** Short
- **Implementation Time:** Short
- **Applicability to Higher Speed Roads:** FAIR (This treatment requires good coordination with police but can be funded by NHTSA funds)

2.2.9 Enforcement of 5 or 3 Foot Bicycle Passing Laws

Michigan has a 3 ft minimum passing law which requires leaving a 3 ft passing distance when passing bicycles. Many cities have a 5 ft bicycle passing law. Bloomberg and Van Houten developed a high visibility program to reduce unsafe passing of bicycles similar high visibility program to developed to increase yielding right of way to pedestrians. Their study supported by the NHTSA was carried out in Grand Rapids, MI and Knoxville, TN. In Grand Rapids, a local ordinance required leaving minimum 5 ft passing distance, and in Knoxville, the State law and local ordinance required a minimum 3 ft pass. The program involved high visibility enforcement, public outreach, and posted feedback on the percentage of drivers passing less than 5 ft and less than 3 ft. Police in both cities used the C3FT™ ultrasonic measuring device to determine if drivers passing a decoy officer on a bicycle were too close. The same C3FT™ device was modified to store data and used to collect evaluation measures by two groups of data collection riders—Staged Riders who rode repeatedly on routes on which enforcement was focused and Random Riders who used their bicycles as a primary means of transportation. Each city developed its own publicity program to increase the visibility of enforcement. The High Visibility Enforcement (HVE) program continued for approximately 4 months in each city. Results showed that the average passing distance in both cities were level during the baseline condition. By the end of the HVE programs, statistically significant increases in average passing distance and significant decreases in violations were achieved in both cities. Police had no problems using the C3FT™ device to identify violators and chose to issue more warnings than tickets.

Effectiveness
The program increased passing distance and driver awareness of bicyclists. Although this program was successful in changing driver behavior in both cities, there is no data on whether it can reduce motor vehicle/bicycle crashes.

Implementation and Operational Considerations
- **Planning Time:** Short
- **Implementation Time:** Short
- **Applicability to Higher Speed Roads:** FAIR (This treatment requires good coordination with police but may be funded by NHTSA funds.

2.3 Corridor Improvements

2.3.1 Raised Medians

Raised medians provide a physical separation between lanes traveling in the opposite direction of travel. These can serve as a continuous pedestrian refuge island particularly at unmarked crosswalk locations. Medians can reduce crashes with pedestrians and head on collision but do not offer individuals with wheelchairs a safe crossing unless there are cuts in the medians at intersections. Because most pedestrian crashes in Michigan occur mid-block at unsignalized locations, raised medians were shown to produce a 69% reduction in overall pedestrian crashes. The installation of a median reduced crashes by 69% at unsignalized intersections, 46% at marked crosswalks, and signalized intersections, pedestrian crashes were reduced by 69%. Crashes were reduced by 46% when installed at marked crosswalks, 29% at unmarked crosswalks, and an average reduction in pedestrian crashes of 25% for all intersection locations. The design of raised medians is covered in the Michigan Design Guide Section 7.01.54 and the Michigan MUTCD Section 3I.06.

Effectiveness
Refuge islands have a CRF of 31.5% with a 4 Star Rating.

Implementation and Operational Considerations
- **Planning Time**: Long for full medians, moderate for small refuge islands
- **Build Time**: Long for full medians, short for small refuge islands
- **Applicability to Higher Speed Roads:** GOOD

2.3.2 Curb Extensions

Curb extensions (also known as bulb outs or bump-outs) extend the sidewalk or planting space out into the existing roadway, taking up space in a parking lane. Curb extensions should be considered to reduce crossing length on multilane roads. This treatment also increases the visibility between pedestrians and drivers because it places the pedestrian in a location where the view is not screened by a parked vehicle. To introduce this treatment, it is necessary to reconstruct curbs. The new curb line should not encroach the traveled way where bicyclists or motor vehicles may be traveling.

Effectiveness

Curb extensions have not been widely studied, though they may be effective at improving motorist yielding as part of a larger package of treatments and countermeasures, according to NCHRP Synthesis 498.

Implementation and Operational Considerations

- **Planning Time**: Medium: identify sites based on public input and traffic data analysis, then must plan and design the installation. The design time will vary greatly depending upon the permanence of the installation. Permanent installations may approach long-term planning due to engineering requirements.
- **Build Time**: Short-Medium: if installing a paint extension, 1-3 days is reasonable. For longer-term installations using vertical barriers, the installation process may take 1-2 weeks.
- **Applicability to Higher Speed Roads:** POOR (Many of the higher speed roads do not have sufficient room for this treatment. It is typically used where there is on street parking lanes)

2.3.3 Intersection Bicycle Crossing Markings

On streets with bike lanes, Bicycle pavement markings are continued through the intersection to indicate the intended position for bicyclists, as well as alert motorists that the bicycle facility continue through the intersection. This treatment can be used at signalized and unsignalized intersections. Intersection crossing markings should be considered at wide intersections or at intersections where the intended direction for bicyclists is complex or unclear. This marking guides cyclists to ride where they are most visible and expected. The intended path may be colored pavement, dashed lines or shared lane markings. For additional background and design details, refer to the NACTO Urban Bikeway Design Guide: www.nacto.org

Effectiveness

This treatment does not have a CMF associated with its use. However, there is a CMF of .61 for colored bicycle lanes at signalized intersections. However, this countermeasure only has a 2 star rating.

Implementation and Operational Considerations

- **Planning Time**: Short
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** POOR (There are few higher speed facilities

for bicycles because sufficient right way does not exist to include them).

2.3.4 Sidewalks and Paved Shoulders

Sidewalks are facilities separated from the roadway by a curb and sometimes a setback for the exclusive use by pedestrians. Paved shoulders are paved extensions of the roadway outside the traveled way which can provide room for cyclists. Sidewalks should be installed as part of every urban arterial and collector street where there is developed frontage. Paved shoulders should be considered on any roadway where sidewalk construction is not feasible due to grade or right-of-way constraints. When sidewalks are added to a roadway, pedestrian crashes are reduced by 88% (FHWA, 2007). When paved shoulders are added to the roadway, pedestrian crashes are reduced by 70% (FHWA, 2007). Another advantage offered by paved shoulders can be to increase the pavement life of roadways and reduce cracking. Sidewalks and shoulders are most cost effective when incorporated as part of roadway construction. If sidewalks cannot be provided at the time of roadway design, right-of-way should be secured, and proper grading should be done in anticipation of sidewalks at a later date. Whenever roadway drainage goes from an open swale to a closed drainage system, sidewalk construction should be considered as a low-cost addition to the project.

Effectiveness
Sidewalks have a CRF as high as 40% while paved shoulders have a CRF of 7.6.

Implementation and Operational Considerations
- **Planning Time**: Long
- **Build Time**: Long
- **Applicability to Higher Speed Roads:** GOOD (Sidewalks reduce crashes that involve pedestrians

2.3.5 Bike Lanes

Bike lanes are narrow lanes delineated with pavement markings for the exclusive use by bicyclists. Normally, one bike lane is provided on the right side of the roadway in each direction and travels in the same direction as the automobile lane. Bike lane signs can be used to supplement the bike lane pavement markings. Bike lanes can reduce wrong way bicycle, which is one of the leading factors in bicycle crashes. Bicycle lanes can also decrease the number of cyclists riding on the sidewalk. Bike lanes are a much more cost-effective method of providing bicycle facilities than a side path, which typically requires additional right-of-way and is subject drainage and alignment issues independent of the roadway. However, data on the effect of installing bike lanes on crashes are equivocal. Bike lanes currently are considered a design option in the Michigan Design Manual Section 12.12. Additional guidance can be found in the AASHTO Guide for the Development of Bicycle Facilities.

Effectiveness
Bike lanes may have different effects midblock than at intersections. Studies in NYC show adverse effects of installing bike lanes at intersections with a CRF of -6.5 and -28.1 (Star Ratings of 3). The CRF for installing them along the roadway segment were 14.5 and -50.9 (Star Ratings of 2). More recent studies in Florida show a CRF of 23 and -124 (3 Star Rating) and -69, -27, -71, and -36 (two Star Ratings).

Implementation and Operational Considerations

- **Planning Time**: High
- **Build Time**: High
- **Applicability to Higher Speed Roads:** POOR (Right of way required to widen lanes does not exist on many higher speed roads)

2.3.6 Increasing Lane Width

Some studies show increasing lane width on arterial roads reduces bicycle crashes. However restricting bicycle travel by installing curb or sidewalk barriers may increase bicycle crashes. These interventions can be viewed as either providing more separation between motor vehicles and bicyclists and precluding escape by bicyclists in emergency situations.

Effectiveness

The effect of increasing lane width is associated with a CMF of 23 and 25 (Three Star Rating) and a CMF of 21, 36, 48 and 76 (Two Star Rating).

Implementation and Operational Considerations

- **Planning Time**: Long
- **Build Time**: Long
- **Applicability to Higher Speed Roads:** POOR (Right of way required to widen lanes does not exist on many higher speed roads)

2.3.7 Buffered Bike Lanes

A buffered bike lane is separated from traffic by a painted median with or without collapsible posts. It provides a greater horizontal separation between the bike lane and the automobile travel lane or between the bike lane and parked cars. In the latter case it reduces the chance of the cyclist colliding with the opening door of a parked vehicle. Buffered bike lanes should be considered wherever greater separation of bicycle and automobile traffic or parked vehicles is desired. They may be placed on either side of the bike lane (next to the through travel lane or the parking lane.) Buffered bike lanes increase the separation between bicycles and automobiles, which may be helpful on roadways with posted speeds above 35 miles per hour.
Refer to the NACTO Urban Bikeway Design Guide for guidance on the design of buffered bike lanes.

Effectiveness

Several studies show that buffered bike lanes increase passing distance. Buffered bike lanes which are separated (Separated Bike Lane) with flexi-posts and other vertical elements have a CMF of 0.567 and a CRF of 43.3) with a 4 star rating.

Implementation and Operational Considerations

- **Planning Time**: Short
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** POOR (There is no room for bicycle facilities

on many high-speed roads)

2.3.8 Cycle Tracks

A cycle track is a partially separated bicycle facility that consists of a one or two-way facility that is separated from automobile traffic between intersections. It can be separated by curb, planters, a change in elevation, markings, flexible posts, or parked vehicles. Cycle tracks can pose a crash risk at intersections where drivers cannot see bicyclists emerging from behind parked cars or standing pedestrians. Ideally the cyclists should be visible between intersections to increase the likelihood they are noticed or expected by drivers turning onto a side street. Another solution to this problem is the installation of bicycle signals at cycle track roadway crossings. This treatment is costly and is typically used mostly on urban streets. Crash data would be expected to vary based on the number of intersections and driveways. The lower crash rate is likely the result of slower bicyclists. Lower cycling speeds may be a major variable at these sites. Cycle tracks physically separate bicycle and automobile traffic, which has been shown to reduce injury crashes by 28% (Lusk et.al., 2010). Guidance for the placement of cycle tracks is provided in the NACTO Urban Bikeway Design Guide. Cycle Tracks.

Effectiveness
Danish research on cycle tracks shows effects with 1 and 2 Star Ratings with CRFs that vary between 63% and 126%. The Montreal study has more favorable CRFs with 2 Star Ratings but has been criticized for using inappropriate control sites. The variation in CRF values shows that many important variables affecting the benefit or adverse effect of this treatment have not yet been identified. Some of the variables that likely influence the safety effects of cycle tracks are the number of intersections that need to be crossed, the treatments available at these intersections, and how bicycle traffic is separated from the roadway.

Implementation and Operational Considerations
- **Planning Time**: High
- **Build Time**: High
- **Applicability to Higher Speed Roads:** POOR (This treatment is not appropriate for higher speed roads)

2.3.9 Shared Use Path

Shared use paths typically provide excellent separation between motor vehicle traffic, and cyclists and pedestrians.

Effectiveness
Shared use paths have a CMF of 25 and a Three Star rating.

Implementation and Operational Considerations
- **Planning Time**: Long
- **Build Time**: Long
- **Applicability to Higher Speed Roads:** GOOD (This could be a good way to separate bicycle and pedestrians from traffic on higher speed roads, but can only be applied

where right-of-way exists)

2.4 Corridor Wide Speed Control

According to Schneider and Stefanich (2015), pedestrian crashes are associated with roadway design characteristics such as higher automobile speeds, more lanes, and more automobile traffic. Pedestrian crashes are also more likely on roads without sidewalks and crossings without median islands. These are also more likely to be major factors at crossing on higher speed roads. Speed control for higher speed corridors can be implemented by spot treating speed at high pedestrian crash locations on higher speed roads (hot spots) or by reducing the speed of the higher speed road. The later involves a balanced analysis of all the relevant variables. However, in some cases this may be the most rational approach to the problem of pedestrian and bicycle crashes. Studies show that motor vehicle speed is closely related to the severity of pedestrian and bicycle crashes. Speed can be the largest factor for fatal pedestrian and bicycle crashes. It is interesting to note that one study (Bhagavathula, et.al., 2015) found that intersections with a posted speed limit of 40 mph or less had lower nighttime crash ratios than intersections with a posted speed limit greater than 40 mph. These results suggest that slowing speeds at night on higher speed roads would be a good approach to reducing pedestrian and bicycle crashes.

2.4.1 Altering Progression Along High Crash Suburban Corridors

Progression involves timing a series of signals to produce a green ban along the arterial for vehicles traveling at the posted speed limit. Progression is typically employed to control speeds on arterial roads in high crash suburban zones. Signage informing road users that the appropriate speed will avoid red lights could be of assistance in obtaining improved compliance. LaPlante and McCann (2008) point out that drivers traveling at 45 mph stopping for multiple lights will have the same overall travel time as someone driving 25 or 30 mph with coordinated signals and no stops. However, drivers will not benefit from progression unless they are aware of this state of affairs. On higher speed roadways progression could be used to reduce speeds from 45 to 50 mph along a suburban arterial to 35 mph. This change would greatly reduce the chance of a fatal pedestrian or bicyclist death. However, a strong outreach plan which includes education delivered along the corridor would be key to maximizing the potential benefit in speed reduction and deaths.

Effectiveness

Though no research has documented the safety effects of setting lower progression speeds in terms of crash reduction, there is evidence that these changes do result in lower overall operating speeds which should result in fewer crashes and less serious crashes.

Implementation and Operational Considerations

- **Planning Time**: Medium: planning requires study per state law to determine feasibility of traffic flow changes and appropriate speed reductions.
- **Build Time**: Medium (Several Weeks-Month)
- **Applicability to Higher Speed Roads:** GOOD (This intervention is only likely to be effective in suburban or commercial areas with relatively frequent signalized intersections.)

2.4.2 Use of R2-3P NIGHT Speed Limit Sign

A Night Speed Limit plaque (R2-3P) may be combined with or installed below the standard Speed Limit (R2-1) sign. This plaque should be reversed using white retro reflectorized legend and border on a black background. This application would be warranted to reduce speeds where the posted speed limit does not provide adequate sight distance to recognize a pedestrian with sufficient distance to avoid a possible crash. Because of the headlight effect and limited background field at night, crashes tend to be similar on both straight and curved roads segments. One study showed that reduced nighttime speed limits reduced speeds by 3 to 5 mph on rural two-lane higher speed roads (Corinna, et.al., 2019). Use of this intervention may be dependent on the interpretation of the vehicle code.

Effectiveness

Only one study has examined whether night speed limit signs can reduce night speeds. More research is required to determine whether this intervention can reduce speeds and crashes.

Implementation and Operational Considerations

- **Planning Time**: Long because it is difficult to implement speed limit changes.
- **Build Time**: Minimal
- **Applicability to Higher Speed Roads:** GOOD (However, there is little evidence on their effectiveness)

2.4.3 High Visibility Corridor Wide Speed Enforcement

Although there have been reductions in crashes per vehicle mile driven over the past 25 years, the lives of 1,031,410 men, women, and children have ended violently as the result of motor vehicle crashes in the United States (AAA Foundation for Traffic Safety, 2013). Motor vehicle crashes were also the leading cause of death for people ages 15-24 during this period. A key element of the Toward Zero Deaths (TZD) National Strategy on Highway Safety is to address this problem by promoting change in the traffic safety culture in the United States among road users, including non-motorized users, and other organizations that have an existing or potential role in traffic safety, e.g., agencies responsible for public safety, education, or public health. A behavioral approach to safety culture would suggest changing safety in one target area at a time, and if one changes a number of safety related behaviors in a specific area such as speeding and pedestrian safety one should expect changes to transfer to untreated safety related behaviors.

An unsuccessful approach to changing the driving culture includes programs that emphasize numerous traffic stops alone. For example, Britt, Bergman, and Moffet (1995) reported on the effect of decoy pedestrian right-of-way enforcement operations carried out in Seattle over a period of several years that did not include components targeting the driving culture. The authors concluded "In light of the often-contradictory results, expectations of traffic enforcement to improve pedestrian safety should remain modest."

Research conducted in the 1980s (Van Houten & Nau, 1983) provided evidence that this approach could be effective in producing a culture change in driver speeding on arterial and collector roads.

Van Houten and Nau demonstrated a one week duration warning program that involved stopping drivers who were just a few miles over the speed limit and included social norming and other outreach efforts designed to change the driving culture, producing a marked reduction in serious speeding on neighborhood collectors that persisted for a year. Police gave a warning and an informational flier informing drivers that some of the pedestrians struck in crashes were children and asked them to help make their community safer. When this program also included a large feedback sign on the percentage of drivers not speeding the previous week the effects were considerably larger. Drivers who were stopped often complemented the police for taking action. One important element of this program was the use of publicly posted weekly community feedback, plus the verbal feedback of police officers that complemented the information flier provided with each traffic stop.

An experimental component analysis of the mechanisms behind the efficacy of the feedback signs isolated two factors: A social norming component, and an implied surveillance component. An example of this research was the finding that the use of a lenient criterion for speeding (drivers were not aware of the actual criterion used) lead to significantly larger effects than the use of a more stringent criterion that led to posting lower numbers.

A replication of this speed program carried out in Haifa, Israel (Van Houten, Rolider, Nau, Freidmann, Becker, Chalodovsky & Scherer, 1985) produced a large reduction in speeding, which was associated with a 50% reduction in crashes (Scherer, Freidmann, Rolider, & Van Houten, 1985). These statistically significant reductions in crashes were similar to those produced in pedestrian crashes by Malenfant, & Van Houten (1989).

Effectiveness
The Scherer et.al. (1985) showed large speed reductions and crash reductions that maintained over time. Based on those data a 50% reduction in crashes should be expected if the procedures employed in his study are followed.

Implementation and Operational Considerations

- **Planning Time**: Short
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** GOOD (At locations where corridor wide speeding is responsible for pedestrian and bicycle crashes.)

2.4.4 Road Diets

Road diets can be an effective way to address speed limits and operating speed as well as the number of lanes that need to be crossed. A typical approach involves converting a four-lane road to a three-lane road with a center turn lane and bicycle lanes (FHWA, 2014). Studies show that road diets reduce crashes (Harkey et.al, 2008), however this study does not account for possible crash migration caused by diversion of some traffic to other roads (LeVine, 2017). However, if traffic is diverted to other slower roads, it is likely there would be at minimum, a reduction in serious crashes. Road diets can be implemented on streets with up to 20,000 vehicles per day without greatly impacting motor vehicle travel. Road diets improve safety and mobility for all users by reducing read-end, sideswipe, and left-turn crashes, and freeing up one lane in each direction for uninterrupted travel.

Effectiveness
Road diets may reduce crashes between 10% and 44% (Highway Safety Information System, 2011).

Implementation and Operational Considerations

- **Planning Time**: Long
- **Build Time**: Moderate
- **Applicability to Higher Speed Roads:** POOR (Higher speed road required capacity may limit use of road diets)

2.5 Speed Control in Transition Zones

Often drivers continue driving at faster speeds when they enter a transition zone from a faster trunk road or arterial road to a more suburban area with slower speeds. One reason for this effect is speed adaptation (Alhomaidat, 2020). Matthews (1978) found that drivers travelling at a higher speed will persist in driving at a higher speed for about 4 minutes once they enter a lower speed road. Casey and Lund (1978) showed that this effect can be attenuated if the person is required to slow down or stop prior to entering an area with a new speed limit. Traveling through a roundabout or stopping for a traffic signal are examples of this type of effect.

2.5.1 Use of Solar Powered Dynamic Speed Feedback Signs

These signs show the speed limit and driver speed on High Crash Corridors. Although this treatment is good for suburban areas it could also work where trunk roads enter villages. A recent meta- analysis (Flynn et al., 2020) evaluated the effectiveness of dynamic speed feedback signs in 43 publications which included 57 speed studies at 204 sites. They found a reduction in speed of 4 mph, for passenger vehicles which could be associated with a up to a 40% in pedestrian fatalities on a road with speeds between 30 and 35 mph and perhaps larger reductions on higher speed roadways. Although the reduction in truck speed produced by the signs was somewhat smaller, it was noted that baseline truck speeds were lower than passenger vehicle speeds. This type of sign is likely to be most effective at transition zones near pedestrian facilities or at the beginning of a slower speed zone such as a small town or village along a higher speed trunk road.

Effectiveness
Speed feedback signs have been shown to be most effective at reducing driver speeds.

Implementation and Operational Considerations

- **Planning Time**: Short:
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** GOOD (At locations where the speed limit is reduced on higher speed roads that are associated with speed related crashes.)

2.5.2 Gateway Effect with Speed Limit Signs

This treatment involves the use of highly reflective sheeting material, that is bright during the day and at night, on sign and signposts in a gateway configuration at locations where there is a change in speed limits. This treatment can be used with the W3-5 or W3-5a Reduced Speed Limit Ahead sign as well as the first speed limit sign at the start of the new speed limit. Both the advance warning and the first speed limit signs could be installed and on both sides of the roadway and on a refuge island or median if one exists, using high quality reflective sheeting on the signposts as well as the signs. This treatment could be very effective in reducing speed where trunk routes enter villages or at locations where faster roads transition into suburban areas. The combination of these signs in a gateway configuration could produce an even larger reduction in speeding if larger signs are used.

One study that suggests that this treatment might work is a related treatment evaluated by Van Houten and Van Houten (1987). They demonstrated larger **Begin Slowing Here** sign placed in advance of the first speed limit sign at a speed limit transition produced reductions in the percentage of motorists travelling 10, 15 and 20 km over the speed limit of 26%, 45% and 59%. Although this treatment was effective, it is not in the MUTCD. However, the gateway treatment suggested above may be equally effective. This type of treatment if applied to signs on both sides of the road and on the pedestrian refuge island or median island if one exists can form a gateway like treatment that is very visible to drivers during the day and even more visible at night. This treatment would be implemented with pole mounted signs that conform to 2A.19 to reduce vehicle speed at the beginning of a new slower speed zone.

Effectiveness

This treatment has not yet been evaluated. Data collected in the current project provide some evidence that this treatment can be effective.

Implementation and Operational Considerations

- **Planning Time**: Short
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** GOOD (Particularly at sites where higher speed roads enter lower speed communities with a change in speed limit)

2.5.3 Use of Pavement Patterns to Reduce Speed

Several studies have examined the use of pavement marking patterns to produce the illusion of faster speed to reduce speed. Several studies have found a reduction in all crashes with the use of transverse bar pavement marking at roundabout approaches. This treatment has been shown to have a CRF between 45% and 74%. It would be useful to determine if this treatment also decreases pedestrian and bicycle crashes. Another treatment is the use of a parallelogram-shaped pavement markings on vehicle speed and safety of pedestrian crosswalks on urban roads in China. This study found a reduction in pedestrian crashes when placed on the approaches to unsignalized pedestrian crosswalks. One drawback of this approach is that the markings may not be as visible during when snow is covering the roads. However, vehicle speeds are typically slower when snow is present. Study is required to determine if these markings are in compliance with the MUTCD.

Effectiveness
The use of parallelogram markings on crosswalks had a Star Rating of 3 and a CRF of 21%. The use of Transverse markings has also been evaluated.

Implementation and Operational Considerations

- **Planning Time**: Short
- **Build Time**: Moderate
- **Applicability to Higher Speed Roads:** GOOD (Can be used at locations where the speed has been reduced at the entrance of small communities)

2.5.4 Gateway Use of R1-6 In-Street Signs

The Gateway in-street sign treatment involves installing multiple R1-6 in-street sign in at various locations at a crosswalk. This treatment has been documented to produce a large increase in the percentage of drivers yielding right-of-way to pedestrians at treated crosswalks over the installation of a single sign. The installation of a Gateway in-street sign treatment also produces a large decrease in vehicle speed in the crosswalk (Van Houten et.al., 2018). Currently the MUTCD only allows one R1-6 sign to be installed at a crosswalk either on the centerline, center of the refuge island or on one lane line, so the use of this treatment would require FHWA permission to experiment.

An alternative approach would be to use highly reflective sheeting material, that is bright during the day and at night, on sign and signposts in a gateway configuration at crosswalk locations. This treatment could be studied with the W11-2 sign crosswalk sign or the W11-15 trail crossing sign.

Effectiveness
Although this treatment has been shown to reduce speed it does not have a CMF.

Implementation and Operational Considerations

- **Planning Time**: Short
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** POOR (Maintenance issues would make this a poor choice for higher speed roads)

2.5.5 Roundabouts

A roundabout directs straight and turning traffic through a circular intersection in place of a stop-controlled or signalized intersection. They are designed to ensure yielding upon entry and slow vehicle speeds through the roundabout. Single-lane roundabouts can handle traffic volumes up to 26,000 vehicles per day. While multi-lane roundabouts can be used for traffic volumes up to 50,000 vehicles per day. Roundabouts reduce the number of conflict points for pedestrians at a typical four-leg intersection and have been shown to reduce motor vehicle crashes as well as pedestrian crashes. When future vehicle volumes are unclear, or close to the capacity of a single lane roundabout, it is wise to first install a single lane roundabout but reserve right-of-way to add another lane when it becomes necessary. This treatment consistently has been shown to increase bicycle crashes with negative CRFs.

Effectiveness
Roundabouts research has found negative crash reduction factors for bicyclists with a 2 Star rating (between -1% and -77% increase in crashes). Two studies with 3 Star Ratings show CRFs of -48% and -27%.

Implementation and Operational Considerations

- **Planning Time**: Long
- **Build Time**: Long
- **Applicability to Higher Speed Roads:** GOOD (Can be used as a gateway treatment where speed is reduced for a small community. Poor at other locations).

2.6 Lighting Improvements

An analysis of the crashes on higher speed corridors in Michigan over the past 10 years indicate that 83% of fatal crashes and 65% of incapacitating crashes on higher speed roads occurred at night. Michigan data also indicates that nighttime pedestrian collisions have a 57% chance of being fatal at intersections without street lighting and a 43% chance at those with street lighting. It should be noted that lighting was not directly measured in these studies. The presence of lighting just indicates that a light poll is nearby. Even when the collision is not fatal, injuries sustained by pedestrians at nighttime tend to be much more severe than those incurred during daytime, particularly on higher speed roads. While visibility is obviously the single most important factor impacting pedestrian nighttime safety, there appear to be a host of other factors that interplay with lighting that may also have a role in exacerbating this issue. Therefore, strategies for reducing night crashes on higher speed roads are key to reducing serious crashes.

Lighting and visibility are important components of a safety strategy for pedestrians. Comparisons of pedestrian fatalities before and after transitions with daylight savings time have shown consistently that holding all other factors constant, brighter lighting conditions are associated with fewer pedestrian deaths. The distribution of lighting is also emerging as an important factor, because rather than providing uniform lighting along the roadway surface it is necessary to provide vertical illumination along crosswalks and bikeways to ensure that they can be seen by approaching drivers. Jang et al. (2013) found that severe injury pedestrian crashes are more frequent at night. The number of pedestrian fatalities that occurred at night accounted for 87% of the overall increase in pedestrian fatalities in recent years. Considerable research has examined how to optimize lighting for pedestrians at intersections and crosswalks, but legacy lighting was installed prior to this research. These lights do not provide good color rendering and hence depend on the black and white rod visual system. Because this system degrades during the period of rhodopsin uptake interval following exposure to lighted conditions such as the headlights of another vehicle or passing through a well-lighted area, it can lead to a failure to detect a pedestrian in the roadway. Crash reports provide information on whether lighting is present but not the details about whether lighting was adequate or optimal based on lighting measures. The CMF Clearing house assumes that the lighting was installed at a previously unlighted intersection and treats lighting like a categorical variable (present vs. absent), whereas light levels in real life occur along a continuum. All variables need to be considered when examining the effects of lighting on night crashes.

The efficacy of street lighting is influenced by road surface luminance, lamp color, glare and driver age. Color vision (cones) performs better than black and white vision (rods); however, most street lighting does not provide white light needed for color vision. The most commonly used legacy lighting includes Mercury vapor; high and low pressure sodium, and metal halide; White light appears more uniform than sodium light to the human eye. However, the efficacy of mercury vapor and metal halide are lower than that of sodium lamps. LED lighting which allows excellent color rendering is increasingly being used. This type of lighting is also more coherent and can be better aimed.

Total level of illuminance is also important. Lighting data collected from 100 rural intersections in Virginia showed that for a 1-unit increase in the illuminance, the number of night crashes decreased by 7% (Bhagavathula, Gibbons, & Edwards, 2015). For the lighted intersections, the same increase in average horizontal illuminance decreased the number of night crashes by 9%. The largest decrease in the number of night crashes was for unlighted intersections, where for a 1-unit increase in the average horizontal illuminance the night crashes decreased by 21%. These relationships between illuminance and night crashes may only be valid, however, for the tested illuminance ranges (0.28 to 31.6 lux). Another study (Edwards, 2015) collected illuminance data from 63 intersections in Minnesota and reported that an increase in 1-lux of average intersection illuminance resulted in a 9% reduction in nighttime crash rates. The study also reported that an increase in 1-lux in average illuminance at lighted intersections was associated with a reduction in nighttime crashes by 20%.

To determine the appropriate light level at intersections, a new systems-level approach to intersection lighting design was introduced by VTTI (Bhagavathula, Gibbons, & Nussbaum, 2018). This study compared three intersection lighting designs (Lighted Approach, Lighted Box, and Lighted Approach and Box). This evaluation was done based on drivers' nighttime visual performance, using the objective measure of detection distance for targets located at the entrances, exits, and middle of pedestrian crosswalks at intersections. The results indicate that the design illuminating the intersection box offered better visual performance and had fewer missed target detections, with visual performance plateauing between 7 and 10 lux average intersection illuminance.

2.6.1 Intersection Related Lighting

Intersection lighting is typically accomplished by installing streetlights at the intersection location. Lighting levels can vary considerably as can type of lighting. LED lighting produces color rendering and allows one to use cones rather than rods. Data show that increased lighting reduces night crashes with some studies showing reductions in night pedestrian crashes.

Effectiveness

Four studies, all with 3 Star Ratings show a decrease in pedestrian crashes. Two of the studies with CRF of 42% and 59% show a reduction in serious injury, minor injury and possible injury pedestrian crashes (3 Star Ratings) and two additional studies show a reduction in fatal pedestrian crashes with a CRF of 78% and 82% (3 Star Ratings). One study that examined adding lighting at rural intersections found a CRF of 44% with a 3 Star rating.

Implementation and Operational Considerations

- **Planning Time**: Moderate
- **Build Time**: Moderate
- **Applicability to Higher Speed Roads:** EXCELLENT (This treatment would be very effective on higher speed roads at intersections where crashes occur at night)

2.6.2 Corridor Lighting

More recently, lighting data collected from 100 rural intersections in Virginia showed that for lighted intersections a 1-unit increase in the illuminance, decreased the number of night crashes by 9%. The largest decrease in the number of night crashes was for unlighted intersections, where a 1-unit increase in the average horizontal illuminance decreased night crashes by 21%. These relationships between illuminance and night crashes may only be valid, however, for the tested illuminance ranges (0.28 to 31.6 lux). A previous study collected illuminance data from 63 intersections in Minnesota and reported that an increase in 1-lux of average intersection illuminance resulted in a 9% reduction in nighttime crash rates. The study also reported that an increase in 1-lux in average illuminance at lighted intersections was associated with a reduction in nighttime crashes by 20%. In some instances, increased lighting can be achieved by changing out the lighting source or in the case of solid-state lighting better aiming the light source.

Effectiveness

Adding corridor lighting has a CRF of 20%, 28% and 87% all with a Star Rating of 3.

Implementation and Operational Considerations

- **Planning Time**: Short if changing out lighting to LED. Long if installing new lighting
- **Build Time**: Low if changing out lighting to LED. High if installing new lighting
- **Applicability to Higher Speed Roads:** EXCELLENT (This treatment would be very effective on higher speed roads where crashes occur at night. However, Act 51 prohibits the use of state funds for lighting on non-freeways under the jurisdiction of MDOT.

2.6.3 Spot Lighting Treatment

At some locations legacy lighting with a streetlight on one side of the road lights one side of the crosswalk but not the other side. One solution to this problem would be to install a second LED luminaire on the post with the streetlight and aim the light in such a way to better illuminate the other half of the crosswalk. Because LED lighting is more coherent than traditional street lights it should be possible to better direct the light.

Effectiveness

This treatment has not yet been studied in the current study but could be evaluated in a study project if funds allow.

