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16. Abstract

Reducing crashes involving pedestrians and bicyclists continues to be a major concern in the design of Michigan roads. In seeking to improve the safety of pedestrians, bicyclists, and motorists on Michigan roads, it is important to balance the needs of improved safety and mobility. This report provides a comprehensive review of safety improvements through a series of reports: A pedestrian and bicycle crash analysis in Michigan; a review of national design guidelines with respect to pedestrian and bicycle improvements; a case study analysis of recently completed improvements in Michigan; an analysis of existing guides and manuals that influence the design of roadways in Michigan; finally, and a set of recommended best design practices for walking and bicycling in Michigan.

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MICHIGAN DEPARTMENT OF TRANSPORTATION

SHARING THE ROAD: OPTIMIZING PEDESTRIAN AND BICYCLE SAFETY AND VEHICLE MOBILITY

FINAL REPORT

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4/30/2012

EXECUTIVE SUMMARY

Between 2005 and 2010, 6,948 pedestrians were injured in automobile crashes in the State of Michigan and 775 pedestrians were killed. During this same time, 5,500 bicyclists were injured and 147 bicyclists were killed in automobile crashes. While the number of crashes occurring nationwide is decreasing, automobile crashes continue to be one of the leading causes of death.

This research initiative combines the results of five reports to provide recommendations for improving the multimodal aspects of the MDOT transportation network through the use of practices, guidelines, and policies that MDOT engineers use to design and construct pedestrian, bicycle, and automobile facilities. Recommendations were based on information collected and analyzed in the following reports:

1. An analysis of crashes involving pedestrians and bicyclists in Michigan
2. A review and summary of current roadway improvements summarized by the Federal Highway Administration (FHWA) and their impacts on reducing crashes and their potential impact on mobility for all users
3. A case study analysis at five roadway improvement projects in Michigan and crash impacts at each location
4. A review of emerging design innovations provided by the National Association of City Transportation Officials (NACTO)
5. A summary report of the best design practices for pedestrian, bicycle, and automobile improvements in Michigan

This last report presents the improvements that were found to have the greatest utility in Michigan with respect to pedestrian and bicyclist safety and vehicle mobility. Created as a standalone document, *Best Design Practices for Walking and Bicycling in Michigan* is organized as a toolbox for planners and designers of pedestrian and bicycle facilities.

In addition, as part of the final report, a review was conducted of existing MDOT manuals, guidelines, and other publications that guide the planning and design pedestrian and bicycle facilities in Michigan. Recommendations were provided to facilitate the inclusion of these best practices in various MDOT roadway design documents.

Key Findings

Pedestrians are very vulnerable on MDOT highways. While crashes involving pedestrians account for less than 1% of crashes in Michigan, they account for 12.7% of Michigan fatalities. Young pedestrians ages 5 to 24 are more likely to be involved in crashes, whereas when pedestrians ages 55 and older are more likely to be killed when they are struck than younger pedestrians. Pedestrian crashes occur more often after dark than during daylight hours.

Key findings for bicycles included the finding that approximately 20% of fatal bicycle crashes occur on roadways with posted speeds between 25 and 30 mph. Bicycle crashes in Michigan occur most often between the hours of 3 and 6 pm.

Countermeasures that were associated with the greatest reductions in crashes included:

- Sidewalks reduce pedestrian crashes by 88%, while adding shoulders reduce pedestrian crashes by 70%[1]
- Roundabouts show an overall decrease in all types of crashes by 35%, injury crashes by 76% and fatal crashes by 89%[2]
- Road diets reduce all crashes anywhere from 14% to 49%.[3]
- Raised medians reduce all crashes by 40%, and by as much as 69% at unsignalized intersections[4]
- Pedestrian hybrid beacons were shown to have a 69% reduction in all crashes and a compliance rate of motorists yielding to pedestrians between 94-99%[5]
- Bike lanes can reduce bicycle crashes by 50%[6]

Mobility measurements were more difficult to assess. Most crash impact studies do not include mobility impacts, and educated assumptions were needed to include this information as part of the countermeasure discussions.

The case studies provided mixed results. The improvements for which before-and-after crash data or side-by-side crash results showed the largest overall changes were those that involved improvements that were implemented throughout an entire corridor. Improvements that were installed at intersection locations, such as pedestrian refuge islands or advance stop bars showed less clear results with respect to crashes.

Finally, all of the best practices that were recommended were either shown to reduce crashes involving motor vehicles, pedestrians, and/or bicyclists, or were shown to have no potential impact on one or more of these crash types. In some cases, a best practice was shown to have the potential to decrease mobility for one or two modes. This highlights the assertion that there continues to be tradeoffs between roadway user safety and mobility.

Three matrices are shown below that visually demonstrate the potential crash reductions, mobility effects and relative costs of each recommended practice. Some of the practices presented are still experimental and have not yet been adopted by MDOT as accepted practice. A fuller description of these special cases is provided in the full Recommended Practice Report.

Signalized Intersection Improvements

Best Practice	Potential Crashes			Potential Mobility Effects			Cost
	MotorVehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Proper Walking Speed	No Difference	Reduce	No Difference	Worse	Better	No Difference	Low
Fixed Time Signals/ Pedestrian Push Buttons	No Difference	No Difference	No Difference	No Difference	Better	No Difference	Low
Pedestrian Countdown Signal	Reduce	Reduce	Reduce	No Difference	Better	No Difference	Low
Leading Pedestrian Interval	No Difference	Reduce	No Difference	No Difference	Better	No Difference	Low
Pedestrian-Only Phase (Scramble)	No Difference	Reduce	No Difference	Worse	Better	Worse	Low
Exclusive Left Turn Phase (Leading/Lagging)	Reduce	Reduce	Reduce	Worse	Better	Better	Low
Flashing Yellow Arrow	Reduce	No Difference	No Difference	Better	No Difference	No Difference	Low
Prohibited Left Turns (Michigan Left)	Reduce	Reduce	Reduce	Better	Better	Better	Med/High
Prohibited Right Turn on Red	Reduce	Reduce	No Difference	Worse	Better	Better	Low
Advance Stop Bar	No Difference	Reduce	No Difference	No Difference	Better	No Difference	Low
Pork Chop Island	Reduce	Reduce	No Difference	Better	Better	No Difference	Med/High
Bulb-outs	Reduce	Reduce	No Difference	No Difference	Better	No Difference	Med/High
Roundabout	Reduce	Reduce	Reduce	Better	Better	Better	High
Bicycle Signal Detection	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Low/Med
Intersection Crossing Markings	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Low
Bike Box	No Difference	Reduce	Reduce	No Difference	No Difference	Better	Low
Two-Stage Bike Left Turn	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Low
Combined Bike/Turn Lane	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Low
Bicycle Signals	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Medium

Unsignalized Pedestrian Crossing Improvements

Best Practice	Potential Crash Reduction			Potential Mobility Effects			Cost
	MotorVehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Marked Crosswalk	No Difference	Reduce	Reduce	No Difference	Better	Better	Low
Advance Yield Markings	No Difference	Reduce	Reduce	No Difference	Better	Better	Low
In-roadway Yield Sign	No Difference	Reduce	No Difference	No Difference	Better	No Difference	Low
Pedestrian / Bicycle Refuge Island	Worse	Reduce	Reduce	No Difference	Better	Better	Low/Med
Rectangular Rapid Flashing Beacon	No Difference	Reduce	No Difference	No Difference	Better	No Difference	Medium
Pedestrian Hybrid Beacon	Reduce	Reduce	No Difference	No Difference	Better	Better	Med/High
Midblock Signal	No Difference	Reduce	Reduce	No Difference	Better	Better	Med/High
Roadway Illumination	No Difference	Reduce	Reduce	No Difference	Better	Better	Medium
Overpass/Underpass	No Difference	Reduce	Reduce	Better	Better	Better	High

Corridor Improvements

Best Practice	Potential Crash Reduction			Potential Mobility Effects			Cost
	MotorVehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Sidewalks and Paved Shoulders	Reduce	Reduce	Reduce	No Difference	Better	Better	Med/High
Road Diet	Reduce	Reduce	Reduce	No Difference	Better	Better	Low/Med
Raised Median	Reduce	Reduce	Reduce	Better	Better	Better	High
On-Street Parking	No Difference	Reduce	Reduce	No Difference	Better	Better	Low
Rear-In Diagonal Parking	Reduce	Reduce	Reduce	No Difference	No Difference	Better	Low/Med
Bike Lane	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Medium
Shared Lane Markings	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Low
Buffered Bike Lane	No Difference	No Difference	Reduce	No Difference	Better	Better	Med/High
Colored Bike Lane	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Medium
Contra-flow Bike Lane	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Medium
Left Side Bike Lane	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Medium
Cycle Track	No Difference	No Difference	Reduce	No Difference	No Difference	Better	High

Conclusion

This research initiative provided a comprehensive examination of the impacts of roadway improvements on the safety of pedestrians, bicyclists, and drivers of motor vehicles. In seeking a balance between safety and mobility, each of these aspects was researched to help MDOT use the best practices and employ policies to ensure that Michigan can provide flexibility in design that maximizes safety while at the same time maximizing mobility.

1. Introduction

Between 2005 and 2010, 6,948 pedestrians were injured in automobile crashes in the State of Michigan. 775 pedestrians were killed. During this same time, 5,500 bicyclists were injured and 147 bicyclists were killed in automobile crashes. Fatal pedestrian and bicycle crashes accounted for approximately 15% of fatal crashes that occurred in Michigan during this time period. While the number of crashes occurring nationwide is decreasing, automobile crashes continue to be one of the leading causes of death.

The Michigan Department of Transportation (MDOT) is interested in reducing crashes through innovative approaches to roadway design that accommodates all users, including pedestrians, bicyclists, transit users, and motorists. In addition, MDOT is committed to seeking a balance between pedestrian and bicyclist safety and vehicle mobility through excellence in design and aims to use the latest advances in technology and design to support walking and bicycling as integral modes of Michigan's transportation network.

MDOT has thus undertaken this research initiative to optimize pedestrian and bicycle safety and vehicle mobility through a comprehensive review of the multimodal aspects of the MDOT transportation network. However, there are challenges in striking this balance. Existing MDOT design manuals, agency policies, and practices require periodic updates in order to include emerging design innovations and approaches. In recent years, the concept of Complete Streets has increased focus on how to better integrate pedestrians and bicyclists into the transportation network.

As these new best practices develop, it is important to consider how to incorporate them into existing manuals, policies, and practices as they become nationally accepted standards. And, when attempting to implement innovative and emerging designs that are not yet approved standards, MDOT remains committed to taking precautions and obtaining necessary approvals that are required in order to incorporate new designs into practice.

The purpose of this report is to summarize the research and analysis efforts that have been undertaken to optimize pedestrian and bicycle safety and automobile mobility in the planning and design of roadways in Michigan. Four reports, discussed in the following section, were prepared to explore different aspects of Michigan roads and the safety of pedestrians and bicyclists. Key findings from each report are provided in the next section. A copy of each report is provided in the Appendix.

2. Study Process

The study process for this research initiative involved different aspects of pedestrian and bicycle safety as it relates to roadway design. MDOT provided review and feedback to help guide the research. An overview of each report is provided below.

2.1. Crash Analysis

The first report that was prepared is a crash analysis report that examined crashes involving pedestrians and bicyclists in Michigan for the years 2005 to 2010. Several factors were examined, including age, and gender information for pedestrians, bicyclists, and motorists. Behavior characteristics, including action prior to crash, alcohol consumption, and hit and run crashes also were reviewed; as well as environmental factors, such as roadway condition, time of day, day of week, roadway illumination, location of crash in the roadway, and presence of traffic control.

Key Findings

Pedestrians are very vulnerable on existing MDOT highways. While crashes involving pedestrians account for less than 1% of crashes in Michigan, they account for 12.7% of fatal crashes in Michigan. Young pedestrians ages 5 to 24 are more likely to be involved in crashes, whereas when pedestrians ages 55 and older are more likely to be killed than younger pedestrians when they are struck. Pedestrian crashes occur more often after dark than during daylight hours. Nationally, pedestrians account for 2.7% of fatal and injury crashes and 11.5% of fatal crashes.

Key findings for bicycles included the finding that 20% of fatal bicycle crashes occur on roadways with posted speeds between 25 and 30 miles per hour (mph). Bicycle crashes in Michigan occur most often between the hours of 3 and 6 pm.

MDOT maintains a highway network where many roads have posted speeds at or above 45 mph. Twenty-two percent of pedestrian crashes occur on roads with posted speeds at or above 45 mph, but 53% of fatal pedestrian crashes occur on these roads. This indicates that these roadways are more dangerous than lower speed roads in terms of pedestrian crashes.

The crash analysis provided a framework for understanding where and how pedestrians and bicyclists are at risk in being involved in motor vehicle crashes.

2.2. CRASH COUNTERMEASURE AND MOBILITY EFFECTS

Various improvements are recognized as national standards in design with respect to roadway safety, particularly as they apply to the safety of pedestrians and bicyclists. A review was conducted of highway improvements that have been shown to reduce the occurrence of crashes, particularly those involving pedestrians and bicyclists. These improvements, referred to as countermeasures by the Federal Highway Administration (FHWA), were reviewed based on data compiled from studies conducted using federally-approved engineering roadway treatments. These countermeasures were reviewed to determine what potential crash reductions could be attributed to the countermeasures, as well as what potential effect they could have on automobile mobility.