Implementation and Operational Considerations

- **Planning Time**: Short

- **Build Time**: Moderate
- **Applicability to Higher Speed Roads:** GOOD (This treatment would be effective at crosswalks on higher speed roads associated with night crashes)

2.6.4 Dynamic Lighting Treatments

One approach that has not been systematically examined is increasing the lighting level when a pedestrian enters a crosswalk. Not only would this approach decrease light pollution, but it would also alert the driver that a pedestrian is initiating a crossing at a crosswalk. If this approach proves effective, it could be a low-cost way to increase the visibility of pedestrians crossing at night while the stimulus onset of the light would also alert drivers to pay attention to the area with increased illumination. This approach could be effective at crosswalks at night at dark intersections and at lighted intersections. In the case of the dark intersections, it would "turn on the lights" when the pedestrian enters the crosswalk, and in the latter case it would intensify the lighting when the pedestrian enters the crosswalk. If this approach proves effective, it could also be used in a smart city to alert drivers of pedestrians detected entering the road at midblock locations. It is also possible to use this approach at locations where cyclists are at risk for a nighttime crash. One signal manufacturer is currently selling a smart lighting system for crosswalks.

Effectiveness

This treatment has not yet been studied but a current study is pending in the spring of 2022.

Implementation and Operational Considerations

- **Planning Time:** Short
- **Build Time**: Short
- **Applicability to Higher Speed Roads:** GOOD (Would work if crashes are occurring at specific crossing locations. Can be done in conjunction with an RRFB)

3 REVIEW OF SAMPLE STATE AND FEDERAL GUIDANCE FOR PEDESTRIANS ON HIGHER SPEED ROADS

This chapter provides a summary of the non-motorized treatments on high-speed roads that are adopted by Michigan and its neighboring states. Practices of the states which have similar weather conditions to Michigan such as Minnesota, Pennsylvania, New York, and Iowa were also reviewed. This was done to compare the treatments across these states and identify any differences which can be adapted to Michigan. Additionally, it covers federal guidelines and past research related to this project. The following is a summary of these guideline documents.

3.1 Michigan

Michigan uses the guideline for installing pedestrian crosswalks on state trunklines highways as a standard to implement treatments on high-speed roads. To identify if a location is a potential for a crosswalk, the guideline states that it is important to collect physical (e.g., SSD) and traffic data (e.g., ADT). Afterward, the data collected are to be used to determine the appropriate treatments. The criteria are based on controlled and uncontrolled crossings. Generally, the controlled crossing is categorized into the stop, signalized, and school crossing. The guideline states that pedestrian warning signs will not be installed for stop-controlled crossing unless an engineering study demonstrates the need to do so. On the other hand, signalized crossings are eligible for crosswalks with no or minimum pedestrian treatments. School crossings whether with stop or signalized control are eligible for a crosswalk. Special emphasis crosswalk markings should be installed on these crossings. Also, for the uncontrolled crossing, collected data such as ADT, SSD, and the presence of a shared-use path must be considered to decide to install treatments. Appendix 9.2 show the flowchart for pedestrian crossing treatment and crossing treatment types, respectively, for Michigan. The details of crossing type categories are as follows:

- Crossing Type, A- Consists of marked special emphasis crosswalk, standard pedestrian warning signs (W11-2), or standard school crossing signs (S1-1) for school crossing.
- Crossing Type, B- Consists of marked special emphasis crosswalks, standard pedestrian warning signs, or standard school crossing signs (S1-1) for school crossing. Also, geometric improvements (such as median nose extensions, curb extensions, pork chop island, tighter curb radius, or median refuge islands) or consider pedestrian-activated Rectangular Rapid Flashing Beacons (RRFB) if criteria are met. In-street yield to pedestrian crossing sign (R1-6) should be used only in low-speed urban settings.
- Crossing Type, C- Where the posted speed limit is greater than or equal to 45 mph, determine if traffic calming measures can be installed to effectively reduce the operating speed such that the posted speed limit could be changed to 40 mph and a raised median can be installed. If so, go to Crossing Type B; if not, go to Crossing Type D.
- Crossing Type, D- Consider the Pedestrian Hybrid Beacon (PHB), pedestrian traffic signal, or grade-separated pedestrian crossing. Must consider corridor signal progression, grades, physical constraints, and other engineering factors.

3.2 Indiana

Indiana uses the INDOT Design Manual, which has outlined the treatments which can be implemented at intersection and shared-use paths within the special design elements. Appendix 9.3 shows the recommended treatment of shared-use path and roadway intersection for Indiana. The level of treatments are as follows:

- Level 1 is a basic crosswalk (standard crosswalk which has two transverse lines).
- Level 2 is an enhanced crosswalk treatment that includes longitudinal crosswalk markings, raised midblock crosswalks, or high visibility crosswalk markings.
- Level 3 includes the refuge island and bulbouts. A bulbout is an extension of the sidewalk/curb area that reduces the designated crossing length.
- Level 4 includes flashing beacons and flashing LED signs such as RRFB
- Level 5 includes PHB, traffic signs, and grade separation.

Indiana guidance recommends level 2, 3, 4 or 5 (often used together, depending on the number of lanes and ADT) for higher speed roads (45 mph and above).

3.3 Ohio

The ODOT Multimodal Design Guide provides detail of countermeasures that can improve yielding with specifications on what can be applied on high-speed roads (ODOT, 2022). Appendix 9.4 shows the evaluation table for uncontrolled crossing countermeasures in Ohio. It uses three tiers to identify the treatments which can be used at an uncontrolled crossing at different speeds, traffic volume, and road configurations.

- Tier 1 aims at pointing out the presence of crossing to road users since traffic volumes and speeds are conducive to motorist yielding. Includes improving sight distance, removing adjacent parking which causes sight obstruction, or installing curb extensions. Where minimum intersection sight distances cannot be provided, stopping sight distance must be provided and advance warning beacons and signage should be installed. Additional options for scenarios where neither intersection nor stopping sight distance can be achieved include relocating the crossing or evaluating it for a signal or other traffic control device (i.e., stop sign, rectangular rapid flashing beacon, pedestrian hybrid beacon, etc.). Also, designers can complete a speed study to lower the posted speed limit.

- Tier 2 involves optimizing geometric design. The geometry of the intersection and crossing should be optimized to be as close to 90 degrees as practical to minimize the exposure of crossing users, reduce crossing distances, and maximize sight lines. The crossings should be shortened to reduce exposure and increase the frequency of safe crossing gaps. Strategies to consider include crossing islands, curb extensions, and reducing approach speeds (Tier 1 Countermeasures). Also, providing an active beacon or rectangular rapid flashing beacon should be considered.
- Tier 3 countermeasures require motorists to stop for crossing bicyclists and pedestrians at a pedestrian hybrid beacon or traffic signal or grade separation.

3.4 Illinois

Illinois has established guidelines based on past studies, observations from the field, engineering judgment, and practices from other state agencies (Qi *et al.*, 2017). Unlike other states, Illinois does not recommend uncontrolled crossing on high-speed roads (>=45 mph) regardless of the traffic volume and road configuration. This means that the crossings on high-speed corridors are usually controlled to protect non-motorized traffic from motorized traffic. Appendix 9.5 shows a summary of recommended minimum treatments at uncontrolled pedestrian crossings in Illinois.

3.5 Wisconsin

Wisconsin Guide to Pedestrian Best Practices and Wisconsin Bicycle Facility Design Handbook have some recommendations for treatments and facilities on high-speed roads. These include installing wider bicycle lanes which should be used on higher volume and higher speed roads (>40mph). Also, vertical curbs have to be used to separate traffic and pedestrian traffic where the posted speed limit is over 45 mph. WisDOT (2020) suggests a grade-separated crossing to be considered on rural roadways and trails if the roadway speed is 40 mph or higher with ADT equal to or greater than 3,500. In urban areas with speed limits of 45 mph or more, crosswalk markings may be installed with a traffic signal, an all-way stop sign, or crossing enhancements by adding curb extensions and pedestrian refuge islands. Generally, the installation of a crosswalk follows an engineering traffic study or judgment. Other standards are adopted from Wisconsin Supplement to the Manual on Uniform Traffic Control Devices (WisDOT, 2017).

3.6 Minnesota

Minnesota's source of pedestrian treatment on high-speed roads is “Guidance for Installation of Pedestrian Crosswalks on Minnesota State Highways” (Minnesota Department of Transportation, 2005). The document outlines the procedures to be followed when planning to install crosswalks and treatments. It covers both controlled and uncontrolled crossings. The site has to have adequate stopping sight distance, minimum truck traffic, minimum vehicle turning movements, and minimum driver distractions. For higher speed roads (40 mph and above), a pedestrian bridge or underpass or pedestrian signal should be provided. Also, for a roadway with less than 4 lanes and speed limit above 35 mph, crosswalk may be considered with additional treatments. These include reducing the number of travel lanes, raised median, curb extensions, pedestrian crossing island, advance stop line, and sign and parking restrictions. Appendix 9.6 shows the crosswalk installation guidelines flow chart for Minnesota.

3.7 New York

New York uses the Highway Design Manual where chapter 18 in this manual focuses on pedestrian facility design to guide the installation of pedestrian facilities (NYSDOT, 2017). The manual adopts the treatments which can be applied to uncontrolled crossing according to a study by Zegeer *et al.*, (2002) Exhibit 18-19. Another source is the pedestrian safety action plan (NYSDOT, 2016) which is aimed at recommending countermeasures that can be accomplished to improve pedestrian safety. This plan was created as a response to the requirement of federal surface transportation legislation, where every state must develop a Strategic Highway Safety Plan (SHSP). The plan has outlined treatment packages that can be implemented at uncontrolled crosswalks for the 40-45 mph posted speed limit. All treatment packages include high-visibility crosswalks and pedestrian warning signs with fluorescent yellow and retroreflective signposts. Basic treatments require minimum analysis for implementation however, enhanced treatments require additional site analysis and engineering evaluation for implementation. Appendix 9.7 shows the treatment plan for uncontrolled locations with 40-45 posted speed limit in New York.

For locations where the speed limit is 50 mph and above, the plan recommends implementing measures to reduce operational speeds and restrict parking. Also, HAWK (PHB) has to be installed on a two-stage crossing, and where a two-stage crossing is not possible, consider installing traffic signals. The plan also recommends treatments to be used at uncontrolled on and off ramps.
Other similar states' practices such as Pennsylvania and Iowa were reviewed, but no specific guidelines were documented for treatments to be used on high-speed roads. They adopt their practices from the national MUTCD (U.S. Department of Transportation, 2009) and other guidelines (PENNDOT, 2016; IOWADOT, 2019)

3.8 Federal guidelines

Blackburn *et al.*, (2017) established a Federal Highway Administration (FHWA) guideline for improving pedestrian safety at uncontrolled crossing locations. The guideline documents steps to be followed by agencies before selecting countermeasures. These steps are the collection of data such as crash data, roadway characteristics, and public engagement then analyzing crash types and safety issues. Figure 3.1 is a comprehensive matrix of pedestrian crash countermeasures recommended at uncontrolled crossing locations. The guideline suggests that agencies should reference MUTCD and other national, state, or local standards when making the final selection of countermeasures. Furthermore, Figure 3.2 provides specific countermeasures to address safety concerns such as failure to yield or speeding.

Roadway Configuration	Posted Speed Limit and AADT								
	Vehicle AADT <9,000			Vehicle AADT 9,000–15,000			Vehicle AADT >15,000		
	≤30 mph	35 mph	≥40 mph	≤30 mph	35 mph	≥40 mph	≤30 mph	35 mph	≥40 mph
2 lanes (1 lane in each direction)	❶ 2 4 5 6	❶ 5 6 7 9	① 5 6 ❼ ❾	❶ 4 5 6	❶ 5 6 7 9	① 5 6 ❼ ❾	❶ 4 5 6 7 9	① 5 6 7 9	① 5 6 ❾
3 lanes with raised median (1 lane in each direction)	❶ 2 3 4 5	❶ ❸ 5 7 9	① ❸ 5 ❼ ❾	① 3 4 5 7 9	① ❸ 5 ❼ ❾	① ❸ 5 ❼ ❾	① ❸ 4 5 7 9	① ❸ 5 ❼ ❾	① ❸ 5 ❾
3 lanes w/o raised median (1 lane in each direction with a two-way left-turn lane)	❶ 2 3 4 5 6 7 9	❶ ❸ 5 6 7 9	① ❸ 5 6 ❾	① 3 4 5 6 7 9	① ❸ 5 6 ❼ ❾	① ❸ 5 6 ❾	① ❸ 4 5 6 7 9	① ❸ 5 6 ❾	① ❸ 5 6 ❾
4+ lanes with raised median (2 or more lanes in each direction)	❶ ❸ 5 7 8 9	❶ ❸ 5 7 8 9	① ❸ 5 8 ❾	① ❸ 5 7 8 9	① ❸ 5 ❼ 8 ❾	① ❸ 5 8 ❾	① ❸ 5 ❼ 8 ❾	① ❸ 5 8 ❾	① ❸ 5 8 ❾
4+ lanes w/o raised median (2 or more lanes in each direction)	❶ ❸ 5 6 7 8 9	① ❸ 5 ❻ 7 8 9	① ❸ 5 ❻ 8 ❾	① ❸ 5 ❻ 7 8 9	① ❸ 5 ❻ ❼ 8 ❾	① ❸ 5 ❻ 8 ❾	① ❸ 5 ❻ ❼ 8 ❾	① ❸ 5 ❻ 8 ❾	① ❸ 5 ❻ 8 ❾

Given the set of conditions in a cell,

- # Signifies that the countermeasure is a candidate treatment at a marked uncontrolled crossing location.
- ● Signifies that the countermeasure should always be considered, but not mandated or required, based upon engineering judgment at a marked uncontrolled crossing location.
- ○ Signifies that crosswalk visibility enhancements should always occur in conjunction with other identified countermeasures.*

The absence of a number signifies that the countermeasure is generally not an appropriate treatment, but exceptions may be considered following engineering judgment.

1. High-visibility crosswalk markings, parking restrictions on crosswalk approach, adequate nighttime lighting levels, and crossing warning signs
2. Raised crosswalk
3. Advance Yield Here To (Stop Here For) Pedestrians sign and yield (stop) line
4. In-Street Pedestrian Crossing sign
5. Curb extension
6. Pedestrian refuge island
7. Rectangular Rapid-Flashing Beacon (RRFB)**
8. Road Diet
9. Pedestrian Hybrid Beacon (PHB)**

Figure 3-1. Application of pedestrian crash countermeasures by roadway feature

Pedestrian Crash Countermeasure for Uncontrolled Crossings	Safety Issue Addressed				
	Conflicts at crossing locations	Excessive vehicle speed	Inadequate conspicuity/ visibility	Drivers not yielding to pedestrians in crosswalks	Insufficient separation from traffic
Crosswalk visibility enhancement	✔	✔	✔	✔	✔
High-visibility crosswalk markings*	✔		✔	✔	
Parking restriction on crosswalk approach*	✔		✔	✔	
Improved nighttime lighting*	✔		✔		
Advance Yield Here To (Stop Here For) Pedestrians sign and yield (stop) line*	✔		✔	✔	✔
In-Street Pedestrian Crossing sign*	✔	✔	✔	✔	
Curb extension*	✔	✔	✔		✔
Raised crosswalk	✔	✔	✔	✔	
Pedestrian refuge island	✔	✔	✔		✔
Pedestrian Hybrid Beacon	✔	✔	✔	✔	
Road Diet	✔	✔	✔		✔
Rectangular Rapid-Flashing Beacon	✔		✔	✔	✔

*These countermeasures make up the STEP countermeasure "crosswalk visibility enhancements." Multiple countermeasures may be implemented at a location as part of crosswalk visibility enhancements.

Figure 3-2. Safety issues addressed by specific countermeasure

3.9 Past research on pedestrian treatments on high-speed corridors

Zegeer *et al.*, (2002) examined the safety impacts of marked and unmarked crosswalks at uncontrolled locations. Their study utilized five years of data for pedestrian crashes at marked and unmarked crosswalks in the U.S. These sites didn't have traffic signals or stop signs on all the approaches. Their analysis concluded that marked crosswalks alone are insufficient on roads with posted speed limits which are equal to and greater than 40 mph. Depending on the ADT and road configuration, additional treatments such as traffic calming treatment or traffic signals with pedestrian signals where warranted have to be installed. Most state DOTs developed their guidelines and standards on pedestrian treatments by expanding the findings from this study.

With regards to specific treatments which can be used on high-speed roads, Dougald (2016) evaluated the effectiveness of RRFB at midblock crosswalks on high-speed urban collectors (45 mph). The major interest was to check the number of pedestrians who used the pushbutton to activate RRFB, the driver's behavior when the RRFB is activated compared to when it is not activated, and trail user impressions of the system. Results showed that RRFB had a positive impact on the drivers due to observed speed reductions when RRFB has been activated as well as an increase in yielding rate even when it wasn't activated. Trail users were likely to use the pushbutton to activate RRFB more in the presence of traffic. The survey results also revealed that trail users felt that the system improved safety. Fitzpatrick et al., (2020) analyzed the performance of PHB on high-speed roads with 85th percentile speeds ranging from 44 mph to 54 mph in Arizona. Video data including pedestrians and bicyclists from ten sites with high-speed conditions in Arizona was used. Results showed that the driver yielding on average was found to be 97% which is similar to the locations where PHB is installed on lower-speed streets. This study shows that PHB also performs well on higher-speed roads.

Furthermore, Fitzpatrick & Park, (2021) compared the effectiveness of PHB, RRFB, and LED embedded crossing signs during night conditions. The study employed 10 sites for PHB, 12 sites with RRFB, and 8 sites for LED embedded crossing signs. Site selection was based on the range of speed limit, presence of median, and the presence of treatment. This study employed the use of a staged pedestrian who pushed the button at a specific crosswalk and the driver yielding behavior were then observed. Results showed that RRFB is more effective at night since it increases the driver yielding rate. In contrast to that, LED embedded crossing signs were not effective during night conditions and researchers recommended that they should be used when there is low operating speed and volume with narrow lanes. PHB was found to be the most effective treatment during both night and daytime conditions as well as in higher-speed settings.

The effect of transverse rumble strips on the safety of pedestrian crosswalks on rural roads in China was analyzed by (Liu *et al.*, 2011). The transverse rumble strips were raised rumble strips deployed on both approaches to a non-signalized pedestrian crosswalk on a rural road. Speed data were collected from 12 sites on 3 rural highways with posted speed limits of 40 km/h, 60 km/h, and 80 km/h, respectively. Also, crash data were collected at 366 road segments on 4 neighboring rural highways in the Yangjiang area of Guangdong Province. EB before –after study results showed that the transverse rumble strips may reduce pedestrian crashes by 25%. For the road segments with a speed limit of 80 km/h (49.71 mph), the average speed of drivers declined by 11.9 km/h (7.4 mph). The findings suggest that transverse rumble strips are effective in reducing speed on high-speed facilities.

Another study analyzed the selection of pedestrian crossing treatments at controlled and uncontrolled locations (Ashur and Alhassan, 2015). This was done to develop practical guidelines on pedestrian crossing treatments, especially on multilane roadways, complex intersections, and high-speed roads (45 mph or more). They conducted an online survey on pedestrian crossing treatments and high-speed divided highways and the link to the survey was emailed to the AASHTO Standing Committee. In the case of high-speed divided highways, the main recommendation was to provide adequate crossing time for pedestrians. Since refuge island is not typically used on high-speed roadways, two types of islands were recommended. They recommended ‘‘*Grass Island with mountable curbing around the nose, paved cut through, pedestrian pushbutton provided*,’’ or “*a raised island with ADA pedestrian ramps.”*

3.10 Summary of Reviews

Most state practices reviewed in this chapter had almost similar standards and guidelines for implementing pedestrian treatments on high-speed roads. For instance, for higher speeds (45 mph or more) and high volumes crossing locations, most states consider implementing treatments that compel drivers to stop for pedestrians. These treatments include the use of traffic signals, PHB, or grade separation. The review of federal guidelines provided additional information for the pedestrian treatments since some treatments recommended on high-speed roads are not included in the Michigan standards e.g., road diet. On the other hand, most previous studies on pedestrian treatments on high-speed roads are based on RRFB and PHB showing that these treatments are effective on those roads.

4 IDENTIFICATION OF HIGH CRASH SITES

To identify high crash locations, statewide crash data recorded from the beginning of 2009 to end of 2020 were analyzed by severity, area type (rural vs urban), lighting conditions, and location of crash (intersection vs midblock). Pedestrian crashes and bicycle crashes were analyzed separately. Non-motorized crashes were grouped into low-speed crashes (less or equal to 40 mph) and high-speed crashes (greater or equal to 45 mph and less or equal to 65 mph). Heat maps were generated using ArcGIS software, followed by identification of high-crash sites. The following sections present the findings of crash analysis and selection of high-crash sites.

4.1 Statewide Crash Analysis

Analysis of Michigan statewide non-motorized crashes which occurred from 2009 to 2020 was performed. Out of 51,914 total non-motorized crashes recorded in that period, 29,822 (57.5%) involved pedestrians while 22,092 (42.5%) involved bicyclists. The distribution of these crashes by speed limit category is shown in Table 4.1. The focus of this study is on higher speed corridors (greater or equal to 45 mph and lesser than 65 mph). However, to get a better picture of the difference between higher-speed corridors and lower-speed corridors (less or equal to 40 mph), a comparative analysis of non-motorized crashes was performed. Table 4.1 shows that about 72% of non-motorized crashes occurred in lower speed corridors while only 20% of crashes occurred in higher speed corridors.

Table 4-1. Non-motorized Crashes Proportion by Speed Limit Category

Variable	Total Non-Motorized Crashes	Percent on Low- speed corridors (<=40 mph)	Percent on High-speed corridors (45-65 mph)	Percent on freeways (>65 mph)	Percent on unknown Speed Limit
Total Pedestrian Crashes	29,822	70%	20%	2%	8%
Total Bicycle Crashes	22,092	75%	21%	0.3%	3.7%
Total Non-motorized Crashes	51,914	72%	20%	1%	7%

4.1.1 Crash Severity

It is important to determine how the proportion of severe crashes varies among non-motorized crashes which occurred on lower speed and higher speed corridors. Figure 4.1 shows the total number of pedestrian crashes and proportion of fatal (K) and incapacitating (A) crashes by speed limit. Similarly, Figure 4.2 shows the total number of bicyclist crashes and proportion of fatal (K) and incapacitating (A) crashes by speed limit. Both Figure 4.1 and Figure 4.2 show that the severity increases as the speed limit increases. Although higher number of pedestrian and bicyclist crashes occurred on roads with 25 mph speed limit, only 15% and 2% were KA crashes respectively.

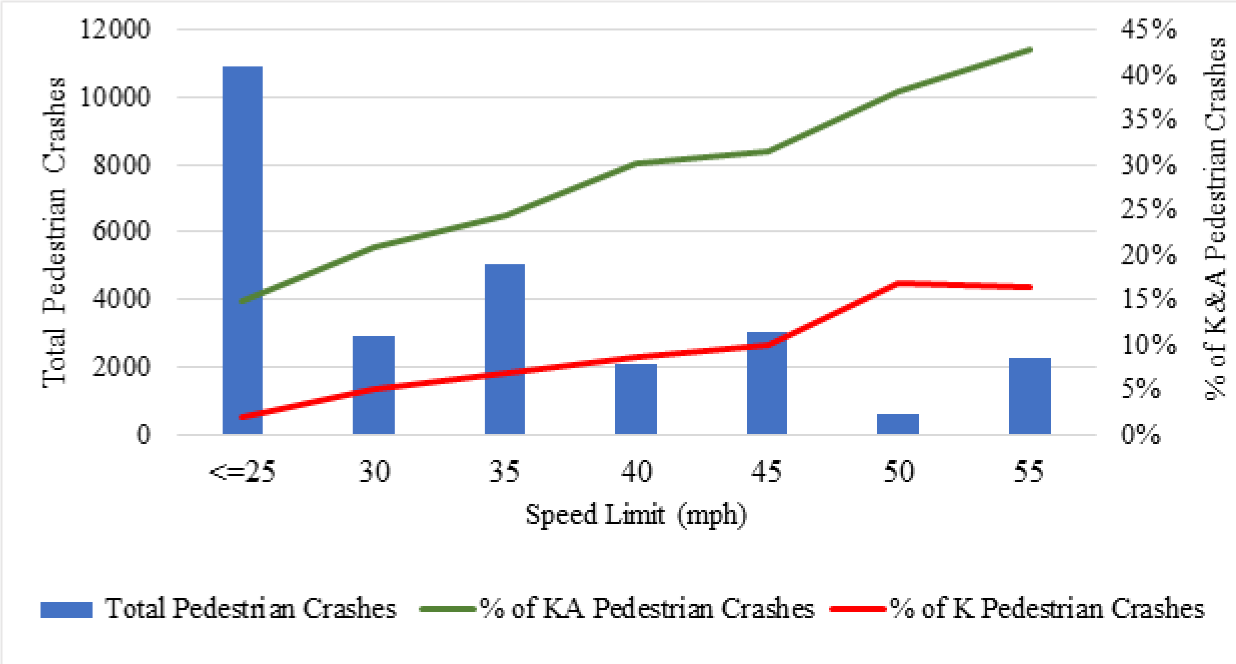


Figure 4-1. Pedestrian Crashes Distribution Based on Speed Limits

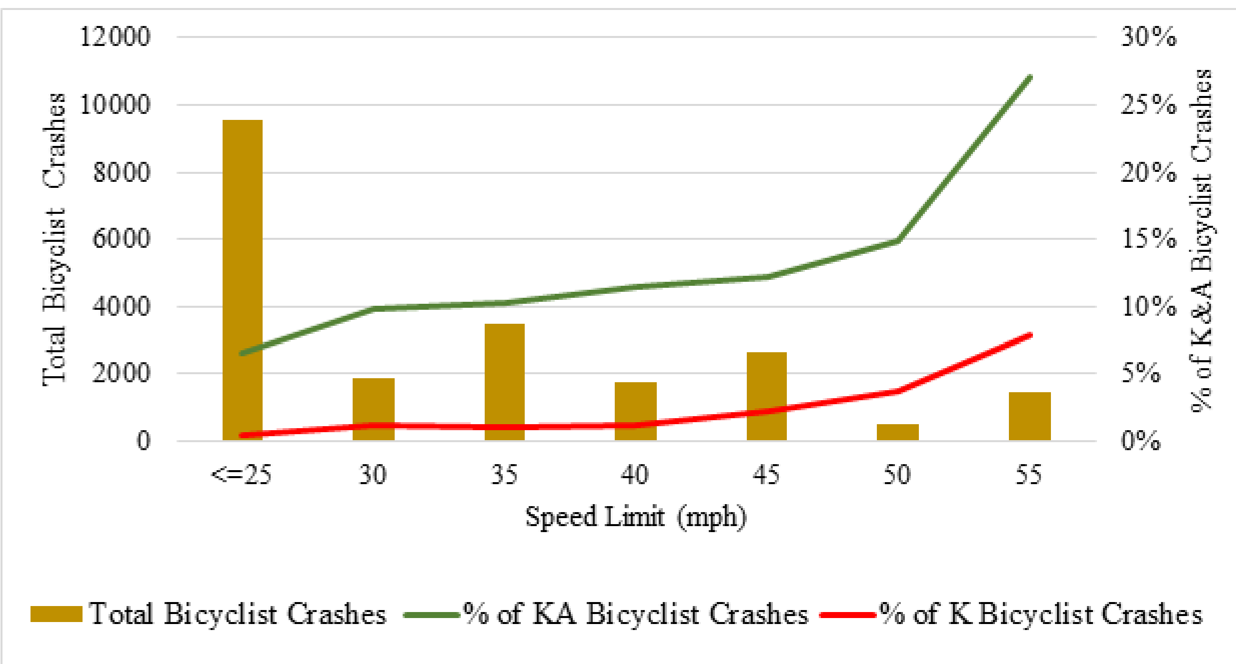


Figure 4-2. Bicyclist Crashes Distribution Based on Speed Limits

4.1.2 Area Type (Urban/Rural)

Crashes were also analyzed based on the area type (urban/rural) to investigate the differences between urban and rural areas. Urban areas are defined as those areas with at least 5,000 population. The non-motorized crashes were imported in ArcGIS to categorize them into either urban or rural according to where they had occurred. The urban boundaries GIS shapefile from MDOT open GIS data were utilized. Out of all non-motorized crashes, 91.5% (47,481) were successfully categorized into either urban or rural while the rest 8.5% (4,433) had missing coordinates information hence couldn't be analyzed in ArcGIS.

Overall, most non-motorized crashes occurred in urban areas, 92% (43,456). Furthermore, Table 4.2 shows the distribution of urban non-motorized crashes by lower and higher speed corridors. It shows that about 79% of urban non-motorized crashes occurred on lower-speed corridors while 18% of all non-motorized crashes occurred on high-speed corridors.

Table 4-2. Urban Non-motorized Crashes Proportion by Speed Limit Category

Variable	Total Urban Non-Motorized Crashes	Percent on Low- speed corridors (<=40 mph)	Percent on High-speed corridors (45-65 mph)	Percent on freeways (>65 mph)	Percent on unknown Speed Limit
Pedestrian Crashes	23,775	79%	18%	2%	1%
Bicycle Crashes	19,681	80%	18%	0.3%	1.7%
Total Non-Motorized Crashes	43,456	79%	18%	1%	2%

Considering severity of these crashes, Table 4.3 shows the percentage of KA crashes for urban lower and higher speed corridors. Although urban lower speed corridors have a high number of crashes, Table 4.3 shows there is a 14% chance that these crashes would be severe (KA crashes). On the other hand, there is a 25% chance that a non-motorized crash on an urban high-speed corridor would be severe. Clearly, there is a high chance that an urban non-motorized crash on high-speed corridors will be severe compared to a crash on urban lower speed corridors.

Table 4-3. Urban KA Non-motorized Crashes Proportion by Speed Limit Category

Variable	Urban Non-Motorized Crashes on Low-Speed Corridors (<=40 mph)	Percent KA Crashes on Low- Speed Corridors (<=40 mph)	Urban Non-Motorized Crashes on High-Speed Corridors (45-65 mph)	Percent KA Crashes on High- Speed Corridors (45-65 mph)
Pedestrian Crashes	18,677	20%	4,102	35%
Bicycle Crashes	15,650	8%	3,545	14%
Total Non-Motorized Crashes	34,317	14%	7,647	25%

For the case of rural crashes, Table 4.4 shows that about 65% of rural non-motorized crashes occur on high-speed corridors while 31% of all non-motorized crashes occur on low-speed corridors. Clearly, more rural non-motorized crashes occur on higher-speed roads compared to lower-speed roads. Similar to urban areas, in rural high-speed corridors there is a high probability of a non-motorized to be severe compared to rural low-speed corridors. Table 4.5 shows there is a 19% chance that non-motorized crashes would be severe (KA crashes) on rural low-speed corridor. On the other hand, there is a 37% chance that a non-motorized crash on a rural high-speed corridor would be severe.

Generally, there is a higher number of non-motorized crashes in urban low-speed corridors compared to high-speed corridors. Also, there are more rural high-speed corridor non-motorized crashes compared to low-speed corridors. However, regardless of the area type (urban or rural), high-speed corridors non-motorized crashes have higher odds of resulting in a severe crash compared to those on low-speed corridors.

Table 4-4. Rural Non-motorized Crashes Proportion by Speed Limit Category

Variable	Total Rural Non-Motorized Crashes	Percent on Low- speed corridors (<=40 mph)	Percent on High-speed corridors (45-65 mph)	Percent on freeways (>65 mph)	Percent on unknown Speed Limit
Pedestrian Crashes	2,522	29%	66%	3%	2%
Bicycle Crashes	1,503	34%	64%	0.2%	1.8%
Total Non-Motorized Crashes	4,025	31%	65%	2.2%	1.8%

Table 4-5. Rural KA Non-motorized Crashes Proportion by Speed Limit Category

Variable	Rural Non-Motorized Crashes on Low-Speed Corridors (<=40 mph)	Percent KA Crashes on Low- Speed Corridors (<=40 mph)	Rural Non-Motorized Crashes on High-Speed Corridors 45-65 mph)	Percent KA Crashes on High- Speed Corridors (45-65 mph)
Pedestrian Crashes	737	**25%**	1,653	41%
Bicycle Crashes	516	**11%**	965	29%
Total Non-Motorized Crashes	1,253	**19%**	2,618	37%

4.1.3 Lighting Condition

Studies suggest that nighttime conditions result in severe crashes compared to daytime conditions (Alogaili & Mannering, 2022). Therefore, it is important to analyze non-motorized crashes with respect to the lighting conditions. Figure 4.3 shows the percentage of total non-motorized crashes by speed limit and lighting conditions. It is evident that more dark-unlighted crashes occur on higher-speed corridors compared to lower speed corridors. Also, Figure 4.4 shows the percentage of KA non-motorized crashes by speed limit and lighting conditions. Similar trend is observed, a higher proportion of fatal or incapacitating injury crashes on dark -unlighted crashes occur on higher speed corridors.