Mobility is a function of speed, access, and delay. Any impedance to these factors is measured in terms of delay. In seeking to maximize mobility, the practice of roadway engineering typically seeks to provide a roadway design where the optimum safe and practicable motor vehicle speed is a primary factor. However, maximizing motor vehicle speed may cause conflicts with access as well as the safety of motor vehicles and other modes. Therefore, total travel time, rather than speed, provides a more comprehensive measure of mobility than speed alone.

Using this understanding, crash countermeasures were reviewed for their potential to reduce crashes involving pedestrians, bicyclists, and motor vehicles. Countermeasures were organized into three categories:

- Intersection and signal improvements
- Roadway improvements
- Operations and enforcement

Countermeasures were reviewed based on studies conducted nationally and consisted primarily of improvements that are approved in national design manuals and guidelines, all of which are supported in design manuals and guidelines used in Michigan. Crash reduction factors are expressed as a percent change in the number of crashes recorded on roadways where improvements were installed compared to roadways without the improvements. Methods used for these studies included before-and-after or comparative crash analyses.

Key Findings:
Countermeasures that were associated with the greatest reductions in crashes included:

- Sidewalks reduce pedestrian crashes by 88%, while adding shoulders reduce pedestrian crashes by 70%[1]
- Roundabouts show an overall decrease in all types of crashes by 35%, injury crashes by 76% and fatal crashes by 89%[2]
- Road diets can be expected to reduce total crashes by 14% to 49%.[7]

- Roadway illumination was shown to help reduce crashes involving all modes, likely those associated with low light conditions, by 42% to 78%[1]
- Raised medians reduce crashes by 40% and by as much as 69% for crashes that occur at unsignalized intersections[8]
- Pedestrian hybrid beacons were shown to have a 69% reduction in all crashes and a compliance rate of motorists yielding to pedestrians between 94-99%.[9]
- Bike lanes can reduce bicycle crashes by 50%[10]

All of the countermeasures that were reviewed reported a crash reduction factor, and none were reviewed that resulted in an increase in crashes.

Mobility impacts were more difficult to assess as corresponding data on motor vehicle delay is usually not available. Oftentimes, it was found that agencies exploring crash impacts conducted research independent of any mobility impacts, and those that considered mobility impacts did not address crashes.

One major finding from this report was that improvements designed to clarify or assist in the enforcement of existing laws are not considered to have a negative impact on mobility. That is, the mobility impacts of many countermeasures were considered to be null if they were helping to enforce laws already in place. One example of this involves improvements to unsignalized crosswalks, such as pedestrian hybrid beacons. Pedestrian hybrid beacons are installed at marked crosswalks at unsignalized locations. Michigan state law requires that drivers of motor vehicles must yield for pedestrians in the crosswalk, and the addition of the pedestrian hybrid signal increases visibility and motorist compliance. Since drivers of motor vehicles are legally obligated to yield already, this type of improvement results in no net decrease in motor vehicle mobility.

2.3. CASE STUDY REPORT

While crash reduction factors identified in the *Crash Countermeasure and Mobility Effects* report were based on various national studies, it is important to consider that crash impacts can be based on a variety of environment factors. To explore these environmental factors and how they impact crashes occurring on Michigan roads, five locations in Michigan were identified for more in-depth study.

A case study report was prepared that reviewed recent highway improvements at five locations in Michigan. Improvements that were reviewed included a reduction in the number of travel lanes (road diet); the installation of raised, non-mountable medians; pedestrian refuge islands; pedestrian signals; roundabouts; curb bump outs; rectangular rapid flashing beacons (RRFB) at pedestrian crossings; and high visibility pedestrian crosswalk pavement markings.

The locations selected for the case studies were as follows:

1. Cutlerville: 60th Street from Division Avenue to Eastern Avenue
   Improvements included a road diet, reducing the roadway from four travel lanes to three lanes including a center two-way left-turn lane (TWLTL), and bike lanes in each direction.
2. Mount Pleasant: Mission Street from East Bluegrass Road to East Pickard Street
   Improvements included signal modernization to include pedestrian signal heads, one intersection with pedestrian countdown clock signal heads, and a pedestrian refuge island and warning signs at Appian Way.
3. Lansing: Michigan Avenue from Capitol Avenue to Pennsylvania Avenue
   Improvements included pedestrian crossing pavement markings, one intersection converted to a roundabout, and curb bump outs at intersections.
4. Detroit: Livernois Avenue from Davison Avenue to 7-Mile Road
   Improvements included a raised median, upgraded signals and crosswalks, and restricted left turns at intersections.
5. Detroit: Davison Avenue from Livernois Avenue to Rosa Parks Boulevard
   Improvements included improved pedestrian crossings with raised pedestrian refuge islands at two unsignalized intersections, rectangular rapid flashing beacons, and high visibility crosswalk pavement markings.

To explore the impact that these improvements had on crashes, crash data were collected for several years before and after the completion of the improvements. For improvements that were completed too recently for crash data to be available after construction, crash data was collected for a control site, consisting of a roadway segment nearby with similar characteristics so that a comparative crash analysis could be conducted.

In addition to crash data, other roadway-related information was collected to determine the mobility impacts of each improvement, including average daily traffic, the 85th percentile speed, and level of service (LOS).

LOS was determined separately for motor vehicles, pedestrians, and bicyclists. A recently developed multimodal LOS model was used to determine LOS for nonmotorized modes. The model took into account average daily traffic of motor vehicles, travel speed, and separation from traffic. LOS results were used to provide a comparative analysis of before-and-after conditions or side-by-side comparisons.

Key Findings

Corridor improvements showed the largest overall crash reductions. However, intersection improvements, such as pedestrian refuge islands or advance stop bars showed a lesser reduction in crashes or provided unclear results with respect to crashes.

We also found that the multimodal LOS model, which was used to determine LOS for motor vehicles, pedestrians, and bicycles, was better suited for assessing LOS along an entire corridor and did not provide a clear understanding of LOS at intersection locations.

Cutlerville, 60th Street

The road diet on 60th Street in Cutlerville resulted in a 57% reduction in total crashes as compared to the control site, which saw a 14% reduction in crashes. Average daily traffic decreased along 60th Street from 11,217 before the road diet to 10,077 after the road diet was installed. However, motor vehicle LOS increased from C to B. This was due mainly to an increase in travel speed that was calculated by the model as a result of lower traffic volumes. Pedestrian LOS improved from D to C after the road diet was completed, and bicycle LOS improved from E to C.

Lansing, Michigan Avenue

A before-and-after crash analysis was conducted on the improvements that were installed on Michigan Avenue in Lansing. The streetscape improvements included curb bump outs and a roundabout on Michigan Avenue and resulted in a 41% reduction in all crashes, as well as a 42% reduction in intersection crashes after the streetscape improvements were installed. Motor vehicle LOS did not change after the completion of the streetscape improvements, pedestrian LOS remained at B, and bicycle LOS remained unchanged at D.

Detroit, Livernois Avenue

A continuous barrier median was installed on Livernois Avenue from Davison Street to 7-Mile Road in Detroit. A pedestrian hybrid beacon was installed at Chalfonte Street and a two-stage pedestrian crossing was installed at Santa Clara Avenue. A before-and-after crash analysis found that intersection crashes decreased by 53% after the project was completed and midblock crashes dropped by 36%. Total crashes dropped by 50%. Pedestrian LOS improved from C to B, bicycle LOS remained at D, and motor vehicle LOS improved from C to B.

Mount Pleasant, Mission Street

The remaining two case studies showed smaller reductions in crashes or the results were unclear. On Mission Street in Mount Pleasant, pedestrian signals heads were added to signalized intersections along Mission Street and pedestrian countdown clocks were added at the Bellows Street intersection in 2004. In 2008, a pedestrian refuge island was installed on Mission Street at Appian Way. In 2009, loop detectors were installed in the pavement at signalized intersection to facilitate actuated signal control to improve traffic flow. Since there was no comparison site to use as a control, a before-and-after crash analysis was conducted using the signal upgrade project in 2004 as the threshold separating the before and after periods. Overall, crashes per year were higher after the pedestrian signal heads were added. However, pedestrian crashes and read end crashes decreased after the pedestrian signal heads were added. Pedestrian LOS remained at C before and after the project was completed, bicycle LOS remained at E, and motor vehicle LOS remained at C.

A regulatory sign stating “Cross Only When Traffic Clears” was posted on the side of the road at the pedestrian crossing and refuge island at Appian Way. This is contradictory to the law and is confusing to pedestrians. One police report filed for a crash at this location stated that the pedestrian “failed to yield to traffic” and cited this sign. The current sign at Appian Way does not communicate how right-of-way is assigned at pedestrian crossings or that motorists shall yield to pedestrians in the crosswalk. MDOT should consider removing the signs and installing advance “Yield to pedestrians” sign in advance of the crossing along with advance yield pavement markings at this location.

Detroit, Davison Avenue

Davison Avenue between Livernois Avenue and Rosa Parks Boulevard in Detroit was improved in 2010 with several midblock pedestrian crossings, advance stop bars at pedestrian crosswalks at signalized intersections, and rectangular rapid flashing beacons (RRFB) at pedestrian crosswalks at unsignalized intersections.

Because the improvements occurred in 2010, there was no crash data available after the improvement was completed. In addition, a site visit revealed that the RRFBs were vandalized which rendered them inactive. The curbs of the pedestrian refuge islands were shown to have sustained crash damage, pedestrians were observed crossing at unsignalized midblock locations and were not using the pedestrian refuge islands to cross. As a result, no conclusions were drawn about the effectiveness of crashes on Davison Avenue.

2.4. Best Design Practices for Walking and Bicycling in Michigan

The results of the three previous reports helped identify which improvements could provide the best means to optimize pedestrian and bicycle safety and vehicle mobility in Michigan.

A best practices report was prepared that summarized these improvements and provided a quick reference summary of impacts. This report, titled *Best Design Practices for Walking and Bicycling in Michigan,* is a toolbox of pedestrian, bicycle, and motor vehicle improvements that are recommended for implementation in Michigan. Best practices are recommended based on roadway conditions, crash impacts, relative costs, and potential mobility impacts.

As noted previously, mobility is a function of speed, access, and delay. For the purposes of the *Best Design Practices in Walking and Bicycling in Michigan*, mobility impacts refer to the potential change in delay that would be experienced by roadway users as a result of implementing a best design practice. As bicyclists are considered roadway users and are subject to the same rights and responsibilities when using the roadway, they are assumed to be traveling in the roadway unless otherwise stated. Pedestrians are assumed to be traveling along the roadway on sidewalks or paths, and are assumed to cross at crosswalks, at signalized intersections, unsignalized intersections, and marked midblock locations.

Regarding mobility impacts, it is important to clarify the circumstances under which potential delay for roadway users is said to increase. For example, since a motorist or bicyclist is required to yield to a pedestrian in a crosswalk according to state law, the addition of a traffic control device that clarifies the law by providing additional awareness, or encouraging improved compliance, is not considered to increase delay, as it clarifies a legal requirement.

While the crash analysis, countermeasures, and case study reports provided the majority of the best practices, there are several innovations in pedestrian, bicycle, and motor vehicle improvement design that have not yet been incorporated into national and Michigan design guidelines and manuals. However, these emerging practices have the potential to provide additional flexibility in providing facilities that improve pedestrian and bicycle safety and vehicle mobility.

In preparing this report, improvements from the National Association of City Transportation Officials (NACTO) *Urban Bikeway Design Guide* (*NACTO Guide*) were also reviewed for additional design best practices that were not reviewed in the previously mentioned reports. The *NACTO Guide* includes innovative improvements that have met with successful implementation in some cities, yet have not been incorporated into federal guidelines and best practices. These improvements were recommended for their potential to increase the options available for accommodating pedestrians and bicyclists on MDOT roadways.

For each best practice, a determination on potential crash reductions, potential mobility impacts, and cost of implementation is provided. Potential crashes and mobility impacts are determined based on information collected in *Crash Countermeasures and Mobility Effects*, the *NACTO Guide*, and other sources. Each best practice was shown to either reduce or have no impact on crashes involving motor vehicles, pedestrians, and bicyclists. The best design practices for walking and bicycling in Michigan are grouped into three categories: signalized intersection improvements, unsignalized intersection improvements, and corridor improvements. For each category, a matrix was prepared to provide a comparison of each best practice with respect to potential crash impacts, potential mobility impacts, and relative costs.

Signalized Intersection Improvements

Included in this category are well recognized practices, such as proper walking speed, fixed time signals or pedestrian push buttons, pedestrian countdown signals, leading pedestrian intervals, exclusive left turn signals (leading or lagging), prohibiting left turns at intersections (Michigan left), prohibited right turn on red, pork chop islands, and curb bulb-outs. Also included are some newer improvements such as flashing yellow arrows, advance stop bars, and roundabouts.

Practices such as bicycle signal detection, intersection bike crossing markings, bike boxes, and bicycle signals, are still considered experimental in Michigan, but also may be considered under certain circumstances.