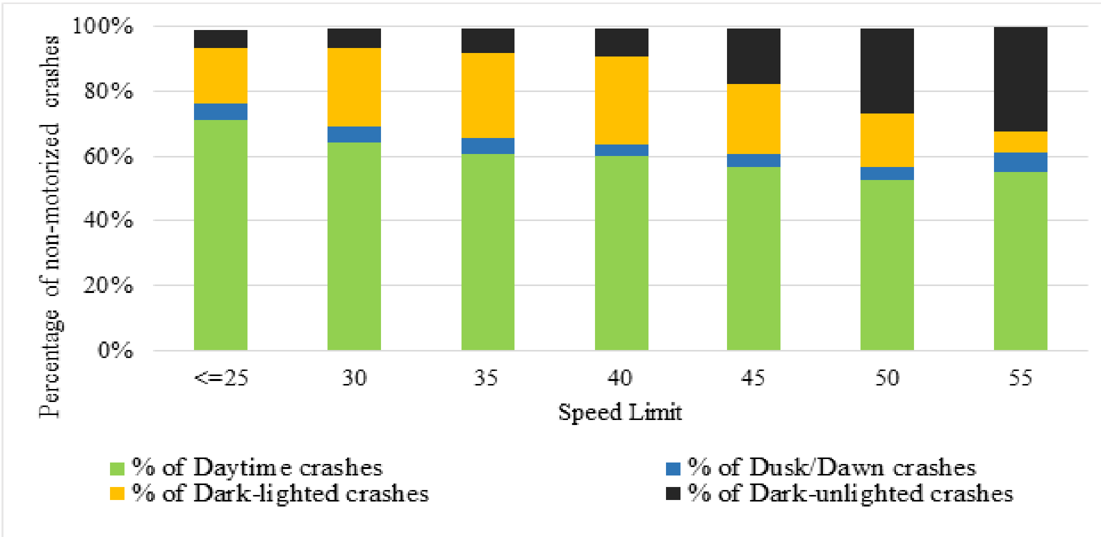


Figure 4-3. Percentage of Non-motorized Crashes Based on Speed Limit and Lighting Conditions

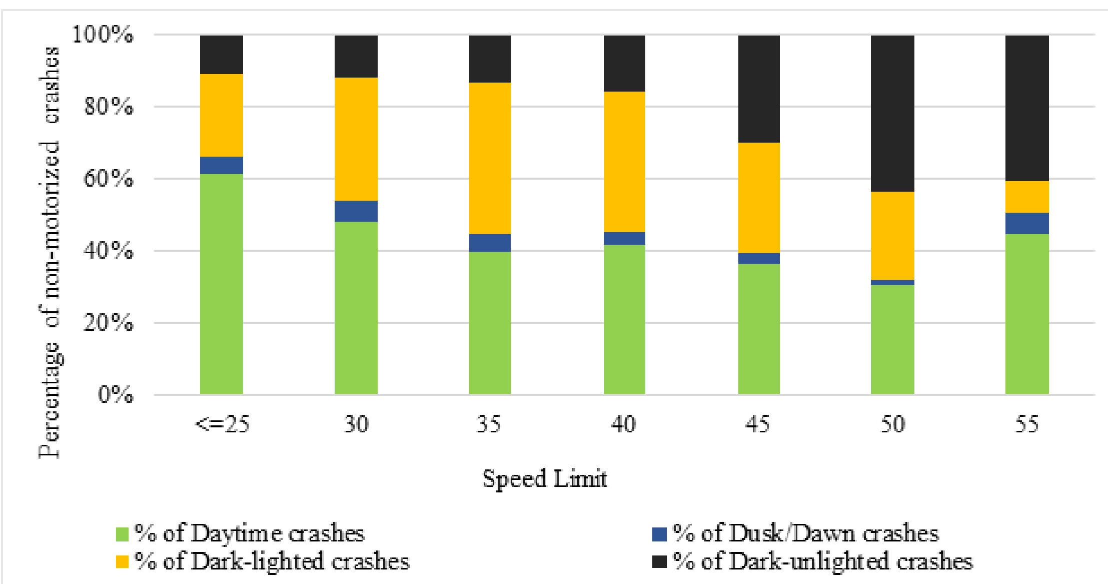


Figure 4-4. Percentage KA Non-motorized Crashes Based on Speed Limit and Lighting Conditions

4.1.4 Location Type (Intersection/Midblock)

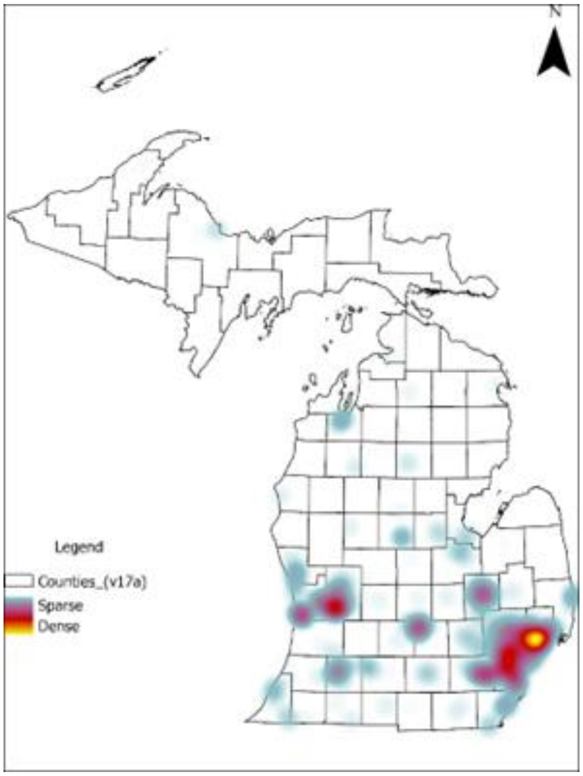
Intersection crashes were classified as those non-motorized crashes which occurred within 150 feet radius of intersection (Dolatsra et al., 2017). Table 4.6 shows the proportion of non-motorized crashes based on location type (intersection/midblock) and speed limit category. In urban low-speed corridors, more crashes occured at intersections (58%) compared to midblock locations. On the other hand, urban high-speed corridors have more crashes occurring on midblock (55%) compared to intersections. For the case of rural areas, both low-speed corridors and high-speed corridors experienced more crashes on midblock compared to intersections. However, a higher proportion of midblock non-motorized crashes is observed in high-speed corridors (85%) compared to low-speed corridors (55%).

Table 4-6. Location Type and Non-motorized Crashes Proportion by Speed Limit Category

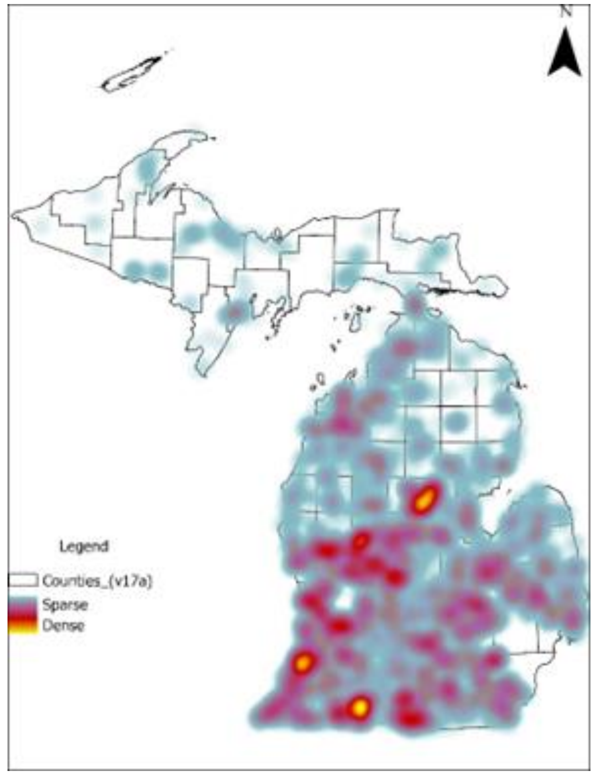
Area Type	Low –Speed Corridors			High –Speed Corridors		
	Non-motorized Crashes	Crash Location	Percent of Non-motorized Crashes	Non-motorized Crashes	Crash Location	Percent of Non-motorized Crashes
Urban	34,317	Intersection	58%	7,647	Intersection	45%
		Midblock	42%		Midblock	55%
Rural	1,253	Intersection	45%	2,618	Intersection	15%
		Midblock	55%		Midblock	85%

4.2 Selection and Site Visits of Higher-Speed High-Risk Corridors

Identifying high risk corridors was necessary so as to understand the crash patterns and identify the most potential locations for improvements. First, heat maps using a larger radius were produced using crashes to identify the MDOT regions where the non-motorized crashes are concentrated. Figure 4.5 shows heatmaps for urban and rural high-speed corridor crashes. The maps show that non-motorized crashes on high-speed corridors are concentrated in Southeast Michigan cities (especially Detroit), Grand Rapids, Lansing, Kalamazoo, Holland, Muskegon and Flint cities. On the other hand, rural crashes are scattered with few hotspots. Rural high-speed corridor non-motorized crashes are concentrated in the following counties: Clare, Montcalm, Van Buren, St. Joseph, Branch, Ottawa, Mecosta, and Hillsdale.



(a)Urban



(b) Rural

Figure 4-5. Heatmaps for Non-motorized High-Speed Crashes in Michigan

4.2.1 Kernel Density Estimation

Kernel Density Estimation (KDE) estimates the density of features in the vicinity around those features. It calculates the magnitude per unit area of point features for this case crashes, around each output raster cell. When more points (crashes) are near the cell, a higher kernel density is attained while if points are far from the cell a lower kernel density is attained. There are two parameters which affect the KDE, which are search radius (bandwidth) and cell size (Thakali et al., 2015). Use of larger sizes results in densities which are over a larger area while smaller sizes result in computation over smaller areas but may take larger computational time. In this analysis, the selection of sizes was a trade-off between the computation area and time. A radius of 1,000 ft was used for high-speed corridors to clearly identify hotspots. Due to the differences between urban and rural areas, crash density maps were produced for urban and rural areas separately. Also, hotspots were also produced for midblock and intersections separately because in some instances corridors can be categorized as high-risk due to the presence of a high number of intersections with crashes. Separating the hotspots for midblock and intersection provides room for picking up corridors with a high number of crashes on both intersection and midblock. Figure 4.6 shows the KDE for the Southeastern area in Michigan for high-speed corridor crashes. The KDE is presented in a raster format which is made up of a grid of cells. Raster calculator tool in ArcGIS was used to remove all cells with zero density. The average density was used as a cutoff so as to remain with locations with high risk. From Figure 4-6, the high-speed KDE had average density of 3 non-motorized crashes per square miles. The corridors which appear as hotspots as shown in Figure 4-7 were selected as high-risk corridors.

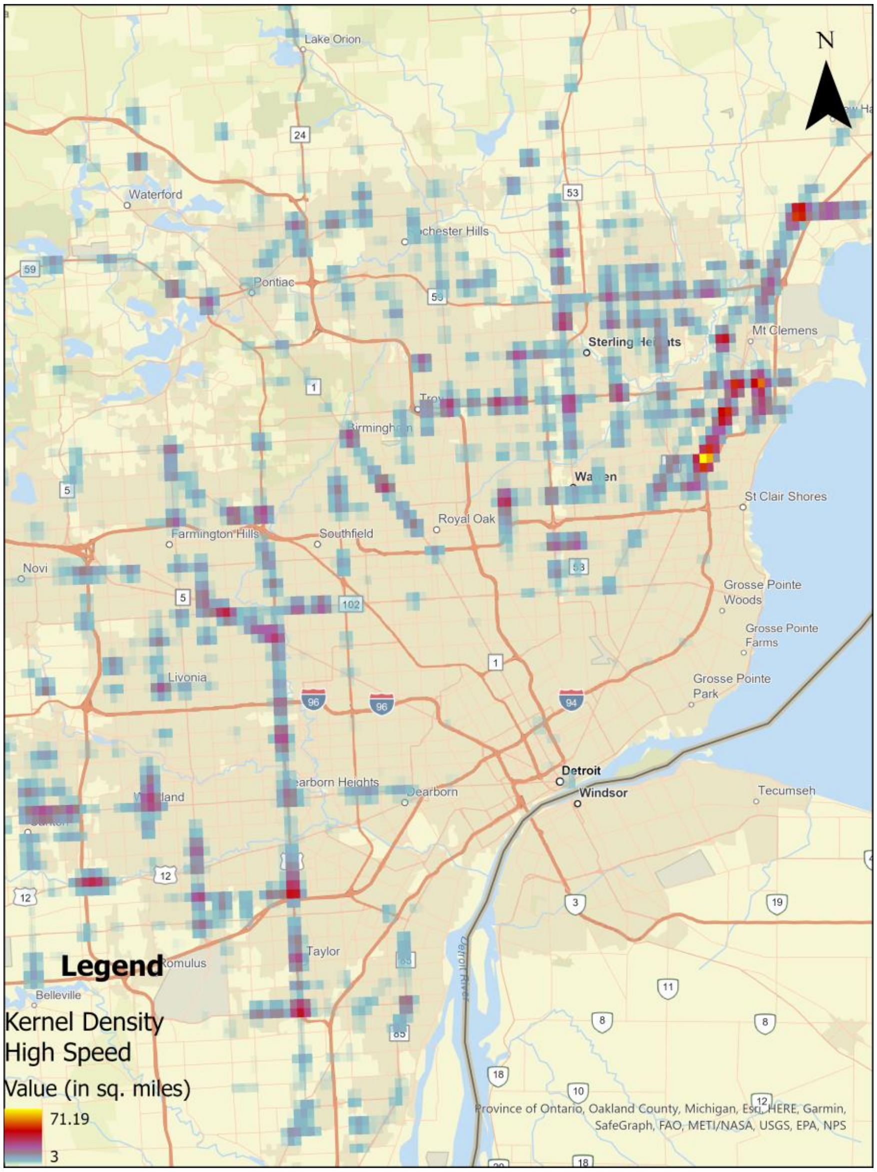


Figure 4-6. KDE for Non-motorized Crashes in Urban Southeast Michigan High-Speed Corridors

4.2.2 High-Speed High-Risk Corridors

A total of 37 corridors were selected from the locations which were observed from KDE raster as high-risk urban high- speed corridors and 27 as high-risk rural high-speed corridors. The complete list of these urban high-speed and rural high-speed high-risk corridors are shown in Appendix 9.8

and Appendix 9.9, respectively. The spreadsheet containing the list of high-risk corridors was also provided to MDOT as a standalone deliverable. Figure 4.7 is a map showing the selected high-speed high-risk corridors in Michigan.

Figure 4-7. Selected Urban and Rural High-Speed High-Risk Corridors

After selecting the high-risk corridors in both urban and rural areas as depicted in Figure 4-7, the crash rates were calculated so as to rank these corridors. Non-motorized crash rate was calculated based on total non-motorized crash on a given corridor over the twelve years of crash data. The roadway miles were used as the measure of exposure. The highest non-motorized crash rate in urban high-speed corridor is 3.8 crashes per mile per year while the highest crash rate in rural high-speed corridor is 0.5 crashes per mile per year (Figure 4-8).

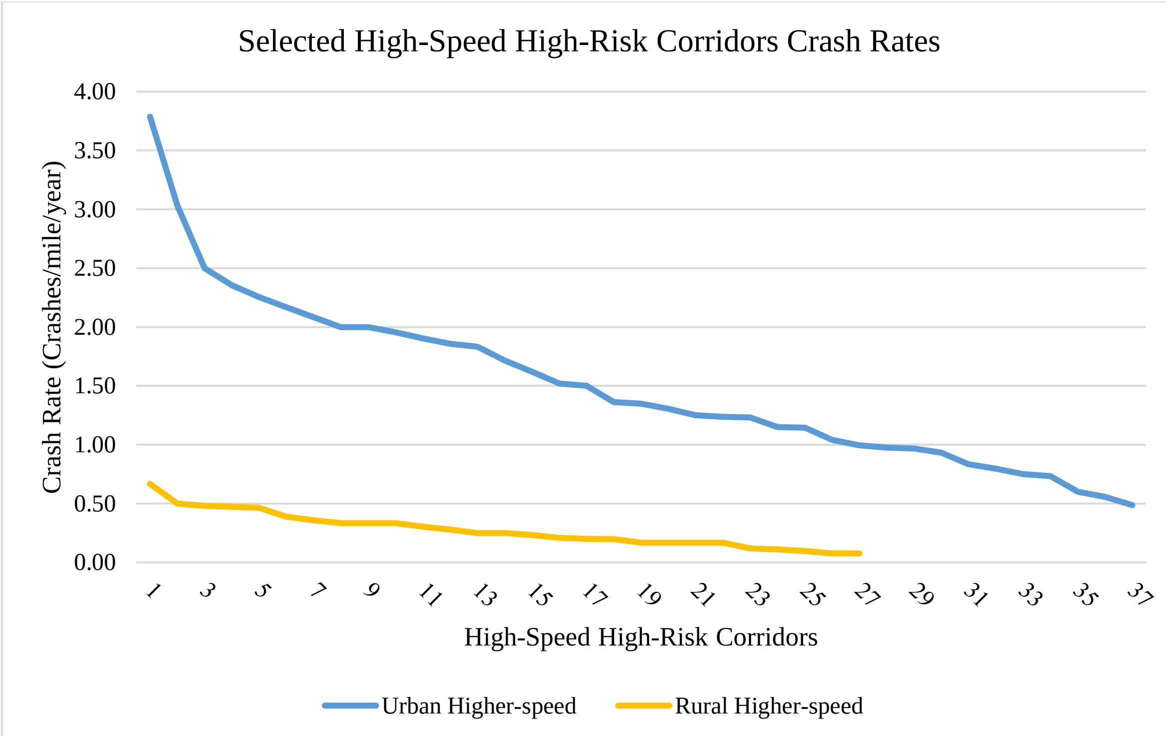


Figure 4-8. Non-motorized Crash Rates on High-Speed High-Risk Corridors

4.2.3 Site Visits for High-Speed Corridors

From the list of selected high-speed high-risk corridors, few sites with high crashes from different cities were selected for a site visit. Selection was based on the number of crashes as well as their severity. Also, the geographical location of the site was considered. The list of visited high-speed corridors is presented in Table 4-7.

The site visits provided a rich source of information in regard to the causes of crashes on higher speed roads. The WMU team consisting of Ron Van Houten, Jun Oh and Valerian Kwigizile visited crash sites with the UD-10 Traffic Crash Reports in hand and examined the police narrative and crash diagram for day and night crashes. If most crashes occurred at night the team visited the crash sites one hour or more after sundown and measured lighting levels using a Konica Minolta T-10A Illuminance Meter to measure the light intensity in Lux. One Lux is equal to one lumen per square meter. Federal Highway studies indicate that 25 Lux is a good level of illumination to see a pedestrian crossing at night. Based on the crash diagram and narrative the light level reading was taken at the approximate vicinity of each crash. The team also examined all crash sites during the daytime in order to better determine the presence of engineering features at each site, such as lane width, type of crosswalk marking, curb turning radii, and presence or absence of any crash countermeasures that might influence the presence of a crash.

Table 4-7. High-Risk High-Speed Corridors Selected for Site Visit

s/n	Corridor Name	Location	Length (Mi)	Crash Rate (Cr/Mi/Yr)	KA Crash Rate (Cr/Mi/ Yr)	Total Number of KA Crashes	Total Number of KA Nighttim e Crashes	Percentage of KA Nighttime Crashes
1	Harper Avenue	Detroit	0.5	3.79	0.76	4	4	100%
2	S. Groesbeck Highway	Detroit	0.5	3.03	1.13	6	6	100%
3	28th Street SE	Grand Rapids	0.5	2.08	1.14	11	8	73%
4	Division Avenue	Grand Rapids	0.4	3.13	0.42	2	2	100%
5	S. Gratiot Avenue	Detroit	3.3	2.35	0.64	26	14	54%
6	Riley Street	Holland	1.2	2.25	0.34	5	2	40%
7	Washtenaw Avenue	Ann Arbor	1.8	1.62	0.37	8	7	88%
8	Alpine Avenue	Grand Rapids	1.5	1.52	0.34	6	6	100%
9	S. Cedar Street	Lansing	3.3	1.25	0.35	14	8	57%

Examination of corridors with a high percentage of pedestrian crashes at night consistently had extremely low levels of illumination (between 1 and 12 Lux) at the crash sites. When pedestrians were observed crossing, they were difficult to see and appeared as shadows. In many cases the legacy light sources were on low light posts, or poor light sources on higher posts. At some sites higher intensity LED lighting was located near the crash site but was not aimed in such a manner as to illuminate the crosswalk.

4.2.4 Findings from Site Visits on High-Speed Roads

Harper Ave Detroit. North of 16 Mile Rd. Harper Ave has two lanes in each direction and a center turning lane. South of 16 Mile Rd the number of lanes is reduced to one lane in each direction with a center turning lane. The speed limit is 45 mph. Most crashes occurred at night along this corridor and 7 of the 8 K&A crashes along this corridor were at night.

One third of the crashes occurred at the intersection of Harper Ave and 16 Mile Rd. Three of these crashes were K&A crashes. Illumination measurements were taken at each corner at this location. All the lighting readings at this location were very low. Light readings at the NE Corner was 0.87 lux, at the SE corner 0.67 lux, at the NW corner 6.4 lux and at the SE corner 0.17 lux. Figure 4-9 shows the site layout and light readings.

Figure 4-9. Site layout and light readings at Harper Ave, Detroit

Many of the crashes occurred at minor intersections and involved turning or through vehicles. Some crashes involved bicycles.

The following countermeasures would be helpful at this site.

1. Installing LED lighting at all the signalized crosswalks at the intersection with 16 Mile Road, a high crash area, light bars can be inexpensively installed on the signal mast arms to provide excellent lighting at all crosswalks. We also recommend installing high visibility crosswalk markings at this location.
2. Installation of refuge islands at some of the minor intersections could be helpful to pedestrians and possible cyclists crossing this road.
3. Improved spot lighting at all unmarked intersection locations would be helpful as well.

S. Groesbeck Highway at Cass Ave, Detroit. Groesbeck Hwy. has two travel lanes in each direction and a center turning lane with a posted speed of 50 mph. The WMU team visited this corridor on October 24, 2022 and conducted observations at crash sites along this corridor during daytime hours and took light meter readings after dark. At the NW and SW intersections of Groesbeck at Cass the right turn lanes have a wide turning radius. This contributes to the seriousness of crashes involving turning vehicles. Although a luminaire was located at three of the corners of this intersection and placement and aiming of the luminaires produced relatively poor lighting at three of the four corners. The light meter reading at each corner of the intersections are as follows: At the NE corner the light level was 85 lux, at the SW corner the light reading was 1.9 lux, at the NW corner the reading was 4.6 lux and at SE corner the reading was 6.7 lux. Crashes occurred at the intersections with low lighting.

Several of the crashes including the serious crashes occurred close to the Meijer located on Groesbeck Highway. The lighting on the sidewalk at Meijer was 0.6 lux. We saw a person walking a bike with groceries packed straddling the bicycle. He appeared as a shadowy figure because of the poor lighting. People from the community likely walk or use bicycles to shop at this store and better lighting is required. Figure 4-10 shows the site layout and lighting readings.

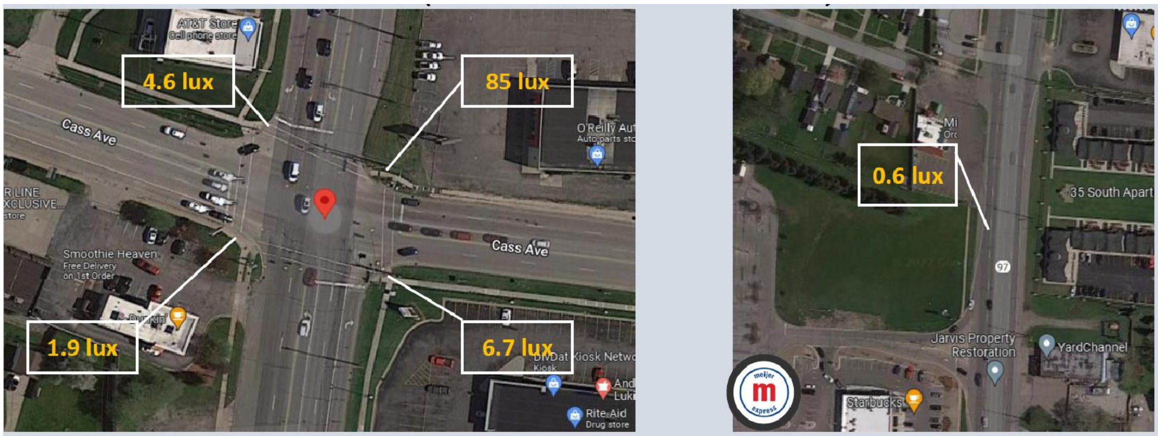


Figure 4-10. Site layout and light readings at S. Groesbeck Highway/Cass Ave, Detroit

The following additional countermeasures would be helpful at this site.

1. We strongly recommend aiming the luminaires at this crosswalk to provide better lighting and installing an additional luminaire on the SW corner of the intersection with 3 Mile Road, a high crash area. We would also recommend tightening the turning radii with rollable curb and installing high visibility crosswalks at this location.
2. We recommend installing LED lighting at the location in front of the Meijer's.
3. A refuge island may also be helpful at the site by the Meijer's store. since people need to cross to get to the store.
4. A high visibility crosswalk with advance stop lines and a RRFB or hybrid beacon should also be considered. Advance yield markings should also be installed.

E Beltline Ave SE/ 28th St SE at Mall Service Dr. Grand Rapids. The segment on E. Beltway Ave SE has two lanes in each direction with a center turn lane that is adjacent to the Woodland Mall and divides the Mall and several businesses and restaurants on the other side of the street as shown in Figure 4-11. There were 18 crashes in this segment with 10 (more than half) comprising K&A crashes. There are sidewalks on the West side of E. Beltline Ave but no sidewalks on the right side. All of the K&A pedestrian crashes but one (a multiple threat crash) along this corridor occurred at night. Two of these crashes were fatal.

Figure 4-11. Site Layout at 28th St SE/E Beltline Ave SE

The portion of this segment on 28th Street has two lanes in each direction with a center turn lane and is at the intersection of 28th St and Mall Service Dr. There were 4 crashes at this site, one which was a fatal crash and one that was an incapacitating crash. The fatal crash occurred at night and the injury crash occurred at Dawn. This intersection connects the Mall with businesses and restaurants. There are no crosswalks between the Mall and the other side of 28th St. or the other side of E. Beltway Ave SE. Figure 4-12 shows the section of the roadway lacking pedestrian crossings.

Figure 4-12. Section of E Beltline Ave SE lacking pedestrian crossings

Although daytime and night crashes were evenly divided at this site, all but one of the most serious crashes occurred at night. The absence of any way to cross to the South or East along this segment except for one signalized crosswalk contributes to the number of crashes. Ten of the 18 crashes occurred at Mall exits at Mall Dr. SE, E Mall Dr SE, and Mall Service Drive. It is possible that some of those struck may have arrived at the Mall by bus and were traveling between the Mall and other businesses. Others may have been staying at motels and traveling to a place to eat.

The following additional countermeasures would be helpful at this site.

1. Installation of LED lighting at all mall exit areas along this route.
2. Installation of refuge islands without crosswalks at the unsignalized exits to the mall on E. Beltline Ave.
3. Consideration of installing a signal at the intersection of 28th St. and Mall Service Road/Shaffer Ave SE. If a signal is installed it is recommended that the turning radii be reduced and that a high visibility crosswalk be added. If a signal with a mast arm is installed we recommend installing light bars under the mast arm to fully illuminate the crosswalks.

Division Ave S, Grand Rapids. Division Ave S is a five-lane road with two lanes in each direction and a center turn lane and a speed limit of 45 mph. On October 19, 2022 WMU team visited this corridor and conducted observations at crash sites along this corridor during daytime and nighttime hours. Eighty percent of the crashes along this corridor segment occurred at night. The lighting levels in this area are very poor with old style streetlights with 3.4 lux reading directly under the light and 0.7 lux between lights. Half of the crashes occurred at the signalized intersection at 60th Street. The pedestrian crashes in this area were all at night typically involving a turning vehicle. Illumination readings at this location are as follows. At the NW departure points the light readings were 1.4 and 1.1 lux, at the SW departure points the light readings were 10.5 and 13.8 lux, at the NE departure points the light readings were 5.5 and 0.43 lux, and at the SE departure points light readings were 1.52 and 1.75 lux. There was only one streetlight at this location at the SW corner. None of the crashes occurred at the corner that had the highest lighting level. Figure 4-13 shows the layout of the intersection of Division Ave and 60th Street as well as the light readings.

Figure 4-13. Site layout and light readings at the intersection of Division Ave and 60th Street, Grand Rapids

Several cyclists were also struck along this corridor, some at night and some during the day, many were struck by turning vehicles. In some cases, the cyclists were traveling in the wrong direction on the sidewalk. The wide turning radii at intersections may have contributed to these crashes. Observation along this corridor included pedestrians that appeared as shadows under poor lighting. Many of the crashes involved turning vehicles. Police reports typically mentioned the driver saying they did not see the pedestrian.

The following additional countermeasures would be helpful at this site.

1. Installing LED lighting at all the signalized intersections at 60th Street.
2. Replacing the street lighting along this segment with LED lighting.
3. Tightening the turning radius at crosswalks using rollable curb to facilitate trucks making turns.
4. Installing refuge islands without crosswalks or with an RRFB at the intersections at Violet St., Peony St., N. Kenbrook St., and Hyacinth St. If an RRFB is installed we recommend high visibility markings, advance yield markings, and dynamic LED lighting. If islands alone are installed, we do not recommend crosswalk markings.

S. Gratiot Ave., Detroit. South Gratiot Ave is a divided eight lane road with three lanes in one direction, four lanes in other directions and a center turn lane. This road has a speed limit of 50 mph. There is currently extensive construction at this site. On October 19. 2022 the WMU team visited this corridor and conducted observations at crash sites along this corridor during daytime and nighttime hours. The lighting of businesses along the route may contribute to the poor visibility at night on this roadway.

The majority of crashes occurred at intersections with a high percentage of serious and fatal crashes involving pedestrians occurring at the intersection with 3 Mile Road and the ramps for I-96.

Working from the UD 10 forms with close attention to the narrative and crash diagrams, we noted very poor lighting at these locations. At one fatal pedestrian crash location we noted that the crash occurred in an area with a turn lane onto the highway with a large turning radius and complete darkness (lighting level measured to be 0.1 lux. We noted many drivers making this turn at a high rate of speed.

Observation on the site included pedestrians as shadows under poor lighting. Many of the crashes involved turning vehicles.

The following countermeasures would be helpful at this site.

- We strongly recommend installing LED lighting at all the signalized crosswalks. If mast arms are installed as part of construction light bars could be installed under the mast arms to fully illuminate the crosswalks.
- Not all the crosswalks along S. Gratiot Road had high visibility crosswalk markings. We recommend installing them for all crosswalk legs along this corridor.
- We also recommend tightening the turning radii at crosswalks using rollable curb to facilitate trucks making turns.

Riley St., Holland. Riley street is a four-lane road with two lanes in each direction and a center turn lane and a posted speed of 50 mph. Most of the crashes on this road involved bicycles. On October 19, 2022 the WMU team visited this corridor and observed crash sites during daytime hours because most of the crashes occurred during the day. The road is too fast for bike lanes and there is only sidewalk on the North side of the road. This compels cyclists to travel against traffic. We noted cyclists riding on the sidewalk in both directions. At the signal at Riley and US-31 pedestrians need to wait too long to cross and need to make two separate crossings, one at the start and one at the median island. Pedestrians will not wait that long to cross. Most of the bicycle crashes (6) along this corridor involved bicycles hit by a right turning vehicle. The turning radius is so wide that vehicles turn at a high rate of speed. Tightening the radii with rollable curbs could help at these intersections. Figure 4-14 shows the intersection layout of Riley St and Highway 31.

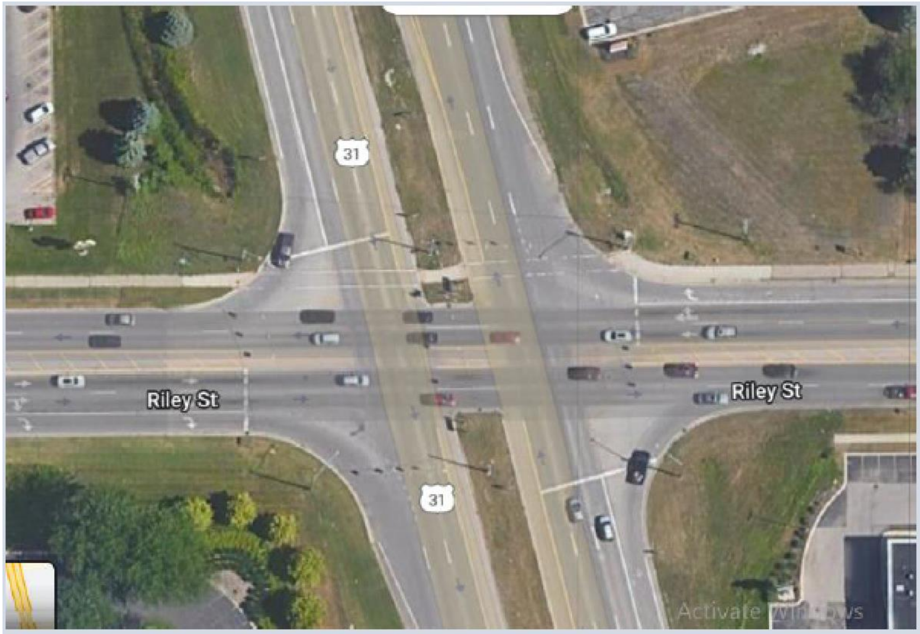


Figure 4-14. Intersection layout for Riley St. and US 31, Holland

At minor street such as John F Donnelly Dr. and Windquest Dr. there were crashes between bicycles and vehicles turning onto Riley St. Drivers do not expect cyclist on the sidewalk and they do not expect wrong way cyclists. The following countermeasures would by helpful this site.