Signalized Intersection Improvements

	Potential Crashes			Potential Mobility Effects			
Best Practice	MotorVehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	Cost
Proper Walking Speed	No Difference	Reduce	No Difference	Worse	Better	No Difference	Low
Fixed Time Signals/ Pedestrian Push Buttons	No Difference	No Difference	No Difference	No Difference	Better	No Difference	Low
Pedestrian Countdown Signal	Reduce	Reduce	Reduce	No Difference	Better	No Difference	Low
Leading Pedestrian Interval	No Difference	Reduce	No Difference	No Difference	Better	No Difference	Low
Pedestrian-Only Phase (Scramble)	No Difference	Reduce	No Difference	Worse	Better	Worse	Low
Exclusive Left Turn Phase (Leading/Lagging)	Reduce	Reduce	Reduce	Worse	Better	Better	Low
Flashing Yellow Arrow	Reduce	No Difference	No Difference	Better	No Difference	No Difference	Low
Prohibited Left Turns (Michigan Left)	Reduce	Reduce	Reduce	Better	Better	Better	Med/High
Prohibited Right Turn on Red	Reduce	Reduce	No Difference	Worse	Better	Better	Low
Advance Stop Bar	No Difference	Reduce	No Difference	No Difference	Better	No Difference	Low
Pork Chop Island	Reduce	Reduce	No Difference	Better	Better	No Difference	Med/High
Bulb-outs	Reduce	Reduce	No Difference	No Difference	Better	No Difference	Med/High
Roundabout	Reduce	Reduce	Reduce	Better	Better	Better	High
Bicycle Signal Detection	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Low/Med
Intersection Crossing Markings	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Low
Bike Box	No Difference	Reduce	Reduce	No Difference	No Difference	Better	Low
Two-Stage Bike Left Turn	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Low
Combined Bike/Turn Lane	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Low
Bicycle Signals	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Medium

Unsignalized Pedestrian Crossing Improvements

This category includes improvements such as marked crosswalks, advance yield markings, in-roadway yield signs, and pedestrian/bicycle refuge islands. Also included are rectangular rapid flashing beacons, pedestrian hybrid beacons, and midblock signals.

Unsignalized Pedestrian Crossing Improvements

Best Practice	Potential Crash Reduction			Potential Mobility Effects			Cost
	MotorVehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Marked Crosswalk	No Difference	Reduce	Reduce	No Difference	Better	Better	Low
Advance Yield Markings	No Difference	Reduce	Reduce	No Difference	Better	Better	Low
In-roadway Yield Sign	No Difference	Reduce	No Difference	No Difference	Better	No Difference	Low
Pedestrian / Bicycle Refuge Island	Worse	Reduce	Reduce	No Difference	Better	Better	Low/Med
Rectangular Rapid Flashing Beacon	No Difference	Reduce	No Difference	No Difference	Better	No Difference	Medium
Pedestrian Hybrid Beacon	Reduce	Reduce	No Difference	No Difference	Better	Better	Med/High
Midblock Signal	No Difference	Reduce	Reduce	No Difference	Better	Better	Med/High
Roadway Illumination	No Difference	Reduce	Reduce	No Difference	Better	Better	Medium
Overpass/Underpass	No Difference	Reduce	Reduce	Better	Better	Better	High

Corridor Improvements

Corridor improvements include standard improvements such as sidewalks and paved shoulders, road diets, and raised medians. Also included are the effects of on-street parking and rear-in diagonal parking. Bicycle improvements include bike lanes, shared lane markings, buffered bike lanes, colored bike lanes, contra-flow bike lanes, and cycle tracks.

Corridor Improvements

Best Practice	Potential Crash Reduction			Potential Mobility Effects			Cost
	MotorVehicles	Pedestrians	Bicyclists	Motor Vehicles	Pedestrians	Bicyclists	
Sidewalks and Paved Shoulders	Reduce	Reduce	Reduce	No Difference	Better	Better	Med/High
Road Diet	Reduce	Reduce	Reduce	No Difference	Better	Better	Low/Med
Raised Median	Reduce	Reduce	Reduce	Better	Better	Better	High
On-Street Parking	No Difference	Reduce	Reduce	No Difference	Better	Better	Low
Rear-In Diagonal Parking	Reduce	Reduce	Reduce	No Difference	No Difference	Better	Low/Med
Bike Lane	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Medium
Shared Lane Markings	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Low
Buffered Bike Lane	No Difference	No Difference	Reduce	No Difference	Better	Better	Med/High
Colored Bike Lane	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Medium
Contra-flow Bike Lane	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Medium
Left Side Bike Lane	No Difference	No Difference	Reduce	No Difference	No Difference	Better	Medium
Cycle Track	No Difference	No Difference	Reduce	No Difference	No Difference	Better	High

All of the best practices were either shown to reduce crashes involving motor vehicles, pedestrians, and bicyclists, or were shown to have no potential impact. In some cases, a best practice was shown to have the potential to decrease mobility for one or two modes. While this did not happen often, the matrices provide a visual indication where there may be tradeoffs between roadway user safety and mobility.

3. Review of Michigan Department of Transportation Design Guides and Manuals

In addition to the previously described reports that examined different aspects of optimizing pedestrian and bicycle safety and vehicle mobility, a review was conducted of existing policies, standards, and practices currently employed by MDOT for the provision of pedestrian and bicycle facilities.

As advances in traffic safety reveals new best practices in the design of pedestrian and bicycle facilities, the existing MDOT policies, standards, and practices may need to be updated to accommodate improved design practices. In order to ensure that MDOT is equipped to incorporate these best practices into the design of roadways, MDOT manuals and guidelines were reviewed to identify where recommendations could be made to make it possible to utilize these best practices. The following documents were reviewed:

- 2011 MDOT Road Design Manual
- 2011 Michigan Manual on Uniform Traffic Control Devices (MMUTCD)
- MDOT Traffic and Safety Notes (various dates)
- MDOT Michigan Intersection Guide
- MDOT Roundabout Guidance Document
- MDOT Project Scoping Manual

Items provided below are grouped in the same three categories as the best design practices: signalized intersection improvements, unsignalized intersection improvements, and corridor improvements. Suggested changes to language within these manuals and guidelines is provided where additions or revisions would better accommodate the planning and design of pedestrian and bicycle facilities. Where recommendations are provided <u>the text has been underlined</u>. Sections of manuals that are referenced in these recommendations have been included with the text.