1. At Riley St at 132nd Ave we would recommend reducing the turning radii and installing a RRFB along with high visibility markings, and advance yield markings.
2. At the intersection with US-31 we recommend providing pedestrians and cyclists more time to cross. We also recommend tightening the turning radii.
3. Widening the sidewalk so it looks like a walking and bicycle trail and tighten the turnings radii along the entire route.
4. At the trail crossing west of US-31 we recommend installing an RRFB along with advance yield lines and a high visibility crosswalk.
5. At the intersection of Riley and 128th Ave we recommend tightening the turning radii and installing high visibility crosswalk markings.
6. At minor intersections at John F Donnelly Drive, and Windquest Dr. place stop signs for bicycles. High visibility crosswalks. Place bicycle signs with reflective bases. Also consider Look for bicycles both ways sign in paint in roadway.
7. As a general countermeasure, painting bicycle symbols in the roadway just before the sidewalk going in both directions is another potential option.

Washtenaw Ave, Ann Arbor.

Washtenaw Ave is a five-lane road with two lanes in each direction and a center turn lane with a speed limit of 45 mph. On October 24, 2022 the WMU team visited this corridor and conducted observations at crash sites along this corridor during daytime and nighttime hours. There is no street lighting along this road. The lighting of businesses along the route may contribute to the poor visibility at night along this roadway. We measured lighting at one gas station along the route at 690 lux.

Most crashes along this corridor and all K&A crashes occurred at intersections locations, both signalized and unsignalized sites. Most crashes including K&A crashes occurred at minor intersections without a traffic signal. The light levels measured at these locations were between 0.2 and 0.6 lux. Observation on the site included pedestrians as shadows under poor lighting. Many of the crashes involved turning vehicles. Some of these crashes involved pedestrians crossing at a bus stop location.

Light meter readings at signals were better with only one K&A crash at a signalized location at Washington and Carpenter with readings with illumination readings at the corners varying between 26.5 lux and 45.3 lux except for the one corner with a light level of 13.2 lux. The single K&A crash at this location involved a pedestrian struck starting the crossing from the darkest corner. Two K&A Crashes occurred at the signalized intersection at Golfside Road. Both pedestrians began crossing from the corner with the poorest lighting (5.1 and 4.5 lux, 2.1 and 5.2 lux). The remaining intersections with no crashes had higher reading with on at 37.2 and 34.2 lux and 22.4 and 7.4 lux. Eight crashes occurred at the signalized intersection of Glencoe Hills Drive and Dalton Ave. This is the only signalized intersection with mast arms.

The following countermeasures would be helpful at this site.

1. We recommend installing LED light bars on all of the mast arms at the intersection of Glencoe Hills and Dalton Ave.
2. We recommend installing LED lighting at each of the minor intersection along this route.
3. As speed is also a factor in these crashes, we would recommend reducing the speed limit at this site. Solar powered feedback signs and other countermeasures could be helpful in improving compliance with a reduced speed limit if supported by a speed study.
4. We also recommend tightening the turning radius at crosswalks using rollable curb to facilitate trucks making turns. Installing refuge islands at locations with crashes would also be helpful. In some cases, an RRFB with advance stop lines and a high visibility marked crosswalk could be considered if the speed is reduced. We also recommend that the dynamic lighting feature be included with the RRFB.

Alpine Ave. Grand Rapids. Alpine Ave NW is a five-lane road with three lanes in one direction two lanes in the other direction and a center turn lane and a speed limit of 45-50 mph. On October 19th the WMU team visited this corridor along with one of our graduate students conducted observations at crash sites along this corridor during daytime and nighttime hours. The lighting of businesses along the route may contribute to the poor visibility at night on the roadway. The majority of these crashes occurred at intersections with a high percentage serious and fatal crashes involved pedestrians and occurred at the intersection with Alpine Ave and the ramps for I 96 (Figure 4-15).

Figure 4-15. Site Layout at Alpine Ave showing its intersection with ramps for Interstate 96

Working from the UD 10 forms with close attention to the narrative and crash diagrams, we noted very poor lighting at these locations. At one fatal location we noted that the crash occurred in an area with a turn with a large turning radius and complete darkness (lighting level measured to be 0.1 lux). Figure 4-16 shows nighttime conditions at the location where a fatal crash was recorded.

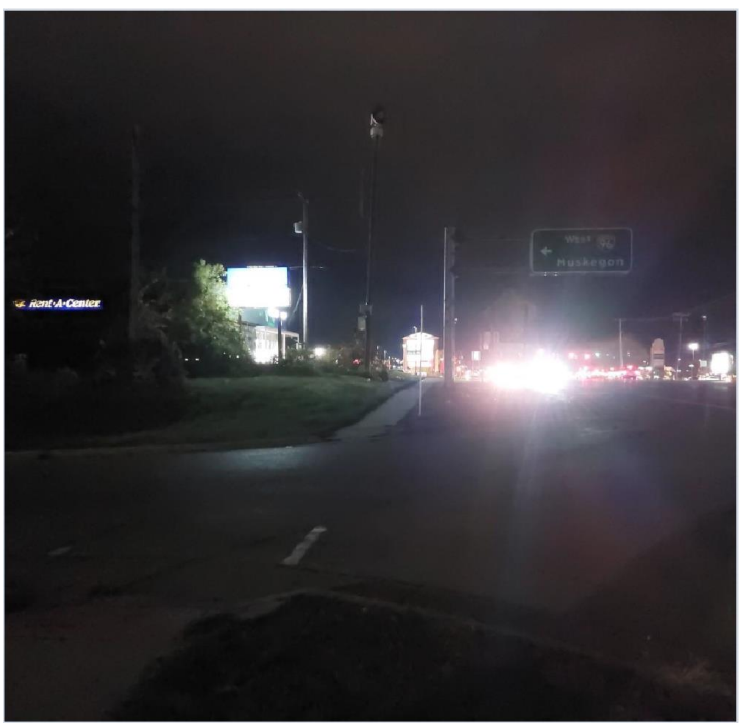


Figure 4-16. Nighttime condition at Alpine Ave and the I-96 ramp

Observation on the site included pedestrians as shadows under poor lighting. Many of the crashes involved turning vehicles.

The following additional countermeasures would be helpful at this site.

- We strongly recommend installing LED lighting at all the signalized crosswalks.
- Not all of the crosswalks on Alpine Ave NW had high visibility crosswalk markings. We recommend installing them for all legs along this corridor.
- We also recommend tightening the turning radius at crosswalks using rollable curb to facilitate trucks making turns.

S. Cedar St. Lansing. S Cedar Street is a five-lane road with two lanes in each direction, a center turn lane and a speed limit of 45 mph (Figure 4-17). On November 9, 2022 the WMU team visited this corridor and conducted observations at crash sites during daytime hours and a light reading at and between crosswalks. There are many access points along this road and only a few signals and one Hybrid Beacon at a trail crossing. Most of the crashes along this corridor occurred during the day. Working from the UD 10 forms with close attention to the narrative and crash diagrams, we noted a high proportion of crashes involved bicycles. These crashes during the day and at night tended to occur midblock. We also observed the behavior of drivers, pedestrians, and cyclists. Observation along this corridor included seeing pedestrians crossing midblock and seeing cyclists riding on the sidewalk. The major issues were speed and lack of adequate opportunities to cross the street.

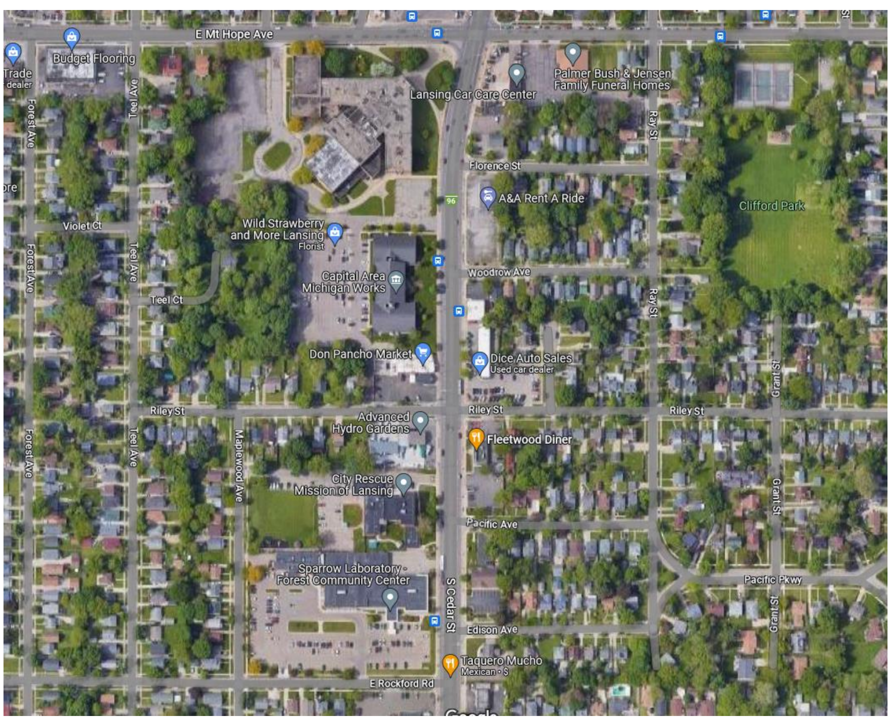


Figure 4-17. Site Layout at S Cedar St showing a segment from E Mt Hope Ave to E Rockford Rd

Because of the speed and few places to cross the street, cyclists on one side of the road tended to ride against the direction of traffic on the sidewalk. Cyclists were also struck crossing the roadway midblock or at the location of a minor street without a crosswalk. S. Cedar Street is a bus route and some crashes involve pedestrians crossing the street near bus stops. Pedestrian generators such as businesses and restaurants were located on both sides of the street. The northern portion of the street passed through a residential area with houses located close to the street. At traffic signals some crashes involved pedestrians starting during the flashing Don't Walk indication

This site had LED street lighting on both sides of the road. We took light meter readings an hour after sunset below the LED lighting at the curb and between two lights at the curb. After examining the lighting, we noticed that the lighting for the area under the streetlights was 57.5 lux which is above the recommended lighting level of 20 lux. Between crosswalks the lighting level was 18.8 lux which is just a bit below 20 lux. Given the LED lighting allowed use of the daytime vision (cones), we felt that nighttime visibility along this corridor was excellent. Figure 4-18 shows the nighttime condition during site visit.

Figure 4-18. Lighting condition along S. Cedar St., Lansing

The following crash countermeasures would be helpful at this site.

- Because there are few places to cross the street, we would recommend pedestrian refuge islands to be installed in the areas with multiple midblock crashes. This would allow pedestrians to cross one half of the roadway at a time. This countermeasure is associated with a robust crash reduction factor. These islands could be placed close to street lighting to help reduce midblock crashes at night. We do not recommend installing crosswalks at these sites because of the risk of multiple threat crashes.

- Installing count down timers at signalized locations might be helpful because some crashes involved starting to cross late in the cycle. We also recommend installing high visibility crosswalk markings and tightening the turning radii at these sites. High visibility crosswalks should be considered if RRFB or PHB are installed with advance yield or advance stop lines.
- We also recommend reducing the speed of this corridor to 35 mph if supported by a speed study. Compliance with the new speed could be improved by using paint to reduce lane width and using solar speed feedback signs. We would also recommend using large signs at the start of the reduced speed zone with signs on both sides of the road facing the reduced speed zone, and a third sign on an island in the center lane.

4.3 Identification of High-Risk Corridors on Lower Speed Roads

Although the focus of this study was on high-speed roads (those with a posted speed limit of 45 mph and above), the research team replicated the methodology to identify high-risk corridors in lower speed roads at the request of MDOT. The main goal of this added task was to generate necessary information needed by MDOT to perform assessments of vulnerable road user (VRU) crashes.

4.3.1 Selection of Lower Speed High-Risk Corridors

A total of 155 urban corridors and 28 rural corridors were selected from the locations which were observed from KDE raster as high-risk. Figure 4-19 is a map showing the selected urban and rural high-risk low-speed corridors in Michigan. The complete list of these urban lower speed high-risk corridors is shown in Appendix 9.10 while the complete list for rural lower-speed corridors is shown in Appendix 9.11. The spreadsheet containing the list of high-risk corridors was also provided to MDOT as a standalone deliverable. The list shows that 96% (27) of the selected high-risk rural low speed corridors passed through either a village or city. Moreover, 80% (22) of these corridors were connected to high-speed road segments less than 2 miles away. After selecting the corridors which are shown in Figure 4-19, the crash rates were calculated so as to rank these corridors. Figure 4-20 shows the crash rates of the selected low-speed corridors.

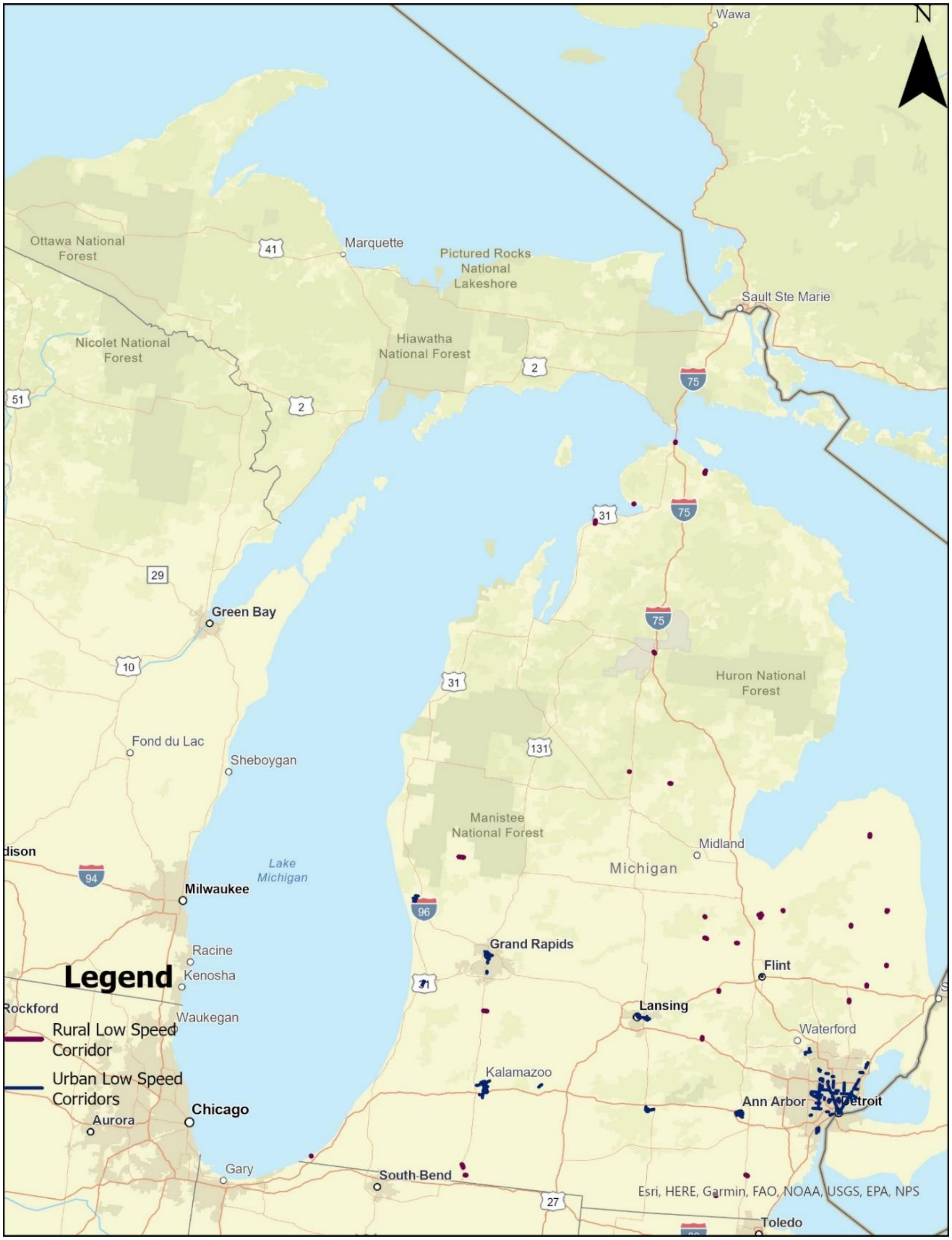


Figure 4-19. Selected Urban and Rural Low-Speed High-Risk Corridors

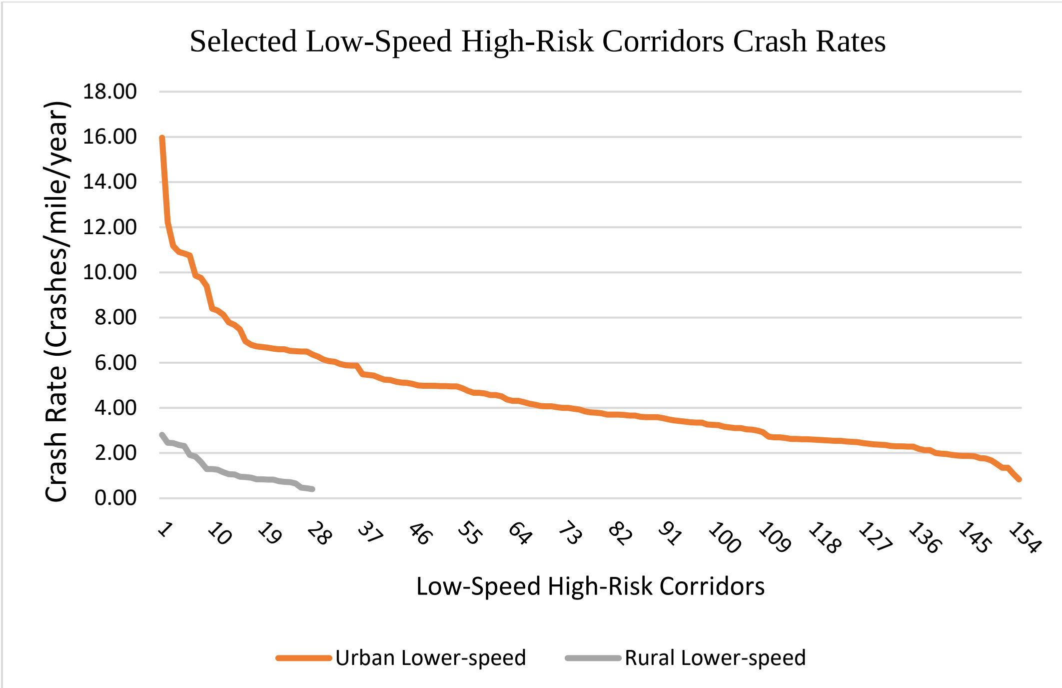


Figure 4-20. Non-motorized Crash Rates on Low-Speed High-Risk Corridors

From the list of selected low-speed high-risk corridors, eight sites with high crashes from different cities were selected for a site visit. Selection was based on the number of crashes as well as their severity. Also, the geographical location of the site was considered. The list of visited low-speed corridors is presented in **Table 4.8**.

Table 4-8. High-Risk Low-Speed Corridors Selected for Site Visit

s/n	Corridor Name	Location	Length (Mi)	Crash Rate (Cr/Mi/Yr)	KA Crash Rate (Cr/Mi/ Yr)	Total Number of KA Crashes	Total Number of KA Nighttime Crashes	Percentage of KA Nighttime Crashes
1	Fulton Road	Grand Rapids	0.59	12.2	1.26	9	3	33%
2	Martin Luther King Boulevard	Detroit	0.44	10.91	150	8	8	100%
3	E Grand River Avenue	E Lansing	1.16	10.76	1.15	16	2	13%
4	S University Avenue	Ann Arbor	0.38	8.4	1.11	5	0	0%
5	E Michigan Avenue	Lansing	0.65	7.47	0.9	7	6	86%
6	S River Avenue	Holland	0.57	6.05	0.59	4	1	25%
7	Gratiot Avenue	Detroit	1.76	5.9	2.04	43	38	88%
8	W Michigan Avenue	Kalamazoo	1.21	4.1	0.76	11	8	73%

4.3.2 Findings from Site Visits on Lower Speed Roads

West Michigan Ave between S. Drake Rd. and Howard St. This road has two lanes in each direction and a center turning lane. The speed limit along this corridor is 35 mph. An extra turn lane exists at the intersection of Howard St. On June 15, 2023, the WMU team visited this corridor and conducted observations at crash sites during daytime hours and light readings were made at all night crash sites beginning one hour after sunset. This site was interesting because all the fatal crashes occurred at night and 73% of all crashes occurred at night. Eighty six percent of the night crashes occurred at lighted locations. Light readings at crash sites varied between 0.3 lux and 12.9 lux. and most crash sites had light readings below 5 lux.

The following crash countermeasures would be helpful at this site.

1. Because most crashes occurred at night, we recommend installing LED lighting at intersections along this corridor. The signalized intersection at Emajean St. has signal mast arms and we recommend installing light bars under the mast arm crossing West Michigan. This was the site of one of the fatal crashes. We also recommend installing light bars at the signalized intersections of Eldridge Dr., Dobbin Dr., and Greenwood Ave. which also have signal mast arms.

2. Several crashes occurred at night at the signalized intersection of West Michigan Avenue and Howard St. Because this intersection has span wires, we recommend installing luminaires at each corner of the intersection at this location.

3. We also recommend installing refuge islands and improved LED lighting at minor street locations along with RRFBs with adding dynamic lighting and advance yield markings and signs.

E. Grand River Ave between and Abbot Rd. and Hagadorn Road. This road has three lanes in each direction divided by a median island between Abbot Rd, and just before Durand St. and two lanes in each direction from Durand Rd. and Hagadorn Rd. There is a wide sidewalk on the NE side of the intersection that serves as a multiuse pedestrian/bicycle path. We observed many pedestrians and bicyclists using this sidewalk as a trail. The speed limit along this corridor is 25 mph for the portions divided by a median island and 35 mph for the remainder of the corridor. The WMU team visited this corridor on August 9, 2023, and conducted observations at crash sites during daytime hours. Only 13% of K&A crashes occurred at night at this site. Along the road segment divided with a solid median there are six crosswalks marked with high visibility markings and four crosswalks with signals with transverse markings. There is one crosswalk at a bus stop along the remainder of the corridor that is marked and two traffic signals also four crosswalks marked with transverse lines with traffic signals along this portion of the road with a paved median marked with high visibility markings and two crosswalks marked with transverse lines. At Hagadorn each crosswalk traverses six lanes.

The following crash countermeasures would be helpful at this site.

1. At the intersection of E. Grand River Ave. and Hagadorn Rd. Lansing. we recommend high visibility markings and improved lighting. We also recommend high visibility markings at all signalized crosswalks along this corridor.

2. Many of the crashes along this corridor occurred at intersections with wide sidewalks which serves as a walking/bicycling path. These crashes involved a pedestrian or cyclist in the crosswalk being struck by a vehicle proceeding at the stop sign to cross E. Grand River Ave. We recommend high visibility crosswalk markings at each of these crosswalks and the installation of pedestrian warning signs on both sides of the road facing the intersection to warn drivers to watch for pedestrians and cyclists in the crosswalk. This is most critical at the T intersections with Spartan Ave, Milford St., and Division St.

East Michigan Ave between N. Grand Ave. and S. Pennsylvania Ave. Lansing. This road has four lanes and a center turning lane and some on road parking. The speed limit along this corridor is 30 mph The WMU team visited this corridor on August 9, 2023, and conducted observations at crash sites during daytime hours and light readings were made at all night crash sites beginning one hour after sunset. At this site 86% of K&A crashes occurred at night. Light readings were taken at most departure points varied between 17.8 lux and 158 lux. At one of the two departure points with low readings one of two bulbs was burned out and at the other the post was further away from the intersection. However, the current light sources provided less illumination within the crosswalk with readings between 5 lux and 10.8 lux. Seven the eight K&A crashes that occurred at this site occurred within the crosswalk at locations with poor lighting.

The following crash countermeasures would be helpful at this site.

1. Because most crashes occurred at night, we recommend installing LED lighting at intersections along this corridor. This type of lighting would illuminate most of each crosswalk.

2. A couple of crashes occurred close to a bus stop. We also recommend consideration of far side bus stops to discourage transit users from crossing in front of the bus.

W. Fulton St. between Monroe Ave. NW and Lafayette Ave SE., Grand Rapids. This road has four lanes and a center turning lane and median between Monroe Ave and Jefferson Ave SE and is 4 lanes from there to Lafayette Ave SE. with some on street parking. The speed limit along this corridor is 25 mph and most of the K&A crashes occurred during daylight conditions. The WMU team visited this corridor on August 9th and conducted observations at crash sites during daytime hours. There are no bicycle lanes on Fulton St. and many cyclists ride in the street. High speed cycling down a hill led to several serious bicycle crashes at this site. The hill and cyclist speed and inability to brake effected these crashes. Several of the cyclists were trying to beat the signal and crashed with through vehicles.

The following crash countermeasures would be helpful at this site.

1. We recommend warning signs for bicyclists to maintain a safe speed on the downhill section to avoid a serious crash. These signs should be large and conspicuous and marking could be added with a message to support these signs.

S. River Road, between E. 16th St. and W. 7th St. Holland. This road has two north bound lanes and one south bound lane and a center turn lane. The speed limit is 30 mph transitioning to 25 mph north of 9th Street. The WMU team visited this site on Aug 9, 2023, during daylight hours because only 25% of K&A crashes occurred during nighttime hours. We observed many pedestrians and bicyclists at this site. Most bicyclist's road on the sidewalk. This is a downtown site with a high traffic volume and a large amount of truck traffic.

The following crash countermeasures would be helpful at this site.

1. We suggest high visibility crosswalks at each of the signalized intersections.

2. We also suggest installation of signage to prompt motorists to look for cyclists.

3. Many cyclists were struck at stop sign locations. We recommend placing multiple stop signs, one on each side of the road to encourage drivers to come to a complete stop and look for bikes. Painting "look for bicycles" in the roadway at approaches is another possible alternative. Because many pedestrians and cyclists were struck by turning vehicles at signal locations, signage next to traffic signal may help.

South University Ave between Tappan St. and Walnut St. Ann Arbor. This road has one lane in each direction with on street parking and a speed limit of 25 mph. The WMU team visited this corridor on August 23, 2023, and conducted observations at crash sites during daytime hours. At this site 100% of K&A crashes occurred during daytime hours. All but one of the pedestrian crashes involved a through or turning vehicle striking a pedestrian in a crosswalk at a street with four way stop signs. One bicycle crash involved a vehicle traveling too fast. At stop sign controlled intersection of S. University and E. University and Church Street there was a total of 14 crashes including one K and one A crash.

The following crash countermeasures would be helpful at this site.

1. Because the pedestrian and bicycle crashes involved speed on a street with four way stop sign control we recommend raised crosswalks at each of the stop controlled crosswalk legs.

2. We recommend high visibility crosswalk markings at Elm Street and turning vehicles yield to pedestrian signs on the signal mast arms at the signalized intersection at S. University and S. Forest Ave.

Martin Luther King Blvd. between 3rd Ave and Woodward Ave. Detroit. This road has three lanes in each direction and a median island at 3rd Ave between Cass Ave and Woodward Ave and one lane in each direction with on street parking and a speed limit of 25 mph. The WMU team visited this corridor on August 23, 2023, and conducted observations at crash sites during daytime and nighttime hours. At this site 75% of K&A crashes occurred during nighttime hours. All intersections had LED street lighting except for Martin Luther King at Woodward Ave which had low streetlights that appeared to have compact fluorescent light bulbs. Intersections with LED lighting did not have lights at all departure points. Several bicycle crashes occurred on Martin Luther King Ave including two A crashes. Pedestrian Crashes occurred in crosswalks including one K crash. Lighting levels at Martin Luther King Blvd were below 20 lux at many sites but not below 10 lux at any site. At the intersection of Martin Luther King Blvd and Woodward Ave the light levels at crosswalks on the North and South legs were good but were low at the center of road on the East West Crosswalks. The light reading obtained at Martin Luther King Ave and Woodward Street are shown in Figure 4-21.

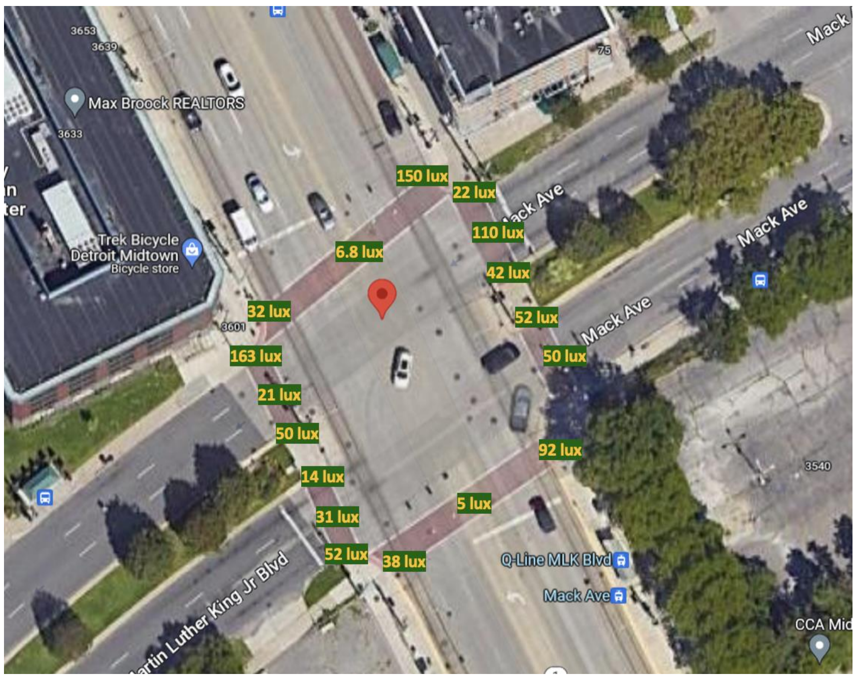


Figure 4-21. Lighting at Martin Luther King Ave and Woodward Street, Detroit

The following crash countermeasures would be helpful at this site.

1. There appears to be a high level of bicycle use on Martin Luther King Blvd. We recommend examining whether MV volume would allow adding bike lanes with posts to discourage driving in the bike lane.

2. We recommend high visibility crosswalk markings at all crosswalks and improved lighting by ensuring all crosswalks are adequately illuminated. Consider adding LED lighting at Woodward.

Gratiot Ave between Seymour St. and 8 Mile Road. This road has three lanes in each direction and a turning lane. The speed limit along this corridor is 35 mph and most of the K&A crashes occurred during nighttime conditions. The WMU team visited this corridor on August 23, 2023, and conducted observations at crash sites during daytime and nighttime hours. Most of the F&A

crashes (88%) along this corridor occurred at night. There were many serious crashes along this corridor. Roadway lighting was typically LED street lights. However, we noticed that the lights were not always close to the crosswalk location. We were only able to take readings at Gratiot Ave at 8 Mile Road because the onset of rain prevented readings because of the risk to damaging the light meter. The light meter reading taken at Gratiot Ave and 8 Mile Road are shown Figure 4-22.

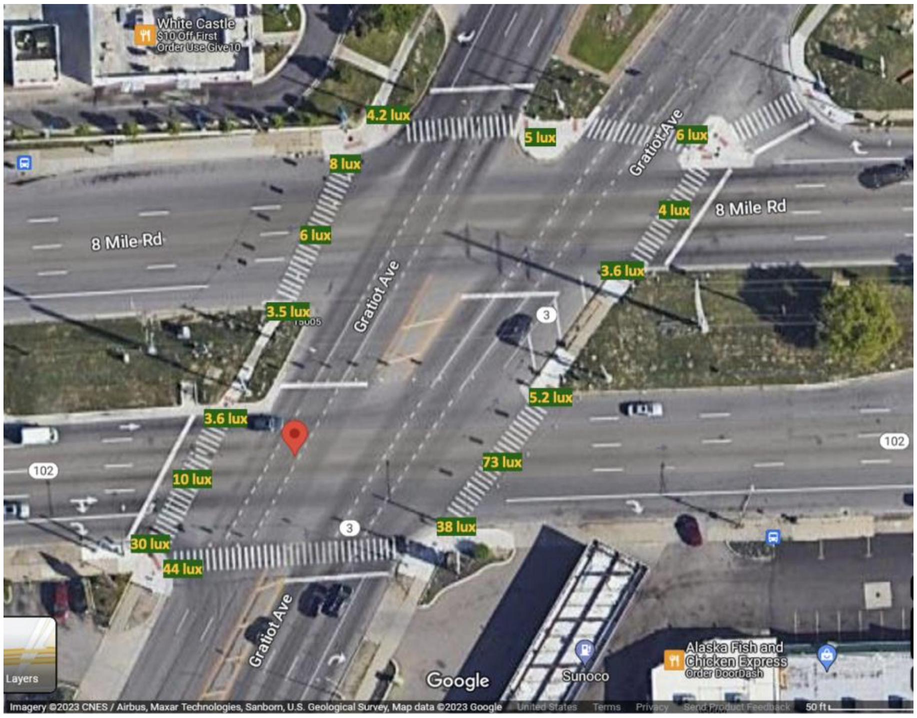


Figure 4-22. Lighting at Gratiot Ave and 8 Mile Road, Detroit

All three of the K&A crashes that occurred in a crosswalk at this site occurred in a crosswalk with lower light readings. In addition to these crashes an additional four K&A crashes occurred outside the crosswalks. Regarding lighting it is not known when LED lighting was installed along Gratiot Ave. However, it was most likely in recent years. Although a number of these crashes occurred at midblock locations many occurred at signal control intersections or close to or at off set stop-controlled T intersections for the same road or adjacent roads.

1. We recommend installation of high visibility crosswalks at all signalized intersections along this corridor along with improved lightings at locations where the street lights are not close to the intersection.

2. Between adjacent off set T intersections were recommend installing refuge islands and assuring that these areas have good illumination because many of these crashes occurred between intersections. We would also consider placing pedestrian hybrid beacons with advance stop lines or Rectangular Rapid Flashing Beacons with advance yield markings at sites with frequent pedestrian crossing activity.

5 TREATMENTS SELECTED FOR PEDESTRIAN AND BICYCLE CRASHES ON HIGHER SPEED ROADS

5.1 General Guidance for Selecting Countermeasures

The selection of countermeasures for higher speed roads was based on appropriateness and effectiveness of countermeasures along with the findings obtained from the crash analysis and crash site visits along each corridor. It is imperative to consider the time of the day during which the most severe crashes occur when selecting for a particular location. The general guidance for selecting countermeasures for higher speed roads are described below.

5.1.1 General Guidance for Nighttime Crashes

When crashes occur predominately at night, poor lighting is likely the most important factor leading to crashes. To confirm this hypothesis, it is important to measure lighting at the crash locations. This can be done by visiting the locations, an hour after sundown with a light meter and taking readings. FHWA recommends a light level of 20 lux or more. You may obtain readings which are considerably less, often between 2 and 7 lux. At these lighting levels people appear as shadows and are typically not seen by a driver until moments before the crash. The results of the work done by WMU for MDOT found UD 10 Police Crash Reports indicating the pedestrian or bicyclist was struck in a lighting location does not typically lead to high light level readings. Officers will check the lighted box if there is a streetlight nearby. Often light level will be 7 lux or less at the crash site. There are many new lighting solutions available for treating these crashes.

A good treatment set for night crashes at traffic signals are LED light bars installed under a mast arm and high visibility crosswalk lighting. If lighting is mounted on span wires, LED luminaires should be installed and aimed toward the crosswalk and entry locations. High visibility crosswalk markings can also help reduce the occurrence of this type of crash. LED lights are easier to aim than legacy lighting, but it is necessary to do so to ensure crosswalks are properly illuminated.

The good treatments for night crashes at uncontrolled intersections include refuge islands and improved LED street lighting. Other possible countermeasures include installation of an RRFB or a PHB with improved lighting. Advance stop lines should be installed along with either of these treatments. In instances where these cannot be installed, consider just installing an island along with improved lighting without crosswalk markings.

5.1.2 General Guidance for Daytime Crashes

When crashes occur predominately during the day, it is important to determine factors associated with the crashes. At traffic signals and other intersections reducing the turning radii may be an important factor. If the turning radii are wide tightening the radii can reduce crashes with pedestrians and bicyclists using the sidewalk. Most bicyclists ride on the sidewalk rather than the roadway along higher speed roads. Often bicyclists ride against the traffic on sidewalks because there are few opportunities to cross the road. Reducing the turning radii can reduce these crashes.

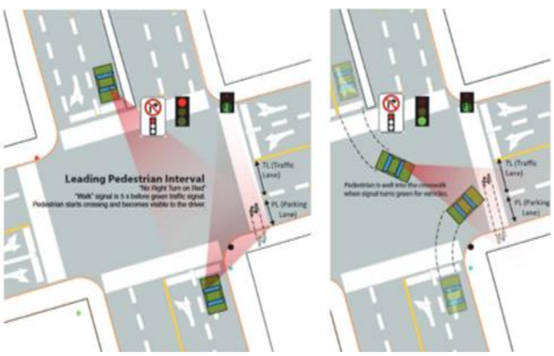
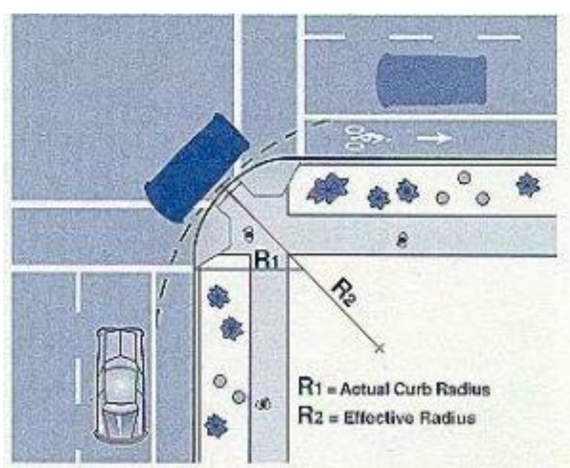
A good treatment set for day crashes at traffic signals is the use of high visibility crosswalk markings and the use of a leading pedestrian phase. These treatments can be used along with tightening the turning radii.

5.2 Countermeasures Recommended for Higher Speed Roads

5.2.1 Countermeasures Selected for Crosswalks at Traffic Signals

The countermeasures recommended for crosswalks at signalized intersections include Leading Pedestrian Interval (LPI), tightening the turning radius, LED lighting on the existing mast arm, and installing high visibility crosswalks. Table 5-1 shows the pictures of the recommended countermeasures and their justification.

Table 5-1. Countermeasures recommended for crosswalks at signalized intersections on higher speed roads

Countermeasure	Justification/Remarks
Leading Pedestrian Interval (LPI)  Source: Saneinejad & Lo (2015)	✓ Statewide, 23% of non-motorized crashes on high-speed corridors involved left or right-turning vehicles. ✓ LPI may reduce pedestrian crashes by 13%.
Tightening the turning radius  Source: FHWA (2013)	✓ Statewide, 13% of Non-motorized crashes on high-speed corridors involved right-turning vehicles. ✓ High turning speeds were observed at some visited sites. ✓ May reduce pedestrian crashes by up to 59%.

Countermeasure	Justification/Remarks
LED lighting on the existing mast arm 	✓ The lighting of 20 lux may reduce nighttime crashes by 20%
High Visibility Crosswalks  Source:Holeywell (2016)	✓ High visibility crosswalks may reduce pedestrian crashes by 23-48%

5.2.2 Countermeasures Selected for Unsignalized Intersections and Midblock Crosswalks

The countermeasures recommended for unsignalized intersections and midblock crosswalks include advanced stop/yield markings and sign, installing rectangular rapid flashing beacon (RRFB), installing pedestrian hybrid beacon (PHB), and installing refuge island or raised medians. Table 5-2 shows the recommended countermeasures and their justification.

Table 5-2. Countermeasures recommended for unsignalized intersections and midblock crosswalks on higher speed roads

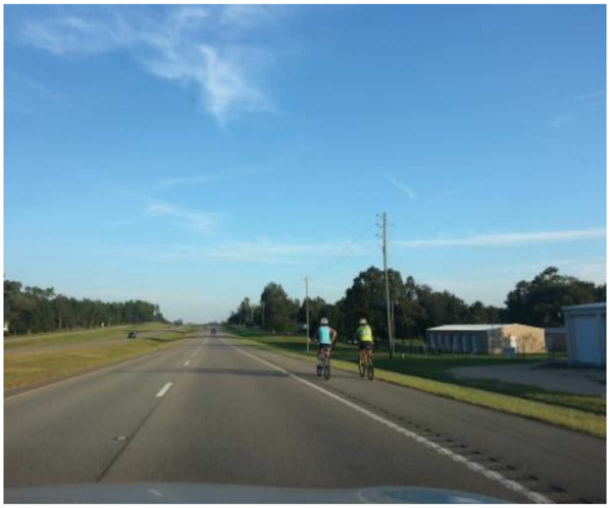
Countermeasure	Justification/Remarks
Advanced stop/ yield markings and sign  Source: PEDSAFE 2013	✓ Advanced stop/yield markings and sign may reduce pedestrian crashes by 25%
Rectangular rapid flashing beacon  Source: Lieswyn & Gregory (2018)	✓ RRFB may reduce pedestrian crashes by 47.4%
Pedestrian hybrid beacon (PHB)  Source: Georgia DOT	✓ PHB may reduce pedestrian crashes by 45.7%

Countermeasure	Justification/Remarks
Refuge island or raised median  Source: NACTO	✓ Refuge island may reduce pedestrian crashes by 31.5%

5.2.3 Corridor Wide Improvements

The countermeasures recommended for higher speed corridor-wide improvements include widening shoulders, adding sidewalks, using solar-powered dynamic feedback signs, and changing out existing streetlight to LED light. Table 5-3 shows the recommended countermeasures and their justification.

Table 5-3. Countermeasures recommended for corridor-wide improvements on higher speed roads

Countermeasure	Justification/Remarks
Widening Shoulders  Source: Small Town and Rural Design Guide	✓ Widening shoulders may reduce bicycle crashes up to 18% depending on the increased width.

Countermeasure	Justification/Remarks
Adding Sidewalks  Source: PEDSAFE 2013	✓ Sidewalks may reduce pedestrian crashes by 40%
Solar-powered dynamic feedback signs  Source: Johnston (2021)	✓ Solar-powered dynamic feedback signs may reduce pedestrian crashes by 5%
Change out existing streetlight to LED light  Source: AGC Lighting (2020)	✓ The lighting of 20 lux may reduce nighttime crashes by 20%

5.2.4 Countermeasures for Transitions from Higher Speed Roads to Lower Speed Roads in Rural Communities

Small rural communities (rural villages and rural cities) are mostly located along a major state or county road and hence most of the traffic is just passing through rather than being local traffic.

These major state or county roads that go through the small rural communities are usually characterized by a high-speed limit which is reduced within the rural communities. Due to this, most drivers are likely to continue driving at a higher speed through these communities and endanger the safety of non-motorized traffic (FHWA, 2018). Frequently, the transition from the rural environment to the urbanized (small rural communities) consists only of the lower posted speed limit sign, and this condition is inadequate to encourage appropriate behaviors (Hallmark, Hawkins, and Knickerbocker, 2015).

In the crash analysis of this study, clusters of rural low-speed non-motorized crashes were identified as high-risk rural low-speed corridors. Out of the identified rural low-speed corridors (28 corridors), 96% (27 corridors) were going through small rural communities. Moreover, 80% (22 corridors) were connected to a high-speed segment less than 2 miles away. Analysis of the non-motorized crashes in the small rural communities showed that on average 14% of the crashes on these corridors are KA crashes. Also, about 18% of the crashes on the corridors occur during nighttime conditions. This study reasons that most of these crashes could be speed-related due to the speed spillover effect. Therefore, effective countermeasures to manage speed in high-speed to low-speed transition areas are suggested. Another variable at work in this situation is speed adaptation. Data showed that drivers traveling at a higher speed for a prolonged period of time underestimate their speed when transitioning to a lower speed limit (Matthews, 1978). Because speeding is one of the major causes of crashes (National Safety Council 2020), and because speeding is also related to fatal crashes; It is important to explore methods to decrease driver speeding when drivers are going through areas that have a speed limit decrease of 24 km/h (15 mp/h) or higher. Because these areas involve a transition in driving context a clear transition element would be expected to assist making drivers aware that they need to reduce their speed.
One type of gateway approach that could be considered is the use of roundabouts at the entrances of the communities along the higher speed road. However, it may be difficult to consistently implement roundabouts at the start of speed zones because of cost and availability of right-of-way. One inexpensive alternative would be to use speed illusions which would assist the driver to perceive they are traveling too fast. Several studies demonstrated the efficacy of using pavement markings to produce the illusion of faster speed to reduce speed and a number of studies have found a reduction in all crashes with the use of transverse bar pavement marking. It would be valuable to determine whether this treatment also decreases pedestrian and bicycle crashes in small communities along higher speed roads. Another treatment is the use of a parallelogram-shaped pavement markings to reduce vehicle speed.

Another low speed approach which has not been adequately evaluated is installing large speed limit signs in a gateway configuration (one sign on the right and one side on the left of a two lane road, or one side on the right, one side on the left and one in an island in the middle lane on a three lane road. As part of this research project the WMU team evaluated a three sign gateway approach on a four lane road with an island in the middle. Appendix 12 shows the details of this study.

The setting was a segment of Gull Road in the city of Kalamazoo where the speed limit for East bound traffic was reduced from 45 mph to 30 mph beyond the signalized intersection with Riverview Drive. Gull Road has four travel lanes with two lanes in each direction. A trail crossing and a roundabout are beyond the intersection. A Light detection and ranging device radar (LiDAR) was used to measure vehicle speeds. All speed measures were taken within a narrow zone measuring 50 ft in length at a location that started 158 feet beyond the first 30 mph speed limit sign. The target behavior in this study was the percentage of drivers traveling 6, 9, and 12 mph over the speed limit.

Design and Procedure

The design employed in this study was a reversal ABCDEB design. Condition A was baseline, no changes were made to the site during this condition, and there was one sign facing incoming traffic (the sign was 24 inches wide and 30 inches high). The site had a yellow gore marking on the ground as a painted splitter island, but nothing was placed on it. In condition B delineators were placed around the splitter island. The splitter island then consisted of delineators around the center painted median island. Condition C consisted of a splitter island with delineators and 2 signs (30 inches wide and 36 inches high) on each side of the road. Each sign faced the same direction, which was facing the direction of approaching cars. This was done to create a gateway-like structure. Condition D was similar to condition C, however there was a third sign placed in the splitter island producing a three-sign gateway effect. Condition E was similar to condition D except the signs in this condition were larger than the signs in the previous conditions. The signs in this condition measured 36 inches wide and 48 inches high. This design then reversed back to condition B condition rather than the A condition because a splitter island with delineators around the turning lane was required to create the gatelike structure for this intervention. Therefore, reversing back to condition B served as a better benchmark to evaluate the effect of the gateway speed limit signs. The three signs were then reintroduced. The full gateway effect is shown in Figure 5-1.

Figure 5-1. A photo of the gateway treatment

Results

The percentage of drivers traveling 6 mph, 9 mph and 12 mph over the speed limit are shown in Figure 5-2. Figure 5-2. depicts the speed of drivers during all conditions. The line with triangular markers shows the percentage of drivers speeding 6 mph over the limit per session. The line with circles markers shows the percentage of drivers speeding 9 mph over the speed limit per session. The line with square markers shows the percentage of drivers speeding 12 miles per hour over the speed limit per session. The largest reduction in speeding occurred during the three large sign gateway condition, speeds increased when the small single sign condition was reintroduced and decreased again when the gateway condition was reintroduced.

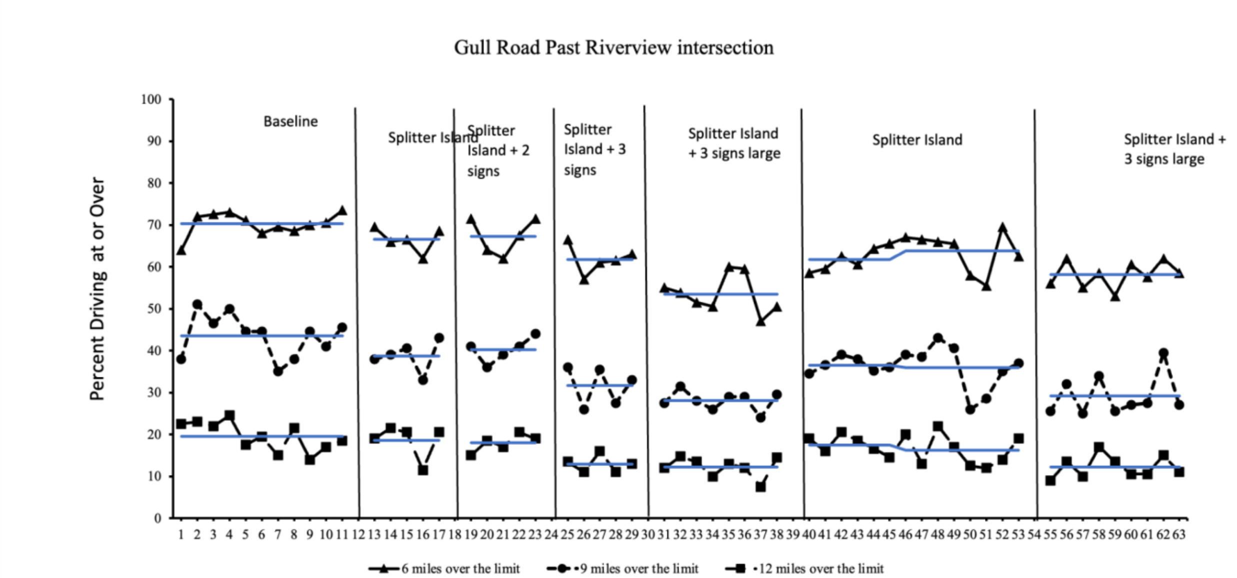


Figure 5-2. Speed of drivers during all conditions

Figure 5-3 shows the speed distribution graphs of baseline (gray bars), splitter island with delineators condition and the small speed limit sign (orange bars) and the splitter island with 3 large signs condition (blue bars). This graph allows for comparison of speed distributions between conditions. The use of the large gateway speed signs produced a shift in the speed distribution toward lower speeds.

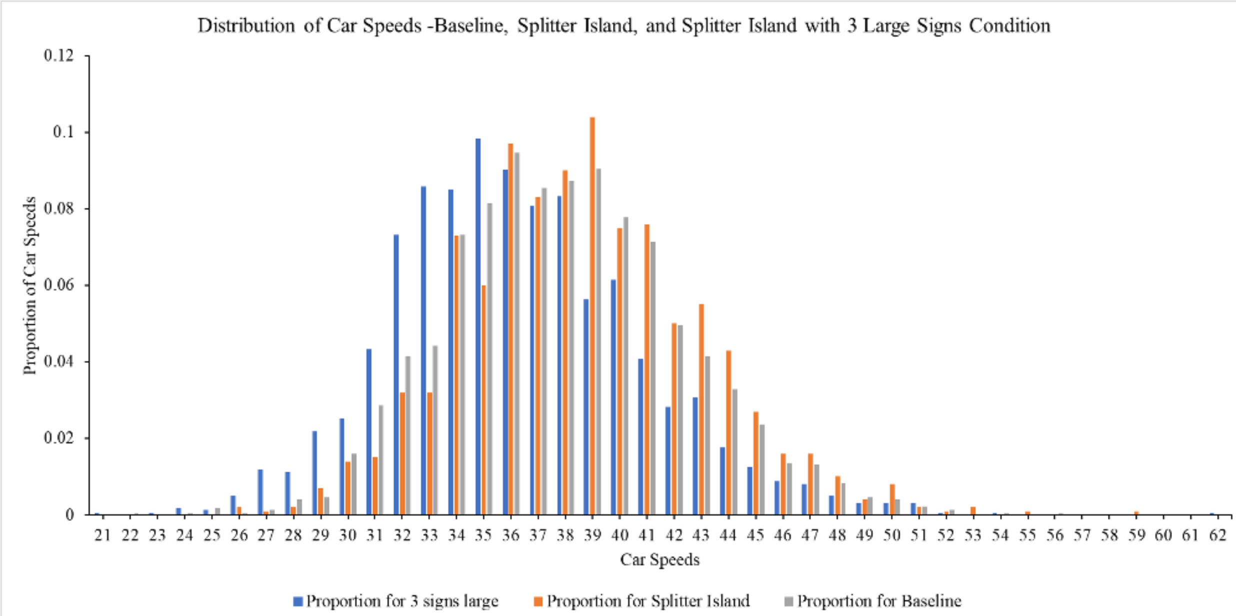


Figure 5-3. Speed distribution for gateway treatment

The results of this study indicate that this use of gateway speed signs may be an effective way to increase speed compliance when the speed limit is reduced.

5.3 The Importance of Combining Compatible Countermeasures to the Crash History

Many of the countermeasures used to reduce pedestrian crashes are designed to be used together in order to produce synergistic effects. For example, the use of the RRFB on multilane roads can lead to the occurrence of a multiple threat crash. This effect can be reduced by installing advance yield markings to reduce the chance of a multiple threat crash. Similarly, advance stop lines should be used at PHB locations to reduce multiple threat crashes. If the crashes occur at night an RRFB should also be equipped with solar LED lighting that turns on when a pedestrian is detected or presses a call button. Another way to reduce multiple threat crashes at RRFB sites is to place an RRFB on both sides of a refuge island in addition to the signs placed on both sides of the road. At PHB locations LED lighting should also be added if the crashes occur at night.

Other items which can work together are a refuge island with or without crosswalk markings at uncontrolled intersections and LED lighting that lights the departure point as well as the path across the street. Because LED lighting is more directional than other types of lighting it can be better aimed.

At traffic signal locations high visibility markings can be combined with tightening turning radii, a leading pedestrian phase and better lighting of the departure points and the crosswalk. One inexpensive way to increase lighting at signal locations with mast arms are light bars mounted under the mast arm.

6 COST-BENEFIT ANALYSIS

6.1 Introduction

The cost-benefit analysis was performed to evaluate the cost-effectiveness of selected potential countermeasures for higher-speed roads. This chapter entails the data used, procedures, and assumptions adopted in the analysis. The benefits considered are from the crash saving while the costs were the costs of the countermeasure.

6.2 Countermeasure Costs

The cost of the countermeasures included the total initial cost, the annual operation cost, and the maintenance cost. Costs of individual countermeasures were obtained from past studies (e.g. Bushell *et al.*, 2013) or communications with agencies. Table 6-1 shows the list of potential treatments in high-speed locations and their costs.

Table 6-1. Potential countermeasures costs and service life

Countermeasure Name	Total Initial Cost ($)	Operational/Maintenance-Cost ($)	Service Life (Years)
Leading Pedestrian Interval (LPI)	100	Nil	20
Tightening Turning Radius	63,700	30 paint curb/yr	20
Advanced Stop/ Yield Markings and Sign	700	New Markings every 5 yrs	5
Two Rectangular Rapid Flashing Beacon with Refuge Island and Advanced Markings	62,900 (without lighting) 71,900 (with dynamic lighting)	Battery 100 /3yr, + 41/yr for replacement of struck units	12
Pedestrian Hybrid Beacon (PHB/HAWK)	67,400	$3200/yr	10
High Visibility Crosswalk Markings	4,000	Renew Markings Every 5 years	5
Refuge Island or Raised Median	12.8/sq foot	Replacement of signs paint 130/yr	20
Adding Sidewalks (5 ft wide-Asphalt)	16/foot	0.4/sq foot after 5 years	5
Adding Sidewalks (5 ft wide-Concrete)	27/foot	8/sq foot every 5 years	20
Use Of Solar Powered Dynamic Speed Feedback Signs	3,800	100/3yr battery replacement	10
Led Crosswalk Lighting on Existing Mast Arm	1,200	200	20

Countermeasure Name	Total Initial Cost ($)	Operational/Maintenance-Cost ($)	Service Life (Years)
Street Light Pole + Led Lighting for Midblock Crosswalks	3,500	200	15
Change Out Existing Street Light to Led Light	275	200	15
Solar Powered Dynamic Lighting	10,600	Battery 100 /3yr, + 41/yr for replacement of struck units	15
Widening Shoulders for Asphalt	8/sq foot	3.5/ sq foot every 5 years	5
Widening Shoulders for Concrete	8/sq foot	8/sq foot every 5 years	20

6.3 Crash Costs

Table 6-2 shows the crash costs based on the societal costs of traffic crashes and crime in Michigan. When considering total crashes, a high proportion of them are Property Damage Only (PDO) while non-motorized crashes have a high proportion of fatal and incapacitating injury crashes. Therefore, it was important to recalculate an average crash cost that would be typical for higher-speed locations.

Table 6-2. Crash Cost in Michigan -2017 update (Streff and Molnar, 2017)

Variable	Traffic Crash Casualties	Proportion out of total crashes	Unit Costs
K	1,011	0.18	$8,875,391
A	5,212	0.90	$487,390
B	17,499	3.03	$134,943
C	53, 354	9.24	$67,200
O	500,614	86.66	$4,347
Average Crash Cost			$38,555

Table 6-3 shows the recalculated average crash cost for different scenarios. Due to differences in the crash severity distribution between day/night, urban/rural, and intersection/midblock, it was important to calculate the average crash cost separately for all these different scenarios. The costs were updated to 2023 costs using an inflation rate of 1.22. This was obtained as the ratio of the consumer price index for urban consumers of February 2023 to the consumer price index for urban consumers of 2017 (300.94/246.5 = 1.22). Table 6-3 shows that crashes are more severe at nighttime conditions than daytime, as well as rural crashes are more severe than urban crashes.

Table 6-3. Average non-motorized crash 2023 cost on high-speed locations

Severity		Non-motorized Crashes	By Day/Night		By Location Type			
			Daytime	Nighttime	Urban Intersection	Urban Midblock	Rural Intersection	Rural Midblock
Yearly crashes (2023)		880	534	346	281	338	41	220
Proportion by Severity	K	9.2%	4.4%	16.8%	3.7%	11.0%	7.6%	13.1%
	A	18.9%	15.9%	23.6%	12.5%	20.5%	18.3%	23.7%
	B	31.3%	33.9%	27.2%	34.3%	31.1%	28.6%	27.8%
	C	29.1%	32.3%	24.0%	35.7%	28.2%	28.6%	24.0%
	O	11.5%	13.5%	8.4%	13.7%	9.2%	17.0%	11.5%
Average Crash Cost (2023)		**$1,188,692**	**$651,194**	**$2,022,466**	**$561,049**	**$1,384,569**	**$1,002,232**	**$1,623,043**

6.4 Cost-Benefit Analysis

The benefits were calculated from the number of crashes reduced using Crash Reduction Factors (CRF) obtained from the Crash Modification Factors Clearinghouse and the corresponding crash cost analyzed in Section 6.3. The total benefit within the service year of the treatment was estimated using the present value formula in Equation 1.

$$PV = \frac{FV}{(1+i)^n}$$

Whereby PV is the Present Value, FV is the Future Value, i is the discount rate and n is the year.

The service life of the treatment was obtained from the countermeasure service life guide, a FHWA safety program by Himes *et al.*, (2021). In this analysis, a discount rate of 2% was adopted according to Office of Management and Budget (OMB) Circular A-94, the real discount rate of 2023. The BCR was calculated as the ratio of total benefits to total cost within the service life of the treatment.

The benefits of selected countermeasures are proportional to the number of crashes. To compare with individual countermeasures with the same ground, Table 6-4 is the summary of the cost-benefit ratio of crash savings to countermeasure costs based on 0.1 non-motorized crashes per year. For countermeasures specifically impacting the total number of crashes including vehicle crashes or nighttime crashes, 17 crashes per year (for countermeasures reducing the total crashes) and 1 nighttime crash per year (for countermeasures reducing the nighttime crashes) were applied, considering the proportional characteristics. For the LPI, the traffic delay cost was included in the BCR calculation. Also, the table presents the annual number of crashes required to realize the BCR of 1.0.

Table 6-4. Summary of Cost-Benefit Analysis

	Treatment	**CRF (%)**	**Yearly number of crashes**	**BCR**	**Yearly number of crashes to achieve a BCR of 1**
1	Advanced stop/yield markings and sign	25	0.1	176.4	0.001
2	Solar Powered Dynamic Speed Feedback Sign	5	17*	136.5	0.15*
3	Refuge Island (small refuge island)	31.5	0.1	72.7	0.002
4	LED crosswalk lighting on an existing mast arm	20	1**	66.8	0.02**
5	Street light pole to LED lighting	20	1**	63.8	0.02**
6	Street light pole and LED lighting	20	1**	32.2	0.04**
7	High visibility crosswalks	23	0.1	28	0.004
8	Adding sidewalks (asphalt-1 mile, 5ft wide)	40	0.1	2.37	0.02
9	Tightening the curb radius (20ft to 10ft)	15	0.1	2.14	0.05
10	Widening shoulders (asphalt from 3ft to 5ft, 1 mile)	7.6	0.1	1.44	0.1
11	Pedestrian Hybrid Beacon (PHB) with LED lighting	57	0.1	0.6	0.2
12	Pedestrian Hybrid Beacon (PHB)	45.7	0.1	0.5	0.25

	Treatment	CRF (%)	Yearly number of crashes	BCR	Yearly number of crashes to achieve a BCR of 1
13	LPI (considered delay costs)	13	0.1	0.16	0.7

*Total crashes, ** Nighttime crashes, otherwise non-motorized crashes

6.5 Analysis Tool Development

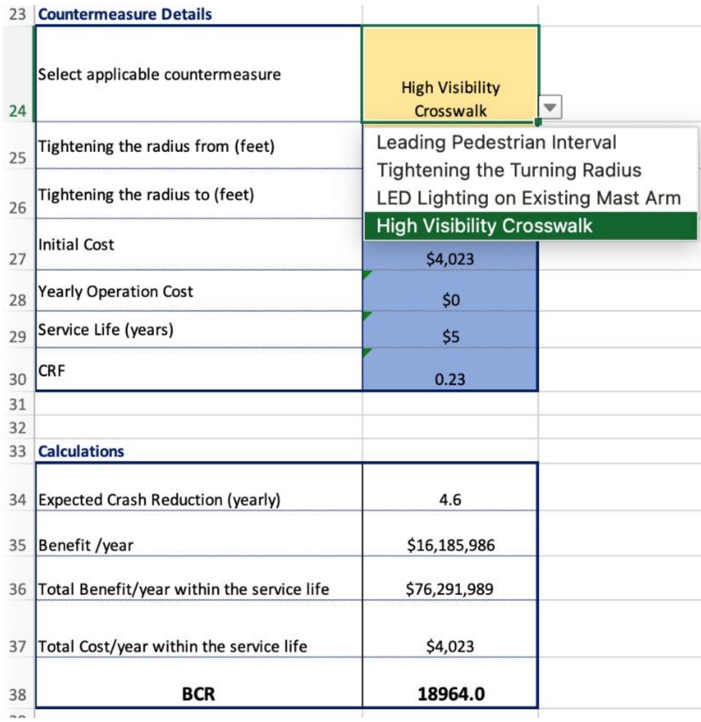
While the result in Section 6.4 presents BCRs for each countermeasure, actual BCR depends on the number of non-motorized crashes at each site. To help analyze the BCR at a site, a spreadsheet program was developed. The tool is based on four location types: Urban Intersection, Rural Intersection, Urban Midblock, and Rural Midblock. Intersections are also classified into two types (signalized and unsignalized), and midblock is differentiated whether it is a crosswalk or not.

As input data, the tool requires yearly non-motorized crash data by severity and day/night as shown in Table 6-5. Due to randomness of crash occurrence, it is desired to use five-year average values.

Table 6-5. Non-motorized crash data input

Non-motorized Crash Data (in a year)	Day	Night	Total
K	0	0	0
A	0	0	0
B	0	0	0
C	0	0	0
O	0	0	0
TOTAL	**0**	**0**	**0**

Once the crash data input is completed, the tool allows the user to choose applicable countermeasures for consideration and further feasibility and automatically provides the cost-benefit analysis result along with corresponding cost data as shown in Figure 6-1.



23	**Countermeasure Details**	
24	Select applicable countermeasure	High Visibility Crosswalk
25	Tightening the radius from (feet)	
26	Tightening the radius to (feet)	
27	Initial Cost	$4,023
28	Yearly Operation Cost	$0
29	Service Life (years)	$5
30	CRF	0.23
31		
32		
33	**Calculations**	
34	Expected Crash Reduction (yearly)	4.6
35	Benefit /year	$16,185,986
36	Total Benefit/year within the service life	$76,291,989
37	Total Cost/year within the service life	$4,023
38	**BCR**	**18964.0**

Figure 6-1. Example application of the cost-benefit analysis tool

6.6 Case Example

As a case example, the 28th Street in Grand Rapids was chosen. The speed limit of the corridor is 45 mph with six crashes during the past 12 years. Out of the six crashes, four crashes occurred during nighttime. The site is characterized as below:

- Speed: 45 mph,
- AADT= 25K,
- Land use: Commercial,
- Non-motorized Crash Rate = 1.67 crashes/yr,
- Corridor Length = 0.8 mile,
- 1-2 Buffered sidewalks,
- Undivided Road,
- Number of lanes = 5 lanes with TWLTL.

Figure 6-2. Case Study Site (28th Street, Grand Rapids, MI)

As shown in Figure 6-2, there were fatal crashes during nighttime at the midblock of 28th Street. Unavailability of crosswalk and the lack of lightings were identified as the main causes of crashes. Accordingly, there is a need to provide a crosswalk with better lighting conditions. Table 6-6. includes applicable countermeasures as well as their costs.

Table 6-6. Applicable countermeasures and cost

Countermeasures	**Cost**
Extended sidewalk (350 ft) Refuge island & Maintenance cost	$31.44/ft $12.84/sq. ft $130/year
High visibility crosswalk & 2 Pedestrian signs	$4,000 $600
LED lights on streetlight poles	$3,500
2 RRFB with dynamic lighting	$56,200

Combining applicable countermeasures, four alternatives were developed in the order of comprehensiveness. Proposed alternatives are expected reduce crashes from 45% to 78%, respectively, and their BCRs range from 112.4 to 324.8 as summarized in Table 6-7.