3.1. General Recommendations

Manuals and Publications Update Process:

- *MDOT Traffic and Safety Notes* provide information on recent innovations in traffic safety, including pedestrian and bicycle facility improvements and how they apply in Michigan. Design guidance from these notes is helpful, but the notes are released infrequently and are difficult to search. <u>Because of the additional valuable guidance in the notes, it would be helpful to incorporate these into the *Michigan Intersection Guide*, *Roundabout Guidance Document*, or the *Road Design Manual* on an annual or quarterly basis.</u>

3.2. Signalized Intersection Improvement Recommendations

Pedestrian Signals:

- MMUTCD 4E.03 states that pedestrian signals are appropriate in cases of assisting pedestrians at intersections to reduce conflicts, to cross one portion of the roadway at a time, or where it is necessary to provide additional signals because pedestrians would have a difficult time seeing existing traffic control signals at an intersection.
- MMUTCD 4E.06 covers signal timing, including phasing options and signal operations. A pedestrian walking speed of 3.5 feet per second is standard, but MMUTCD states that a slower speed can be used if it is needed. The shortest pedestrian phase allowed is 4 seconds. Additional guidance is provided on signal phasing as well as the clearance phase.
- Michigan Design Manual 6.08.05I provides the circumstances under which crossing upgrades are recommended. Push button pedestrian signal guidance is briefly discussed. MDOT should consider adding guidance that encourages the provision of a pedestrian walk phase during every signal cycle instead of installing pedestrian push buttons. Pedestrian push buttons should be added to signals only if it would be problematic to provide a walk phase during every signal cycle.
- MMUTCD 4D.03 “Provisions for Pedestrians” states that traffic signals should take into consideration the needs of pedestrians as well as vehicles. No changes are recommended.
- MMUTCD Chapter 7 provides guidance for Traffic Control for School Areas. Topics include walk to school routes, signage for motorists, and crossing guard procedures.
- MMUTCD 7A.02-03 provides more specific guidance on the placement of school crossings and references the frequency of gaps in motor vehicle traffic to determine when additional improvements are needed to facilitate pedestrian crossings.
- MMUTCD 7.B provides additional guidance for school zone speed limit signage and optional plaques. School zone designation is discussed.

Pedestrian Countdown Clocks

- MMUTCD 4E.07 states that all pedestrian signals used at crosswalks with pedestrian intervals greater than 7 seconds should use countdown clocks. This section includes guidance on operations and placement.

Leading Pedestrian Intervals (LPI):

- MMUTCD 4E.09 - Accessible Pedestrian Signals and Detectors section mentions LPI. No specific guidance on LPI application is included, including the caveat that right turn on red restrictions should be implemented in concert with the use of LPI. A discussion on the need to include right turn on red restrictions as part of any LPI installation should be added.

Right Turn on Red Restriction:

- MMUTCD 2B.54 authorizes the uses of right turn on red restriction.
- Traffic and Safety Note 123A – Guidelines are provided for evaluating the need for restricting right turn on red, appropriate signage, and how to determine their appropriate location. Signs are recommended in cases where high volumes of pedestrian traffic are observed.

Protected Left Turns:

- MMUTCD 4D.18 focuses entirely on operations for leading or lagging left turns, and does not discuss the safety implications for pedestrians. <u>Additional language should be added that identifies the benefit of reducing conflicts between turning vehicles and pedestrians in the crosswalk.</u>

Pork Chop Islands:

- Traffic and Safety Note 602A "Roadside Traffic Control Islands" states that pork chop islands should be considered under certain conditions but does not mention the benefits they provide to pedestrians.
- MMUTCD 2A.16 Provides guidance on the placement of signs regarding channelized intersections, which involve the use of pork chop islands. The attached figure below shows the recommended placement of traffic control signs at a channelized intersection with a pork chop island. <u>The figure should be revised to include all pavement markings that should be provided at an intersection of this type, including pedestrian crosswalk markings.</u>

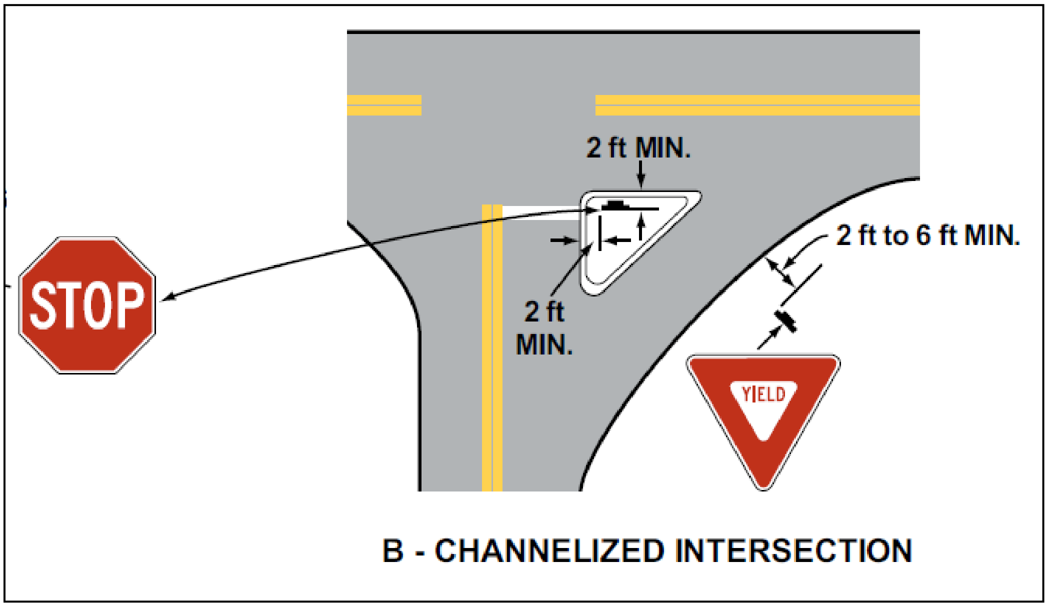

Figure 2A-3B

Curb Bulb-Outs:

- MMUTCD 4B.04. Curb bulb-outs (curb extensions) are discussed as a potential alternative to installing traffic control signal. However, curb extensions are discussed specifically as a pedestrian safety improvement. Additional language should be considered that states that adding curb extensions at signalized intersections helps to reduce pedestrian crossing distances, and they improve vehicular traffic flow.
- Traffic and Safety Note 602A refers to bulb-outs as "Roadside Traffic Control Islands" and states that they should be considered under certain conditions. Curb bulb-outs should not be included under traffic control islands, or the wording should be changed to include all roadside geometric features. In addition, the shortening of pedestrian crossing distance and the increased visibility of crossing pedestrians should be cited as significant safety features of curb bulb-outs.

Roundabouts:

- MMUTCD 3.C "Roundabout Markings" provides guidance for crosswalk placement and pavement markings.
- MDOT Roundabout Guidance Document Section 3.3 discusses roundabouts as a safety countermeasure for vehicle crashes. Accommodations for pedestrians and bicycles are located in Section 4.9 and 4.10. The operational benefits of single lane roundabouts vs. multilane roundabouts are not discussed.