Table 6-7. Alternative analysis result

Alternatives	Countermeasures	Total Installation Cost ($)	Annual Operation Cost ($)	Total Crash Reduction (%)	BCR
1	Refuge island & LED Lighting	34,300	130	45.2	324.8
2	Extended sidewalk (350 ft) Refuge island, and high visibility crosswalk	45,800	130	47.0	246.7
3	Alt 2 + LED lights on streetlight poles	49,300	130	58.0	230.0
4	Alt 2 + RRFB with dynamic lighting	87,500	200	78.0	130.4

7 CONCLUSIONS AND RECOMMENDATIONS

This study examined crashes that occurred along higher speed roads. Many fatal or incapacitating (K&A) pedestrian and bicycle crashes in Michigan have occurred on higher speed corridors with a speed limit of 45 mph or higher and 70% of these occurred at night. A review of the literature on pedestrian and bicycle crash countermeasures identified potential countermeasures that could be used on Michigan's higher speed roads. The research team relied heavily on the revised star rating for each of the Crash Reduction Factors (CRF) for potential countermeasures, and because of the relationship between crash severity and night crashes also focused on lighting countermeasures.

A detailed analysis of statewide crash data recorded between 2009 and the end of 2020 were analyzed by severity, area type (rural vs urban), lighting conditions, and location of crash (intersection vs midblock). Pedestrian crashes and bicycle crashes were analyzed separately. Non-motorized crashes were grouped into low-speed crashes (less or equal to 40 mph) and high-speed crashes (greater or equal to 45 mph and less or equal to 65 mph). Most crashes along higher speed roads occurred in clusters along corridors where these roads transitioned through urban and suburban locations. Rural crash locations were more randomly distributed and when they occurred in clusters, they occurred along higher speed roads where they transitioned to a lower speed as they traversed smaller towns, villages, and cities.

The site visits allowed the research team to determine factors related to each crash and the types of countermeasures that would likely be effective. If most crashes occurred at night the team visited the crash sites measured lighting levels using a Konica Minolta T-10A Illuminance Meter. Federal Highway studies indicate that 25 Lux is a good level of illumination to see a pedestrian crossing at night. Based on the crash diagram and narrative the light level reading was taken at the approximate vicinity of each crash.

One very important finding was that there was poor corridor lighting along all but one of the high crash corridors. One surprising finding was the low level of lighting (essentially dark) at many of the night crash sites classified as lighted. Visiting these sites also allowed the team to view pedestrians and bicyclists and observe their behavior. At many of the sites with poor lighting pedestrians and bicyclists appeared as shadowy figures. In many cases the police report would mention the driver stating they did not see the pedestrian. Regardless of potential right-of-way issues these crashes would have been less likely during the day because the driver in many cases would have seen the pedestrian in time to avoid a crash.

Another interesting finding was that wide turning radii often contributed both to pedestrian and bicycle crashes at crosswalks particularly at night. Reducing the turning radii could help reduce crashes in crosswalks but may need to use roll over curb to facilitate trucks turning right at these locations.

Another value of site visits was it enabled us to recommend countermeasures for each site. This enables the research team to narrow down the number of countermeasures that were most useful for pedestrian and bicycle crashes on higher speed roads. Countermeasures most useful for crashes at traffic signal locations included: LED light bars installed under mast arms, LED luminaires installed and aimed toward the crosswalk and entry locations at traffic signal sites with span wires; tightening the turning radii; installation of high visibility crosswalk markings; and adding a leading pedestrian interval. Countermeasures most useful at unsignalized intersections and midblock crosswalks included: Installation of a PHB or RRFB along with advance stop or yield markings; and refuge or median islands. If an RRFB is installed adding dynamic crosswalk lighting is also recommended. Countermeasures most useful for corridor wide improvements included: Adding sidewalks, solar powered dynamic feedback signs; widening shoulders; and changing out legacy street lighting to LED street lighting. MDOT may be able to change out lighting at all crosswalk or intersection locations as a crosswalk treatment.

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9 APPENDICES

9.1 Photos of Sample Crosswalk Treatments

(a) **Signalized Intersection Improvements**

<table>
<tr>
<td>Advanced Stop Line

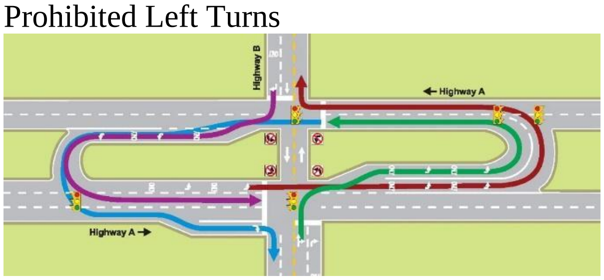
Source: Ulster County Transportation Council Safe Routes to School (SRTS) Toolbox</td>
<td>Flashing Yellow Arrow

Source: LMCS Staff Report (2022)</td>
</tr>
<tr>
<td>Countdown Signals

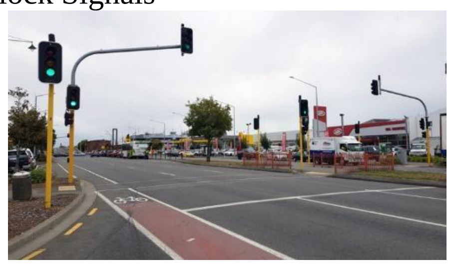
Source: Oh et al., (2018)</td>
<td>Turning Vehicles Yield to Pedestrian

Source: Pécheux, Bauer and Mcleod (2009)</td>
</tr>
<tr>
<td>Exclusive Left Turn

Source: Spector (2012)</td>
<td>Right-turn Slip Lanes

Source: Delaware Valley Regional Planning Commission (2019)</td>
</tr>
<tr>
<td>Prohibited Left Turns

Source: MDOT (2022)</td>
<td>Bicycle Signal Detection

Source: NACTO</td>
</tr>
</table>

Bicycle Signal  Source: BIKESAFE 2014	Prohibited or Restricted Right Turn  Source: PEDSAFE 2013
Combined Bike/Turn Lanes  Source: NACTO	Midblock Signals  Source: Waka Kotahi NZ Transport Agency
Exclusive Pedestrian Phase  Source: Flickr	

(b) **Unsignalized Improvements**

High Visibility Crosswalk Signage 	R1-6 In-street Pedestrian Sign  Source: Newschannel (2019)

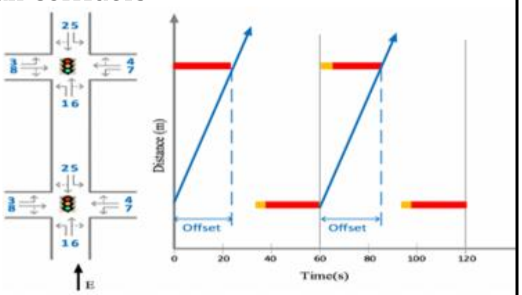
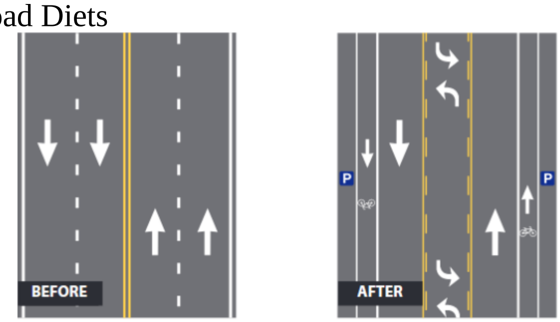
Enforcement of Pedestrian Right of Way Laws  Source: Newschannel (2019)	Enforcement of 5- or 3-Foot Bicycle Passing Laws  Source: Blomberg *et al.*, (2022)

(c) **Corridor Improvements**

Raised Median  Source: FHWA (2008)	Increasing Lane Width  Source: PEDSAFE 2013
Curb Extension  Source: Minnesota DOT	Buffered Bike Lanes  Source: NACTO
Intersection Bicycle crossing  Source: NACTO	Cycle Tracks  Source: NACTO

Bike Lanes  Source: [NACTO]	Shared Use Path  Source: WSDOT (2022)

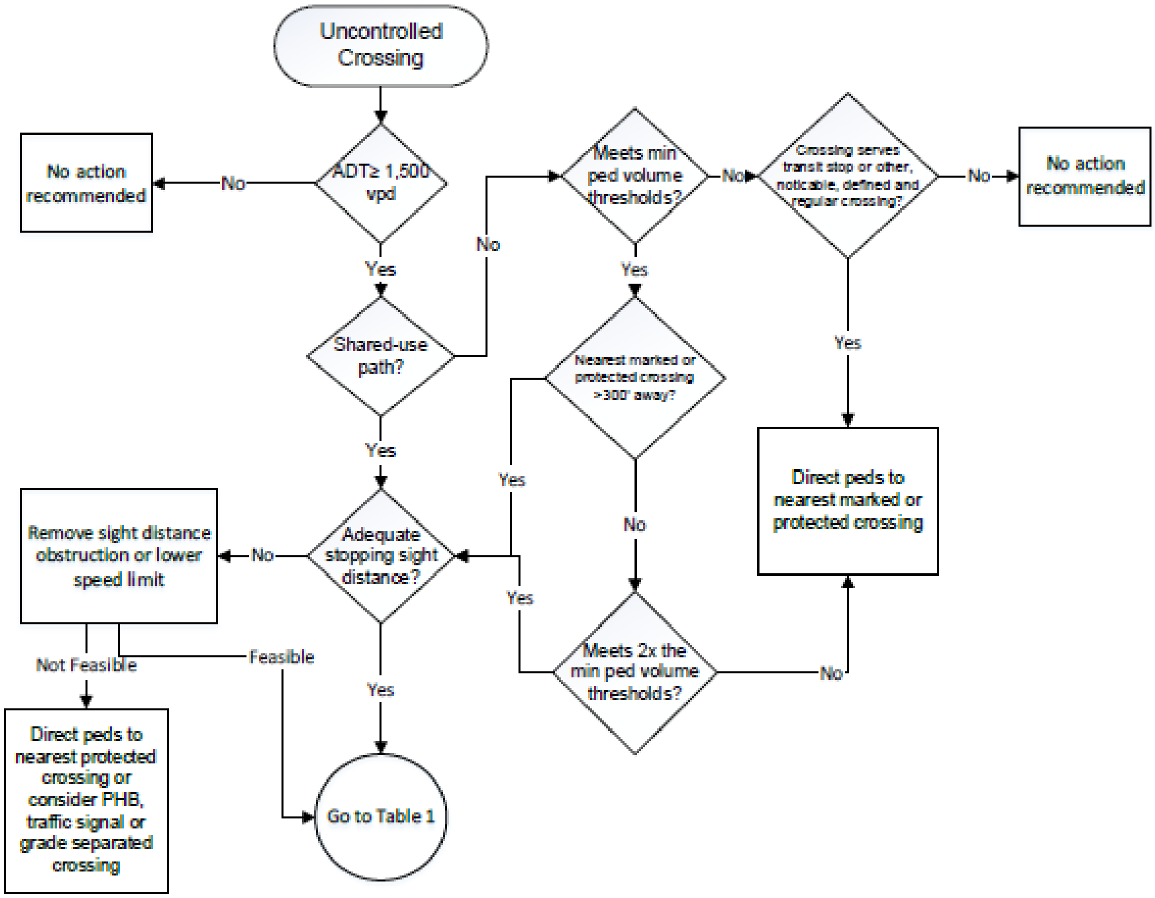
(d) **Corridor Wide Speed Control**

Altering progression along high-crash suburban corridors  Source: Li and Ban (2020)	High Visibility Corridor Speed Enforcement  Source: Houten et al., (2013)
Use of R2-3P Night Speed Limit Sign  Source: [Flickr]	Road Diets  Source: FHWA (2015)

(e) **Speed Control in Transition Zones**

Gateway Effect with Speed Limit Signs 	Gateway Use of R1-6 In-street Pedestrian Sign  Source: Bennett (2013)
Use of Pavement Patterns  Source: Guo *et al.* (2016)	Roundabouts  Source: FHWA (2022)

9.2 Michigan Guidelines for Installing Pedestrian Crosswalks on State Trunklines



Pedestrian Crossing Treatment Flow Chart for Uncontrolled Crossing

Roadway configuration	# of lanes crossed to reach a refuge	# of multiple threat lanes‡ per crossing	Roadway ADT and Posted Speed															
			1,500 - 9,000 vpd				9,000 - 12,000 vpd				12,000 - 15,000 vpd				>15,000 vpd			
			≤ 30 mph	35 mph	40 mph	≥ 45 mph	≤ 30 mph	35 mph	40 mph	≥ 45 mph	≤ 30 mph	35 mph	40 mph	≥ 45 mph	≤ 30 mph	35 mph	40 mph	≥ 45 mph
2 Lanes (one way street)	2	1	A	A	A	B	A	A	B	B	A	A	B	B	A	A	B	B
2 Lanes (two way street with no median)	2	0	A	A	A	B	A	A	B	B	A	A	B	B	A	A	B	B
3 Lanes w/refuge island or 2 Lanes w/raised median	1	0	A	A	A	B	A	A	B	B	A	A	B	B	A	B	B	B
3 Lanes (center turn lane)	3	1	A	A	B	B	A	B	B	B	A	B	B	B	A	B	B	B
4 Lanes (two way street with no median)	4	2	A	B	B	C	A	B	C	C	A	B	C	D	B	B	C	D
5 Lanes w/ refuge island or 4 lanes w/raised median	2	2	A	A	B	B	A	B	B	C	A	B	C	C	B	B	C	D
5 Lanes (center turn lane)	5	2	A	B	C	C	B	B	C	C	C	C	C	D	C	C	C	D
6 lanes (two way street with or without median)	3 to 6	4	A	B	D	D	B	B	D	D	D	D	D	D	D	D	D	D
‡ Minimum pedestrian volumes (page 6) must be met before consideration of uncontrolled crossing treatments.																		

Criteria for types of crossing treatments at uncontrolled locations

9.3 Recommended treatment of shared-use path and roadway intersection for Indiana

Speed Limit	Roadway Type	ADT	Proposed Treatments Levels
≤ 30 mph	2 Lanes	<12,000	1 or 2
		≥12,000	2 + (3 or 4)
	3 Lanes	<12,000	1 or 2
		≥12,000	2 + (3 or 4)
	≥ 4 Lanes with Raised Median	<12,000	1 or 2
		12,000 ≤ ADT < 15,000	2 + (3 or 4)
		≥15,000	[2 + (3 or 4)] or 5
	≥ 4 Lanes without Raised Median	< 9,000	1 or 2
		9,000 ≤ ADT < 12,000	2 + (3 or 4)
		≥12,000	[2 + (3 or 4)] or 5
35 mph or 40 mph	2 Lanes	<12,000	2
		≥12,000	2 + (3 or 4)
	3 Lanes	<9,000	2
		9,000 ≤ ADT < 15,000	2 + (3 or 4)
		≥15,000	[2 + (3 or 4)] or 5
	≥ 4 Lanes with Raised Median	<9,000	2
		9,000 ≤ ADT < 15,000	2 + (3 or 4)
		≥15,000	[2 + (3 or 4)] or 5
	≥ 4 Lanes without Raised Median	<12,000	2 + (3 or 4)
		≥12,000	[2 + (3 or 4)] or 5
≥ 45 mph	2 Lanes	<12,000	2 + (3 or 4)
		≥12,000	[2 + (3 or 4)] or 5
	3 Lanes	<12,000	2 + (3 or 4)
		≥12,000	[2 + (3 or 4)] or 5
	≥ 4 Lanes with Raised Median	<15,000	2 + (3 or 4)
		≥15,000	5
	≥ 4 Lanes without Raised Median	<12,000	[2 + (3 or 4)] or 5
		≥12,000	5

9.4 Uncontrolled Crossing Countermeasure Evaluation Table for Ohio

Uncontrolled Crossing Countermeasure Evaluation Table												
Roadway Type	Vehicle ADT < 9,000			Vehicle ADT 9,000 - 12,000			Vehicle ADT 12,000 - 15,000			Vehicle ADT > 15,000		
(Number of Travel Lanes and Median Type)	Speed Limit (mph)											
	≤30	35	40≥*	≤30	35	40≥*	≤30	35	40≥	≤30	35	40≥
2 Lanes	1	1	2	1	1	2	1	1	3	1	2	3
3 Lanes with raised median	1	1	2	1	1	2	1	2	3	2	2	3
3 Lanes without raised median	1	1	2	1	2	2	2	3	3	2	3	3
4 Lanes with raised median**	1	1	2	1	2	2	2	3	3	3	3	3
4+ Lanes without raised median	1	2	3	2	2	2	3	3	3	3	3	3

* Where the speed limit exceeds 40 mph, Tier 3 should be considered

** Raised medians must be at least 6 feet wide to serve pedestrians. See Figure 3-2 for different bicycle lengths to serve bicyclists. Where median width is less than these values, review category of 4+ lanes without raised median.

legend

Tier 1: 1

Tier 2: 2

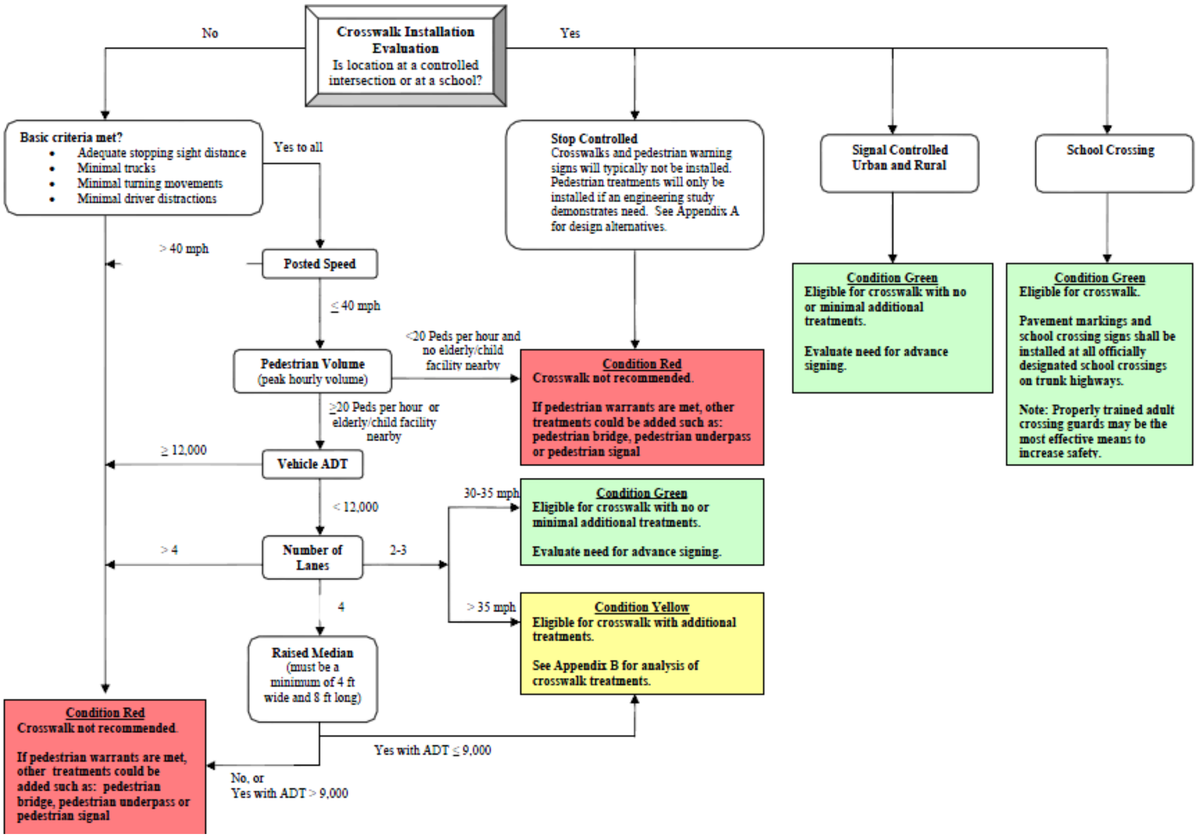
Tier 3: 3

9.5 Summary of Recommended Minimum Treatments at Uncontrolled Pedestrian Crossings in Illinois

*Lane Configuration	ADT≤ 9,000				9,000<ADT<15,000				15,000<ADT≤ 25,000				25,000< ADT≤35,000				ADT>35,000
	posted speed, mph																
	≤ 30	35	40	45	≤ 30	35	40	45	≤ 30	35	40	45	≤ 30	35	40	45	≤ 30 to 45
2 lanes or 3 lanes with raised median	BT	In-street sign	RRFB (or FB) + ASLS	uncontrolled pedestrian crossing is not recommended	BT	FB	RRFB (or FB) + ASLS	Uncontrolled pedestrian crossing is not recommended	In-street sign	FB	RRFB (or FB) + ASLS	Uncontrolled pedestrian crossing is not recommended	In-street sign	RRFB (or FB) + ASLS	RRFB (or FB) + ASLS	Uncontrolled pedestrian crossing is not recommended	Uncontrolled pedestrian crossing is not recommended
3 lanes without raised median	BT	In-street sign	RRFB (or FB) + ASLS		BT	RRFB (or FB) + ASLS	RRFB (or FB) + ASLS		FB	RRFB (or FB) + ASLS	RRFB + ASLS		RRFB (or FB) + ASLS	RRFB (or FB) + ASLS	**PHB+ CSOR		
4 lanes with raised median	In-street sign	ASLS	4RRFB (or overhead FB) + ASLS		ASLS	ASLS (consider 4RRFB)	4RRFB (or overhead FB) + ASLS		4RRFB (or overhead FB) + ASLS	4RRFB (or overhead FB) + ASLS	**4 RRFB (consider PHB)+ ASLS		4 RRFB (or overhead FB)+ ASLS	** PHB + CSOR	**PHB+ CSOR		
6 lanes with raised median	ASLS	4RRFB (or overhead FB) + ASLS	4RRFB (or overheadFB) + ASLS		ASLS	4RRFB (or overhead FB)+ ASLS	PHB+ ASLS		4RRFB (or overhead FB)+ ASLS	4RRFB (or overhead FB) + ASLS	**PHB+ ASLS		PHB+ CSOR	** PHB + CSOR	**PHB+ CSOR		
4, 5, or 6 lanes without raised median	**Consider pedestrian refuge island or road diet, if feasible.** If raised median, or road diet is feasible then follow the recommendatons for the above lane configurations, other wise follow the recommendation below for 4-lane without raised median to decide pedestrian crossing treatments, providing uncontrolled crossings of more than four lanes without a raised median is not recommended																
4 lanes, raised median not feasible	ASLS	ASLS	PHB+ CSOR		ASLS	RRFB (or overhead FB)+ ASLS	PHB +CSOR		RRFB (or overhead FB)+ ASLS	PHB +CSOR	** PHB+ CSOR		PHB +CSOR	** PHB +CSOR	**PHB +CSOR		

BT= Basic Treatment (W11-2 with W16-7P)
In-street sign= In-street stop for pedestrian sign (R1-6a);
Overhead sign= Overhead crossing sign (R1-9a) may be used based on engineering judgment
ASLS= Advanced stop line and sign (R1-5b and R1-5c)
FB= Pedestrian activated flashing beacon (pole mounted)
RRFB= Non-median installation of RRFB; 4 RRFB= Median installation of RRFB
PHB=Pedestrian Hybrid Beacon; CSOR=Crosswalk Stop on Red line and sign

9.6 Crosswalk Installation Guidelines Flow Chart for Minnesota



9.7 Treatment Plan for Uncontrolled Locations with 40-45 Posted Speed Limit in New York

2. For Posted Speed Limits 40 and 45 mph		
Number of Lanes	Basic Treatment	Enhanced Treatment
2	**Basic Treatment Package C** • High-visibility crosswalk • Retroreflective sign posts (for pedestrian signs at crosswalk and in advance of crosswalk) At crosswalk • Double posted (back to back) fluorescent yellow-green Pedestrian Crossing signs (W11-2) or School signs (S1-1). Pedestrian on sign should always face the crosswalk. • Fluorescent yellow-green diagonal downward pointing arrow plaque (W16-7P) In advance of crosswalk • Fluorescent yellow-green Pedestrian Crossing sign (W11-2) or School sign (S1-1). • Fluorescent yellow-green ahead plaque (W16-9P) • Advance yield line (sharks teeth) – midblock only • Yield Here to Pedestrian sign (R1-5) – midblock only	• Rectangular Rapid Flashing Beacon (RRFB) -(Solar Powered) • Restrict parking – midblock locations

2. For Posted Speed Limits 40 and 45 mph		
Number of Lanes	Basic Treatment	Enhanced Treatment

3 or more	**Basic Treatment Package C**
	• High-visibility crosswalk
	Retroreflective signposts (for pedestrian signs at crosswalk and in advance of crosswalk)
	At crosswalk
	• Double posted (back to back) fluorescent yellow-green Pedestrian Crossing signs (W11-2) or School signs (S1-1). Pedestrian on sign should always face the crosswalk.
	• Fluorescent yellow-green diagonal downward pointing arrow plaque (W16-7P)
	In advance of crosswalk
	• Fluorescent yellow-green Pedestrian Crossing sign (W11-2) or School sign (S1-1).
	• Fluorescent yellow-green ahead plaque (W16-9P)
	• Advance yield line (sharks teeth) – midblock only
	• Yield Here to Pedestrian sign (R1-5) – midblock only
	• Restrict Parking between
		• Rectangular Rapid Flashing Beacon (RRFB) -(Solar Powered)
		• Raised pedestrian median refuge and/or corner island and/or curb extension
		• Signalize the Crossing
		  o If a 2 stage crossing can be implemented consider High-Intensity Activated crosswalk beacon (HAWK)
		  o If a 2 stage crossing is not possible and a crash history exists consider a 3 Color Traffic Signal

9.8 High-risk Corridors on Urban Higher Speed Roads

CorridorID	CorridorName	From	To	pr	bmp	emp	Countyname	AADT	Speed1	Speed2	Length	Ped_Crashes	Bic_Crashes	Nighttime_Crashes	KA_Crashes	KA Nighttime	Total_nonmotorized	Ownership	Crash rate (/mile/yr)	KA Crash Rate (/mile/yr)	Nighttime crash rate (/mile/yr)	Nighttime KA crash rate (/mile/yr)	Pedestrian Crash rate	Bicyclist Crash rate
1	HARPER AVE	WELLINGTON CRES	16 MILE ROAD	798408	8.8	9.195	Macomb	17,300	45	45	0.44	14	6	8	4	4	20	County	3.788	0.758	1.515	0.758	2.652	1.136
2	Division Ave	60th ST SW	S COMELOT BLVD SW	3030181	6.259	6.552	Kent	14,100	45	45	0.4	9	6	10	2	2	15	County	3.125	0.417	2.083	0.417	1.875	1.250
3	S-GROESBECK HWY	CASS AVE	CHURCH ST	803009	11.477	11.715	Macomb	23,000	50	50	0.44	12	4	10	6	6	16	MDOT	3.030	1.136	1.894	1.136	2.273	0.758
4	S-GRATIOT AVE	16th MILE RD	E 13th MILE RD	804806	5.752	9.128	Macomb	50,900	45	45	3.36	45	50	32	26	14	95	MDOT	2.356	0.645	0.794	0.347	1.116	1.240
5	Riley St	136th Ave	US Highway 31	731703	4.741	5.938	Ottawa	18,600	50	50	1.22	8	26	5	5	2	34	County	2.322	0.342	0.342	0.137	0.546	1.776
6	Kalamazoo Ave	60th ST SE	68th ST SE	434905	5.183	6.127	Kent	22,900	45	45	1	10	17	16	3	3	27	County	2.250	0.250	1.333	0.250	0.833	1.417
7	28th ST SE	Shaffer Ave	Lake Eastbrook	409008/407204	15.707/8.211	15.959/8.694	Kent	27,848	45	45	0.8	18	2	11	11	8	20	MDOT	2.083	1.146	1.146	0.833	1.875	0.208
8	28th ST SE	Byron Center Ave	Burlingame Ave SW	409008	8.786	9.779	Kent	22,500	40	45	1	15	9	15	4	4	24	MDOT	2.000	0.333	1.250	0.333	1.250	0.750
9	Lake Michigan Dr	56th Ave	48th Ave	3702045	1.848	2.863	Ottawa	25,000	55	55	1	3	21	3	1	1	24	MDOT	2.000	0.083	0.250	0.083	0.250	1.750
10	Vanborn	Telegraph RD	Beech Daly RD	1670203	7.027	8.022	Wayne	20,000	45	45	1	11	12	11	7	6	23	County	1.917	0.583	0.917	0.500	0.917	1.000
11	Van Dyke Ave	16th MILE RD	Brougham DR	4210208	0.615	1.222	Macomb	44,100	45	45	0.7	7	9	2	2	1	16	MDOT	1.905	0.238	0.238	0.119	0.833	1.071
12	Baldwin ST	20th Ave	Pete Ave	752104	6.575	8.062	Ottawa	22,000	45	45	1.48	8	25	6	5	0	33	County	1.858	0.282	0.338	0.000	0.450	1.408
13	S Mission St	Preston St	E Broomfield St	246704	2.571	3.074	Isabella	21,000	45	45	0.5	5	6	7	3	3	11	MDOT	1.833	0.500	1.167	0.500	0.833	1.000
14	Telegraph	Oxford RD	Van Born RD	4700038	12.432	14.111	Wayne	54,700	45	45	1.7	10	25	10	8	4	35	MDOT	1.716	0.392	0.490	0.196	0.490	1.225
15	Washtenaw Ave	Carpenter RD	N Hewitt RD	1427706	3.586	5.327	Washtenaw	21,000	45	45	1.8	27	8	20	8	7	35	MDOT	1.620	0.370	0.926	0.324	1.250	0.370
16	Alpine Ave RD	Henze	3 Mile RD	423610	2.661	4.125	Kent	36,100	45	50	1.48	21	6	19	6	6	27	MDOT	1.520	0.338	1.070	0.338	1.182	0.338
17	Van Dyke Ave	Hall RD	Utica RD	4211016	0.688	1.68	Macomb	19,400	45	45	1	14	4	13	6	6	18	County	1.500	0.500	1.083	0.500	1.167	0.333
18	23rd Mile	Donner RD	Sass Road	807106	14.266	15.81	Macomb	31,000	50	50	1.53	18	8	13	4	3	26	MDOT	1.416	0.218	0.708	0.163	0.980	0.436
19	James	136th Ave	US Highway 31	731701	4.637	6.114	Ottawa	13,900	45	45	1.47	3	21	2	1	0	24	County	1.361	0.057	0.113	0.000	0.170	1.190
20	N Center Rd	Leith RD	Davison Rd	1498409	7.126	7.81	Genesee	13,000	45	45	0.68	10	1	6	0	0	11	City	1.348	0.000	0.735	0.000	1.225	0.123
21	S Cedar RD	Baker RD	E Miller RD	359606	6.66	9.965	Ingham	21,300	45	45	3.33	32	18	19	14	8	50	MDOT	1.251	0.350	0.475	0.200	0.801	0.450
22	W Saginaw St	Coolidge RD	Alton RD	341208	5.086	6.751	Ingham	27,200	45	45	1.67	11	14	12	5	4	25	MDOT	1.248	0.250	0.599	0.200	0.549	0.699
23	Eureka Rd	Inkster RD	Telegraph RD	1578308	5.094	7.066	Wayne	23,600	45	45	2.02	18	12	13	7	5	30	County	1.238	0.289	0.536	0.206	0.743	0.495
24	N Telegraph RD	Hayes St	Goddard RD	4700038	9.484	11.216	Wayne	55,400	45	45	1.74	9	15	8	3	1	24	MDOT	1.149	0.144	0.383	0.048	0.431	0.718
25	Wilson Ave NW	Leonard St NW	Lake Michigan DR NW	409008	1.529	2.534	Kent	16,100	55	55	1.02	10	4	9	3	3	14	MDOT	1.144	0.245	0.735	0.245	0.817	0.327
26	16 th Mile RD	Dodge Park RD	Schoenherr RD	803608	4.014	5.147	Macomb	53,600	45	45	1.2	3	12	1	0	0	15	County	1.042	0.000	0.069	0.000	0.208	0.833
27	N gratiot Ave	23rd Mile RD	S Gratiot Ave	832010	0.912	5.508	Macomb	21,100	45	50	4.61	39	18	35	15	12	57	MDOT	1.030	0.271	0.633	0.217	0.705	0.325
28	Garfield	19 Mile RD	17 Mile RD	798703	3.502	5.524	Macomb	29,000	45	45	2	14	10	11	9	7	24	County	1.000	0.375	0.458	0.292	0.583	0.417
29	S Martin Luther King	W MT Hope Ave	W Miller RD	352303	1.456	4.709	Ingham	17,300	45	45	3.25	31	8	14	13	7	39	MDOT	1.000	0.333	0.359	0.179	0.795	0.205
30	S Drake Rd	W Main St	Stadium Dr	21704	0.677	2.512	Kalamazoo	26,500	45	45	1.79	14	6	7	4	2	20	County	0.931	0.186	0.326	0.093	0.652	0.279
31	Gull	G Ave	N Sprinkle Rd	7407	3.251	4.396	Kalamazoo	12,500	50	55	1.15	4	8	5	4	2	12	MDOT	0.870	0.290	0.362	0.145	0.290	0.580
32	N Telegraph RD	Stewart RD	Custer Dr	4300001	15.308	16.701	Monroe	22,300	45	45	1.4	8	6	6	4	2	14	MDOT	0.833	0.238	0.357	0.119	0.476	0.357
33	N Telegraph RD	W 7th ST	Community Dr	4300001	14.037	14.623	Monroe	11,900	45	45	1	2	7	6	3	2	9	MDOT	0.750	0.250	0.500	0.167	0.167	0.583
34	Grand River Ave	E Brookfield DR	Dobie RD	335601	5.554	8.038	Ingham	21,900	45	45	2.48	13	5	11	7	6	18	MDOT	0.605	0.235	0.370	0.202	0.437	0.168
35	N Telegraph RD	Newport	Grafton	4300001	20.172	21.855	Monroe	18,400	55	55	1.65	8	3	9	7	7	11	MDOT	0.556	0.354	0.455	0.354	0.404	0.152
36	W Main St	Maple Hill	Spice LN	21502	5.534	6.777	Kalamazoo	23,600	45	45	1.25	7	1	3	4	2	8	MDOT	0.533	0.267	0.200	0.133	0.467	0.067
37	S 11th St	Bell RD	State Line RD	1361302	0.008	2.604	Berrien	17,800	50	50	2.57	11	4	10	8	6	15	MDOT	0.486	0.259	0.324	0.195	0.357	0.130

9.9 High-risk Corridors on Rural Higher-Speed Roads

CorridorID	CorridorName	From	To	pr	bmp	emp	Countyname	AADT	Speed1	Speed2	Length	Ped_Crashes	Bic_Crashes	Nighttime_Crashes	KA_Crashes	KA Nighttime	Total_nonmotorized	Ownership	Crash rate (/mile/yr)	KA Crash Rate (/mile/yr)	Nighttime crash rate (/mile/yr)	Nighttime KA crash rate (/mile/yr)	Pedestrian Crash rate	Bicyclist Crash rate
5	S Cedar St	W Borland	Newark RD	755909	8.465	8.967	Lapeer	19,651	45	45	0.5	4	0	1	1	1	4	MDOT	0.667	0.167	0.167	0.167	0.667	0.000
15	W Randall	Conrad Dr	Mason Dr	742204	7.702	8.153	Ottawa	4,800	45	45	0.45	1	2	2	1	1	3	City	0.556	0.185	0.370	0.185	0.185	0.370
14	124th Ave	59th ST	58th St	3030103	4.985	5.485	Allegan	2,800	45	45	0.5	1	2	0	1	0	3	MDOT	0.500	0.167	0.000	0.000	0.167	0.333
23	Northland DR	Polk RD	6 Mile RD	524603	6.093	6.591	Mecosta	3,800	55	55	0.5	3	0	1	1	1	3	MDOT	0.500	0.167	0.167	0.167	0.500	0.000
17	Johnsville RD	Clarendon RD	N Briggs RD	924201	7.568	8.479	Branch	3,200	55	55	0.9	5	0	2	1	0	5	County	0.463	0.093	0.185	0.000	0.463	0.000
1	M66	Spring Creek	Marvin RD	238204	12.157	13.665	St Joseph	3,800	55	55	1.5	6	1	3	2	0	7	MDOT	0.389	0.111	0.167	0.000	0.333	0.056
9	W Chicago RD	Blue School RD	US Highway 131	232106	4.006	5.162	St Joseph	5,400	55	55	1.2	3	2	1	2	1	5	MDOT	0.347	0.139	0.069	0.069	0.208	0.139
6	S Hillsdale RD	E Reading Rd	Lilac Rd	3300902	8.375	9.594	Hillsdale	2,300	55	55	1.22	3	2	0	2	0	5	County	0.342	0.137	0.000	0.000	0.205	0.137
19	Baldwin RD	Hogan RD	Sharp Rd	1519309	6.284	7.044	Genesee	-	55	55	0.76	2	1	0	0	0	3	County	0.329	0.000	0.000	0.000	0.219	0.110
3	D Ave W	Owen Dr	Adobe RD	3390103	5.032	5.823	Kalamazoo	6,100	55	55	0.8	1	2	1	1	1	3	County	0.313	0.104	0.104	0.104	0.104	0.208
26	S Lake Shore Dr	E Amore RD	Laskey RD	1151708	6.922	8.085	St Joseph	1,500	55	55	1.15	2	2	0	3	0	4	County	0.290	0.217	0.000	0.000	0.145	0.145
4	County RD 378	63rd ST	60th ST	578005	7.483	8.979	Van Buren	2,000	55	55	1.5	5	0	4	1	1	5	County	0.278	0.056	0.222	0.056	0.278	0.000
7	Reading	Abbott Rd	1st Street	518707/518909	3.569/0	3.743/0.672	Hillsdale	1,400	55	55	0.9	3	0	2	1	0	3	County	0.278	0.093	0.185	0.000	0.278	0.000
12	Edgar RD	Amy School Rd	Edgar Rd	1205602/1205603	0.871/0	1.268/0.833	Montcalm	7,600	55	55	1.28	2	2	3	3	2	4	MDOT	0.260	0.195	0.195	0.130	0.130	0.130
2	Nottawa	Spring Creek	M86	233209	3.499	6.011	St Joseph	1,200	55	55	2.5	5	2	0	2	0	7	County	0.233	0.067	0.000	0.000	0.167	0.067
16	Fawn River RD	Big Hill RD	Kime RD	232707	11.143	12.625	St Joseph	1,100	55	55	1.5	2	2	1	1	1	4	County	0.222	0.056	0.056	0.056	0.111	0.111
18	Telegraph	Carleton rockwood	Indian Trail RD	4300001	22.979	24.272	Monroe	6,300	55	55	2	3	2	3	1	1	5	MDOT	0.208	0.042	0.125	0.042	0.125	0.083
25	N Eagle HWY	N Lake Leelanau	E Obrien RD	1148506	14.259	16.045	Leelanau	1,800	55	55	1.8	1	3	0	1	0	4	County	0.185	0.046	0.000	0.000	0.046	0.139
8	N Edon	LiLac RD	Bigelow	518708	8.108	9.11	Hillsdale	2,000	55	55	1	2	0	0	1	0	2	MDOT	0.167	0.083	0.000	0.000	0.167	0.000
10	Skeels	S Maple Island RD	192nd Ave	868201	6.492	8.505	Newaygo	1,600	55	55	2	2	2	0	2	0	4	County	0.167	0.083	0.000	0.000	0.083	0.083
13	W 72nd ST	S Luce Ave	Bingham Ave	3620011	0.811	3.8	Newaygo	6,500	55	55	3.03	4	2	1	3	1	6	MDOT	0.165	0.083	0.028	0.028	0.110	0.055
11	E 36th ST	Chestnut Ave	Beech Ave	718008	1.635	3.243	Newaygo	1,300	45	45	1.6	1	2	3	2	2	3	County	0.156	0.104	0.156	0.104	0.052	0.104
22	Pierce RD	Stanwood Dr	140th Ave	528804	0.079	4.259	Mecosta	1,700	55	55	4.2	6	0	1	0	0	6	County	0.119	0.000	0.020	0.000	0.119	0.000
24	W Kittle RD	N Galbraith RD	Caldwell RD	1334702	4.128	7.053	Branch	1,000	55	55	2.93	3	1	1	2	0	4	MDOT	0.114	0.057	0.028	0.000	0.085	0.028
27	State HWY	Takala Rd	Lohrey Ln	1277904/1276808	14.129/0.377	16.186/1.739	Iron	5,000	55	55	3.55	3	1	2	1	0	4	MDOT	0.094	0.023	0.047	0.000	0.070	0.023
20	Peck RD	Davis ST	Babcock RD	1013004	9.155	12.962	Sanilac	5,900	45	45	3.81	3	0	1	2	0	3	MDOT	0.066	0.044	0.022	0.000	0.066	0.000
21	W Isabella RD	S Greendale Rd	N 11 Mile RD	885110	1.486	6.975	Isabella	12,300	55	55	5.5	4	0	4	3	3	4	MDOT	0.061	0.045	0.061	0.045	0.061	0.000

9.10 High-risk Corridors on Urban Lower-Speed Roads

id	Corridor_Name	From	To	pr	bmp	emp	Area	AADT	Speedlimit	Length	Ped_Crashes	Bic_Crashes	Nighttime _Crashes	KA_Crashes	Nighttime_KA Crashes	Total_nonmotorized	Ownership	Crash rate (/mile/yr)	KA Crash Rate (/mile/yr)	Nighttime crash rate (/mile/yr)	Nighttime KA crash rate (/mile/yr)	Pedestrian Crash rate	Bicyclist Crash rate
1	Gratiot Ave3	8 Mile Rd	Seymour St	4705742	7.268	9.028	Detroit	31500	35	1.76	108	16	72	43	38	124	State	5.871	2.036	3.409	1.799	5.114	0.758
2	S Telegraph Rd	W Huron St	James K Blvd	710110	2.387	3.128	Pontiac	27800	40	0.74	35	10	22	15	11	45	State	5.061	1.687	2.474	1.237	3.936	1.125
3	Jefferson Ave	Woodward Ave	Beaubien St	1577510	12.652	12.782	Detroit	16200	25	0.30	27	12	12	6	4	39	State	10.833	1.667	3.333	1.111	7.500	3.333
4	artin Luther King Blv	3rd St	Woodward Ave	1581907	1.946	2.389	Detroit	12900	25	0.44	43	15	23	8	8	58	City	10.910	1.506	4.327	1.506	8.089	2.822
5	Hayes St	7 Mile Rd	Seymour St	1602506	1.549	2.118	Detroit	9700	30	0.57	23	3	15	9	6	26	City	3.801	1.316	2.193	0.877	3.363	0.439
6	Abbott Rd	Albert Ave	Burcham Dr	349410	0.175	0.496	Lansing	15300	25	0.32	11	19	8	5	1	30	City	7.788	1.298	2.077	0.260	2.856	4.933
7	Furton rd	Market Ave	Lafayette Ave	409005	1.565	2.158	rand Rapid	12200	25	0.59	52	35	33	9	3	87	City	12.226	1.265	4.637	0.422	7.307	4.918
8	Davison W	Dexter Ave	Rosa Parks	4702009	1.501	2.512	Detroit	46000	35	1.01	41	4	16	15	9	45	State	3.709	1.236	1.319	0.742	3.379	0.330
9	Market Ave	Oakes St SW	Pearl St	5703/3410	6.155/0	5.332/0.23	rand Rapid	9400	25	0.41	31	17	29	6	4	48	City	9.756	1.220	5.894	0.813	6.301	3.455
10	Greenfield Rd4	Schoolcraft St	Fenkell Rd	1651002	8.313	9.311	Detroit	21600	30	1.00	47	7	29	14	12	54	County	4.509	1.169	2.422	1.002	3.925	0.585
11	E Grand River Ave	Abbott Rd	N Hagadorn Rd	335601	4.088	5.25	Lansing	18700	25/35	1.16	60	90	35	16	2	150	State	10.757	1.147	2.510	0.143	4.303	6.454
12	Michigan Ave1	Central St	Livernois Ave	1577103	2.881	3.764	Detroit	16000	35	0.88	51	12	32	12	11	63	State	5.946	1.133	3.020	1.038	4.813	1.133
13	Dexter Ave	Elmhurst St	Davison W	1613006	1.93	2.604	Detroit	5800	35	0.67	31	1	9	9	4	32	City	3.956	1.113	1.113	0.495	3.833	0.124
14	S University Ave	Tappan St	Walnut St	1429310	0.127	0.504	Ann-Arbor	-	25	0.38	24	14	13	5	0	38	City	8.400	1.105	2.874	0.000	5.305	3.095
15	Van Dyke1	E 9 Mile Rd	8 Mile Rd	799108	0.02	1.037	Detroit	23900	35	1.02	45	27	25	13	9	72	State	5.882	1.062	2.042	0.735	3.676	2.206
16	Caniff St	alter P Chrysler Fw	Conant St	1632110	0.555	1.424	Detroit	9400	25	0.87	38	14	12	11	4	52	City	4.981	1.054	1.149	0.383	3.640	1.341
17	Greenfield Rd5	Joy Rd	Plymouth Rd	1651002	6.314	7.311	Detroit	20400	35	1.00	43	7	26	12	11	50	County	4.179	1.003	2.173	0.919	3.594	0.585
18	Division Ave2	50th St	44th St	3030181	7.807	8.559	rand Rapid	18700	40	0.75	27	18	11	9	3	45	City	4.987	0.997	1.219	0.332	2.992	1.995
19	S Washington Ave	W 11 Mile Rd	E Lincoln Ave	644804	0.518	0.959	Royal Oak	5100	25	0.45	18	5	13	5	2	23	City	4.259	0.926	2.407	0.370	3.333	0.926
20	E Huron St	State St N	Glen Ave	4604878	2.666	2.941	Ann-Arbor	19700	25	0.28	20	11	14	3	1	31	State	9.394	0.909	4.242	0.303	6.061	3.333
21	E Michigan Ave12	N Grand Ave	Pennsylvania	335507	0.168	0.815	Lansing	8300	30/35	0.65	39	19	18	7	6	58	State/City	7.470	0.902	2.318	0.773	5.023	2.447
22	Gratiot Ave4	Seymour St	Pennsylvania St	4705742	4.675	7.268	Detroit	31500	35	2.59	93	24	58	28	22	117	State	3.760	0.900	1.864	0.707	2.989	0.771
23	S Cedar St	W Kalamazoo St	esar E Chavez Av	3330526	0.341	1.545	Lansing	10600	40	1.20	37	30	21	13	7	67	State	4.637	0.900	1.453	0.484	2.561	2.076
24	7 Mile Rd	Outer Dr E	Schoenherr St	1700106	21.419	22.913	Detroit	13300	30	1.5	58	14	39	16	11	72	City	4.000	0.889	2.167	0.611	3.222	0.778
25	Congress St	Cadillac Sq	1st st	1585505	0.134	0.608	Detroit	5800	25	0.47	26	1	7	5	1	27	City	4.747	0.879	1.231	0.176	4.571	0.176
26	W Washington St	Blackstone St	S Cooper St	900903	0.321	0.905	Jackson	8200	30	0.584	9	7	4	6	2	16	State	2.283	0.856	0.571	0.285	1.284	0.999
27	Michigan Ave2	S Military St	S Brady St	1600206	15.826	16.423	Dearborn	31900	35	0.60	30	14	14	6	4	44	State	6.142	0.838	1.954	0.558	4.188	1.954
28	E 8 Mile Rd	Dequindre Rd	Ryan Rd	802604	0	0.998	Warren	29100	40	1.00	34	14	12	10	4	48	State	4.008	0.835	1.002	0.334	2.839	1.169
29	Greenfield Rd3	Fenkell Rd	McNichols Rd W	1651002	9.311	10.31	Detroit	20600	35	1.00	34	9	23	10	8	43	County	3.587	0.834	1.919	0.667	2.836	0.751
30	Division St	Packard St	E Ann St	1430304	0.568	0.876	Ann-Arbor	13700	25	0.31	35	24	22	3	0	59	City	15.963	0.812	5.952	0.000	9.470	6.494
31	Gratiot Ave1	Commons Rd	Martin Rd	4208203	3.998	5.14	Detroit	24500	40	1.14	31	39	19	11	5	70	State	5.108	0.803	1.386	0.365	2.262	2.846
32	Linwood St	Highland St	Oakman Blvd	1584609	2.435	3.271	Detroit	11600	30	0.84	23	4	12	8	5	27	City	2.691	0.797	1.196	0.498	2.293	0.399
33	Gratiot Ave6	Mt Elliott St	Antietam Ave	4705742	0.613	2.5	Detroit	14900	35	1.89	40	17	24	18	12	57	State	2.517	0.795	1.060	0.530	1.766	0.751
34	S State St	E Stadium Blvd	W Huron St	1427508	5.568	6.844	Ann-Arbor	12500	30	1.28	55	47	44	12	5	102	City	6.661	0.784	2.874	0.327	3.592	3.069
35	Baldwin Ave	W Montcalm St	esar E Chavez Av	672209	0	0.851	Pontiac	8500	35	0.85	13	13	9	8	4	26	City	2.546	0.783	0.881	0.392	1.273	1.273
36	4th Ave	Packard St	Beakes St	1430302	0.143	0.782	Ann-Arbor	5800	25	0.64	25	20	10	6	0	45	City	5.869	0.782	1.304	0.000	3.260	2.608
37	Chalmers St	Houston Whittier St	Harper Ave	1578102	2.428	3.65	Detroit	7800	30	1.2	24	12	19	11	6	36	City	2.500	0.764	1.319	0.417	1.667	0.833
38	Michigan Ave	W Michigan Ave	S Howard St	3392196	0.087	1.293	Kalamazoo	17600	35	1.21	39	20	36	11	8	59	City	4.077	0.760	2.488	0.553	2.695	1.382
39	Division Ave1	Burton Ave	Canton St	3030181	11.567	12.591	rand Rapid	14700	30	1.02	34	27	18	9	4	61	City	4.964	0.732	1.465	0.326	2.767	2.197
40	W 11 Mile Rd	S Lafayette Ave	N Troy St	4400088	7.311	7.654	Royal Oak	16400	25	0.34	14	11	11	3	2	25	County	6.074	0.729	2.672	0.486	3.401	2.672
41	Woodward Ave	Oakland Park	Fielding St	614101	11.184	12.796	easant Rid	17900	35	1.61	39	61	28	14	8	100	State	5.170	0.724	1.447	0.414	2.016	3.153
42	Gratiot Ave5	McClellan St	Mt Elliott St	4705742	2.5	4.46	Detroit	35200	35	1.96	44	16	27	17	15	60	State	2.551	0.723	1.148	0.638	1.871	0.680
43	W Huron St	Dexter Ave	7th St	4604878	1.397	1.745	Ann-Arbor	17400	35	0.35	6	7	6	3	2	13	State	3.113	0.718	1.437	0.479	1.437	1.676
44	McNichols Rd W	Southfield Rd	Schaefer Hwy	1680701	17.017	18.991	Detroit	23300	35	1.97	63	12	33	17	12	75	County	3.166	0.718	1.393	0.507	2.660	0.507
45	Woodward Ave6	Montcalm St E	Gratiot Ave	1591001	6.08	6.551	Detroit	9300	25	0.47	30	6	8	4	2	36	City	6.369	0.708	1.415	0.354	5.308	1.062
46	8 Mile Rd W	Greenfield Rd	Woodward Ave	640807	6.189	10.033	Ferndale	27400	40	3.84	79	30	41	32	24	109	State	2.363	0.694	0.889	0.520	1.713	0.650
47	Division Ave	Cherry St SW	Lyon St	3030181	13.776	14.623	rand Rapid	10600	25	0.85	56	22	25	7	1	78	City_State	7.674	0.689	2.460	0.098	5.510	2.165
48	Ashley St	Miller Ave	W William St	1430210	0.359	0.725	Ann-Arbor	5000	25	0.37	24	5	17	3	2	29	City	6.603	0.683	3.871	0.455	5.464	1.138
49	Holrook St	Lumpkin St	Conant St	1585801	1.218	1.96	Detroit	6500	25	0.74	26	7	9	6	4	33	City	3.706	0.674	1.011	0.449	2.920	0.786
50	W Warren Ave2	Greenfield Rd	Schaefer Rd	1628604	0	0.994	Dearborn	21300	35	0.99	32	8	18	8	5	40	County	3.353	0.671	1.509	0.419	2.683	0.671
51	7 Mile Rd2	Lahser St	Greenfield Rd	1700106	8.941	11.929	Detroit	27700	35	2.99	83	22	45	24	19	105	County	2.928	0.669	1.255	0.530	2.315	0.614
52	Rose St	Walnut St	W Kalamazoo Ave	6606	0.295	0.803	Kalamazoo	7400	25	0.51	14	18	7	4	1	32	City	5.249	0.656	1.148	0.164	2.297	2.953
53	W Kalamazoo Ave	N Westnedge Ave	Harrison St	7405	0.503	1.269	Kalamazoo	11100	30/35	0.77	26	34	10	6	1	60	State	6.527	0.653	1.088	0.109	2.829	3.699
54	Gratiot Ave2	E 9 Mile Rd	E 11 Mile Rd	4208203	1.109	3.424	Detroit	27400	40	2.32	62	89	45	18	7	151	State	5.436	0.648	1.620	0.252	2.232	3.204
55	Michigan St1	Monroe Ave	College Ave	407408	2.393	3.171	rand Rapid	19200	25	0.78	26	25	15	6	2	51	City	5.463	0.643	1.607	0.214	2.785	2.678
56	Cass Ave	Warren Ave W	Fisher Fwy	1577605	0.779	2.083	Detroit	7800	25	1.30	45	33	30	10	4	78	City	4.985	0.639	1.917	0.256	2.876	2.109
57	Gull Rd	Riverview Dr	Inverness Ln	7407	0.3778	1.429	Kalamazoo	20100	40	1.05	17	17	10	8	4	34	State	2.695	0.634	0.793	0.317	1.348	1.348
58	Douglas Ave	W North St	Alamo Ave	7810	0.368	0.635	Kalamazoo	6900	25	0.267	9	5	7	2	2	14	City	4.370	0.624	2.185	0.624	2.809	1.561
59	Woodward Ave3	McNichols Rd W	Calvert St	1591001	0	2.186	Detroit	19700	30	2.19	77	26	35	16	11	103	State	3.927	0.610	1.334	0.419	2.935	0.991
60	W Huron St	N Telegraph Rd	Woodward Ave	648906	19.26	21.175	Pontiac	33800	25/35	1.92	55	20	33	14	12	75	State	3.264	0.609	1.436	0.522	2.393	0.870

id	Corridor_Name	From	To	pr	bmp	emp	Area	AADT	Speedlimit	Length	Ped_Crashes	Bic_Crashes	Nighttime_Crashes	KA_Crashes	Nighttime_KA Crashes	Total_nonmotorized	Ownership	Crash rate (/mile/yr)	KA Crash Rate (/mile/yr)	Nighttime crash rate (/mile/yr)	Nighttime KA crash rate (/mile/yr)	Pedestrian Crash rate	Bicyclist Crash rate
61	Bridge St	Lane Ave	Turner Ave	407408	1.366	2.055	rand Rapid	9300	25	0.69	18	23	17	5	2	41	City	4.959	0.605	2.056	0.242	2.177	2.782
62	Woodward Ave5	Edsel Ford Fwy	Fisher Fwy	1591001	4.189	5.986	Detroit	24900	30	1.80	80	33	32	13	5	113	State	5.240	0.603	1.484	0.232	3.710	1.530
63	Wealthy St	Ionia Ave	Lafayette Ave	408907	0.874	1.427	rand Rapid	30600	25	0.55	16	15	10	4	3	31	City	4.671	0.603	1.507	0.452	2.411	2.260
64	Michigan St NE1	Collage Ave	Fuller Ave	407408	3.171	4.017	rand Rapid	15200	25	0.85	31	21	20	6	2	52	City	5.122	0.591	1.970	0.197	3.054	2.069
65	S River Ave	E 16th St	W 7th St	740204	1.098	1.663	Holland	16200	25/30	0.565	14	27	9	4	1	41	City	6.047	0.590	1.327	0.147	2.065	3.982
66	Martin Luther King Jr	Division Ave	Madison Ave SE	408807	0.625	1.063	rand Rapid	11600	25	0.43	23	11	10	3	1	34	City	6.620	0.584	1.947	0.195	4.478	2.142
67	E Michigan Ave	Bingham St	Charles St	335507	0.897	2.043	Lansing	21900	25/35	1.15	22	25	12	8	4	47	City	3.418	0.582	0.873	0.291	1.600	1.818
68	Lahser Rd	7 Mile Rd W	Grand River Ave	1582205	2.387	3.26	Detroit	14300	35	0.87	30	2	16	6	3	32	County	3.055	0.573	1.527	0.286	2.864	0.191
69	W 9th St	Pine Ave	Columbia Ave	745906	0	0.438	Holland	6600	30	0.438	9	15	5	3	1	24	County	4.566	0.571	0.951	0.190	1.712	2.854
70	E Michigan Ave	Cooper St	N Dettman Rd	3381123	0	1.906	Jackson	15500	30/35/40	1.906	43	36	21	13	7	79	State	3.454	0.568	0.918	0.306	1.880	1.574
71	Warren Ave	John C Lodge Fwy	Chrysler Dr	4700429	0.32	1.368	Detroit	13000	30	1.04	60	21	24	7	3	81	City	6.503	0.562	1.927	0.241	4.817	1.686
72	W Vernor Hwy	Livernois Ave	Grand Blvd W	1581909	1.853	3.04	Detroit	15700	25/30	1.19	32	16	13	8	4	48	City	3.370	0.562	0.913	0.281	2.247	1.123
73	E Kilgore Rd	Woodmont Dr	Milham Park Dr	6903	1.743	2.357	Kalamazoo	13600	35	0.61	10	7	6	4	1	17	City	2.307	0.543	0.814	0.136	1.357	0.960
74	Van Dyke 2	Walter P Reuther Fw	E 9 Mile Rd	799108	1.037	2.981	Detroit	27300	35	2	46	45	27	13	7	91	State	3.792	0.542	1.125	0.292	1.917	1.875
75	2nd Ave	rtin Luther King Jr B	Warren Ave	1607905	0.284	1.057	Detroit	1700	30	0.77	22	12	13	5	2	34	City	3.665	0.539	1.401	0.216	2.372	1.294
76	S Westnedge Ave	Howard St	E Kalamazoo Ave	10208	4.779	6.173	Kalamazoo	11900	35	1.39	28	34	14	9	3	62	State	3.706	0.538	0.837	0.179	1.674	2.033
77	Woodward Ave4	Chicago Blvd	Edsel Ford Fwy	1591001	2.421	4.135	Detroit	18700	30	1.71	54	20	21	11	4	74	State	3.598	0.535	1.021	0.194	2.625	0.972
78	Joseph Campau St	Carpenter St	Hamtramck Dr	1591101	0	1.564	Detroit	7300	35	1.564	47	34	17	10	5	81	County	4.316	0.533	0.906	0.266	2.504	1.812
79	Baldwin Ave	New York Ave	E Fairmount Ave	672209	1.557	2.344	Pontiac	16000	35	0.79	15	8	9	5	4	23	City	2.435	0.529	0.953	0.424	1.588	0.847
80	Saginaw St	N Pine St	N Grand Ave	341208	2.199	2.675	Lansing	10900	35	0.476	11	12	4	3	1	23	State	4.027	0.525	0.700	0.175	1.926	2.101
81	Brush St	Montcalm St E	Jefferson Ave E	4718307	0	0.8	Detroit	6400	25	0.80	31	3	16	5	5	34	City	3.542	0.521	1.667	0.521	3.229	0.313
82	Harper Ave	Whittier St	Morang Dr	1578108	4.805	5.451	Detroit	8000	30	0.65	24	6	16	4	4	30	City	3.846	0.513	2.051	0.513	3.077	0.769
83	7 Mile Rd W	Woodward Ave	Conant St	1700106	16.272	18.385	Detroit	11700	30	2.11	52	14	27	13	24	66	City	2.603	0.513	1.065	0.947	2.051	0.552
84	Warren Ave	Evergreen Ave	Greenfield Rd	1591804	1.38	3.382	Detroit	19900	35	2.00	63	15	30	12	10	78	County	3.247	0.500	1.249	0.416	2.622	0.624
85	Stadium Dr	W Lovell St	W Main St	22207	9.428	9.762	Kalamazoo	17700	35	0.33	10	12	5	2	1	22	State	5.489	0.499	1.248	0.250	2.495	2.994
86	N Main St2	W Huron St	W Summit	4603186	1.684	2.187	Ann-Arbor	17700	30	0.50	28	13	14	3	2	41	State	6.793	0.497	2.319	0.331	4.639	2.154
87	John R Rd2	F 10 Mile Rd	E 9 Mile Rd	646806	0.997	2.017	Hazel Park	15400	40	1.02	25	19	16	6	5	44	City	3.595	0.490	1.307	0.408	2.042	1.552
88	N Main St1	Pauline Blvd	W Huron St	4603186	0.801	1.694	Ann-Arbor	13500	25	0.89	29	24	15	5	3	53	City	4.946	0.467	1.400	0.280	2.706	2.240
89	Wyoming St	Lyndon St	mes Couzens Fw	4700001	4.509	5.228	Detroit	20400	30	0.72	23	8	8	4	3	31	City	3.593	0.464	0.927	0.348	2.666	0.927
90	Capital Ave1	E Bidwell St	Goguac St W	3130001	5.144	5.687	attle Cree	9600	30	0.543	3	12	2	3	0	15	City	2.302	0.460	0.307	0.000	0.460	1.842
91	S Main St	E Farnum Ave	E Lincoln Ave	644806	0.681	1.405	Royal Oak	14800	25	0.73	44	13	26	4	1	57	City	6.507	0.457	2.968	0.114	5.023	1.484
92	Woodward Ave2	8 Mile Rd W	7 Mile Rd W	1598507	0.034	1.13	Detroit	14400	40	1.10	27	17	10	6	3	44	State	3.345	0.456	0.760	0.228	2.053	1.293
93	Lyon St	Monroe Ave	Ransom Ave	419802	0.102	0.468	rand Rapid	3500	25	0.37	23	6	3	2	0	29	City	6.603	0.455	0.683	0.000	5.237	1.366
94	1st St	Miller Ave	W William St	4600034	0.362	0.729	Ann-Arbor	6800	25	0.37	13	9	7	2	2	22	City	4.995	0.454	1.589	0.454	2.952	2.044
95	Griswold St	W Larned St	Grand River Ave	1581609	0.071	0.442	Detroit	11100	25	0.37	30	7	5	2	0	37	City	8.311	0.449	1.123	0.000	6.739	1.572
96	Morrell St	1st St	Martin Luther Ki	899909	2.268	2.828	Jackson	6200	25	0.56	10	6	9	3	3	16	City	2.381	0.446	1.339	0.446	1.488	0.893
97	Plymouth Rd	Southfield Rd	Hubbell St	1604102	17.276	18.778	Detroit	15500	30	1.50	37	10	22	8	6	47	City	2.608	0.444	1.221	0.333	2.053	0.555
98	Grand River Ave	Redford St	Outer Dr W	1577408	0.401	1.908	Detroit	24000	35	1.51	47	8	25	8	4	55	State	3.041	0.442	1.382	0.221	2.599	0.442
99	E Larned St	Washington Blvd	St Antoine St	1585504	0.123	0.707	Detroit	8800	25	0.58	25	4	4	3	1	29	City	4.138	0.428	0.571	0.143	3.567	0.571
100	Packard St	S Division St	E Stadium Blvd	1430704	0.283	1.479	Ann-Arbor	11700	30	1.20	28	62	26	6	4	90	City	6.271	0.418	1.812	0.279	1.951	4.320
101	Morang Dr	Kelly Rd	Edsel Ford Fwy	1578203	0.08	1.447	Detroit	5100	30	1.4	26	7	14	7	4	33	City	1.964	0.417	0.833	0.238	1.548	0.417
102	7 Mile Rd E2	Mound Rd	Outer Dr E	1700106	19.933	21.159	Detroit	11700	30	1.23	38	6	16	6	5	44	City	2.991	0.408	1.088	0.340	2.583	0.408
103	E Shearman Blvd	7th St	Reynolds St	859506	3.539	4.171	Muskegon	13000	30	0.632	20	8	16	3	2	28	City	3.692	0.396	2.110	0.264	2.637	1.055
104	Conant St	Carpenter St	Hamtramck Dr	1629706	0.28	1.845	Detroit	8400	25	1.56	26	9	9	7	4	35	County	1.870	0.374	0.481	0.214	1.339	0.481
105	S Gratiot Ave	E Joy Blvd	Harrington St	4208203	10.02347	12.17962	Mt Clemen	16700	35	2.08	30	34	24	9	6	64	State	2.564	0.361	0.962	0.240	1.202	1.362
106	John R Rd3	Mack Ave	E Warren Ave	4705731	0.663	1.37	Detroit	9600	25	0.71	34	23	9	3	2	57	City	6.719	0.354	1.061	0.236	4.008	2.711
107	5th Ave	Packard St	Beakes St	1430303	0.267	0.987	Ann-Arbor	9900	25	0.72	31	11	11	3	2	42	City	4.861	0.347	1.273	0.231	3.588	1.273
108	Fort St	Goddard Rd	Champaign Rd	1592106	10.894	12.358	Lincoln Par	14800	35	1.46	10	36	11	6	3	46	State	2.618	0.342	0.626	0.171	0.569	2.049
109	Ionia Ave	Cherry St SW	W Fulton St	405301	0.755	1	rand Rapid	5600	25	0.25	17	12	11	1	0	29	City	9.864	0.340	3.741	0.000	5.782	4.082
110	E Stockbridge Ave	Portage St	Cameron St	3609	0.812	1.302	Kalamazoo	5600	25	0.49	16	8	10	2	2	24	City	4.082	0.340	1.701	0.340	2.721	1.361
111	N West Ave	W Michigan Ave	W Monroe St	898201	0.517	1.746	Jackson	15000	30/40	1.229	19	16	12	5	3	35	State	2.373	0.339	0.814	0.203	1.288	1.085
112	15 Mile Rd	Groesbeck Hwy	S Gratiot Ave	803805	8.408	9.628	Detroit	26000	40	1.23	12	8	9	5	3	20	County	1.355	0.339	0.610	0.203	0.813	0.542
113	Funkell St	outhfield Service R	Hubbell St	1579605	4.97	6.453	Detroit	12100	30	1.48	29	4	14	6	4	33	County	1.854	0.337	0.787	0.225	1.630	0.225
114	N Pennysylvania Ave	E Kalamazoo St	E Shiawassee St	335905	4.76	5.26	Lansing	19200	30/35	0.50	24	15	8	2	2	39	City	6.500	0.333	1.333	0.333	4.000	2.500
115	Portage St1	E Alcott St	Lake St	24703	13.436	14.186	Kalamazoo	17400	30	0.75	30	12	9	3	1	42	City	4.667	0.333	1.000	0.111	3.333	1.333
116	Coolidge Hwy	W 12 Mile Rd	W 11 Mile Rd	644004	3.006	4.011	Berkley	15000	30	1.01	11	28	10	4	2	39	City	3.234	0.332	0.829	0.166	0.912	2.322
117	W Main St	S Dartmouth St	Douglas Ave	21502	7.817	8.572	Kalamazoo	15000	35	0.75	5	16	4	3	3	21	State	2.318	0.331	0.442	0.331	0.552	1.766
118	John R Rd	W Gardenia Ave	W Lincoln Ave	646806	2.52	3.527	dison Heig	24900	40	1.01	14	16	10	4	3	30	City	2.483	0.331	0.828	0.248	1.159	1.324
119	Dix Hwy	Northline Rd	Moore Ave	1688707	3.844	5.623	Southgate	31600	40	1.78	26	41	18	7	5	67	County	3.138	0.328	0.843	0.234	1.218	1.921
120	E9 Mile RD	Gratiot Ave	Kelly Rd	803006	6.45	8.031	Eastpointe	22400	30	1.58	24	25	13	6	4	49	City	2.583	0.316	0.685	0.211	1.265	1.318