3.3. UNSIGNALIZED INTERSECTION IMPROVEMENT RECOMMENDATIONS

Marked Crosswalk

- MMUTCD 3B.18 provides standards for crosswalk pavement markings. The types of crosswalk markings are shown in the attached figure. Factors to consider in crosswalk placement include: number of lanes, median type, distance from adjacent intersections, pedestrian volumes and delays, ADT, speed, and additional considerations.

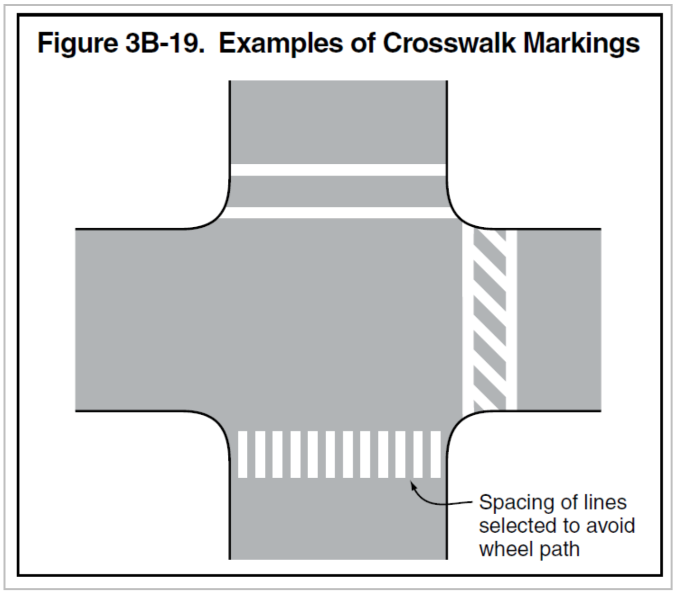

Figure 3B-19

Advance Yield Markings

- MMUTCD 3B.18 provides guidance on the placement of advance yield markings. The attached figure below shows the "sharks teeth" lines and yield here to pedestrian signs on advance yield markings, typically placed between 20 and 50 feet from the crosswalk. Section 3B.16.16-17 states that yield lines may be staggered to further improve visibility of pedestrians to motorists.

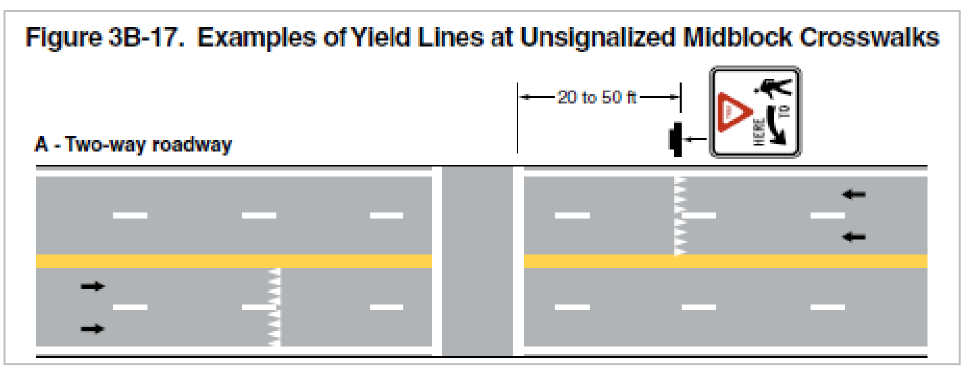

Figure 3B-17

- Additional guidance is provided for placing advance pedestrian and bicycle warning signs in MMUTCD 2B.51. The warning signs for bikes and pedestrians are included in this section. Guidance on when and how to use these warning signs should be included.

In-Roadway Yield Sign

- MMUTCD 2B.11 provides guidance on in-roadway yield signs. These signs should only be used where local jurisdiction specifically requires a driver to yield or stop. Placement of the signs for various situations is covered. The signage can be used with or without the advanced yield markings.

Pedestrian Refuge Island

- MMUTCD 3I.06 provides guidance on pedestrian islands and medians. They can be used for refuge if they have adequate width. Refers to ADAAG Section 1A.11 for ADA compliance guidelines.
- MMUTCD 4B.04 states that median refuge islands are an alternative to providing traffic control devices. Guidance is included on how to revise geometrics to add median refuge islands.

Pedestrian Beacons:

- MMUTCD 4N.02 provides guidance on application, placement, and operations of "in-roadway warning lights at crosswalk." These are seldom used due to issues with motorist compliance and roadway maintenance, particularly due to concerns over winter snow plowing activities.
- MMUTCD 4F.01 provides guidelines and warrants for application of "pedestrian hybrid beacons". MMUTCD 4F.02 provides guidance in the design of pedestrian hybrid beacons. Crosswalk length guideline tables based on amount of pedestrians and vehicles per hour are included. The attached figure shows the sequence for a pedestrian hybrid beacon.

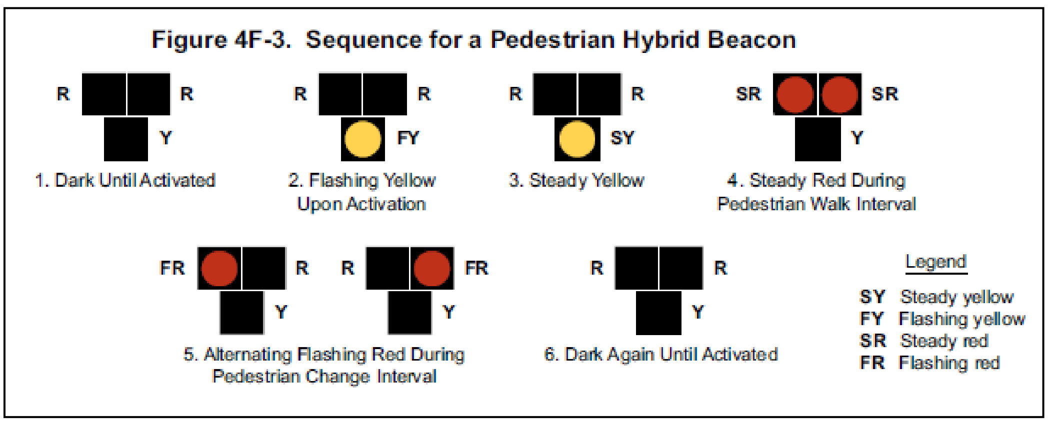

Figure 4F-3

Rectangular Rapid Flashing Beacon (RRFB):

- Traffic and Safety Note 212A – Guidance on application, design, and operations of RRFB. Signage used with RRFB is specified. <u>This guidance should be incorporated into the MMUTCD.</u>

Mid-block Signal

- MMUTCD 4C.05 provides guidance on the warrants used for installing pedestrian signals at midblock crossings.
- Traffic and Safety Note 401C provides guidelines on mid-block crossings. <u>This guidance should be incorporated into the MMUTCD.</u>

Roadway Illumination

- Michigan Design Guide 9.03-01 provides guidance on the placement, authorization, and offset design dimensions of roadway illumination. High pedestrian activity is a consideration for providing lighting. However, the quantity of pedestrians is not specified. Guidance should be revised to also encourage the provision of roadway illumination at pedestrian crosswalks whenever engineering judgment identifies a need, which may include but is not dependent upon pedestrian traffic volume.