id	Corridor_Name	From	To	pr	bmp	emp	Area	AADT	Speedlimit	Length	Ped_Crashes	Bic_Crashes	Nighttime_Crashes	KA_Crashes	Nighttime_KA Crashes	Total_nonmotorized	Ownership	Crash rate (/mile/yr)	KA Crash Rate (/mile/yr)	Nighttime crash rate (/mile/yr)	Nighttime KA crash rate (/mile/yr)	Pedestrian Crash rate	Bicyclist Crash rate
121	Leonard St	White Ave NW	Turner Ave	3415604	5.414	6.476	rand Rapid	16300	30	1.06	33	35	20	4	0	68	City	5.336	0.314	1.569	0.000	2.589	2.746
122	Capital Ave2	W Dickman Rd	E Van Buren St	0001/3130	6.032/0	5.405/0.17	attle Cree	8500	30	0.55	9	14	6	2	1	23	City	3.485	0.303	0.909	0.152	1.364	2.121
123	W Wesley St	1st St	Martin Luther Ki	900907	0	0.555	Jackson	-	25	0.555	6	3	0	2	0	9	City	1.351	0.300	0.000	0.000	0.901	0.450
124	Coolidge Hwy2	Oak Park Blvd	8 Mile Rd W	644004	0.021	1.424	Oak Park	21600	35	1.40	36	21	15	5	3	57	City	3.386	0.297	0.891	0.178	2.138	1.247
125	Miller Ave	Newport Rd	1st St	1430906	4.339	5.188	Ann-Arbor	8200	30	0.85	2	16	4	3	2	18	City	1.767	0.294	0.393	0.196	0.196	1.570
126	S Westnedge Ave2	Romence Rd	Andy Ave	10208	0.729	2.456	Kalamazoo	34500	35	1.73	12	27	11	6	3	39	City	1.882	0.290	0.531	0.145	0.579	1.303
127	W Stadium Blvd	S Maple Rd	Pauline Blvd	1429506	0	0.882	Ann-Arbor	22700	35	0.88	4	16	5	3	1	20	City	1.890	0.283	0.472	0.094	0.378	1.512
128	S Burdick St	Dixie Ave	E Vine St	4210	0.381	1.27	Kalamazoo	8000	25	0.89	11	17	5	3	3	28	City	2.625	0.281	0.469	0.281	1.031	1.594
129	Michigan Ave	W 32nd St	W 19th St	740204	0	0.911	Holland	14200	30/35	0.911	11	14	2	3	0	25	City	2.287	0.274	0.183	0.000	1.006	1.281
130	Michigan Ave3	S Homer St	V Grand River Av	5507/33314	2.252/0	2.582/0.798	Lansing	16700	35	1.25	13	48	15	4	1	61	City/State	4.067	0.267	1.000	0.067	0.867	3.200
131	Greenfield Rd2	Outer Dr W	ames Couzens Fw	1651002	10.551	12.156	Detroit	22000	35	1.61	31	11	11	5	1	42	County	2.181	0.260	0.571	0.052	1.610	0.571
132	Hill St	Oakland Ave	S Forest Ave	1429402	0.533	0.857	Ann-Arbor	10900	25	0.32	14	13	9	1	1	27	City	6.944	0.257	2.315	0.257	3.601	3.344
133	W 13 Mile Rd	Stephenson Hwy	John R Rd	607408	1.033	1.69	dison Heig	25200	40	0.66	8	13	8	2	0	21	City	2.664	0.254	1.015	0.000	1.015	1.649
134	Park St	E Paterson St	W Vine St	5007/9308	0.952/0	1.47/0.814	Kalamazoo	9800	35	1.43	24	21	16	4	2	45	State	2.622	0.233	0.932	0.117	1.399	1.224
135	Greenfield Rd	8 Mile Rd	W 10 Mile Rd	648307	0.016	2.008	Southfield	16600	40	1.99	29	19	11	5	3	48	County	2.008	0.209	0.460	0.126	1.213	0.795
136	Dexter Ave	Maple Rd	W Huron St	1446002	7.484	8.283	Ann-Arbor	7100	30	0.80	3	5	3	2	2	8	City	0.834	0.209	0.313	0.209	0.313	0.521
137	E Laketon Ave	N SeawayDr	Wood St	859710	1.073	2.359	Muskegon	17000	25	1.286	11	31	9	3	2	42	City	2.722	0.194	0.583	0.130	0.713	2.009
138	W Ganson St	N West Ave	N Mechanic St	901809	0.763	1.65	Jackson	11100	25	0.887	7	14	4	2	0	21	City	1.973	0.188	0.376	0.000	0.658	1.315
139	Portage St2	Kilgore Rd	Palmer Ave	24703	11.58	13.355	Kalamazoo	19200	30/35	1.775	13	10	8	4	4	23	City	1.080	0.188	0.376	0.188	0.610	0.469
140	Catalpa Dr	Greenfield Rd	Coolidge Hwy	656010	0.817	1.792	Berkley	26600	25	0.98	9	16	5	2	1	25	City	2.137	0.171	0.427	0.085	0.769	1.368
141	Cass Ave	N Groesbeck Hwy	S Gratiot Ave	819209	1.881	2.865	Mt Clemen	16200	35	0.98	13	8	7	2	1	21	County	1.778	0.169	0.593	0.085	1.101	0.678
142	W 14 Mile Rd	N Crooke Rd	N Livernois Rd	625804	3.032	4.03	Clawson	27600	40	1.00	5	18	3	2	1	23	City	1.921	0.167	0.251	0.084	0.418	1.503
143	N Old Woodward Ave	Oak Blvd	Landon St	613810	0.215	1.261	irminghar	10400	25	1.05	26	13	10	2	1	39	City	3.107	0.159	0.797	0.080	2.071	1.036
144	Beaubien St	Madison St	Jefferson Ave E	1587305	0.182	0.723	Detroit	3000	25	0.54	27	1	10	1	1	28	City	4.313	0.154	1.540	0.154	4.159	0.154
145	Shaw Ln	S Harrison Rd	S Hagadorn Rd	3332005	0.046	1.153	Lansing	-	25	1.107	35	54	14	2	1	89	County	6.700	0.151	1.054	0.075	2.635	4.065
146	W Milham Ave	Oakland Dr	S Westnedge Ave	13006	1.757	3.012	Kalamazoo	16300	35	1.26	7	16	4	2	0	23	City	1.527	0.133	0.266	0.000	0.465	1.062
147	E Maple Rd	S Chester St	S Adams Rd	683906	13.581	14.219	irminghar	14100	40	0.64	22	6	5	1	0	28	City	3.657	0.131	0.653	0.000	2.874	0.784
148	W 12 Mile Rd	Greenfield Rd	Coolidge Hwy	4462980	16.011	16.99	Berkley	15000	30	0.98	17	8	4	1	0	25	County	2.128	0.085	0.340	0.000	1.447	0.681
149	E Maple Ave	Peck St	S Getty St	857803	0.217	1.235	Muskegon	8500	30	1.018	13	18	10	1	0	31	State	2.538	0.082	0.819	0.000	1.064	1.473
150	S Westnedge Ave1	W Kilgore Rd	Whites Rd	10208	2.773	3.821	Kalamazoo	23200	40	1.05	13	8	4	1	0	21	State	1.670	0.080	0.318	0.000	1.034	0.636
151	Farm Ln	Trowbridge Rd	Audotorium Rd	3332003	1.165	1.709	Lansing	11000	25	0.54	22	51	10	0	0	73	Uncertified	11.183	0.000	1.532	0.000	3.370	7.813
152	University Ave	State St	Washtenaw Ave	9304/1429	0/0	0.246/0.161	Ann-Arbor	3400	25	0.41	22	18	14	0	0	40	City	8.130	0.000	2.846	0.000	4.472	3.659
153	Mack Ave	John R St	Chyster Dr	1585609	0.12	0.541	Detroit	12800	25	0.42	13	12	6	0	0	25	City	4.949	0.000	1.188	0.000	2.573	2.375
154	S Saginaw St	E Court St	W Kearsley St	1497102	11.185	11.532	Flint	7500	25	0.35	16	3	2	0	0	19	City	4.563	0.000	0.480	0.000	3.842	0.720
155	N Maple Rd	Dexter Ave	S Maple Rd	1452206	1.627	2.077	Ann-Arbor	24800	35	0.45	5	8	1	0	0	13	City	2.407	0.000	0.185	0.000	0.926	1.481

9.11 High-risk Corridors on Rural Lower-Speed Roads

id	Corridor_Name	From	To	pr	bmp	emp	Village/City	Name_smallcommunity	Connected to high speed corridor	Nearest Distance (mi)	Area (County)	AADT	Speedlimit	Length	Ped_Crashes	Bic_Crashes	Nighttime_Crashes	KA_Crashes	Nighttime_KA Crashes	Total_nonmotorized	Ownership	Crash rate (/mile/yr)	KA Crash Rate (/mile/yr)	Nighttime crash rate (/mile/yr)	Nighttime KA crash rate (/mile/yr)	Pedestrian Crash rate	Bicyclist Crash rate
1	N Main St 2	E Wood St	1st St	962207	2.012	2.409	City	Yale	Yes	0.00	St. Clair	4900	30	0.40	7	4	3	2	0	11	State	2.309	0.420	0.630	0.000	1.469	0.840
2	E Huron Ave	S Main St	Goodrich St	274603	10.888	11.092	City	Vassar	Yes	0.45	Tuscola	8800	30	0.20	3	3	0	1	0	6	State	2.451	0.408	0.000	0.000	1.225	1.225
3	E Main St2	State St	Judd St	1164905	6.752	6.991	City	Harbor Springs	Yes	0.77	Emmet	4400	30	0.24	5	2	1	1	0	7	State	2.441	0.349	0.349	0.000	1.743	0.697
4	N Oak St	W Main St	W Monroe St	556307	5.34	5.842	City	Durand	-	-	Shiawassee	6400	25	0.502	3	2	0	2	0	5	City	0.830	0.332	0.000	0.000	0.498	0.332
5	Cedar St	Cemetery St	S Silverleaf St	1120210	5.496	6.063	City	Gladwin	Yes	0.40	Gladwin	9900	30	0.57	9	7	0	2	0	16	State	2.352	0.294	0.000	0.000	1.323	1.029
6	Bridge St	M-66 N	Thistledowns Dr	1243507	0.401	1.559	City	Charlevoix	Yes	0.00	Charlevoix	14200	25/35	1.16	12	6	0	4	0	18	State	1.295	0.288	0.000	0.000	0.864	0.432
7	E State St	Grover St	Nanita Dr	1494503	1.707	2.305	City	Montrose	Yes	0.00	Genesee	6800	30/35	0.598	2	4	2	2	1	6	State	0.836	0.279	0.279	0.139	0.279	0.557
8	S Main St	E Curtis Rd	Koester Dr	467707	7.009	8.535	City	Frankenmuth	Yes	0	Saginaw	11000	30	1.526	12	3	1	4	0	15	State	0.819	0.218	0.055	0.000	0.655	0.164
9	N Main St	W St Clair St	Research Dr	755909/756104	2.1/0	2.472/0.428	Village	Almond	Yes	0.50	Lapeer	15400	30	0.8	8	3	3	2	1	11	State/County	1.146	0.208	0.313	0.104	0.833	0.313
10	W Broad St	S 4th St	S Washington St	470008	12.23	13.184	Village	Chesaning	Yes	0.1	Saginaw	6700	25/35	0.954	4	1	0	2	0	5	State	0.437	0.175	0.000	0.000	0.349	0.087
11	Main St	Euclid St	W Marlette Rd	1012410	2.512	3.016	City	Marlette	Yes	0.34	Sanilac	9100	30	0.504	4	0	1	1	1	4	State	0.661	0.165	0.165	0.165	0.661	0.000
12	W Main St/E Main St	Market St	Southwoods Ave	712309	3.607	5.458	City	Fremont	Yes	0.23	Newaygo	11600	25/35	1.851	10	6	2	3	0	16	State/City	0.720	0.135	0.090	0.000	0.450	0.270
13	N/S Main St	County Dr	Backus St	550501	15.428	16.679	City	Cheboygan	Yes	0.71	Cheboygan	11300	25/35	1.251	3	4	1	2	0	7	State	0.466	0.133	0.067	0.000	0.200	0.266
14	W Superior St	Reno Dr	Wildcat Dr	797705	6.84	8.218	City	Wayland	Yes	0.43	Alegan	7000	25	1.378	9	6	2	2	0	15	City	0.907	0.121	0.121	0.000	0.544	0.363
15	S James St	Huron St	M 72	535604	0.677	1.387	City	Grayling	Yes	0.30	Crawford	13600	30/40	0.71	2	6	1	1	0	8	State	0.939	0.117	0.117	0.000	0.235	0.704
16	S Grand Ave	Van Riper Rd	Power St	935004	3.518	4.302	Village	Fowlerville	-	-	Livingston	11000	25	0.784	8	2	5	1	0	10	City	1.063	0.106	0.531	0.000	0.850	0.213
17	Sanilac Ave/ Elk St	Margaret St	Gaige St	1014806/3760048	13.912/11.793	14.249/12.275	City	Sandusky	Yes	0.00	Sanilac	6800	30/35	0.82	3	4	0	1	0	7	State	0.711	0.102	0.000	0.000	0.305	0.407
18	W Genesee St	Mayer Rd	Park Rd	472301	4.044	5.252	City	Frankenmuth	Yes	2.00	Saginaw	9500	30	1.208	6	5	1	1	0	11	City	0.759	0.069	0.069	0.000	0.414	0.345
19	S Washington St	W 6th St	Youngs Prairie Rd	238201	5.732	6.974	Village	Constastine	Yes	0.32	St. Joseph	3800	30	1.242	3	3	0	1	0	6	County/State	0.403	0.067	0.000	0.000	0.201	0.201
20	N Main St 3	W Mejer Ave	Park St	4210003	8.804	9.401	Village	Capac	Yes	1.00	St. Clair	7600	25	0.597	3	3	2	0	0	6	City	0.838	0.000	0.279	0.000	0.419	0.419
21	Van Dyke Rd	Huron Ave	Buschlen Rd	1034303	8.475	9.344	-	-	Yes	0.00	Huron	10700	30/40	0.869	6	5	0	0	0	11	State	1.055	0.000	0.000	0.000	0.575	0.479
22	Tecumseh St/ Monroe St	Outer Dr	Oak St	1223803	5.379	6.313	Village	Dundee	Yes	0.00	Monroe	14600	30/35	0.93	11	7	3	0	0	18	State	1.606	0.000	0.268	0.000	0.981	0.625
23	W Adrian St	S Monroe St	Newspaper St	947102	0.851	1.246	Village	Blissfield	Yes	0.64	Lenawee	11400	30	0.395	3	3	3	0	0	6	State	1.266	0.000	0.633	0.000	0.633	0.633
24	W Chicago Rd	S Elkhart St	N Glenwood St	232106	5.912	6.435	Village	White Pigeon	Yes	0.00	St. Joseph	8000	35	0.523	2	4	1	0	0	6	State	0.956	0.000	0.159	0.000	0.319	0.637
25	N Whittaker St	E Buffalo St	E Water St	1361307	2.634	2.895	City	New Buffalo	-	-	Berrien	-	25	0.26	5	1	1	0	0	6	City	1.916	0.000	0.319	0.000	1.596	0.319
26	E Main St	S Broad St	1st St	1042405	14.578	14.756	City	Harrison	Yes	0.00	Clare	5400	35	0.18	3	3	4	0	0	6	State	2.809	0.000	1.873	0.000	1.404	1.404
27	S Huron Ave	E Central Ave	W Lake St	3160785	0.143	0.592	Village	Mackinaw City	-	-	Cheboygan	3900	25	0.45	3	4	2	0	0	7	City	1.299	0.000	0.371	0.000	0.557	0.742
28	N Saginaw St	E Clinton St	W Spruce St	3730210	0.172	0.442	Village	St Charles	Yes	1.48	Saginaw	9400	25/35	0.27	5	1	1	0	0	6	State/City	1.852	0.000	0.309	0.000	1.543	0.309

9.12 A Study on Use of Gateway to Reducing Speeding on Higher Speed Roads Entering Slower Speed Small Rural Communities

Alhomaidat et al. (2020) investigated the effects of increased speed limit at freeways in relation to crashes. The authors found that increasing the freeway speed limit increased crashes at the freeway by 11.5%. The increased speed limit also influenced crashes on nearby roads; crashes on nearby roads increased by 13.9% and 13.4%. This study demonstrates that drivers that are traveling at high speeds are more likely to speed when entering nearby roads with lower speed limits, and that speeding is the likely cause of crashes. One potential explanation for this effect is speed adaptation. Data showed that drivers traveling at a higher speed for a prolonged period overestimate their speed when transitioning to a lower speed limit (Matthews, 1978). Casey and Lund (1978) showed that this effect can be attenuated if the person is required to slow down or stop prior to entering an area with a new speed limit. Traveling through a roundabout or stopping for a traffic signal are examples of this type of effect.

Because speeding is one of the major causes of crashes (National Safety Council 2020), and because speeding is also related to fatal crashes; It is important to explore methods to decrease driver speeding when drivers are going through areas that have a speed limit decrease of 24 km/h (15 mp/h) or higher. Analysis of high pedestrian/bicycle crash corridors in rural areas revealed that almost all high crash corridors occurred in locations where the speed limit was reduced for a village, town or small city. Although these data alone do not confirm that speed is a major issue in these corridors, the presence of K&A crashes does support this hypothesis to some degree. One type of gateway approach that could be considered is the use of roundabouts at the entrances of the communities along the higher speed road. However, this may be difficult to consistently implement One inexpensive alternative would be to use a gateway of larger speed limit signs at the start of the lower speed zone.

In one study researchers found that the R1-6 in street pedestrian sign placed in a gateway configuration with multiple signs reduced vehicle speed (Van Houten, Hochmuth, & McQuisten, 2018). Many jurisdictions in Michigan have used multiple stop signs in a similar gateway configuration, one on each side of the road facing oncoming drivers, and some have used a similar configuration of speed limit signs to reduce speed at road construction sites. One way to reduce speeding may be the use of a gateway configuration of speed limit signs at the start of the lower speed corridor. A three-sign could be easily set up on a three lane road by placing a small island on the middle lane. On a two-lane road a three sign configuration could be constructed by a small deflection separating the two lanes in order to construct such an island. In the following experiment, the WMU team examined the use of a gateway speed limit sign configuration where drivers on a higher speed road entered a lower speed more urban environment.

Method

Settings and Participants
The setting was a segment of Gull Road in the city of Kalamazoo where the speed limit for East bound traffic was reduced from 45 mph to 30 mph. The 30 mph speed limit sign is located 342 ft beyond the signalized intersection with Riverview Drive. Gull road has four travel lanes with two lanes in each direction. A trail crossing and a roundabout are beyond the intersection. Each travel lane is 10 ft wide. At the point where the speed is reduced to 30 mph there is a short painted median island marked with painted yellow gore stripe markings. At a location 1270 ft downstream from the speed limit reduction location is a trail crossing, and at the end of the road (1900 ft away from the speed limit sign) is a roundabout. Participants were any drivers that entered the 30 mph speed limit zone.

Materials

A Light detection and ranging device radar (LiDAR) model ultra lyte LTI 20 – 20 made by Laser Tech INC was used to measure vehicle speeds. All speed measures were taken within a narrow zone measuring 50 ft in length at a location that started 158 feet beyond the first 30 mph speed limit sign. The LiDAR was secured to a tripod to stabilize it. Measurements were made by the researcher wearing a yellow safety helmet and a reflective vest like those worn by surveyors to reduce driver reactivity.

A data sheet was used to record the number of cars, and the speed of each vehicle. The sheet also had a space to record the date, the start of a session and end time, and the condition in effect. Speed limit signs were used to construct each of the treatment conditions. The signs were constructed using white diamond grade retroreflective sheeting with black letters and numbers. This type of sheeting is highly reflective during day and nighttime conditions. The posts used metal and were not covered with the same diamond grade retroreflective sheeting used for the signs. The signs had two different sizes, the smaller sign was 36 inches high and 30 inches wide and the larger size was 48 inches high and 36 inches wide. Plastic flexible delineators marked the splitter island and were placed in the beginning of the painted yellow gore area marking around the middle sign.

Target Behavior
The target behavior in this study was driver speed in mph, measured with the LiDAR device. Speeds were divided into three categories, the percentage of drivers traveling 6 mph over the limit, 9 mph over the limit, and 12 mph over the limit. The formula that was used to calculate the percentage of vehicles traveling over these three speed categories calculated by dividing the number of cars traveling over each category by 200 (the size of each daily speed sample) and multiplying the result by 100.

Data Collection

The speed of each vehicle was obtained using the Lidar and was written down on a data sheet (appendix A). Cars were tagged using the lidar when driving through the measurement zone. The measurement zone was a 50 ft zone that all drivers passed through when driving down the experimental road. The researchers obtained the speed of each car when it was within the measurement zone. Speeds were not recorded for cars outside of the measurement zone. Use of this measurement zone allowed the drivers that had stopped at the light time to resume their selected speed. Therefore, any speeds obtained within the measurement zone were a result of driver speed and not confounded by drivers yielding or slowing down at the traffic light. Each session consisted of 200 car speeds obtained within the measurement zone.The position of the observer and the measurement zone were identified based on objects in the environment. The observer stood 700 feet away from the intersection. This allowed the observer to collect data at the same exact point during each session. The middle of the measurement zone was identified by a green box on the side of the road. The observer identified the beginning and the end of the measurement zone based on the light poles that were before and after the green box.

IOA

A second observer collected exact IOA on driver speed in mph by reading the driver speed in mph through the Lidar and writing it down on their own data sheet independently. IOA was collected for 33% of sessions. The driver speeds were then compared between data sheets, each car number had the same driver speed written next to it. Otherwise, it counted as a disagreement. IOA was calculated as the number of agreements/number of agreements + number of disagreements * 100.

Measurement Integrity

Procedural Integrity was collected on whether data were obtained on driver speed within the measurement zone. Whenever the primary observer captures any speed using the Lidar, the Lidar made a beeping noise. Based on when the beeping noise occurs, the secondary observer would then mark on their own data sheet if the driver's speed was obtained within the measurement zone. Procedural integrity was calculated by the number of cars that both observers judged to be in the measurement zone divided by the number of time they both judged the vehicle to be in the measurement zone plus the number of times the second observe disagreed the vehicle was in the measurement zone multiplied by 100.

Design and Procedure

The design employed in this study was a reversal ABCDEBE design. Condition A was baseline, no changes were made to the site during this condition, and there was one sign facing incoming traffic (the sign was 24 inches wide and 30 inches high). The site had a yellow gore marking on the ground as a painted splitter island, but nothing was placed on it. In condition B delineators were placed around the splitter island. The delineators were placed where the yellow line splits into two lines (and is placed around 150 ft up the painted median island). Condition C consisted of a splitter island with delineators and 2 signs (36 inches high and 30 inches wide) on each side of the road. Each sign faced the direction of approaching cars. This was done to create a gateway-like structure. Condition D was similar to condition C, however there was a third sign placed in the splitter island facing approaching vehicles. This sign also faced the direction of travel where cars were driving from the intersection into the experimental road and produced a three-sign gateway effect. Condition E was similar to condition D except the signs in this condition were larger than the signs in the previous conditions, the signs in this condition measured 48 inches high and 36 inches wide. This design then reversed back to condition B condition rather than the A condition because a splitter island with delineators around the turning lane was required to create the gatelike structure for this intervention. Therefore, reversing back to condition B served as a better benchmark to evaluate the effect of the gateway speed limit signs. The reintroduction of the signs produced a reduction in speed serving as a final replication of the effect. Figure 1 shows a photo of the three sign condition.

Figure 1. Photo of the three large sign condition

Results

The percentage of drivers traveling 6 mph, 9 mph and 12 mph over the speed limit during each condition is shown in Figure 2. The line with triangular markers shows the percentage of drivers speeding 6 mph over the limit per session. The line with circles markers shows shows the percentage of drivers speeding 9 mph over the speed limit per session. The line with square markers shows the percentage of drivers speeding 12 mph over the speed limit per session.

During baseline (A), 70% of drivers were at least 6 mph over the limit, 44% of drivers drove 9 mph over the limit, and 20% of drivers drove 12 mph over the speed limit. During the splitter island condition (B), 67% of drivers were 6 mph over the speed limit, 39% of drivers were 9 mph over the limit, and 19% of drivers were 12 mph over the limit. During the splitter island and two signs condition (C), 67% of drivers were 6 mph over the limit, 40% of drivers were 9 mph over the speed limit, and 18% of drivers were 12 mph over the speed limit. During the splitter island with three signs condition (D), 62% of drivers were 6 mph over the limit, 32% were 9 mph over the limit, and 13% were 12 mph over the speed limit. During the splitter island with three large signs condition (E), 53% of drivers were 6 mph over the speed limit, 28% of cars were 9 mph over the speed limit, and 12% of cars were 12 mph over the speed limit. When the treatment was reversed to splitter island only (B) 62% of drivers were 6 mph over the speed limit, 37% of drivers were 9 mph over the speed limit, and 18% of drivers were 12 mph over the speed limit. Reintroduction of the three signs reduced speeding to previous treatment levels.

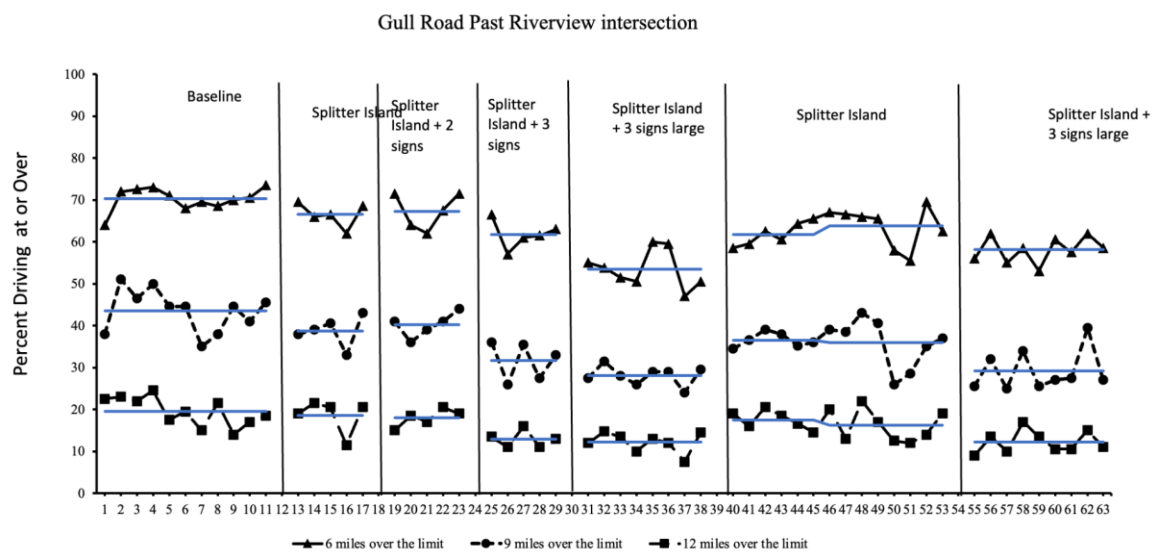


Figure 2. The percentage of drivers traveling over each of the three speed categories during each observational session.

Figure 3 shows the average speed distribution across three conditions: splitter Island without delineators gray markings, the splitter island with delineators (orange markings), and splitter island with three signs measuring 48 high and 36 wide (blue markings). The splitter island with 3 large signs condition showed the largest reduction in average driver speed followed by splitter island with delineators. It is clear from the graph that the gateway sign condition shifted the speed distribution toward slower speeds.

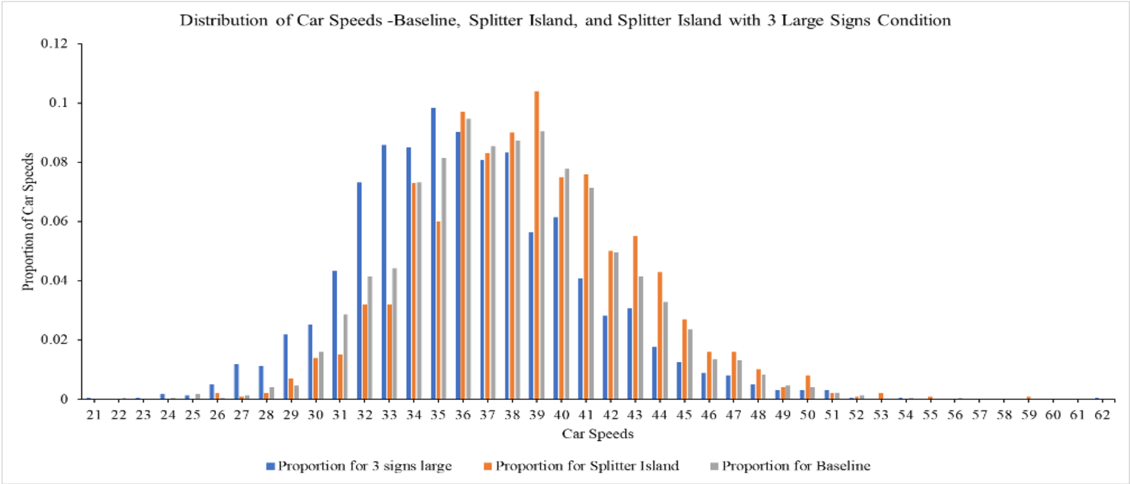


Figure 3. The distribution of driver speeds for the baseline, splitter island and 3 large signs conditions.

IOA

Two Independent observers collected IOA data for 33% of sessions. Agreement for both observers ranged between 98% and 100% and averaged 99.

Procedural Integrity

Two Independent observers collected procedural integrity data for approximately 33% of sessions. Procedural integrity for both observers ranged from 97% to 100% and averaged 99%.

Discussion

The purpose of this study was to systematically investigate the effectiveness of a gateway like structure to decrease driver speeding. Splitter Island with 3 large signs (36x48 inches) had the greatest effect in reducing driver speed. Splitter Island with 3 smaller signs (36x30 inches) showed the second greatest effect in decreasing driver speed. The splitter island alone with flexible delineators on it had a smaller effect, however adding two signs on each side of the road did not decrease driver speeding in comparison to the splitter island alone condition. Looking at the distribution of speeds, the average driver speed decreased the most during the splitter island with 3 large signs condition. The decrease in driver speeding and the decrease in average speed during the splitter island with 3 large signs condition may decrease the likelihood of crashes. The gatelike structure decreasing driver speeding supports the findings of Van Houten et al. (2018). It seems that the use of speed limit signs is an effective prompt, and putting larger signs in a gateway like structure is a better prompt than the use of only one small sign (36x30) on each side of the road.

There are multiple limitations to note; first we were not able to get long term follow-up study. However, data collection is ongoing and should reveal whether the effects persist. Another limitation is that the location of the speeding reduction does not have a large contextual change which would serve as a Motivating Operation to reduce driver speed. An example of an MO to decrease driver speeding would be a trail or consistent foot traffic of some sort. While there is a trail at the end of the experimental road, that walking trail has been closed for the duration of the study for renovation, and hence was not available to serve as a Motivating Operation to slow drivers down. We think replicating this study in a site where there is a greater context change that could serve as an MO would yield greater level changes than those produced in this study.

Because speeding is related to vehicle crashes (National Highway Traffic Safety Administration 2020) placing three large signs (36x48 inches) with a splitter island in the middle is likely to decrease speeding and the average speed of traffic in and therefore likely to decrease the likelihood of crashes. One advantage of the gateway sign condition is its low installation and maintenance costs. Another advantage is the long-life span of this treatment.