3.4. CORRIDOR IMPROVEMENT RECOMMENDATIONS

Sidewalks and Paved Shoulders

- Michigan Design Guide 6.08 covers sidewalks, including design guidance and placement with respect to other roadway elements.
- Michigan Design Guide 5.05 discusses "Consent to Construct Sidewalk" and states that new or reconstructed sidewalks should be placed 1 foot within the right-of-way line.

Road Diets

- While Road Diets are not discussed explicitly, some guidance on design can be found within Michigan Design Guide DG 3.07-04. This includes Two-Way Left Turn Lane (TWLTL) widths, transitioning to center lanes for left turns, or passing flares that may be required at certain intersections.
- Scoping Manual 3-9 "Safety Programs for Roads" states that adding a center left turn lane is a design option.

Raised Median

- MMUTCD 3H.01 "Channelizing Devices" states that raised medians may be used to prevent turns, or direct motorists based on engineering judgment. No discussion is provided on the pedestrian safety impacts of medians. It should be added that continuous raised medians can reduce crashes by 40% and include reference to the FHWA report (See *Crash Countermeasure and Mobility Effects* report).

On-Street Parking

- MMUTCD 3B.19 provides guidance for on-street parking and pavement markings, including pavement markings in proximity to intersections and crosswalks, as shown in the attached figure.

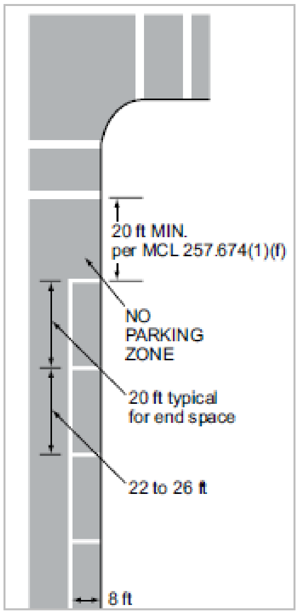

Figure 3B-21 Placement of Parking Space Markings

Bike Lanes

- MMUTCD Ch 9 is dedicated to Traffic Control for Bicycle Facilities. Shared-use paths and bike lanes are included. Signage and pavement markings specific for bikes and for vehicles are included. Signage placement diagrams are included for typical applications.
- Michigan Design Guide 12.12 provides guidance for bicycle facilities under the "Miscellaneous Roads" section. It provides guidance on legislation required for non-motorized facilities, procedures for project review, and official Department Policy. Facility types include widened paved shoulder bike lanes and shared-use paths. Design features including design speed, grades, horizontal alignment, crown and superelevation, width, clearances, grading, surface type, drainage and structures, railings and retaining walls, and railroad crossings are discussed. <u>It is suggested that this could be the basis for a separate Michigan Design Guide chapter dedicated to accommodating bicycles.</u>

Shared Lane Markings

- Traffic and Safety Note 306A states that shared lane markings can be used to reduce the incidence of wrong-way bicycling. <u>It is recommended that this guidance should be incorporated in the MMUTCD.</u>

Lane Width:

- Michigan Design Guide Appendix 3A provides lane width guidance for 10', 11', and 12' roads. Minimum lane width requirements are based on facility type, design speed and ADT for new construction or reconstruction. 10-foot lanes are permitted under some conditions. <u>This portion of the Michigan Design Guide should be modified to incorporate the latest AASHTO Green Book guidance with respect to urban arterials.</u>

Design Speed:

- Traffic and Safety Note 506A "Establishing Speed Limits" provides guidance on establishing advisory, regulatory, and statutory speed limits. Procedures for conducting speed studies are also included.
- School zones speed limits are discussed in MMUTCD 7.B. Speed limit signage and optional plaque design and placement is included. School zone designation is discussed.
- None of the publications mentioned above directly addressed establishing a target speed or reducing travel speeds as a means of reducing crashes. However, with an established relationship between travel speeds and fatal crashes, it is recommended that MDOT should permit the establishment of target speeds as potential solution when conducting speed studies, using the ITE Proposed Recommended Practice *Context Sensitive Solutions in Designing Major Urban Thoroughfares for Walkable Communities*.

4. Conclusions

This research initiative provided a comprehensive examination of the factors that influence the planning and design of facilities intended to reduce crashes involving pedestrians and bicyclists. While there are several design options available to improve pedestrian, bicyclist, and motor vehicle safety, engineers and designers often lack clear guidance on the impacts that these improvements will have on mobility.

These reports should inform and guide MDOT in the provision of future facilities and encourage increased flexibility and interpretation of existing guides, as well as help to incorporate best practices in the planning and design of pedestrian and bicycle facilities.

In order to stay current in the provision of pedestrian and bicycle facilities, this report helps MDOT to incorporate these practices in a manner that does not adversely impact vehicle mobility in Michigan.

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1. Gan, A., Shen, J., and Rodriquez, A., "Update of Florida Crash Reduction Factors and Countermeasures to Improve the Development of District Safety Improvement Projects." Florida Department of Transportation. Tallahassee, FL, 2005.
2. Federal Highway Administration, Roundabouts: Technical Summary. 2010. P. 4.
3. Highway Safety Information System. Evaluation of Lane Reduction "Road Diet" Measures on Crashes. Federal Highway Administration. Washington, D. C., 2011.
4. Zegeer, C. Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations. Federal Highway Administration. Washington, D. C., 2005. p.36-39.
5. Fitzpatrick, K., et al., "Improving Pedestrian Safety at Unsignalized Crossings." NCHRP Report 112/562, Transportation Research Board. Washington, D. C., 2006.
6. Moritz, W. "Survey of North American Bicycle Commuters; Design and Aggregate Results." Transportation Research Record. Washington, D. C., 2003.

[7]. Highway Safety Information System. Evaluation of Lane Reduction "Road Diet" Measures on Crashes. Federal Highway Administration. Washington, D. C., 2011.

[8]. Zegeer, C. Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations. Federal Highway Administration. Washington, D. C., 2005. p.36-39.

[9]. Fitzpatrick, K., et al., "Improving Pedestrian Safety at Unsignalized Crossings." NCHRP Report 112/562, Transportation Research Board. Washington, D. C., 2006.

[10]. Moritz, W. "Survey of North American Bicycle Commuters; Design and Aggregate Results." Transportation Research Record. Washington, D. C., 2003.

APPENDIX – INDIVIDUAL REPORTS